Displaced Capital: A Study of Aerospace Plant Closings

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Using equipment-level data from aerospace plants that closed during the 1990s, this paper studies the process of moving installed physical capital to a new use. The analysis yields three results that suggest significant sectoral specificity of physical capital and substantial costs of redeploying the capital. First, other aerospace companies are overrepresented among buyers of the used capital relative to their representation in the market for new investment goods. Second, even after age-related depreciation is taken into account, capital sells for a substantial discount relative to replacement cost; the more specialized the type of capital, the greater the discount. Yet, capital sold to other aerospace firms fetches a higher price than capital sold to industry outsiders. Finally, the process of winding down operations and selling the equipment takes several years.

We are greatly indebted to the managers, auctioneers, and machine tool salesmen who provided us with data and valuable insights. We have also benefited from the helpful comments of an anonymous referee as well as seminar participants at the University of California, San Diego, University of Michigan, Massachusetts Institute of Technology, University of Texas at Austin, University of California, Riverside, University of California, Santa Barbara, Northwestern, Rand, Princeton, Wharton, Indiana, Hebrew University, Tel Aviv, Haifa, Stanford, Yale, the Federal Reserve Bank of New York, and the National Bureau of Economic Research's Economic Fluctuations and Growth and Sloan Project conferences. We both gratefully acknowledge financial support from Sloan Foundation fellowships, funding from the Alfred P. Sloan Foundation via a grant to the Industrial Technology and Productivity Project of the National Bureau of Economic Research, and National Science Foundation grant SBR-9617437. We thank Marina Anastasia Vladimirovna and Elizabeth Vega for very capable research assistance. We have agreed to keep confidential the identity of the companies and the source data on which this study is based.

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I. Introduction

Changes in technology, the demand for output, or factor prices can lead to the displacement of capital from its original use. The efficiency with which that capital can be redeployed to other firms and sectors is an important determinant of the economy's speed of transition after a shock. It is also an important element in firms' initial investment decisions. Recent empirical work has provided indirect evidence of costly adjustment of capital by showing that investment behavior is consistent with the presence of costly disinvestment. There is little direct evidence, however, on the sectoral specificity of capital or the speed with which capital can be redeployed.

We seek to fill this gap by collecting and analyzing data in order to shed light on capital specificity and the efficiency of resale markets in redeploying displaced capital. To this end, we collected confidential information from auctions of equipment from three large southern California aerospace plants that discontinued operations. We then used information on sales prices and the characteristics of buyers to determine the extent of capital specificity for this particular industry. We shall argue below that the aerospace industry is particularly interesting because it has undergone significant, exogenous downsizing.

Our findings suggest that much capital is very specialized by sector and that reallocating capital across sectors entails substantial costs. The estimated average market value of equipment in our sample is 28 cents per dollar of replacement cost. Even machine tools, which typically have good resale markets, sell for less than 40 percent of replacement cost. Types of capital that we identify as being more specialized sell at a greater discount. Yet, capital that sells to other aerospace firms sells at a smaller discount than capital that sells to outsiders. This loss of value is not the only cost of displacement. The process of winding down operations before selling the capital results in significant periods of low utilization before the capital is finally sold. Moreover, the process of selling also takes substantial time, so there is a time cost of reallocation. Nevertheless, the assumption of zero fungibility of capital is also far from true. We find that capital is sold to firms in a wide range of sectors as well as in far-flung geographical locations.

The estimates of this paper should prove useful for at least two different lines of research. First, by providing direct evidence on the costs of reversing investment decisions, this paper contributes to the macroeconomics literature on the role of costly reversibility at the firm level and in the economy as a whole.[1] Theoretical models of firm behavior (e.g., Abel and Eberly 1994; Dixit and Pindyck 1994) make predictions about how these kinds of adjustment costs affect the timing and magnitude of investment. Other studies, such as Veracierto (1997) and Ramey and Shapiro (1998*a*), consider the role of costly reversibility in dynamic general equilibrium models. Our direct estimates of the loss of value for reversing an investment can be used to calibrate the theoretical models and to generate predictions about how uncertainty might delay investment. Moreover, our evidence concerning the delays in the process of disinvestment provides direct support for some of the predictions of these models.

A second line of research to which our results relate is the literature on depreciation measurement. A by-product of our study is a set of estimates of annual depreciation rates of equipment. The depreciation measurement studies, such as those by Hall (1971), Hulten and Wykoff (1981), Bond (1982), Cockburn and Frank (1992), and Oliner (1996), also employ sales of used assets to infer the productive value of assets.[2] Those studies do not have information on the original purchase price of equipment, so they use hedonic techniques to infer depreciation rates. Even though we use a different type of data and technique, our depreciation estimates are very similar to the estimates from that literature.

The remainder of the paper is organized as follows. Section II discusses the role of specificity in the marketing of used equipment. Section III describes the data that we have collected. Section IV presents the results on to whom and how the equipment was sold. These results provide some evidence on the extent of specificity of the equipment. Section V presents a regression model based on a subset of the equipment in which we observe the original cost. We present estimates of the discount from replacement cost from selling the equipment and the way in which the discount varies by the industry of the buyer or mode of sale. These estimates provide quantitative evidence of the value of specificity. As a by-product, the regression model produces estimates on the rate of depreciation. In the last part of this section, we also discuss how the specificity of capital in aerospace compares to other industries. Section VI provides evidence on the time cost of the process of reallocation. Section VII relates our findings to the literature on displaced workers and offers our conclusions.

[1] Indirect empirical evidence on the importance of adjustment costs is provided by Caballero and Engel (1999), who use industry-level data; by Abel and Eberly (1996), who use firm-level data; and by Caballero, Engel, and Haltiwanger (1995), who use plant-level data.

[2] See Jorgenson (1996) and Fraumeni (1997) for excellent surveys of empirical studies of depreciation.

II. The Market for Used Capital: The Importance of Specificity and Market Thinness

On the basis of discussions with auctioneers, industry insiders, and machine tool manufacturers, we consider the following characterization to be a plausible depiction of the market for used capital. Most capital is specialized by industry, so that used capital typically has greater value inside the industry than outside the industry. Even within an industry, though, capital from one firm may not be a perfect match for another firm. Thin markets and costly search complicate the process of finding buyers whose needs best match the capital's characteristics. The cost of search includes not only monetary costs but also the time it takes to find good matches within the industry. As a result, firms will not search exhaustively for the best match for all their pieces of capital. Firms with high time discount factors may resort to "fire sales," resulting in significantly inferior matches and the reallocation of capital to lower-value uses. This story contains two key elements: sectoral specificity and market thinness. Sectoral specificity can arise when each piece of capital has a certain set of physical characteristics. When new capital is built for sale to a specific sector, it will have the best match of features for that sector.[3] Despite the specificity of these characteristics, capital can be reallocated across sectors. The key is that only some of the characteristics of a particular piece of capital will have value in another sector.

We illustrate this idea with three examples from the aerospace industry and one example from the educational services industry. The first example of specificity is a wind tunnel. A low-speed wind tunnel, capable of producing winds from 10 to 270 miles per hour, was sold to a company outside of the aerospace industry (*San Diego Union-Tribune,* October 23, 1994). This company rents the wind tunnel for $900 an hour to businesses such as bicycle helmet designers and architects who wish to gauge air flows between buildings. Most of the users require only low wind speeds and do not value the fact that the tunnel can produce wind speeds of 270 miles per hour. Thus a key characteristic of this wind tunnel—high wind speeds—has no value outside of aerospace.

A second example is the machine tools used by aerospace manufacturers. The resale market for machine tools is one of the thickest markets for used capital equipment. Nevertheless, there is reason to believe that many of the machine tools used by aerospace industries have features

[3] Firms might design or purchase equipment with ex post flexibility in mind (see Stigler 1939; Fuss and McFadden 1978). (In a visit to an automobile assembly plant, we were told that the firm paid an extra 10 or 15 percent to purchase machine tools that could be easily reconfigured.) Even if this flexibility is built in ex ante, the capital will lose some value if the flexibility needs to be employed ex post, except in the unlikely event that the design made the capital perfectly flexible.

that are substantially less valuable for other industries. As explained to us by a leading machine tool manufacturer, the manufacture of aerospace goods involves much larger pieces of metal than the manufacture of most other goods. As a result, machine tools for aerospace are much bigger and must have significantly higher horsepower than the average machine tool. Consider the example of dual and triple gantry profilers, which constitute some of the equipment in our sample. These pieces of machinery, which can move large portions of fuselage or wing to the cutting area, are 75 feet or more in length and weigh several tons.[4] They have limited use outside of aerospace.

A third example consists of the instruments used by aerospace manufacturers. Because precision is crucial in the manufacture of aerospace parts, the extra precision built into the tools and instruments has a higher value in aerospace than outside aerospace. For example, one coordinate-measuring machine in our sample could test the accuracy of parts at tolerances of less than 0.0001 of an inch. This piece of machinery sold at a substantial discount to a machinery dealer.

Our final example, from outside the aerospace industry, consists of the building currently housing the Department of Economics at the University of California at Riverside. This building is a converted motel, so it is an example of a piece of capital that moved from standard industrial classification (SIC) code 70 (hotels) to SIC code 82 (educational services). Each office has a bathroom complete with shower, and the department has its own swimming pool. While these features have significant value for lodgers and thus affect the value of services offered by a motel, one may question whether these amenities contribute to the productivity of research or teaching of the economics faculty.

These examples show how capital can consist of a bundle of specialized features. Although capital from one industry can be used in another industry in many cases, many of the features will have little or no value to the second industry. Thus the value of the capital decreases when it crosses industries.[5]

The second key element in our story is thin markets. We believe that thin markets for used capital are an important impediment to the efficient reallocation of capital. Our discussions with professional liquidators and auctioneers suggested several transaction costs in the reallocation of capital. Finding buyers whose needs closely match the characteristics of the equipment is a costly and time-consuming process.

[4] An article on the first page of the October 21, 1996, *Wall Street Journal* discusses the case of a dual gantry profiler, purchased new for $5 million and sold for $2,500 at auction. Our empirical results show that this case is not unusual.

[5] Bond (1983) considers a different type of heterogeneity in order to explain why there is substantial trade in used assets. He argues that differences in firms' factor prices and capital utilization lead to different valuations of new vs. used assets.

The sale of the equipment must be advertised, and the process of inspection, negotiation, and capital budgeting can be lengthy. On the other hand, the firm can hold a public auction, which takes place over a couple of days, but it may result in inferior matches between capital characteristics and buyers' needs. Thus firms face a trade-off between selling early at a low price and searching at length for high-valuation buyers. Ramey and Shapiro (1998*b*) provide a model taking into account specificity and market thinness that analyzes this trade-off and shows how firms might endogenously switch between different modes of sale.

The combination of capital specificity and market thinness can serve to add costs to the reallocation of capital across firms and industries. We use these theoretical considerations to motivate our econometric specification in Section V. By examining how the value of reallocated capital varies by who purchased it and by the mode of the sale, we can quantify the equilibrium consequences of capital specificity and market thinness.

III. Data Description

Our data consist of information on capital sales from southern California plants belonging to three large aerospace companies. The aerospace industry underwent enormous downsizing and restructuring in the 1990s owing to the end of the Cold War. The exogeneity and large size of the shock driving the decision to reallocate the capital essentially eliminate concerns about the endogeneity of demand for the factories' output and about nonrandom selection of pieces of equipment.

Variations in defense spending represent major shifts in total demand for aerospace goods. In 1987, shipments to the Department of Defense accounted for 60 percent of total shipments of aircraft (SIC 372) and missiles and space vehicles (SIC 376).[6] Furthermore, Defense Department demand is highly variable. Figure 1 shows real defense purchases of aerospace equipment over time. From 1977 to 1988, real purchases rose 225 percent. From 1988 to 1995, real purchases reversed themselves, declining back to their 1977 levels.

We study three of the many plants that closed in the 1990s. All three plants, which were owned by different firms, were important manufacturers of military or commercial airplanes, as well as missiles. Two of the plants were over 40 years old, and the third was about 20 years old. At the time we obtained the data, the third plant was in the process of slowly paring down operations but had not completely closed. In all cases, after several years of declining production and employment, the

[6] Shipments to the National Aeronautics and Space Administration accounted for another 6 percent of total shipments of aerospace equipment.

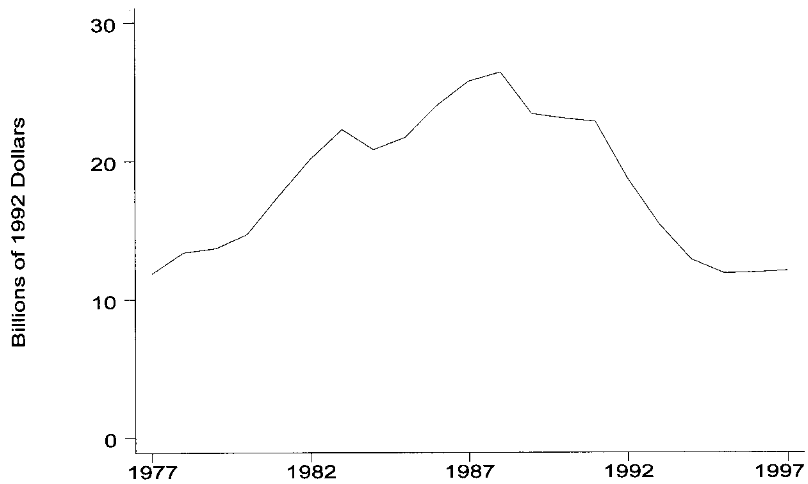

FIG. 1.—Defense purchases of aerospace equipment

firms decided to discontinue operations. The decisions on all these plants, however, came several years after the majority of plant closures, so none of these plants was a marginal plant.

Two of the firms held their sales through the same liquidation and auction company. Plant 1 sold equipment through private negotiation ("private liquidation sale") over the space of four months and then sold the remaining equipment at a public auction that took approximately one week. Plant 2 held no liquidation sale but held a series of public auctions over the year and a half that it was winding down operations. Plant 3 held a public auction through another company. All the public auctions were conducted as English auctions. According to the auctioneers, most of the larger items had multiple bidders. The total proceeds from the sales were $18.7 million. Over 1,000 buyers purchased equipment. Three times as many buyers attended the auctions.

A significant part of the equipment sold was machine tools, such as milling machines, jig mills, and lathes. These are the standard metal-cutting and metal-forming equipment used in manufacturing aircraft parts. But there was also a great variety of other goods sold, such as forklifts, cranes, generators, vibratory finishers, drill bits, and even cafeteria chairs. Thus our data cover a fairly wide span of equipment.

It is interesting to note that the manufacturers did not sell any buildings.[7] Not selling buildings is not unusual for plant closings involving

[7] We do not yet know the outcome for the buildings of plant 3.

plants that are more than 25 years old. Many have found that the cost of bringing the plants up to current environmental standards (e.g., removing asbestos) is greater than the potential sales price, so they simply raze the buildings.

For every item sold in the liquidation sale and public auctions (over 20,000 lots), we obtained information on the complete equipment description, the sales price, and the identity of the buyer. Using business directories, as well as direct phone calls to buyers, we assigned buyers to a four-digit SIC industry. Buyers whose industries we could not identify accounted for less than 4 percent of total sales. The industry information allowed us to track the reallocation of the equipment to various industries.

The most useful data are the information we obtained from plant 1 for an important subset of its equipment. In addition to the information discussed above, the selling company provided us with information on the original purchase year and transaction price as well as the year and cost of any refabrications or rebuilds for almost all the pieces of equipment that sold for $10,000 or more each. We were able to obtain information for 129 lots that accounted for $7.1 million of sales. Hence, though these data are only a small fraction of the number of sales, they account for over half of the value. With this information, we can compare the resale price to the original purchase price and hence estimate the discounts.

The richness of the data set we have collected overcomes many of the criticisms that have been made of studies of sales of used equipment. For example, several features of the data suggest that there should not be a significant "lemons problem." First, the tremendous amount of downsizing that occurred meant that the plants that closed were not marginal plants. Second, we know that the downsizing was due to exogenous demand shifts, not to technological problems in manufacturing aerospace goods. Third, the fact that the plants sold everything they owned means that there is no selection bias in the equipment that was sold.

A second criticism that our data set overcomes is concerns about the price data. Wykoff (1970) questioned his estimates of the steep decline in value in automobiles during the first year because he was forced to compare the price of one-year-old cars to the list price of new cars. If the actual transactions price features discounts off the list price, then the depreciation estimates can be biased. In our case, we have both the actual price that plant 1 paid for the equipment when new and the actual price it received when it resold the equipment. Thus our estimates are based on actual transactions prices.

We conduct three types of analyses of the data that shed light on capital mobility. In Section IV, we compute the distribution of sales of equipment across industries. The extent to which the sales are more concentrated in aerospace or manufacturing relative to the aggregate gives an indication of the specialization of equipment. We also distinguish the distribution of sales according to whether the good was sold through private negotiation or public auction. In Section V, we shall use the subset of sales for which we have original purchase prices to estimate a model of economic depreciation. We shall estimate depreciation rates and compare them to others in the literature. In Section VI, we shall discuss the time lags that were involved in the sale of capital.

IV. Who Bought the Capital and How Was It Sold?

Before we present our results on the sectoral flows of capital from the three plants, it is useful to give an indication of the aggregate demands for equipment for comparison purposes. The Annual Capital Expenditures Survey reports that in 1993 the aerospace industry represented just 0.78 percent of total private expenditures on producers' durable equipment and just 2.5 percent of manufacturing expenditures. Although the aerospace industry is more heavily concentrated in California, it is unlikely that its fraction of investment was much higher, given the downsizing that was occurring. The manufacturing sector as a whole accounted for 32 percent of all investment in producers' durable equipment in 1993.

Against this backdrop, we calculate the flow across sectors of equipment from our data. To our knowledge, this is the first study to track capital equipment as it flows out of a shrinking industry. Using every item sold, we calculated the fraction of goods that went to each industry, by both the value of sales and the number of buyers. Tables 1, 2, and 3 present the distribution of sales of equipment by buyers' industries and locations. Table 1 shows the results for all types of sales combined, table 2 shows the results for the private liquidation sales, and table 3 shows the results for the public auctions.

Table 1 shows one of the central findings of our paper. The equipment is sold disproportionately to buyers within aerospace. A quarter of equipment stays within the sector, 30 times the share of aerospace in overall equipment investment. Nonetheless, three-quarters of the equipment leaves the sector. Hence, specificity is important but not absolute.

Table 1 also shows several other sectors that were major buyers. Machinery dealers bought 23 percent of the equipment. We are not able to track this equipment to its final destination. It is likely that some of this equipment was resold to aerospace manufacturers. The other important set of buyers was firms in the fabricated metals and machinery industries, who together bought 28 percent of the equipment. Many of these industries use the types of machine tools used by aircraft manu-

TABLE 1
Distribution of Sales by Industry and Region: All Sales Included

Industry	Percentage of Sales Value	Percentage of Buyers (N=1,207)
Aerospace (SIC 372, 376)	24.2	5.2
Other transportation equipment	1.6	1.7
Fabricated metals and machinery	27.8	25.9
Other manufacturing	4.0	6.1
Machinery dealers	22.8	14.3
Construction	2.5	3.4
Transportation and public utilities	1.1	1.3
Retail trade	2.8	2.9
Services	5.0	7.9
Individuals	3.9	12.3
Other	.6	.3
Unknown	3.7	18.6
Region:		
California	63.8	89.2
Rest of United States	32.3	9.9
Foreign	4.0	.8
Total sales value	$18,723,607	

Note.—Table includes data from plants 1, 2, and 3.

facturers. Manufacturing as a whole accounted for 58 percent of sales, which is about twice its share in aggregate equipment investment.

We also note the geographic dispersion of sales at the bottom of the table. Over one-third of the equipment was sold to buyers outside of California, and 4 percent was sold to buyers from outside the United States. This calculation of the percentage sold to foreigners is probably an underestimate. Many sales to foreign countries go through U.S. dealers or through individuals who serve as agents.[8]

The data show that capital is not absolutely stationary since more than one-third of it left California. Yet, that California accounted for a much larger share of sales than it does in the aggregate investment data shows that there are costs to geographic mobility. Some of the equipment, such as the double gantry profilers, weighs several tons, so transport costs are nontrivial. In any case, just as with industry, geographical specificity is substantial, but not absolute.

Tables 2 and 3 show that there is a significant difference in the buyers through private liquidation and public auction. Table 2 shows that two-thirds of the sales value from the liquidation sale went to other aerospace

[8] According to some auctioneers, a significant part of the equipment sold at aerospace auctions was sold to foreign manufacturers in China and India. China obtained some weapons-manufacturing equipment illegally through individuals who attended defense industry auctions (*Wall Street Journal,* October 21, 1996, p. A1).

TABLE 2
Distribution of Sales by Industry and Region: Private Liquidation Sales

Industry	Percentage of Sales Value	Percentage of Buyers ($N=22$)
Aerospace (SIC 372, 376)	66.8	36.4
Other transportation equipment	0	0
Fabricated metals and machinery	10.1	22.7
Other manufacturing	.7	4.5
Machinery dealers	22.4	36.4
Construction	0	0
Transportation and public utilities	0	0
Retail trade	0	0
Services	0	0
Individuals	0	0
Other	0	0
Unknown	0	0
Region:		
California	36.4	36.4
Rest of United States	54.6	59.0
Foreign	9.0	4.6
Total sales value	$4,688,528	

Note.—Table includes data from plant 1.

firms, whereas table 3 shows that only 10 percent of the public auction sales went to aerospace firms. The characterization of markets for used capital discussed in Section II is helpful for interpreting these results. If aerospace firms have higher valuations for the equipment but are harder to locate because of thin market effects, the selling firms must spend time and effort seeking out other aerospace firms. Thus we would expect most of the private liquidation sales to go to other aerospace firms. When the expected return from this process becomes low enough, the firm sells all remaining units at a public auction. Most of the sales at public auction are made to industry outsiders. Firms that cannot afford to wait during the search process sell all their equipment at public auction.

We can also explain why some plants had private liquidation sales and others did not. Plant 1 had a private liquidation sale before its public auction, whereas plant 2 did not. Plant 3 had an initial public auction (from which our data for the plant are taken) but planned to have a liquidation sale later as production decreased. At the time of its closing, plant 1 was owned by a firm that was cash rich. In contrast, at the time of its closing, plant 2 was owned by a firm that was heavily indebted and had low bond ratings. Plant 3 was also more heavily indebted than plant 1. On the basis of these factors, one would expect the time discount rate of the owner of plant 1 to be much lower than those of the owners

TABLE 3
DISTRIBUTION OF SALES BY INDUSTRY AND REGION: PUBLIC AUCTIONS

Industry	Percentage of Sales Value	Percentage of Buyers (N=1,185)
Aerospace (SIC 372, 376)	10.0	4.6
Other transportation equipment	2.2	1.7
Fabricated metals and machinery	33.7	26.0
Other manufacturing	5.1	6.2
Machinery dealers	22.9	13.9
Construction	3.4	3.5
Transportation and public utilities	1.5	1.4
Retail trade	3.8	3.0
Services	6.7	8.0
Individuals	5.2	12.6
Other	.8	.3
Unknown	4.9	18.9
Region:		
California	72.9	90.2
Rest of United States	24.8	9.0
Foreign	2.3	.8
Total sales value	$14,035,080	

NOTE.—Table includes data from plants 1, 2, and 3.

of plants 2 and 3. Thus these two plants would be expected to spend less time searching for other buyers inside the industry. This appears to be exactly what happened in plant 2. Only 4.6 percent of plant 2's sales went to aerospace buyers. In contrast, 32 percent of the sales from plant 1 went to aerospace buyers. Since the plants appear to have similar equipment, we attribute the difference in the pattern in sales to the impatience of the firms rather than to differences in the quality of potential matches to buyers within the industry.

These results are consistent with Pulvino's (1998) findings for airlines. He found that financially constrained airlines receive lower prices than unconstrained airlines when selling used aircraft. Furthermore, also consistent with our results, he found that financially constrained airlines are more likely to sell their aircraft to a financial institution.

V. Estimates of Discounts and Economic Depreciation

A. *Overview*

In this section we use the subset of equipment from plant 1, for which we have data on original purchase prices, to obtain estimates of the loss of value suffered by capital sold as part of the consolidation and downsizing of an industry. We begin with a summary of the data and a discussion of depreciation estimates from other studies. We then estimate several versions of a model of economic depreciation. Three main results emerge from the estimation: (1) equipment sold for significant discounts relative to the estimated replacement cost, (2) more specialized equipment sold for a higher discount, and (3) equipment bought by other aerospace firms or through the private liquidation sale sold for a higher premium.

As discussed in Section III, this subset of data consists of 129 lots with a total sales value of $7.1 million. To put the data on a current-cost basis, we reflate the original acquisition cost plus the cost of subsequent investment for rebuilds using implicit deflators for investment goods.[9] In theory, these indexes should measure the change in price when quality is held constant, so the reflated values represent replacement cost.[10]

Figure 2 shows a plot of the ratio of the sales price to the reflated original acquisition cost against age. The figure shows the raw data on initial purchase cost except for the adjustment for price change. In subsequent analysis, we shall take into account depreciation and rebuilds. The size of the circle is proportional to the reflated original cost. Several features stand out in the data. First, it is clear that there were several large items with ages up to 15 years that suffered huge declines in value. Second, some of the equipment that was nearly 50 years old sold for a large fraction of its original purchase price. We double-checked these data to make sure they were not errors. We were told that there were certain types of machinery manufactured 50 years ago that were used only by aircraft manufacturers at the time. Later, however, other manufacturers started using this type of machinery, and since these exact types are no longer manufactured, many non–aircraft manufacturers are willing to pay a high premium to acquire it. There is also significant selectivity in these data since our sample excludes previously retired equipment.

Before we estimate rates of depreciation, it is useful to review estimates

[9] We are not revealing the price year of the auction to protect the confidentiality of the company. We reflate the acquisition cost by multiplying the historical cost by the ratio of the deflator in the year of the auction to the year of the purchase. We calculate the implicit deflator as the ratio of historical cost to the chain-weighted quantity index using the investment series from the Bureau of Economic Analysis's (BEA) capital stock data. We use the deflator for investment in metalworking machinery for the machine tools and similar equipment, the instruments investment deflator for the instruments, the deflator for investment in computers for computers, the price deflator for turbines for a generator, the deflator for construction tractors for gas-driven forklifts, and the deflator for investment in industrial equipment for the remaining items.

[10] Of course, price indexes can systematically miss changes in quality and therefore grow too fast or too slow. According to Gordon's (1990) estimates, Bureau of Labor Statistics price indexes miss quality improvements at the rate of roughly 1 percent per year. If the rate of omitted quality change is roughly constant per year, it will lead us to overstate the estimated rate of depreciation.

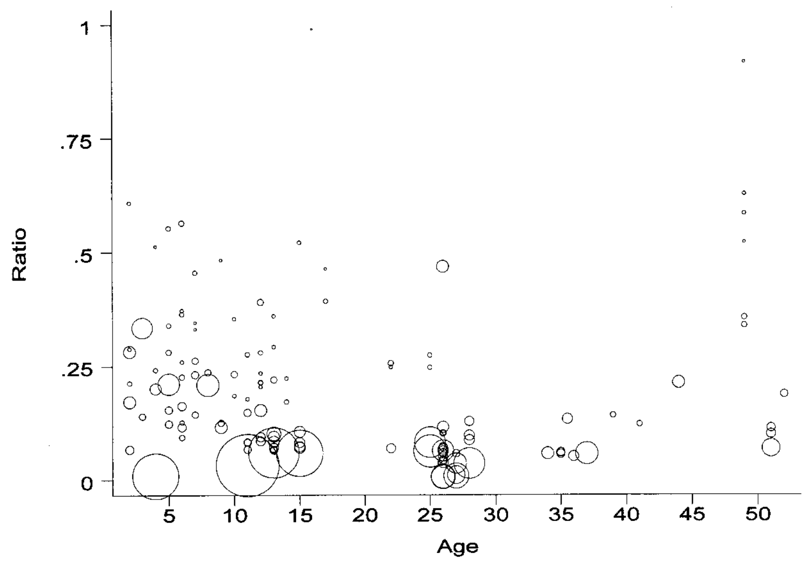

FIG. 2.—Ratio of sales price to reflated initial cost. The size of the circle is proportional to the reflated initial cost (not adjusted for depreciation).

obtained by others of economic depreciation rates. Hulten and Wykoff (1981) and Hulten, Robertson, and Wykoff (1989) applied Hall's (1971) hedonic model of asset prices to data on used capital sales to estimate economic depreciation rates. For example, Hulten et al. used data from the Machine Dealers National Association from 1954 to 1983 to estimate economic depreciation rates for machine tools. Their data have many more observations (almost 3,000) than ours, but unfortunately have no information on the original cost or the industry of the buyers and sellers. Several of their findings are of interest. First, geometric depreciation is a good approximation to the estimates they obtain using more flexible functional forms. Second, in a summary of their work, Hulten and Wykoff (1996) report estimated depreciation rates for a variety of equipment. They report an annual depreciation rate of 12 percent for industrial machinery and rates varying from 12 to 18 percent for other equipment (excluding automobiles and computers, which have depreciation rates up to 30 percent).

In estimating the depreciation rates, these authors correct for sample selection problems induced by the fact that some equipment is retired rather than sold. Our plant may have retired or sold equipment in the normal course of business prior to the liquidation. Thus it would be correct to make comparisons with estimates from other studies that are *not* corrected for sample selectivity. According to Oliner (1996), Hulten et al.'s (1989) parameter estimates imply an unadjusted annual depreciation rate of 4.97 percent for a 12-year-old milling machine. Oliner himself surveyed machinery dealers in the mid 1980s and estimated a depreciation rate of 3.5 percent for the group of machine tools still in operation. Beidleman (1976) estimated a geometric depreciation rate of 7.48 percent for unretired equipment. Thus the relevant estimates for our comparison range from 3.5 to 7.5 percent.[11]

Finally, it is important to bear in mind that because we examine the liquidation of an entire factory, our data do not suffer from the selection problem of equipment that is kept in service versus equipment that is disposed of (whether through retirement or sale).

B. *Depreciation by Type of Equipment and the Value of Rebuilds*

We begin by examining the age-related depreciation structure of the equipment and the returns on different categories of equipment. We estimate the following model that relates the sales price to the replacement cost of capital and the replacement cost of capital to age and other characteristics. Equation (1) relates the sales prices of lot i, S_i, to the current-dollar (reflated), depreciated acquisition cost of initial investments in the lot, K_i. Equation (2) *defines* K_i as a function of the current-dollar investment I_{iv}. These equations are as follows:

$$S_i = c_0 + (1 - \alpha_m - \gamma_r) \cdot K_i + \epsilon_i \tag{1}$$

and

$$K_i = \sum_v I_{iv} \cdot \exp[-(\delta_1 \cdot \text{age}_{iv} + \delta_2 \cdot \text{age}^2_{iv})]. \tag{2}$$

Let us explain in detail the parameterizations of these equations. (Table 4 summarizes the notation.) Equation (2) is the standard definition of the net capital stock from depreciated, current-dollar investment flows with several modifications. First, we need to sum over the items in the lots, indexed by v. For most lots, there is only one item, but for several there are two. Second, we strongly reject that depreciation is geometric in the *age* of the equipment, so we include a quadratic as well to capture

[11] The BEA uses estimates based on the work of Hulten and Wykoff for its new data on the capital stock (see Fraumeni 1997). Since the BEA uses a perpetual inventory of investment with no systematic data on retirements, the appropriate depreciation rate for its calculation does take into account the fact that some of the past investment flows are no longer in service. Since our data exclude previously retired equipment, we estimate a lower rate of depreciation than would be appropriate for the BEA's calculation.

TABLE 4
NOTATION USED IN EQUATIONS (1), (2), (1′), AND (1″)

Variable	Definition
Indices:	
i	Index for lots
v	Index for investments (within a single lot)
m	Index for types of equipment
Parameters to be estimated:	
c_0	Constant term
α_m	Discount on replacement cost of capital of machinery type m
γ_r	Discount on rebuilt equipment
δ_1	Depreciation parameter on age
δ_2	Depreciation parameter on the square of age
λ_{aero}	Premium for goods sold to aerospace buyers
λ_{liq}	Premium for goods sold at the private liquidation sale
Variables:	
S_i	Price at which lot i sold, in thousands of dollars
K_i	Estimated replacement cost, in thousands of dollars
ϵ_i	Error term
I_{iv}	Investment expenditure v on lot i, reflated cost in thousands of dollars
Age_{iv}	Years since vth investment on lot i

the nonconstancy of the depreciation rate. The coefficients δ parameterize the depreciation rate.

We substitute the definition (2) into equation (1), so we estimate a single equation with a single error term ϵ_i. With γ_r and α_m equal to zero, equation (1) provides an estimate of the depreciation rate parameters from (2), so all loss in value of initial investment is related to age. A key finding of this paper, however, is that not all loss of value is related to age. Hence, we introduce the parameters α_m and γ_r to capture discounts not related to age. The m subscript on α indexes type of equipment. We want to examine whether the discounts or premia vary by how specialized the types of equipment are. (To avoid a lot of dummy variables in the notation, we use the following convention: If the lot contains equipment type m, α_m is nonzero; otherwise it is zero. We use similar notation for the other subscripted parameters.)

Some of the equipment was rebuilt. The parameter γ_r allows these lots to sell at a premium or discount. (Again, $\gamma_r = 0$ for lots that have no rebuilds.) There are a number of ways that we could capture the effect of rebuilds. In the Appendix, we explore various possibilities, including the expenditure on rebuilds explicitly in equation (2). We find that the parsimonious specification of equation (1) is supported by the data, so we use it in all the main results.

The error term ϵ in equation (1) arises from different preferences for machinery features, different outcomes in the search process, and idiosyncratic differences in the rate of physical depreciation, all of which are assumed to be independent of the original purchase price. The constant term is included to ensure a mean zero error term.

An important result is the extent to which the discount or premium α varies by type of equipment m. In defining the types of equipment, we aimed to group similar equipment within type and highlight the specialization of the equipment across types. We classified the equipment into the following six categories (N denotes the number of lots in each category): machine tools ($N = 99$), bridge and gantry-type profilers ($N = 7$), instruments and measuring devices ($N = 7$), forklift-type equipment ($N = 6$), miscellaneous equipment ($N = 8$), and structural equipment ($N = 2$). Machine tools are the largest category and represent a variety of milling machines, grinders, and other similar types of equipment. We could not find any meaningful way to break this category up any further.

The other groups contain much smaller numbers of items, although in some cases they represent significant amounts of revenue. Although profilers are technically machine tools, we classified them as a separate group. Recall that profilers are relatively specialized to aerospace because they contain large gantry systems for moving large pieces of metal. Similarly, we put instruments in a separate category in case these items also have some specificity to aerospace. The forklifts category represents the most general capital of any in our subsample, containing forklifts and electric loaders.[12] Even these items were somewhat specialized in that they were large enough to be able to move large parts of a fuselage. Miscellaneous equipment contains items such as ovens, vibratory finishers, and computers.

The final category, structural equipment, consists of only two very large, complex, and expensive items that required costly disassembly and reassembly in order to be sold. Initial estimation showed that the two structural pieces of equipment noticeably lowered the exponential depreciation estimates, even after we allowed for a different discount α. These two lots are influential observations because of their very high initial cost and very high discount. We do not believe that they add any real information on age-related depreciation because there is heterogeneity between the two items within this category. Nor do they provide information for the later analysis by buyer and mode of sale because

[12] Recall that this sample for the regressions contains only items that sold for \$10,000 or more. Thus the items such as cafeteria chairs are not in the sample.

TABLE 5
ESTIMATES OF DEPRECIATION RATES AND DISCOUNTS BY TYPE OF EQUIPMENT

Parameter and Variable	Quadratic (1)	Geometric (2)
c_0: Constant	1.764 (2.404)	4.132 (2.496)
δ_1: Age	.090 (.014)	.051 (.0072)
δ_2: Age^2	−.0013 (.0003)	0
α_m:		
Discount on machine tools	.629 (.048)	.698 (.039)
Discount on instruments	.631 (.072)	.739 (.053)
Discount on miscellaneous	.688 (.022)	.738 (.013)
Discount on profilers	.836 (.024)	.879 (.013)
Discount on forklifts	.419 (.126)	.576 (.082)
γ_r: Discount on rebuilt equipment	.110 (.017)	.087 (.013)
Standard error of regression	26.432	28.011
Log likelihood	−591.4	−599.3
$\bar{R}^2$	.931	.922

NOTE.—Heteroskedastic-consistent standard errors are in parentheses. The sample consists of the 127 pieces of equipment from plant 1. The data are measured in thousands of current dollars. The estimated model is given in eqq. (1) and (2).

they were both bought by dealers and sold during the liquidation sale. Thus we decided to omit them from the basic regression analysis. Appendix table A2 shows estimates with these pieces of equipment included.

With these preliminary specification choices out of the way, we can now present estimates of equations (1) and (2) for the 127 nonstructural items, broken into the five equipment categories. Column 1 of table 5 shows the main results. The age-related depreciation rates, given by the δ's, imply annual depreciation rates that are consistent with the literature. These very precise estimates imply an average annual depreciation rate for our sample of 4.9 percent per year. The δ_2 parameter is estimated to be significantly different from zero, so our model statistically rejects geometric depreciation. We shall discuss the depreciation rates in greater detail below in the context of another table.

Of particular interest are the estimates of the α's for the various types of equipment. Recall that most other studies of depreciation of used industrial equipment could not estimate an α for lack of information on the initial purchase price. Our estimates indicate that the estimate of α for every group of equipment is significantly positive, meaning that all groups of equipment sold for significant discounts relative to estimated replacement cost. The discounts range from 42 percent for forklifts to 84 percent for profilers. Thus the most specialized equipment —profilers—appears to have suffered substantially higher discounts than the least specialized equipment—forklifts. Machine tools, instru-

TABLE 6
Depreciation Rates

Age in Years	Type of Equipment	Depreciation Rate
0	Machine tools	.620 (.045)
0	Instruments	.621 (.063)
0	Miscellaneous	.678 (.019)
0	Profilers	.826 (.022)
0	Forklifts	.409 (.119)
1	All	.088 (.013)
5	All	.078 (.011)
10	All	.065 (.008)
15	All	.053 (.006)
20	All	.040 (.004)
30	All	.015 (.006)
Average age (weighted by net capital stock)		15.7 years

Note.—The estimated depreciation rates are based on the preferred specification, col. 1 of table 5, and are calculated analytically from the coefficient estimates. The age 0 depreciation rate represents the "instantaneous depreciation" from selling a "new" piece of equipment; i.e., it is one minus the ratio of the predicted sales price to the estimated replacement cost of a new item. For age greater than zero, the table reports the *annual* depreciation rate implied by the estimates. They are constrained to be equal across types of equipment.

ments, and miscellaneous equipment all have discounts estimated to be between 63 and 69 percent.[13]

Finally, the results suggest that since γ_r is estimated to be significantly positive, rebuilt equipment receives a discount in the market. That is, rebuilt equipment sells for less than nonrebuilt equipment, even though the specification in equations (1) and (2) omits the cost of the rebuilds (see the Appendix). The fact that a piece of equipment was rebuilt may be a signal that it was more worn or more customized.

Although we reject the geometric specification for depreciation, it is nevertheless of interest to examine the results from such a model since it is so widely used. Column 2 of table 5 shows the estimates of the model when we constrain the age-related depreciation structure to be geometric. This specification, which we can reject in favor of the more flexible one in column 1, implies a geometric depreciation rate of 5 percent. In this specification, all the α's are estimated to be somewhat higher than in the previous specification.

Table 6 uses the estimates from the preferred specification in column 1 of table 5 to show various depreciation rates at different ages. Two kinds of estimates are shown. The first set of estimates is the estimated depreciation rates at age 0. These numbers represent the "instantane-

[13] Recall that we omitted the two structural items from the sample when estimating the equations for table 5. As App. table A2 shows, when structures are included, the estimated α for structures is .96, with a standard error of .019. Thus the discount on structures is the highest of any capital in our sample, presumably because of high costs of disassembly and transportation.

ous" depreciation, that is, the estimated fall in price when an item that was just bought new has to be resold immediately. The instantaneous depreciation rate is calculated from the estimates as one minus the ratio of the predicted sales price to the estimated replacement cost of an item of age 0, that is,

$$\text{instantaneous depreciation rate} = 1 - \frac{\hat{c}_0 + (1 - \hat{\alpha}_m) \cdot I}{I}.$$

If the constant term were equal to zero, this number would be equal to the marginal discount, α_m. Because of the constant term, this value can differ across lots with different original costs. In practice, however, the constant term is estimated to be very small relative to the original reflated cost of the items. The age-dependent depreciation estimates are based on δ_1 and δ_2 and show the annualized rates of depreciation for selected ages between one year and 30 years.

The instantaneous depreciation rates are estimated to be very high. They range from .409 for forklifts to .826 for profilers. The estimate of a 62 percent instantaneous depreciation for machine tools implies that a machine bought for $100,000 and immediately resold in the used market would fetch only $38,000. The discount is even greater for profilers. A $100,000 machine would fetch only $17,000. On the other hand, the estimate for forklifts suggests an instantaneous depreciation rate of "only" 41 percent.

As discussed earlier, the estimated age-related depreciation rates are similar to those from the literature. Recall that our sample excludes any equipment that was scrapped earlier, so the relevant comparison is made to estimates unadjusted for previous retirements. According to our estimates, the annual depreciation rate declines with age, from 8.8 percent at one year to 1.5 percent at 30 years. The average age of the net of depreciation stock of equipment in our sample is 15.7 years. The average depreciation rate is 4.9 percent. This number lies in the range found in the literature.

It is also informative to compute the ratio of total revenue from sales to the estimate of total replacement cost. This average return (i.e., average Brainard-Tobin's q) can be calculated as

$$\text{average } q = \frac{\sum_N S_i}{\sum_N \sum_V I_{iv} \cdot \exp\,[-(\hat{\delta}_1 \cdot \text{age}_{iv} + \hat{\delta}_2 \cdot \text{age}^2_{iv})]}.$$

The numerator is the sum of the sales prices, and the denominator is the estimated replacement cost. We use the estimated values of the δ's from the preferred model in column 1 of table 5. According to these estimates, average q is 0.28.

Overall, the estimation by type of equipment shows several results.

TABLE 7
Distribution of Sales: Regression Sample

Industry of Buyer	Mode of Sale: Private Liquidation (1)	Mode of Sale: Auction (2)	Total (3)
Aerospace	45.3	3.9	49.2
Nonaerospace	9.1	41.7	50.8
Total	54.4	45.6	100.0

Note.—The figures in the table are percentages of total sales. The sample is the same as in table 5.

First, the estimated depreciation rates are very similar to those from the literature. Our estimates range from 1.5 to almost 9 percent, which accords well with the estimates from the literature that do not adjust for selectivity due to retirement. Second, all types of equipment sold for a substantial discount relative to their estimated replacement cost. The average return on the estimated replacement cost was only 28 cents on the dollar. Third, the items specialized to aerospace suffered the largest discounts.

C. *Estimates by Industry of Buyer and Mode of Sale*

We now study whether the price received varies systematically with the industry that bought the equipment or with the mode of sale. In particular, we distinguish between aerospace buyers and nonaerospace buyers and between sale through private liquidation and sale through public auction. Recall that the company sold some of the equipment through a private liquidation sale that lasted several months before it sold the rest of the equipment at auction. A priori, one could expect the results by industry of buyer to go in either direction. For example, if aerospace buyers are the only potential buyers for the more specialized equipment, we might expect that equipment bought by aerospace buyers would sell for less than the more general equipment that sold outside the industry. On the other hand, if aerospace buyers have higher valuations for the equipment because it is specialized, they might end up paying more.

Table 7 shows the breakdown of sales between industries of buyers and modes of sale for the lots that we use in our estimation. The value of sales is split roughly equally by industry of buyer and by mode of sale, as column 3 and the last row make clear. There is, however, a strong correlation of buyer industry and mode of sale. Most purchases of aerospace buyers occurred at the private liquidation sale. Most sales at the public auction went to nonaerospace buyers.

To determine whether there is any difference between the discounts between aerospace buyers and industry outsiders and between modes

TABLE 8
ESTIMATES OF DEPRECIATION BY INDUSTRY OF BUYER AND MODE OF SALE

Parameter and Variable	By Industry of Buyer (1)	By Mode of Sale (2)	By Industry of Buyer and Mode of Sale (3)
c_0: Constant	7.003 (2.479)	8.343 (2.408)	8.282 (2.634)
δ_1: Age	.093 (.012)	.087 (.011)	.091 (.011)
δ_2: Age^2	−.0014 (.0003)	−.0011 (.0002)	−.0012 (.0003)
α_m:			
Discount on machine tools	.717 (.034)	.753 (.039)	.745 (.042)
Discount on instruments	.709 (.063)	.733 (.060)	.730 (.062)
Discount on miscellaneous	.772 (.024)	.807 (.030)	.798 (.033)
Discount on profilers	.881 (.018)	.896 (.018)	.893 (.020)
Discount on forklifts	.592 (.130)	.576 (.105)	.607 (.121)
γ_r: Discount on rebuilt equipment	.069 (.024)	.030 (.034)	.049 (.032)
λ_{aero}: Aerospace premium	.396 (.136)		.291 (.106)
λ_{liq}: Liquidation sale premium		.548 (.227)	.246 (.198)
Standard error of regression	24.854	25.037	24.801
Log likelihood	−583.0	−584.0	−582.2
$\bar{R}^2$	.939	.938	.939

NOTE.—Heteroskedastic-consistent standard errors are in parentheses. The sample consists of 127 pieces of equipment from plant 1. The data are measured in thousands of current dollars. The estimated model is given by eqq. (1′) and (2).

of sale, we estimate the following extension of equation (1) of the earlier model:

$$S_i = c_0 + (1 + \lambda_{aero} + \lambda_{liq}) \cdot (1 - \alpha_m - \gamma_r) \cdot K_i + \epsilon_i. \qquad (1')$$

The definition of K_i in equation (2) remains unchanged. This model allows the premium λ to differ by industry of buyer and mode of sale in addition to the difference by type of equipment. We do not have enough data to estimate separate premia by type of equipment and by industry of buyer or mode of sale. Hence, we use the common premia λ_{aero} and λ_{liq} multiplied by $1 - \alpha_m - \gamma_r$ to allow for this heterogeneity. (Again, λ_{aero} is nonzero for lots sold to aerospace and zero otherwise; λ_{liq} is nonzero for lots sold in the private liquidation sale and zero for lots sold at the public auction.) Below, we also show results for machine tools alone, which is a more homogeneous sample.

Table 8 shows the results of estimating the model. Column 1 shows the results when we distinguish by industry of buyer but not by mode of sale. The estimate of λ_{aero} is .396 and is significantly different from zero. This estimate implies that goods that sold to other aerospace companies sold for a 40 percent premium relative to goods that sold to outsiders. The estimates of the discounts by equipment (the α_m's) are higher since in this specification they represent the discounts for selling to outsiders. The parameters for the age-related depreciation rate, the δ's, do not change noticeably.[14]

Column 2 distinguishes by mode of sale, but not by industry of buyer. The estimated premium for a piece of equipment sold through the private liquidation sale is 55 percent and is significantly different from zero. Comparison of the standard errors of the regressions across columns 1 and 2 suggests that distinguishing by type of buyer fits the data slightly better than distinguishing by mode of sale.

Column 3 shows the results of the model in which we distinguish by both industry of buyer and mode of sale. The estimate for the aerospace premium is 29 percent and for the liquidation sale premium is 25 percent. These estimates imply that equipment sold to an aerospace firm at the private liquidation sale had a premium of 54 percent.[15]

In order to determine whether the difference across industry of buyers and mode of sale is due to differences in types of equipment bought, we reestimate the model for machine tools alone, which is a relatively homogeneous category. These estimates are shown in table 9. These results suggest even higher premia for equipment sold to aerospace buyers or through the private liquidation sale. The premium for aerospace is 57 percent, and the premium for the liquidation sale is 76 percent. When both types of premia are included, both are estimated to be positive. The premium for aerospace buyers is larger and more precisely estimated than the premium for the private liquidation sale.

The results of tables 8 and 9 indicate that equipment sold for significantly more if it sold to buyers from within the industry. Thus the equipment sold by this aerospace plant appeared to have a significantly higher value to other aerospace firms than to firms outside the industry. The results also suggest a mechanism by which the selling firm was able to search out other aerospace buyers who had particularly high values for the equipment: The selling firm may have used the private liquidation sale to seek out these buyers.

Our preliminary data analysis suggested that the premium paid by insiders is most pronounced for machines of relatively recent vintage. To document this finding, we consider one final variation on our model in which we allow the buyer and mode of sale premia to differ with the age of the equipment. In particular, we introduce new parameters into

[14] On the other hand, the constant term, for which we do not have a good economic interpretation, becomes larger and significantly different from zero in this specification. The estimate of 7 (which is in units of a thousand dollars) implies that the average discount is lower on the items with lower initial cost. We do not have a good explanation for this fact.

[15] We also examined whether there was a premium or discount for selling to foreign buyers. Introducing a λ_f into eq. (1′) in place of the λ_{aero} and λ_{liq} yields an estimated premium for sales to foreign buyers of .39 with a standard error of .15.

TABLE 9
ESTIMATES OF DEPRECIATION BY INDUSTRY OF BUYER AND MODE OF SALE: MACHINE TOOLS ONLY

Parameter Variable	Baseline (1)	By Industry of Buyer (2)	By Mode of Sale (3)	By Industry of Buyer and Mode of Sale (4)
c_0: Constant	2.802	9.455	11.851	11.277
	(2.633)	(2.287)	(2.096)	(2.102)
δ_1: Age	.096	.103	.093	.099
	(.015)	(.009)	(.010)	(.008)
δ_2: Age^2	−.0014	−.0015	−.0011	−.0013
	(.0003)	(.0002)	(.0002)	(.0002)
α_m: Discount on machine tools	.620	.733	.777	.765
	(.051)	(.030)	(.033)	(.035)
γ_r: Discount on rebuilt equipment	.079	−.008	−.048	−.034
	(.031)	(.044)	(.047)	(.050)
λ_{aero}: Aerospace premium		.566		.417
		(.175)		(.122)
λ_{liq}: Liquidation sale premium			.764	.335
			(.250)	(.211)
Standard error of regression	28.802	26.245	26.500	26.174
Log likelihood	−470.6	−460.9	−461.8	−460.1
$\bar{R}^2$	.830	.859	.856	.859

NOTE.—Heteroskedastic-consistent standard errors are in parentheses. The data are measured in thousands of current dollars. The sample consists of 99 machine tools. The estimated model is given by eqq. (1′) and (2).

equation (1′) to allow the premium by industry of buyer and mode of sale to be a function of age:

$$S_i = c_0 + (1 + \lambda_{1,\text{aero}} + \lambda_{2,\text{aero}} \cdot \text{age}_i + \lambda_{1,\text{liq}} + \lambda_{2,\text{liq}} \cdot \text{age}_i) \cdot (1 - \alpha_m - \gamma_r) \cdot K_i + \epsilon_i. \quad (1'')$$

Table 10 shows the estimates of the more general model. Columns 1 and 2 show the estimates for the sample of all equipment, and columns 3 and 4 show the estimates for machine tools only. We find similar results across all columns. The premia for both aerospace buyers and the private liquidation sale appear to be a significant negative function of age. At age equal to zero, the aerospace premium is estimated to be between 74 percent and 100 percent, depending on the sample. At age equal to zero, the liquidation sale premium is estimated to be between 90 percent and 110 percent.

Figures 3 and 4 illustrate the temporal patterns implied by the estimates by showing the fitted values of q, which is the ratio of the predicted sales price to the reflated original cost. Using the estimates from columns 1 and 2 of table 10, we calculate the fitted values for a machine tool with the median reflated original cost and no rebuilds. Each age for which we have at least one observation is represented by a point. In figure 3, an A indicates the fitted value for an item bought by an

TABLE 10
ESTIMATES OF DEPRECIATION BY INDUSTRY OF BUYER AND MODE OF SALE: AGE-VARYING PREMIA

	ALL EQUIPMENT		MACHINE TOOLS ONLY	
PARAMETER AND VARIABLE	By Industry of Buyer (1)	By Mode of Sale (2)	By Industry of Buyer (3)	By Mode of Sale (4)
c_0: Constant	7.069	5.918	9.506	9.074
	(2.201)	(1.699)	(2.232)	(1.678)
δ_1: Age	.072	.076	.083	.083
	(.016)	(.010)	(.015)	(.009)
δ_2: Age^2	−.0011	−.0015	−.0013	−.0015
	(.0003)	(.0003)	(.0003)	(.0002)
α_m:				
Discount on machine tools	.774	.790	.789	.808
	(.039)	(.025)	(.042)	(.025)
Discount on instruments	.755	.734		
	(.062)	(.050)		
Discount on miscellaneous	.821	.837		
	(.030)	(.019)		
Discount on profilers	.907	.911		
	(.019)	(.012)		
Discount on forklifts	.675	.579		
	(.117)	(.081)		
γ_r: Discount on rebuilt equipment	.057	.058	.001	.016
	(.018)	(.022)	(.031)	(.038)
$\lambda_{1,\text{aero}}$: Aerospace dummy	.735		.969	
	(.231)		(.337)	
$\lambda_{2,\text{aero}}$: Aerospace × age	−.023		−.026	
	(.010)		(.013)	
$\lambda_{1,\text{liq}}$: Liquidation dummy		.898		1.136
		(.226)		(.308)
$\lambda_{2,\text{liq}}$: Liquidation × age		−.032		−.036
		(.004)		(.005)
Standard error of regression	24.375	23.529	25.817	25.243
Log likelihood	−580.0	−575.5	−458.7	−456.5
$\bar{R}^2$	.941	.945	.863	.869

NOTE.—Heteroskedastic-consistent standard errors are in parentheses. There are 127 lots in the "all equipment" sample and 99 lots in the "machine tool" sample. The data are measured in thousands of current dollars. The estimated model is given by eqq. (1″) and (2).

aerospace firm and an *O* indicates an item bought by an outsider. Figure 4 shows the similar fitted values by mode of sale, where an *X* denotes an item sold at public auction and an *L* denotes an item sold at the private liquidation sale.

Both figures 3 and 4 show a similar pattern: Equipment sold to aerospace buyers or sold through the private liquidation sale had higher premia. In both cases, though, the premium declines with the age of the item. The graphs indicate that for items 30 years and older, there is no extra premium for either aerospace buyers or liquidation sale.

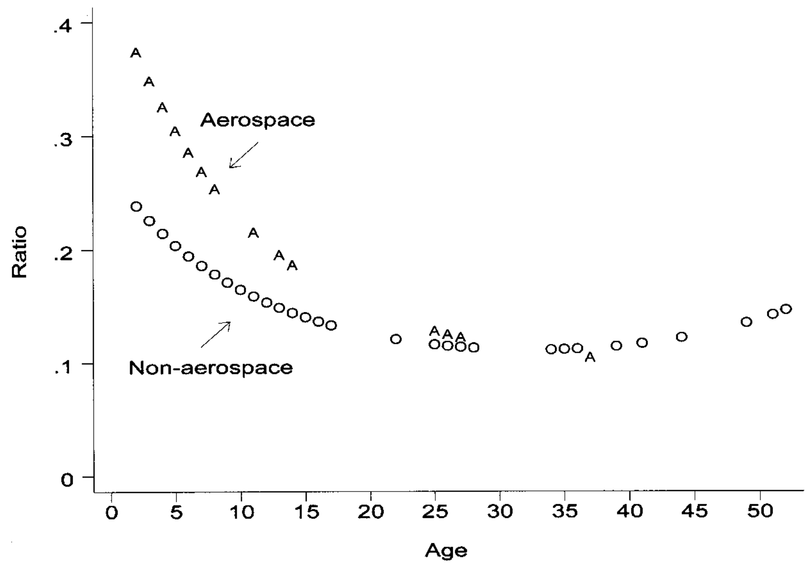

FIG. 3.—Fitted ratio of sales price to replacement cost by industry of buyer. Estimates are based on col. 1 of table 10. An *A* denotes a lot sold to a buyer from the aerospace industry; an *O* denotes a lot sold to a buyer from a nonaerospace industry.

D. Limitations of the Estimates

The results of this section present evidence of a sizable wedge between the replacement cost of capital and the value that a firm obtains when it sells it. As the next section documents, these estimates need to be augmented by the time cost of reallocation. This subsection briefly considers other reasons why our estimates might not be representative or might not tell the whole story.

First, the value of the seller and the buyer of the equipment need not be equal. The prices we analyze are what the seller received. The buyer typically pays an additional premium to the auction company (usually 10 percent). The buyer is also responsible for the cost of transportation and reinstallation. Additionally, standard auction theory suggests that the price paid at auction, on average, is equal to the second-highest valuation. The distance between the first- and second-highest valuation depends on the distribution of valuations of the buyers. Since we were told that there were usually a good number of bidders on many items, we are led to believe that this wedge is not too large. In the case of the private liquidation sales, the markets are thinner. Our results show that the selling firm is able to extract more value in the private

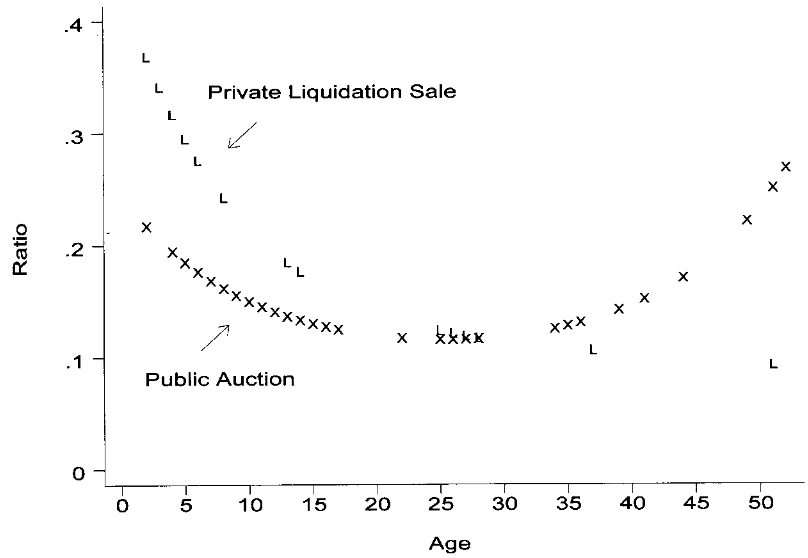

FIG. 4.—Fitted ratio of sales price to replacement cost by mode of sale. Estimates are based on col. 2 of table 10. An *L* denotes a lot sold in the private liquidation sale; an *X* denotes a lot sold in the public auction.

sale than in the auction. Our interpretation of this finding is that the costly mechanism of the private liquidation sale facilitates achieving a better match between buyer and seller. We do not know, however, how many actual and potential customers there were in the private sales. Hence, though our results suggest that the private sale improved the match between buyer and seller, we cannot assess quantitatively the efficiency of the market.

Second, the high discounts we find for the sale of capital could arise from adverse selection or low quality of the equipment. Yet, as mentioned earlier, the equipment sold is not subject to the usual lemons problems because the plants we study were among the last closed by their respective firms and all their equipment was sold.[16] Indeed, basing the sample for the regressions on equipment that sold for more than $10,000 might bias our estimates upward. It is also unlikely that the large discounts were due to poor-quality equipment. Our industry sources report that the equipment in the aerospace industry is typically

[16] Bond (1982) finds no evidence of lemons problems even in the market for used trucks. He compares maintenance costs of trucks bought used to those of trucks that have not been traded and finds no significant difference.

well maintained. Finally, it is unlikely that the high discounts are due to technological obsolescence. Our industry sources also told us that there has not been much technological advance in the type of machine tools used in aerospace manufacturing. The main advance is the use of computer numerical control, which can be added to existing machines. In fact, many of the rebuilds in our sample consist of the addition of computer numerical control. Thus we do not believe that lemons problems, equipment quality, or technological obsolescence accounts for the high discounts we estimate.

Third, our estimates apply to the aerospace industry. To what extent are they applicable to other industries and to the economy overall? The aerospace industry was in the midst of a dramatic downsizing. Hence, demand for aerospace-specific equipment was depressed relative to demand for equipment in general. Therefore, our estimates of the insider premia λ are lower bounds on the value of specificity. Apart from these aggregate demand conditions, how representative is aerospace in terms of the ex post flexibility of its capital? One of the auction experts told us that in ratings of the ability to sell capital to other sectors, where 0 implies no resale ability and 10 indicates great resale ability, the aerospace industry ranks a 10 compared to the steel industry at a 2. Thus one might expect other industries to suffer much larger losses during a downturn.

It is enlightening to compare our results, which apply to a dramatic industry downsizing and in which capital is only moderately fungible, to those for the resale of highly fungible capital in a growing industry. As mentioned above, Pulvino (1998, 1999) has analyzed the sale of used aircraft by airlines. His data cover a period of industry expansion (1978–91) in which firms sold aircraft for idiosyncratic reasons rather than because of industrywide downsizing. At our request, he kindly estimated a model similar to ours using his data on 391 aircraft sales. For the equation $S_i = (1 - \alpha)[(1 - \delta)^{\text{age}} I_i]$, he estimated δ to be .0280 (with a standard error of .0048) and α to be .0315 (with a standard error of .030). The $\bar{R}^2$ was .9317. Thus, in contrast to our results, the estimates from sales in the airline industry imply a Brainard-Tobin's q of unity since α is not significantly different from zero. Of course, aircraft are among the easiest capital to reallocate *within industry*. Yet, were an airplane ever sold for some use other than air transport (an updated diner?), the industry premium in such a regression would surely be very large.

E. *Comparison with Labor*

It is interesting to compare our findings for the cost of capital reallocation with similar results for labor. The loss in value appears to be much higher than that found for workers in the aerospace industry. A Rand report by Schoeni et al. (1996) studies the experiences of aerospace workers over this time period and thus is complementary to our study of capital flows. Using state unemployment insurance records, the authors gathered data on every worker who was employed in the aerospace industry in California in the first quarter of 1989. They found that one-third of the workers who remained with the same firm experienced an 8 percent increase in real wages through the third quarter of 1994. The other two-thirds experienced some losses on average, though not out of line with the control group of displaced workers from other durable goods industries. Nevertheless, even those workers who were employed each quarter in California after separation from their firm experienced average wage losses of 4–5 percent relative to their preseparation earnings. Furthermore, one-quarter of this group suffered real wage losses of 15 percent or more. Thus these numbers are consistent with the literature showing that displaced workers generally experience persistent income losses (e.g., Ruhm 1991).

It is difficult, however, to make a direct comparison to the estimates presented in their study because they were unable to track individuals who left California. Thus the estimates they present pertain only to subsamples. It is unlikely, though, that the unobserved group had such large losses that they would raise the average loss to labor to anything near the estimates we found for capital. In summary, while substantial, these losses are far less than those suffered by capital.

VI. Time Costs of Capital Mobility

In the previous section, we document the high discounts relative to depreciated replacement cost incurred when equipment is liquidated. These discounts understate the cost of capital reallocation because they do not account for the time cost of reallocation. In this section, we present evidence on the length of time the capital was out of production or underutilized before it was sold. To maintain the confidentiality of the manufacturer, we denote the time of the auction by year 0. In plant 1, about which we know the most, employment and production declined by some 75 percent between years -5 and -1. In year -1 (approximately 13 months before the beginning of the equipment sales), the manufacturer decided to discontinue operations. Between year -1 and the auction, production gradually slowed and reached zero at the time of the auction. The last delivery occurred two months after the auction. The announcement to shut down plant 2 was made a little over a year before the first auction. Production had dropped considerably in the years leading up to the announcement and continued to decline until the last equipment was sold. We do not have good information on the pattern of production at plant 3.

Thus, in one sense the sale of capital was swift, for it coincided with the point at which production fell to zero. Capital utilization rates, however, were low both in the few years leading up to the decision to discontinue operations and during the year of winding down. Thus there was a prolonged period of declining utilization before the capital was eventually sold.

One aspect that struck us was that in some respects the dismantling of the enterprise resulted in the more efficient use of the capital by allowing it to be sold. In contrast, there was another time at which production was low but no capital was sold. In an earlier period of slack demand, one of the facilities operated at very low levels of production for almost an entire decade. Our estimates suggest that a decision to disinvest is reversible only at great cost. Hence, this long period of low utilization may well have been optimal.

The final issue on timing is the lag between the purchase of the capital by the buyers and the use of that capital in production. We do not have information on this issue, but we can offer some speculation. It is likely that many pieces of equipment were used in production within a few months of purchase since they did not require much setup. The outcome of the equipment that was sold to dealers is more uncertain. It would be interesting to find out how many dealers were able to resell the equipment quickly and how many dealers held the equipment in inventory for speculation purposes.

We draw two conclusions on timing from this analysis. First, any prolonged decrease in production probably results in significant periods of underutilization of capital. Second, because of the large discounts experienced on the sale of capital, the option value of a piece of installed capital is very high. Thus firms may rationally choose to hold on to capital for long periods of time in case production might rise in the future. It is only at times at which firms decide to cease operations that they sell significant portions of their capital.

VII. Conclusion

Our case study of aerospace suggests that capital is very costly to reallocate. This finding has implications for several important issues.

A. *Investment Is Very Costly to Reverse, Especially during a Sectoral Downturn*

Our results provide direct evidence on the losses incurred when a firm must sell its capital during a large sectoral downturn. For the subset of equipment for which we had information, the estimates imply an average return on replacement cost of only 28 cents on the dollar. We estimate the instantaneous rate of depreciation to be 62 percent on machine tools, instruments, and miscellaneous equipment; 41 percent on forklifts; and 83 percent on profilers (from table 6). This degree of irreversibility can have a major effect on investment behavior, as shown by the theoretical results of Abel and Eberly (1994) and Dixit and Pindyck (1994).

B. *Capital Displays Significant Sectoral Specificity*

According to the auction experts, we are studying a sector with relatively unspecific types of capital. Yet our calculations of the distribution of capital across sectors showed that aerospace was more heavily represented among the buyers than one would expect if the capital were perfectly fungible. Furthermore, we estimate significant premia for capital that sold to industry insiders. For newer machine tools, the premium was 100 percent if it sold to another aerospace firm (table 10).

These results suggest an enormous degree of sectoral specificity. During the time of our study, the marginal revenue product of capital in aerospace relative to other sectors plummeted. Yet, the value of much of the equipment to aerospace was still significantly higher than to outsiders. This fact implies a huge gap in the quality of the match of the capital characteristics to insiders versus outsiders. Owing to the low state of demand for aerospace, our estimates are a lower bound on the value of specificity.

As discussed earlier in the paper, the auctioneers and factory managers provided several reasons why some equipment would have higher value to aerospace than to outsiders. First, the manufacture of aerospace goods involves much larger pieces of metal than the manufacture of most other goods. Thus the machine tools for aerospace are much bigger and must have higher horsepower than the average machine tool. Second, aerospace manufacturing requires much more precision, but lower volume, than many other types of manufacturing, such as automobile production. Thus the high precision but low-volume abilities of the aerospace machine tools have less value to most companies outside the aerospace industry.

C. *Firms Engage in Costly Search and Matching to Overcome Sectoral Specificity and Market Thinness*

Equipment in the private liquidation sale sold at a substantial premium over equipment at the public auction. We believe that this premium arises from the better matching of the specific characteristics of the equipment sold to the needs of the buyer. The relatively thin market for specialized used equipment makes it profitable for both the buyer and seller to expend the time and resources entailed in a private sale to achieve a better match.

In summary, we suggest that the combination of sectoral specificity and thinness of markets impedes the efficiency of matching capital to new owners. Thus reallocated capital is often placed in a lower-value use. If one could costlessly break down a wind tunnel into its constituent elements and costlessly reformulate it into another piece of equipment, it would have a much higher economic value than the immutable wind tunnel that sold outside the aerospace sector.

Appendix

In order to determine how best to treat equipment that was rebuilt, we estimate the following generalized version of the model in equations (1) and (2) in the text:

$$S_i = c_0 + (1 - \alpha_m - \gamma_r) \cdot K_i + \epsilon_i \qquad \text{(A1)}$$

and

$$K_i = \sum_v \beta_r \cdot I_{iv} \cdot \exp\{-[(\delta_1 + \delta_r) \cdot \text{age}_{iv} + \delta_2 \cdot \text{age}_{iv}^2]\}. \qquad \text{(A2)}$$

This specification includes three parameters related to rebuilds: a different overall return on the equipment (parameter γ_r in eq. [A1]), a different return on subsequent investment for rebuilds (β_r in eq. [A2]), and a different depreciation rate on subsequent investments for rebuilds (δ_r in eq. [A2]). There are not enough data to estimate both β_r and δ_r at the same time, so we explore models with only one unconstrained at a time. The parameters γ_r and δ_r are zero for lots without rebuilds and possibly nonzero for lots with rebuilds. The parameter β_r is one for lots without rebuilds; for lots with rebuilds, we consider specifications in which it is nonzero, constrained to be zero, and constrained to be one.

Table A1 shows the results of various specifications. Column 1 allows a different discount on initial investment in equipment that was subsequently rebuilt (γ_r) as well as a different contribution to value for rebuilds (β_r). The results suggest that since γ_r is estimated to be significantly positive, rebuilt equipment actually receives a discount in the market. The estimate of β_r is not significantly different from zero, suggesting no return in the market to any additional investments for rebuilds. Column 2 explores an alternative specification by constraining β_r to be unity and allowing the age-related depreciation rate on rebuilds to differ by δ_r. The very high depreciation rate δ_r has a similar implication to the high, age-invariant discount β_r: the market places little value on subsequent investments for rebuilding equipment. This specification does not fit the data quite as well as the previous one, though, as evidenced by the standard error of the regression or the log likelihood function.

Column 3 gives our preferred specification, in which rebuilds have a discount (γ_r) and there is no return to subsequent investments ($\beta_r = 0$). A likelihood ratio test does not reject this specification relative to the specification in column 1. Moreover, the estimates of the other parameters of the model do not change noticeably as a result of the constraints.

TABLE A1

Estimates of Depreciation Rates and the Value of Rebuilds

Parameter and Variable	β_r Unconstrained, $\delta_r = 0$ (1)	$\beta_r = 1$, δ_r Unconstrained (2)	$\beta_r = 0$, $\delta_r = 0$ (3)
c_0: Constant	1.038	1.192	1.764
	(2.428)	(2.433)	(2.404)
δ_1: Age	.090	.089	.090
	(.013)	(.014)	(.014)
δ_2: Age^2	−.0012	−.0012	−.0013
	(.0003)	(.0003)	(.0003)
α_m:			
Discount on machine tools	.627	.630	.629
	(.048)	(.049)	(.048)
Discount on instruments	.619	.624	.631
	(.072)	(.072)	(.072)
Discount on miscellaneous	.686	.688	.688
	(.021)	(.022)	(.022)
Discount on profilers	.834	.836	.836
	(.024)	(.024)	(.024)
Discount on forklifts	.439	.441	.419
	(.115)	(.117)	(.126)
γ_r: Discount on rebuilt equipment	.119	.116	.110
	(.016)	(.017)	(.017)
β_r: Return on subsequent investment	.243	1	0
	(.148)		
δ_r: Age of subsequent investment	0	.512	0
		(.251)	
Standard error of regression	26.341	26.490	26.432
Log likelihood	−590.4	−591.1	−591.4
$\bar{R}^2$	.931	.930	.931

Note.—Heteroskedastic-consistent standard errors are in parentheses. The sample consists of the 127 pieces of equipment from plant 1. The data are measured in thousands of current dollars. The estimated model is given in eqq. (A1) and (A2).

TABLE A2

Estimates of Depreciation: Structures Included

Parameter and Variable	Baseline
c_0: Constant	1.484 (2.593)
δ_1: Age	.071 (.021)
δ_2: Age^2	−.0008 (.0004)
α_m:	
Discount on machine tools	.674 (.063)
Discount on instruments	.674 (.077)
Discount on miscellaneous	.713 (.029)
Discount on profilers	.864 (.030)
Discount on forklifts	.484 (.126)
Discount on structures	.959 (.019)
γ_r: Discount on rebuilt equipment	.107 (.017)
Standard error of regression	32.461
Log likelihood	−626.8
$\bar{R}^2$	.902

Note.—Heteroskedastic-consistent standard errors are in parentheses. The sample consists of 129 lots from the first sale. The data are measured in thousands of current dollars. The estimated model is given by eqq. (1) and (2).

Table A2 shows estimates including observations on structures. These two observations are quite idiosyncratic, so we exclude them throughout the other estimates in the paper.

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