NBER WORKING PAPER SERIES

DISPLACED CAPITAL

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Working Paper 6775
http://www.nber.org/papers/w6775

NATIONAL BUREAU OF ECONOMIC RESEARCH
1050 Massachusetts Avenue
Cambridge, MA 02138
October 1998

This paper is a revised version of the paper entitled "Sectoral Mobility of Capital: A Case Study of an Aerospace Firm." We are greatly indebted to the managers and the auctioneers who provided us with data and valuable insights. We have benefited from the helpful comments of seminar participants at UCSD, University of Michigan, MIT, UT-Austin, UC-Riverside, UC-Santa Barbara, Northwestern, Rand, Princeton, Wharton, and Stanford. Both authors gratefully acknowledge financial support from Sloan Foundation Fellowships and National Science Foundation Grant SBR-9617437 to the NBER. We thank Marina Anastasia Vladimirovna and Elizabeth Vega for very capable research assistance. The views expressed here are those of the author and do not reflect those of the National Bureau of Economic Research.

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JEL No. E22, D24, D83

ABSTRACT

This paper studies the efficiency with which physical capital can be reallocated across sectors. It presents a model of a firm selling specialized capital in a thin resale market. The model predicts that the selling price depends not only on the sectoral specificity of capital, but also on the thinness of the market and the discount factor of the firm. It then provides empirical evidence on the sectoral mobility of capital based on equipment-level data from aerospace industry auctions. These data track the flow of used capital across industries, as well as the discounts at which the capital sells. The results suggest substantial sectoral specificity of capital. Capital that flowed out of the sector sold for only one-third of its estimated replacement cost.

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I. Introduction

Declining industries, worker layoffs, and factory closings are unavoidable consequences of a continuously evolving market economy. How efficiently does the market reallocate factors of production to productive uses in other sectors? Much is known about the outcomes for labor. Studies, such as those by Topel (1990), Ruhm (1991), Jacobson, LaLonde and Sullivan (1993), and Schoeni et al (1996), estimate the effects of reallocation on individual workers. They find that displaced workers often experience prolonged periods of unemployment, as well as significant losses in permanent income even after they become re-employed. These results suggest that labor market frictions, such as inefficient separations, search costs or industry-specific human capital, may be impediments to the efficient reallocation of labor.

Relatively little is known, however, about the post-displacement outcomes for the other major factor of production - physical capital. Much capital is highly specialized, both in its embodied technology and factor substitution possibilities and in the types of products it can produce. While a substantial amount of theoretical and empirical work on investment behavior has analyzed the effects of costly reversibility on the decision to invest, little direct evidence has been offered on the efficiency with which capital is reallocated across firms and sectors.

We seek to fill this gap in the literature by providing a theory and estimates of the costs of reallocation of capital across firms and sectors. Our theory of used capital sales features specificity of capital and thinness of resale markets. We show how variations in specificity and costs of search affect the reallocation of capital.

Quantifying the costs of capital mobility is more difficult because of data availability. While several data sets, such as the Panel Study of Income Dynamics and the Displaced Workers Survey, allow one to track workers over time as they move between industries, we know of no data set that tracks *physical capital* as it moves between industries. Studies of depreciation, such as those by Hulten and Wykoff (1981) and Hulten, Robertson and Wykoff (1989), use transaction prices from used assets to determine rates of economic depreciation. These data, however, do not contain information on the original purchase price, nor do they link the buyers and sellers of the assets. Bresnahan and Ramey (1993) study capital utilization and reallocation of capital across size classes in the automobile industry during the 1970s and 1980s. Much of that reallocation, though, was within firms.

Thus, to answer these questions it was necessary to construct a new data set. 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 mobility for this particular industry. We will argue below that the aerospace industry is particularly interesting because it has undergone significant downsizing.

Our findings suggest that capital is very specialized by sector and that reallocating capital across sectors entails real costs. For example, we find that capital crossing industries sold for a greater discount than capital that remained in the aerospace industry. Furthermore, the process of winding down operations before selling the capital resulted in significant periods of under-utilization before the capital was finally sold. Thus, there also appears to be a time cost to restructuring. On the other hand, 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.

Recognizing sectoral specificity of capital has the potential to shed light on numerous theoretical and empirical issues. The trade theory literature has a long history of analyzing the effects of changes in the terms of trade under the assumption of imperfect capital mobility.[1] Similarly, in the explosion of work on growth theory in the 1960s, a number of papers addressed vintage capital, variation in the elasticity of substitution, and the macroeconomics of multiple sectors (e.g. Stiglitz and Uzawa (1969)). Most dynamic stochastic general equilibrium macroeconomic models, on the other hand, assume that capital is perfectly malleable and can be costlessly shifted across firms and sectors.[2] Only recently have macroeconomic models begun to incorporate some specificity of capital, such as irreversibility or vintage effects.[3] These models show that incorporation of heterogeneous capital can significantly change the economic predictions of standard models.

Allowing for capital specificity may also shed light on worker reallocation. Nadiri and Rosen (1969) demonstrated the importance of spillover effects of adjustment costs of one factor of production onto the behavior of another. If job creation and destruction are intimately linked with capital creation and destruction, then consideration of the specificity of capital may increase our understanding of the results of Davis and Haltiwanger (1990, 1992). Moreover, slow capital mobility may change the predicted effects of sectoral shocks. The lack of positive comovement

[1] See, for example, Mussa (1974, 1978), Dixit (1989), Neary (1995), and Rauch (1997).
[2] In fact, most real business cycle models also allow capital to be costlessly transformed into consumption goods and back again. A notable exception is the work of Christiano and Fisher (1995), which analyzes a two-sector model with a consumption good sector and an investment good sector.
[3] See, for example, Dixit and Pindyck (1994), Abel and Eberly (1994, 1996), Greenwood, Hercowitz and Krusell (1994), Gilchrist and Williams (1998), Coleman (1996), Faig (1997), Ejarque (1997), Cooley, Greenwood and

between unemployment and vacancies has been taken as evidence against the hypothesis that sectoral shifts are an important contributor to aggregate fluctuations (e.g. Abraham and Katz (1986), Blanchard and Diamond (1989)). If, however, capital is required to create a vacancy, then a sectoral shift may not manifest itself as an increase in vacancies in the short-run.[4]

Our work is related to a growing empirical literature that demonstrates the importance of considering the costs of disinvestment. Caballero and Engel (1994) (using industry-level data), Abel and Eberly (1996) (using firm-level data), Caballero, Engel and Haltiwanger (1995) (using establishment-level data), and Goolsbee and Gross (1997) (using aircraft model data) all provide evidence that the behavior of investment is consistent with the presence of important non-convexities in the adjustment cost function. Pulvino's (1996a,b) analysis of the effect of credit constraints and bankruptcy court protection on asset sales provides further insights into the costs of disinvestment. Using data on the sales of aircraft by commercial airlines, he finds that capital-constrained airlines sell their aircraft at relatively lower prices than airlines that are not constrained. Our empirical work provides further evidence for costs of disinvestment. In addition, our theoretical model offers a plausible interpretation of our empirical findings, as well as of other findings in the literature.

II. Theoretical Framework

A. Overview

Yorukoglu (1997), and Ramey and Shapiro (1997). LeRoy(1983) argues that Keynes investment theory was actually the first analysis of temporary general equilibrium under a two-sector technology with nonshiftable capital.

[4] Caballero and Hammour (1996) obtain an inverse Beveridge curve from their assumption of incomplete contracting. Their model also has capital that is specific to the relationship, but this element alone does not produce an inverse Beveridge curve.

We consider the following story 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 discount factors may resort to "fire-sales," resulting in significantly inferior matches and the reallocation of capital to low valued uses.

This story, which will be formalized below, contains several key assumptions. We begin by motivating the first assumption of sectoral specificity of capital. We view each piece of capital as comprising 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. 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.[5]

We illustrate this idea with an example of 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* Oct. 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

[5] Firms might design or purchase equipment with *ex post* flexibility in mind. (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.

value the fact that the tunnel can produce 270 mile per hour wind speeds. Thus, a key characteristic of this wind tunnel – high air speeds – has no value outside of aerospace.

We also 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 match the characteristics of the equipment closely is a costly and time-consuming process. 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 which may result in inferior matches between capital characteristics and buyers' needs.

Several other models in the literature incorporate some of these features. For example, the specialization of capital by industry is a key assumption used in the literature on debt capacity and liquidation of assets (e.g. Williamson(1988), Shleifer and Vishny (1992)). In Shleifer and Vishny's model, capital may be sold to a lower value use outside the industry because firms inside the industry may be credit-constrained. In our model, capital may be allocated to low-valued uses even with no financial market imperfections because of costs of search.

Our assumption about costly search and matching is related to the large literature on search and matching (e.g. Stigler (1961), McCall (1970), Diamond (1982), Pissarides (1985), Mortenson (1986)). The structure of our model, however, contains a feature not found in other search models (to our knowledge.) In our model, the firm sells multiple units, whose value depends on the total selection available. This feature leads the firm to face a tradeoff between selling early at a low price and preserving the selection available to high-valuation buyers.

For those readers who wish to skip the theoretical details of the model, we briefly summarize the theoretical results to which we allude later in the empirical section. We show that under certain conditions, a firm structures its capital sales to consist of two parts. The first part, which is called the "private liquidation sale," is a period of search for industry insiders. These sales result in high value matches and a higher sales price for the capital. The second part is a "public auction," which involves a large auction in which the remaining capital is sold all at once to industry outsiders. The amount of capital sold to insiders is positively related to the firm's discount factor: more patient firms spend more time searching for high quality matches among industry insiders.

B. Model[6]

The model analyzes the decision problem of a firm that is selling used capital.[7] Consider a firm from sector A (aerospace) that wishes to sell a total of N units of capital so as to maximize the expected present discounted value of revenue from the sale. The units of capital are heterogeneous in that each unit will have a different value for different buyers, but the seller does not know which particular unit the buyer will prefer. For each unit of capital, the firm can decide whether to sell to another firm in sector A or to a firm outside of sector A, called sector O (outsiders).

We assume that selling capital to sector A has the following structure:

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[6] We are indebted to Garey Ramey for very helpful suggestions for the formulation of the model.

[7] We abstract from the original decision on how much capital to sell in order to concentrate on how the capital is sold. The expected outcomes from this second stage would certainly have a significant effect on the original decision to install capital. It would be straightforward to embed this second stage decision problem in a broader model, such as the ones discussed by Dixit and Pindyck (1994).

(i) To take a draw from sector A, the firm must pay a fixed cost C. The firm can only make one draw from sector A per period.

(ii) If the firm takes a draw from sector A, there is a probability q, $0<q \leq 1$, of matching with a firm.

(iii) If a match is made, the firm sells one unit of capital and receives $R_A(n)$. n indexes the remaining number of units of capital the firm has for sale at that point in time.

(iv) $R_A(n)$ is an increasing function of n, owing to the likelihood of making a better match when there is a greater selection of capital.

These assumptions are intended to capture the thinness of the market and the costs of matching with other aerospace firms.

In contrast, we assume that selling capital to sector O has the following structure:

(i) There is no cost of selling to firms in sector O and the firm may make any number of sales during the period.

(ii) If a sale is made to a firm in sector O, the selling firm receives R_O per unit of capital. R_O is independent of n.

Despite the higher costs of selling within the sector, the firm may choose to sell to other firms within the sector if the expected returns are large enough. Once the match is achieved, we make the common simplifying assumption that the selling price is equal to the valuation of the buyer. The valuations of the buyers, R_A for insiders and R_O for outsiders, are given as follows:

(1) $R_A = f_A \cdot S_A(n), \qquad S_A{}'(n) > 0$

(2) $R_O = f_O \cdot S_O,$

(3) $S_A(n) > S_O$ for all n.

The f 's are marginal revenue product shifters for each of the industries. For example, a decline in the demand for aerospace goods would be represented as a decline in f_A. The S functions denote the goodness of the match of the capital's characteristics, and are intended to capture the specificity of capital discussed above.[8] Even within the same industry, capital from one firm may not be a perfect match for another firm. We assume that the value of a match with another industry insider rises with the selection currently available for sale, n. As shown above in equation (3), we also assume that it is always the case that the characteristics of the capital will be better suited to industry insiders than industry outsiders. If, however, f_A falls far enough relative to f_O then R_A can fall below R_O.

We begin the analysis by deriving value functions using backward induction from the last unit sold. When the firm has only one unit left for sale, it can decide to draw from the insider pool or to sell to outsiders. The value function evaluated at the last unit left to sell (n=1) is given by:

(4) $V(1) = \text{Max}\ \{q\ R_A(1) - C + (1- q)\ b\ V(1),\ R_O\}$

The first argument in the brackets is the expected value of taking a draw from inside the industry. The firm receives $R_A(1)$ with probability θ, and must pay a cost to search of C. There is a probability 1 - θ of not making a match, and receiving the discounted value of having one unit left for sale the following period. If R_O is greater than the first argument in the expression, the firm will decide to sell to outsiders. Let that value be given by:

(5) $V_O(1) = R_O$

If the first expression in brackets in equation (4) is greater than R_O, the firm will choose to take a draw from inside its sector. Solving for $V_A(1)$ in this case, we obtain:

(6) $V_A(1) = \dfrac{q\,R_A(1) - C}{1 - b + bq}$

If $R_A(1)$ is sufficiently small that $V_A(1) < V_O(1)$, the firm decides to sell its last unit to outsiders. Iterating backward from the last unit, we obtain the value of each choice when a firm is left with n units to sell, and finds it optimal to sell the last n-1 units to outsiders. These values are given by:

(7) $V_O(n) = nR_O$

(8) $V_A(n) = \dfrac{q\,R_A(n) - C + qb(n-1)R_O}{1 - b + bq}$

$V_O(n)$, the value of selling all n units to sector O now, is linear and increasing in n. The slope is R_O. $V_A(n)$ is also increasing in n, with a slope of $\dfrac{q\,R'_A(n) + q\,b\,R_o}{1 - b + bq}$.

The following proposition establishes conditions under which the firm will sell some equipment to each group of buyers:

[8] For tractability, we assume that $S_A(n)$ is a continuous function of n, even though the n's are discrete. We take into account the discreteness of n in the propositions and proofs.

Proposition 1: (Conditions for selling to both aerospace and outsiders)

If:

(i) $V_A(1) < V_O(1),\ \textit{or equivalently},\ \frac{qR_A(1) - C}{1 - b + bq} < R_O$

(ii) $V_A(n) > V_O(n),\ \textit{or equivalently},\ qR_A(n) - C > [(1-b)n + qb]R_O\ \ \textit{for}\ 1 < n < N.,$

then there exists some n*, 1 < n* < N, such that $V_A(n^*-1) < V_O(n^*-1)$ and $V_A(n^*) \geq V_O(n^*)$, and the optimal policy is to sell at least one unit to sector A before selling all remaining units to outsiders.

Proof: See the technical appendix.

Proposition 1 establishes conditions under which there will be two stages to the selling process. Consider Figure 1, which shows graphs of $V_O(n)$ and $V_A(n)$ against n. Note that time moves backwards as n increases, since higher n means that the firm has more units left to sell. The two conditions together guarantee that $V_O(n)$ and $V_A(n)$ cross, and that there is at least one crossing where $V_A(n)$ crosses $V_O(n)$ from below. If the conditions hold, the first stage of the selling process involves some search for sector A buyers, which we call the "private liquidation sale." The second stage involves selling all remaining units at once to sector O. We call this stage the "public auction." If it is the case that $V_A(n)$ is less than $V_O(n)$ for all n<N, then the firm will skip the first stage and only hold the public auction.

In general, the first stage need not involve only sales to sector A buyers. During the first stage, the firm is faced with the following tradeoff: Selling some units to outsiders now has the advantage of speeding up the time when the firm can realize revenues from the public auction, but has the disadvantage of decreasing the selection available to sector A buyers, hence reducing the expected revenue from those sales. When will the firm not sell units to outsiders during the second stage? The following lemma specifies a sufficient condition to ensure that the gains to speeding up the process by selling to outsiders early are outweighed by the lost revenue from selling to insiders.

Lemma. If, in addition to the conditions in Proposition 1, the following condition holds:

$$\text{(iii) } q\, R_A'(n) \geq \frac{1-b}{1-b+qb}\, [q\, R_A(n-1) - C - (1-b)(n-1)R_O] \quad \text{for } n^* < n < N$$

then the sale will take place in two stages, with a first stage involving only search for sector A buyers and the second stage involving the sale of all remaining units at once to sector O.

Proof: See the technical appendix

While this corollary is not necessary for explaining many of the empirical results, it is useful for clarifying the effects of certain parameters on the nature of the sales process, as shown in the following proposition.

Proposition 2 (The effects of parameters on the structures of sales). Assume that conditions (i)-(iii) as well as the following condition hold:

(iv) $q\, R'_A(n) > (1-b)R_O \;\; \textit{for all } n \textit{ such that } 1 < n < N$.

Then, the firm will sell more units to sector A,

(a) the higher is β

(b) the higher is θ

(c) the lower is R_O

(d) the higher is ϕ_A

Proof: See the technical appendix.

Proposition 2 shows that as a firm becomes more patient, it will search longer for sector A buyers and delay the public auction. This result can explain how a firm's discount factor determines how much capital it sells to industry insiders. The proposition also shows that the firm will search longer for sector A buyers if the efficiency of searching for sector A buyers is higher (higher θ) or if the marginal revenue product of capital in sector A is higher.[9]

The following corollary states how prices of capital will differ across types of buyers, and how the sales revenue will vary with the discount factor.

Corollary: Under the conditions of Proposition 2, the average (undiscounted) price paid by sector A buyers is greater than the average (undiscounted) price paid by sector O buyers. Furthermore, a firm with a higher β will realize higher undiscounted proceeds from the sale of its equipment.

The implications of the model will be useful for interpreting the results we present later. The model also sheds light on several other results in the literature. For example, Shleifer and Vishny (1992) present several interesting anecdotes about how rapid sales of assets lead to price discounts. Pulvino (1997) shows that capital-constrained airlines not only sold their aircraft at lower prices, but were more likely to sell them to industry outsiders. Our model of thin resale markets for heterogeneous capital provides a straightforward explanation for these results. Searching for good match is a time-consuming process. If the firm does not spend the time, the capital ends up in lower valued matches and the firm receives less for its assets.

III. Data Description

Our data consist of information on capital sales from Southern California plants belonging to three large aerospace companies. The aerospace industry has undergone enormous downsizing and restructuring in the last decade. This industry is ideal for our study because the exogeneity of the end of the Cold War eliminates concerns about the endogeneity of demand for the output of the factories we study and the selectivity of which equipment and which factories get liquidated.

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[9] If we do not assume condition (iii) from the Lemma, then the results from Proposition 2 change slightly. Instead of specifying the effect of the parameters on the number of units sold to sector A, the weaker proposition would specify the effect of the parameters on the point at which the firm decides to hold the final public auction, $n^* - 1$.

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 missles and space vehicles (SIC 376).[10] Furthermore, defense department demand is highly variable. Figure 2 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.

A Rand report by Schoeni, Dardia, McCarthy and Vernez (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 the one-third of the workers who remained with the same firm experienced an 8 percent increase in real wages through the third quarter 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 pre-separation 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.

We study three of the many plants that closed in the 1990s. All three plants were important manufacturers of military and/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

[10] Shipments to all Federal government agencies represented 66 percent of shipments.

closed. In all cases, after several years of declining production and employment, the firms decided to discontinue operations. The decisions on all of 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. We have obtained only data from its first auction. All of the public auctions were conducted as English auctions. We were told that most of the larger items had multiple bidders. The total proceeds from the sales were $18.7 million and over 1,000 buyers purchased equipment. Three times that many buyers attended the auctions. Hence, the markets at the auctions are fairly thick.

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 covers a fairly wide span of equipment.

It is interesting to note that the manufacturers did not sell any buildings.[11] Not selling buildings is not unusual for plant closings involving 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) are greater than the potential sales price, so they simply raze the buildings.[12]

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[11] We do not yet know the outcome for the buildings of Plant 3.

[12] The front page of the June 26, 1996 *Wall Street Journal* contains an interesting article describing the problems faced by GM in the closing of its 100 year old Tarrytown automobile assembly plant.

For every item sold in the liquidation sale and public auction (over 20,000 lots), we obtained information on the complete equipment description, the sales price, and 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 dispersion of the equipment to various industries. For Plant 1, the selling company provided us with information on the original purchase year and price as well as the year and cost of any refabrications or rebuilds for almost all of the pieces of equipment that sold for $10,000 or more each. We were able to obtain information for 127 pieces of equipment that accounted for $6.7 million of sales. With this information, we can estimate implied depreciation rates for the equipment sold.

The data set we have collected has features that overcome the “lemons problem” criticism that has been made of some of the other studies of used equipment. First, the tremendous amount of downsizing that occurred meant that the plants that closed were not marginal plants. Second, the fact that the plants sold everything they owned means that there is no selection bias in the equipment that was sold.

We will conduct three types of analyses of the data that shed light on capital mobility. First, we will 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 will also distinguish the distribution of sales according to whether the good was sold through private negotiation or public auction. Second, we will use the subset of sales for which we have original purchase prices to estimate a model of economic depreciation. We will estimate depreciation rates and compare them to others in the literature. Finally, we will discuss the time lags that were involved in the sale of capital.

IV. Empirical Results

A. Sectoral Flows of Capital

Before we present our results on the sectoral flows of capital from the two 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, both by the value of sales and the number of buyers.

Tables 1, 2 and 3 present the distribution of sales of equipment by buyer industry. 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.

Consider first Table 1. The most important fact that emerges from the table is that almost one-quarter of the value of sales was to other aerospace manufacturers. Thus, one-quarter of the equipment remained in the same 3-digit industry. If there were perfect fungibility of capital across sectors, we would expect the equipment to have been sold in proportions similar to aggregate equipment investment. The fact that the sales were over 30 times more concentrated in aerospace relative to the aggregate is an indicator of substantial impediments to the cross-sectoral flow of capital.

Table 1 also shows several other sectors that were major buyers. Machinery dealers bought 23 percent of the equipment. Hence, 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 manufacturers. Manufacturing as a whole accounted for 58 percent of sales. In comparison to the aggregate, sales to manufacturing were almost twice as concentrated.

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 percent sold to foreigners is probably an underestimate. Many sales to foreign countries go through U.S. dealers or through individuals who serve as agents.[13]

There are two ways to view these numbers. In one sense, they show that capital is not absolutely stationary, since more than one-third of it left California. In another sense, though, the fact 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.

Tables 2 and 3 shows that there is a significant difference in the buyers through private liquidation and public auction. Table 2 shows that 66.8 percent of the sales value from the

[13] 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, A1).

liquidation sale went to other aerospace firms, whereas Table 3 shows that only 10 percent of the public auction sales went to aerospace firms.

The theory presented in the last section is helpful for interpreting these results. If aerospace firms have higher valuations for the equipment, but are harder to locate due to 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 be 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 to industry outsiders. Firms who cannot afford to wait during the search process sell all of their equipment at public auction.

The theory 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 (which constitutes our data from the plant), 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 also was more heavily indebted than Plant 1. Based on these factors, one would expect the discount factor b of the owner of Plant 1 to be much higher than the discount factors of the owners of Plant 2 and 3. In the model, a low enough b will result in no time spent 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. We cannot attribute the difference in sales to the difference in the composition of equipment since both appeared to have similar types of machine tools.

B. Econometric Estimates of Economic Depreciation

Overview

In this section we use the subset of data from Plant 1 containing original purchase prices to obtain estimates of the loss of value suffered by capital that must be sold as part of the consolidation and downsizing of an industry. We begin by summarizing the data and discuss depreciation estimates from other studies. We then estimate two types of models: a fairly standard exponential depreciation model and a more flexible functional form model. Both models give similar results.

As discussed in the last section, the subset of data consists of 127 items with a total sales value of $6.7 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.[14] We used the deflator for metal working machinery investment for the machine tools and similar equipment, the instruments investment deflator for the instruments, the deflator for computer investment for computers, the price deflator for turbines for a generator, the deflator for construction tractors for gas-driven forklifts, and the deflator for industrial equipment investment for the remaining items.

Figure 3 shows a plot of the ratio of the sales price to the reflated original acquisition cost against age. This ratio is Brainard-Tobin's q -- the ratio of the market value of capital to the replacement cost.[15] The size of the circle is proportional to the original cost.

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[14] These data are from the BEA's capital stock data. We calculate the implicit deflator as the ratio of historical cost to the chain-weighted quantity index.

[15] Figure 3 does not take into account depreciation. Also, in the figure we make no corrections for the pieces of machinery that had later investment flows. Both depreciation and subsequent investment are taken into account in the econometric analysis presented below.

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 near fifty years old sold for a large fraction of its original purchase price, even after reflation. We double-checked these data to make sure they were not errors. We were told that there were certain types of machinery manufactured fifty 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 some selectivity in these data since our sample excludes retired equipment.

Before we estimate rates of depreciation, it is useful to review estimates obtained by others on 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, Robertson, and Wykoff (1989) used data from the Machine Dealers National Association from 1954 to 1983 to estimate economic depreciation rates for machine tools. Their data has many more observations (almost 3,000) than ours, but unfortunately has no information on the original cost or the industry of the buyer and sellers. They estimate depreciation rates by using dummy variables for characteristics of equipment. 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).

These estimated depreciation rates are not exactly what we need for comparison. In estimating the depreciation rates, the authors correct for sample selection problems induced by the fact that some equipment is retired rather than sold. Because we are only studying equipment that is sold, we need estimates that do not correct for sample selection. Oliner's (1996) study provides such estimates. Oliner surveyed machinery dealers in the mid-1980's and estimated a depreciation rate of 3.5 percent for the group of machine tools still in operation. Survey respondents indicated an average life of these machine tools of 30 years. When he corrected for sample selection, he found depreciation estimates of 9.5 percent. Thus, the relevant estimate for our comparison may be as low as 3.5 percent.

Geometric Depreciation Model

We begin by estimating a model of geometric depreciation. For 127 pieces of equipment representing over a third of the value of all sales, we estimated the following model that relates the sales price to the flow of investment and the age:

(10) $$S_i = C_o + \alpha \left\{ (1-\delta)^{age(i)} I_i + \sum_{j=1}^{3} (1-\delta_r)^{age(i,j)} R(i,j) \right\} + e_i ,$$ where

S_i = price at which machine i sold

C_0 = constant term

α = positive parameter

δ = annual geometric depreciation rate on original cost

age(i) = age of machine i

I_i = initial purchase cost (including installation), reflated to current prices

δ_r = annual geometric depreciation rate on rebuild expenditures.

age(i,j) = years since j^{th} rebuild of machine i

R(i,j) = expenditures for j^{th} rebuild of machine i, relative to current equipment price.

ε_i = error term

The first term in brackets in the equation is the standard formula for geometric depreciation on a capital investment. The second term is included to account for the rebuilds, which constitute additional flows of investment expenditures on the same piece of equipment. 19 of the machines experienced one to three rebuilds or refabrications over the course of their use, so we include those investment flows as well. We assume that the error term ε arises from different preferences for machinery features, different outcomes in the search process, as well as idiosyncratic differences in the rate of physical depreciation, all of which are assumed to be independent of the original price.

Both δ and α are parameters measuring economic depreciation. Most models of economic depreciation in the literature implicitly assume that α is unity, so that all loss of value is related to age. That is, most models for measuring geometric depreciation presume that Brainard-Tobin's q equals one. We will show that it is important to consider losses in value that are unrelated to age, so that α is less than unity.

Because of the linearity induced by the additional terms that allow for rebuilds, we do not estimate equation (10) in logarithms. Thus, we estimate the equation by nonlinear least squares, and use heteroscedasticity-consistent standard errors.

We begin by estimating a simple model in which the rate of depreciation on rebuilds is constrained to equal the rate of depreciation on initial investments and the values of a and δ are common across types of equipment. The results of this specification are presented in the first column of Table 4.

The estimated value of δ is 7.6 percent, which is within the range of estimates in the literature. The value of a, however, is very low, at 0.1, and is significantly different from the commonly assumed value of unity. Thus, the estimates imply that there is a significant decline in value that is independent of age. The positive constant term further implies that the returns are proportionally greater on the less expensive items. Thus, the estimate of α gives the marginal q, not the average q. The first column shows a calculation of the q for the median valued good, after taking into account the estimated seven percent depreciation per year. The parameter estimates imply that Brainard-Tobin's q is only 0.18 on the median-valued good.[16] Thus, the loss was 82 percent.

To see whether the high estimated losses were uniform across the types of capital goods, we estimated a model in which the losses were allowed to differ across types of capital. We classified the equipment into three groups: (1) machine tools; (2) structural equipment; and (3) miscellaneous equipment. Machine tools include equipment such as profilers and jig mills, and represent 104 of the 127 items sold. Structural equipment consists of two very large, complex and expensive items that required costly disassembly and re-assembly in order to be sold. The miscellaneous equipment consisted mainly of instruments and a few items such as forklifts and computers. We allowed the constant term, the geometric depreciation rate and the a to differ for machine tools versus miscellaneous equipment. Because there were only two structural items, we could not separately estimate several parameters for them. Thus, for these two items we preset

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[16] Brainard-Tobin's q was calculated as q = $\frac{C_0 + aI_m}{I_m}$, where I_m is the median reflated original acquisition cost.

the geometric depreciation factor to 12 percent and estimated a separate a. Finally, we also allowed the depreciation rate on rebuilds to differ from the depreciation rate on initial investments.

The second column of Table 4 shows the results of estimating the heterogeneous capital model. The results indicate some heterogeneity across categories. According to the estimates, the annual depreciation rate for machine tools is 12 percent and for miscellaneous equipment is 6 percent. On the other hand, the a is estimated to be higher for machine tools than miscellaneous equipment, 40 percent versus 27 percent. Note also that the depreciation rate on investment for rebuilds is substantially higher than the estimated depreciation rates for initial investments.

The most significant difference is between machine tools and miscellaneous equipment on the one hand and the two pieces of structural equipment on the other. As the table shows, the estimated a for the structures is only 5 percent. Because the original cost of these structures was so great, their discounts affect the estimated discounts for all of the equipment in the homogeneous capital model.

In fact, once we allow for a different coefficient on structures, there is not significant evidence of differences in discounts by type of equipment. The final column shows the estimates from a restricted model in which the constant term, the δ, and the a are constrained to be the same for machine tools and miscellaneous equipment, but the a for the two structures is still allowed to be different. One cannot reject this model in favor the more general model at any reasonable significant level. Thus, all of the nonstructural pieces of equipment included in the sample appear to have similar discounts and rates of depreciation.

There are several ways to calculate the losses on capital from these parameter estimates. The estimate of a for non-structural equipment implies that even after taking into account annual rates of depreciation, the firm would receive only 38 cents on the marginal dollar spent on purchasing the capital, implying a loss of 62 percent on the margin. Because of the positive constant term, though, the average returns were higher. The loss on the median-valued piece of nonstructural equipment was 53 percent. The loss was 95 percent on the structures.

We can also compare the total revenues from the sale to the total value of the goods, depreciated by the estimated annual discount rates. This measure is an average "q." We calculate q as follows:

$$Average\ q = \frac{\sum_{i=1}^{127} S_i}{\sum_{i=1}^{127}[(1-d)^{age(i)} I_i + \sum_{j=1}^{3}(1-d_r)^{age(i,j)} R(i,j))}$$

The numerator is the sum of the sales prices, and the denominator is the replacement cost. We use the estimated values of δ and δ_r from the preferred model in Table 4. For the entire sample, the average value of q is 0.37, implying a discount relative to replacement cost of 63 percent. If we omit the two structures, the average value of q is 0.57, implying a discount relative to replacement cost of 43 percent.

We draw two conclusions from these results. First, all types of equipment sold for significant discounts relative to new equipment, and most of these discounts were from factors that were independent of age. Second, the structural pieces sold for much greater discounts than other types of equipment.

Discounts by Type of Buyer and Mode of Sale

We now study whether the discounts vary systematically with the industry that bought the equipment and with the way in which it was sold. Recall that our theoretical model predicted that the items that sold to other aerospace firms should sell at a higher price than the items that sold outside the industry. The characteristics of the capital should be a better match for other firms in the industry. Furthermore, in the context of our model, the sales to other aerospace firms should have occurred during the private liquidation sale. As shown earlier in Tables 2 and 3, though, there were some sales to outsiders during the private liquidation sale and some sales to aerospace during the public auction. Table 5 shows the distribution of buyer type by mode of sale and vice versa for the sample of 127 items used in our depreciation estimates. The calculations show that 91.5 percent of the value of aerospace purchases in this sample was through the private liquidation sale. The calculations also show that 75 percent of the revenue from the liquidation sale was from sales to other aerospace firms. Thus, the actual data does not have the complete separation that occurs in our model.

To determine whether the identity of the buyer or the mode of sale affects the selling price, we re-estimate the model allowing the a's to differ according to the identity of the buyer's industry and the mode of sale. We exclude the two pieces of structural equipment, which were sold to dealers during the private liquidation sale, because they are so different from the other equipment, and they would skew the results.

Table 6 shows several sets of results. The first column shows an estimate of the previous specification without the structural equipment, to serve as a baseline. The estimated annual depreciation rate is 12 percent on the original investment and the estimated value of a is 38 percent. The second column shows the results from allowing the discount to vary by the identity of the buyer. The estimate of a for equipment that sold to other aerospace manufacturers is 45 percent, whereas the estimated a for equipment that sold to outsiders is only 25 percent. Both estimates imply substantial losses in value and the difference between the two is statistically significant at the one percent significance level. At the median equipment value, the estimates imply that resale of a new piece of equipment to another aerospace firm would result in an average return of 56 cents on the dollar, whereas resale to an outsider would yield 36 cents on the dollar.

The third column presents estimates when the a's are allowed to vary according to whether the item was sold during the private liquidation sale or the public auction. The estimated a for the items sold during the private liquidation sale is 42 percent, which is more than twice the estimated a of 18 percent for the items sold at the public auction. Along with the estimated constant term, the results imply that the loss on the median good sold at the private liquidation sale was 46 percent, whereas the loss on the median good sold at the public auction was 69 percent. The value of the log likelihood function is only slightly greater than the value for the previous specification.

The last column of Table 6 presents results from a model in which the α can differ across both buyer category and sales mode category. The highest estimated return is for equipment that is sold to other aerospace firms at the private liquidation sale, with an estimated value of α of 45 percent. The next highest is sales to outsiders at the private liquidation sale, followed by sales to outsiders at the public auction. Interestingly, the estimate of α for sales to aerospace during the public auction is near zero. This result might be due to the small sample of items in this category or to the fact that these items had very little use outside of aerospace, so that the winning bids were very low.

Neither the buyer model nor the sales mode model can be rejected at the five percent level against the model that includes both distinctions. Both models can, however, be rejected at the ten percent level. All of the results, however, are broadly consistent with the theoretical model that highlights the importance of the type of buyer and the mode of sale for determining the return on the assets. Both the average and marginal returns on sales to industry outsiders are significantly lower than the return on sales to industry insiders.

Flexible Functional Form Estimates

Finally, to test further the robustness of the results, we estimated models with a more flexible functional form. In particular, we regress the log of the ratio of the sales price to the reflated original cost (i.e. the log of q) on the following set of variables: a quadratic in age, dummies for aerospace buyers or private liquidation sale interacted with the quadratic in age, a dummy variable indicating whether the equipment was rebuilt, and the log of the original real cost. We estimate two separate models rather than the combined by buyer – by mode model because it is easier to interpret the separate models. We omit the two structures from the sample, and we weight the regression by the reflated original cost of the equipment. The quadratic in age is included to allow for time-varying depreciation rates, which we also allow to vary according to either the buyer's identity or the mode of sale. We include the log of the original real cost to allow for the possibility that the discount varies with the original price of the equipment.

The estimated parameters from this type of model are shown in Table 7. Several results are noteworthy. First, the significant negative coefficient on the log of the reflated original cost indicates that the higher cost items suffer a greater decline in value. This result is consistent with the positive constant term in the geometric depreciation model. Second, paradoxically the coefficient on the dummy variable for equipment that was rebuilt is negative, indicating that those items experienced a greater decline in value. Both the set of coefficients on aerospace and the liquidation sale dummy interactions are jointly significant.

Because it is difficult to see the age pattern from the coefficients, we calculate the implied rates of depreciation and plot the fitted values of q. Table 8 shows the implied depreciation rates by age for each case. Figures 4 and 5 show the fitted values of the two regressions. In each case, we calculated the fitted values for a piece of equipment with the median reflated original cost and which was not rebuilt. The figures show the implied fitted ratio of sales price to cost, rather than the log. Each age for which we have at least one observation is represented by a point. In Figure 4 the "A's" indicate items bought by aerospace firms and the "O's" indicate items bought by outsiders. Figure 5 shows the similar fitted values from the sales mode model. Here the "X's" denote items sold at public auction and the "L's" denote items sold at the private liquidation sale.

Consider first the patterns shown in Figure 4. The estimates indicate that relatively recent equipment sold to aerospace had significantly higher values of q than the recent equipment sold to outsiders. The values of q for aerospace, however, decline very steeply, and cross below the q for goods sold to outsiders at about 11 years of age. While the q's for the goods sold to outsiders start very low, they decline very gradually with age. As Table 8 shows, the estimated annual rates of depreciation for equipment that sells to aerospace is greater than 15 percent for the first ten years, where as the rates are less than half that for equipment sold to outsiders. Thus, these estimates show that the pattern of discounts is much richer than that suggested by the geometric depreciation model. The basic conclusions from the earlier model, however, remain unchanged: the selling company made significantly higher returns on the items sold to other aerospace firms.

Figure 5 shows the patterns for the mode of sale model. As in the geometric depreciation model, the results indicate that goods sold through the private liquidation sale sold for higher prices relative to their replacement costs. The annual rate of depreciation of these goods appears to be similar to the goods that sold at public auction, as shown in Table 8.

All of the estimated models point to the same pattern. The selling firm received higher prices on goods it sold to aerospace firms rather than outsiders. Similarly, with the exception of the two pieces of structural equipment, the selling firms received significantly higher prices on the goods sold through private liquidation rather than through the public auction.

C. Time Costs of Capital Mobility

Finally, 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 considerable in the years leading up the announcement, and continued to decline until the last equipment was sold.

Thus, in one sense the sale of capital was swift, for it coincided with the point when 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. For almost an entire decade in its existence, one of the facilities operated at very low levels of production with fewer than 500 employees. During this time, most of the equipment and structures were unutilized. The combination of our economic depreciation estimates with current option value theories of investment suggest that this was optimal behavior on the part of the firm. Nevertheless, this behavior represented substantial under-utilization of resources.

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 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 under-utilization 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 when firms decide to cease operations that they sell significant portions of their capital.

V. Interpretation of Empirical Results

We now discuss the implications of our empirical results for the costs of reversing investment decisions and the costs of capital reallocation. We will begin by discussing several issues, including wedges between sellers' receipts and buyers' values and the applicability of this aerospace study to other situations.

The first point to note is that the price received by the seller is less than the value of the equipment to the buyer. There are several reasons for this wedge. First, standard auction theory suggests that the price paid at auction 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. A second wedge between the price received by the sellers and the value to the buyers is the fraction that is paid to the auction company. The prices we recorded are prices received by the sellers, not the price paid by the buyers. Typically buyers must pay an additional buyers premium of approximately ten percent. Thus, the buyers' values are at least ten percent greater than the prices received by sellers.

Our results suggest that sellers receive low prices on their sales of capital. There are various alternative explanations, such as lemons markets or the quality of the capital, that could explain these results. We believe that these explanations are less plausible than the one we offer in our theoretical model. First, as mentioned earlier, the equipment sold is not subject to the usual lemons problems because the plants we study were among the last closed, and all of the equipment was sold. Furthermore, our sample selection device for estimating depreciation rates for equipment that sold for $10,000 or more should bias our estimates upward. Second, it is unlikely that the large discounts were due to poor quality equipment. Industry sources report that the equipment in the aerospace industry is typically well-maintained (Robert Levy (1996)). Finally, it is unlikely that the high discounts are due to technological obsolescence. There has not been much technological advance in the type of machine tools used in aerospace manufacturing. The only advance is the use of computer numerical control, which can be added to existing machines (Robert Levy (1996)). 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 can explain much of the results we found.

It is also important to discuss the applicability of these results to other cases of capital sales. Our study is of an industry in the midst of a dramatic downsizing. One would expect the capital losses to be greatest in such a case. Thus, we would not expect a firm that sold capital due to idiosyncratic reasons to experience such large capital losses. On the other hand, the type of equipment used in the aerospace industry can more readily be used by other sectors than many other types of equipment. One of the auction experts told us that in rating 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.

With these factors in mind, we now offer what we believe to be reasonable implications from our results.

1. 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 goods for which we had information, the estimates from the geometric depreciation model imply losses of 63 percent relative to the replacement value. Even without the two structural items, the losses were 43 percent. This degree of irreversibility can have a major effect on investment behavior, as shown by the theoretical results of Dixit and Pindyck (1994) and Abel and Eberly (1994).

2. Capital displays significant sectoral specificity

According to the auction experts, we are studying one of the sectors with the least specific 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 additional discounts in price on capital that sold outside the sector. The loss on the median good was 64 percent if sold outside of aerospace compared to 44 percent if sold to aerospace.

These results suggest an enormous degree of sectoral specificity. Consider these estimates in the context of the model we presented in which the values to each type of buyer were related to the marginal revenue product (f) times the quality of the match (S) (equations (1) – (3)). 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.

3. Sectoral specificity of capital and thinness of resale markets combine to reduce the economic value of reallocated capital.

As discussed above, the value of the capital to the buyers exceeds the price received by sellers by at least 10 to 15 percent, so the losses in economic value are not as great as the losses to the selling firm. Some of the difference between the selling and buying price must be paid to auctioneers and dealers, so part of the wedge should be seen as a cost of capital mobility. But there is evidence of an economic cost even beyond that amount. Even if the buyers' values were 20 to 50 percent above the purchase price, the results would still indicate a fall in economic value for the used capital.

According to our theory, 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 much higher economic value than the immutable wind tunnel that sold outside the aerospace sector.

The loss in value appears to be much higher than that found for workers in the aerospace industry by Schoeni et. al. (1996)). 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 are for only 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.

IV. Conclusions

In this paper, we have argued that the cost of reallocating capital in response to sectoral shifts has been overlooked. We presented a theoretical model that showed how sectoral specificity of capital and thinness of resale markets could result in low value matches between reallocated capital and buyers. Our empirical results indicate significant costs of capital mobility. There are three separate manifestations of these impediments. First, the equipment sales were concentrated in the aerospace industry to a much greater extent than if equipment was not specialized by industry. Second, equipment that shifted sectors suffered a higher loss of economic value than equipment that stayed in the same industry. Finally, the winding down of operations involved significant periods of time of very low capital utilization.

These results suggest that capital specialization deserves much more study. It is likely that studying capital flows jointly with worker flows will greatly increase our understanding of these and other phenomena.

Technical Appendix

Proof of Proposition 1:

We first demonstrate why conditions (i) and (ii) are sufficient to guarantee the existence of an n* between 1 and N. Consider Figure 1, which shows graphs of $V_O(n)$ and $V_A(n)$ against n. Note that time move backwards as n increases, since higher n means that the firm has more units left to sell. Condition (i) guarantees that $V_A(n)$ is below $V_O(n)$ when n=1. This case will be true as long as the expected value of drawing from aerospace is sufficiently low when only one unit is left. Condition (ii) guarantees that $V_A(n)$ is above $V_O(n)$ for some n < N. This second condition will hold if $q\, R_A'(n)$ is sufficiently large. These two conditions together imply that the curves must cross, and there is at least one crossing where $V_A(n)$ crosses $V_O(n)$ from below. It is clear that once the firm has n ≤ n*-1 units left, it is optimal to sell all remaining units to sector O. Furthermore, at n* it is optimal to sell one unit to sector A before selling all remaining units to sector O.

It remains to be shown that for n > n*, it is not optimal to sell all remaining units to sector O. Consider the value of liquidating an amount k when n units are left to sell. k > n - n* would imply that n – k < n*, meaning the firm would not sell any units to sector A. Thus, we need to show that the value of this strategy is less than the value of selling k < n - n* units to sector O. The value of selling k > n - n* units to sector O is given by $W_O(n,k) = k\, R_O + W(n-k)$. However, since n – k < n*, we know that $W(n-k) = (n-k)\, R_O$, since once the firm has less than n* units left, we know it wants to sell them all to sector O. So the value of selling k > n – n* units to sector O at n > n* is simply the value of selling all remaining units to sector O, $W_O(n,k) = nR_O,\ \ for\ \ k > n - n^*$.   But we know that $nR_O < (n - n^*)\, R_O + W(n^*)$ since

$W(n^*) = V_A(n^*) > n^* R_O = V_O(n^*)$. Therefore, the optimal policy is to sell at least one unit to sector A.

Proof of Lemma:

Consider the firm's decision when n> n* units are left to sell. The value of searching for a buyer from sector A is:

(A-1) $$W_A(n) = \frac{q\, R_A(n) + qbW(n-1) - C}{1 - b + qb}$$

whereas the value of selling the first k units to outsiders is given by:

(A-2) $$W_O(n,k) = k\, R_O + W(n-k)$$

(W(n-k) is the value of the optimal decision when n-k units are left.) In order for the firm to choose to search in sector A, we require that $W_A(n) > W_O(n,k)$. Substitution of equations (A-1) and (A-2) into this condition show that it will hold if the following condition holds:

(A-3) $$q\, R_A(n) - C > (1 - b + qb) R_O + (1 - b) W(n-1)$$

How do we guarantee that (A-3) holds? We know that a similar condition holds at n* (by the definition of n*). Thus, as long as the left hand side (A-3) is increasing faster in n for n*<n<N than the right hand side, the firm will not sell units to sector O while it is still searching for sector A buyers. Taking derivatives of each side, and noting that

$$W'(n-1) = \frac{q\,R_A(n-1) - C - (1-b)W(n-1)}{1-b+qb} \leq \frac{q\,R_A(n-1) - C - (1-b)(n-1)R_O}{1-b+qb}$$

it is clear that condition (iii) of Corollary 1 is sufficient to establish that $W_A(n) > W_O(n,k)$.

Proof of Proposition 2:

At the point where $V_O(n)$ and $V_A(n)$ cross, $q\,R_A(n) - C = [(1-b)n^* + q\,b]R_O$, where n* is the last unit sold to aerospace before the public auction takes place. We implicitly differentiate this equation with respect to n* and the parameters. The effects of the parameters on n*, and thus on the number of units sold to aerospace, are easily established with condition (iv), plus the fact that $n^* > \theta$ and $R_A(n^*) > b\ R_O$.

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Table 1
Distribution of Sales by Industry: All Sales Included

Industry	**Percent of Sales Value**	**Percent of Buyers**
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	0.6	0.3
Unknown	3.7	18.6
Totals	**Sales Value**	**Number of Buyers**
	$18,723,607	1207

Geographic Distribution

California	63.8	89.2
Rest of U.S.	32.3	9.9
Foreign	4.0	0.8

Note: Data from Plants 1, 2, and 3 are included in these tables.

Table 2
Distribution of Sales by Industry: Private Liquidation Sales

Industry	**Percent of Sales Value**	**Percent of Buyers**
Aerospace (SIC 372, 376)	66.8	36.4
Other Transportation Equipment	0	0
Fabricated Metals and Machinery	10.1	22.7
Other Manufacturing	0.7	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
Totals	**Sales Value**	**Number of Buyers**
	$4,688,528	22

Geographic Distribution

California	36.4	36.4
Rest of U.S.	54.6	59.0
Foreign	9.0	4.6

Note: Data from Plant 1 are included in this table.

Table 3
Distribution of Sales by Industry: Public Auctions

Industry	**Percent of Sales Value**	**Percent of Buyers**
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	0.8	0.3
Unknown	4.9	18.9
Totals	**Sales Value**	**Number of Buyers**
	$14,035,080	1185

Geographic Distribution

California	72.9	90.2
Rest of U.S.	24.8	9.0
Foreign	2.3	0.8

Note: Data from Plants 1, 2, and 3 are included in these tables.

Table 4
Depreciation Estimates: Geometric Depreciation Model
(Heteroscedastic-consistent standard errors in parenthesis)

<table>
<tr><th>Parameter</th><th>Homogeneous Capital</th><th>Heterogeneous Capital</th><th>Preferred Model</th></tr>
<tr><td>C_0 (constant term)</td><td>14,584.4
(7474.8)</td><td></td><td></td></tr>
<tr><td>C_0 for machine tools</td><td></td><td>18,360.2
(3699.5)</td><td rowspan="2">17,272.3
(3192.7)</td></tr>
<tr><td>C_0 for miscellaneous equipment</td><td></td><td>9509.5
(4701.5)</td></tr>
<tr><td>δ (annual depreciation)</td><td>0.076
(0.051)</td><td></td><td></td></tr>
<tr><td>δ on machine tools</td><td></td><td>0.122
(0.013)</td><td rowspan="2">0.120
(0.011)</td></tr>
<tr><td>δ on miscellaneous equipment</td><td></td><td>0.059
(0.031)</td></tr>
<tr><td>δ_r (deprec. on rebuilds)</td><td></td><td>0.604
(0.166)</td><td>0.564
(0.155)</td></tr>
<tr><td>a (ratio of sales price to replacement cost)</td><td>0.100
(0.073)</td><td></td><td></td></tr>
<tr><td>a on machine tools</td><td></td><td>0.391
(0.077)</td><td rowspan="2">0.379
(0.062)</td></tr>
<tr><td>a on miscellaneous equipment</td><td></td><td>0.267
(0.041)</td></tr>
<tr><td>a on structures (assuming 12 % geom. depreciation)</td><td></td><td>0.051
(0.037)</td><td>0.049
(0.037)</td></tr>
<tr><td>Brainard-Tobin’s q (median good)*</td><td>0.179</td><td></td><td>0.473 (excluding structures)</td></tr>
<tr><td>Number of Observations</td><td>127</td><td>127</td><td>127</td></tr>
<tr><td>Log Likelihood Function</td><td>-1629.91</td><td>-1532.16</td><td>-1532.60</td></tr>
<tr><td>$\bar{R}^2$</td><td>0.303</td><td>0.822</td><td>0.825</td></tr>
</table>

The p-value of the likelihood ratio test of the preferred model against the heterogeneous capital model is 0.83.

*Brainard-Tobin’s q was calculated as $q = \frac{C_0 + aI_m}{I_m}$, where I_m is the median reflated original acquisition cost.

Table 5
Distribution of Buyer Type and Mode of Sales in Depreciation Subsample
(percentages based on value of purchases)

A. Percent Distribution of Buyer Type by Mode of Sale

	Private Liquidation Sale	Public Auction	Total
Aerospace	91.5	8.5	100
Other	25.0	75.0	100

B. Percent Distribution of Mode of Sale by Buyer Type

	Aerospace	Other	Total
Private Liquidation Sale	74.9	25.1	100
Public Auction	8.5	91.5	100

Table 6
Depreciation Estimates by Type of Buyer and Sale
(Heteroscedastic-consistent standard errors in parenthesis)

Parameter	Baseline (1)	By Type of Buyer (2)	By Type of Sale (3)	By Buyer and Sale (4)
C_0 (constant term)	16,724.5 (3170.8)	21,305.8 (3099.8)	22,721.4 (3173.3)	24,523.4 (3235.9)
δ (annual depreciation rate)	0.120 (0.011)	0.132 (0.009)	0.128 (0.009)	0.133 (.008)
δ_r (depreciation on rebuilds)	0.549 (0.150)	0.464 (0.082)	0.426 (0.059)	0.458 (0.060)
a	0.380 (0.062)			
a if sold to aerospace (col.2), private liquidation (col.3)		0.448 (0.050)	0.419 (0.050)	
a if sold to outsiders (col.2), public auction (col.3)		0.248 (0.047)	0.182 (0.065)	
a if sold to aerospace in private liquidation				0.451 (0.048)
a if sold to aerospace at public auction				-0.001 (0.095)
a if sold to outsiders at private liquidation				0.289 (0.025)
a if sold to outsiders at public auction				0.178 (0.064)
Brainard-Tobin's q, (median good) Aerospace (col. 2), Liquidation (col.3)		0.564	0.543	
Brainard-Tobin's q, Outsiders (col. 2), Auction (col. 3)		0.364	0.306	
Number of observations	125	125	125	125
Log Likelihood Function	-1485.37	-1480.97	-1480.76	-1478.40
P-value of LRT against model in column 4		0.076	0.094	

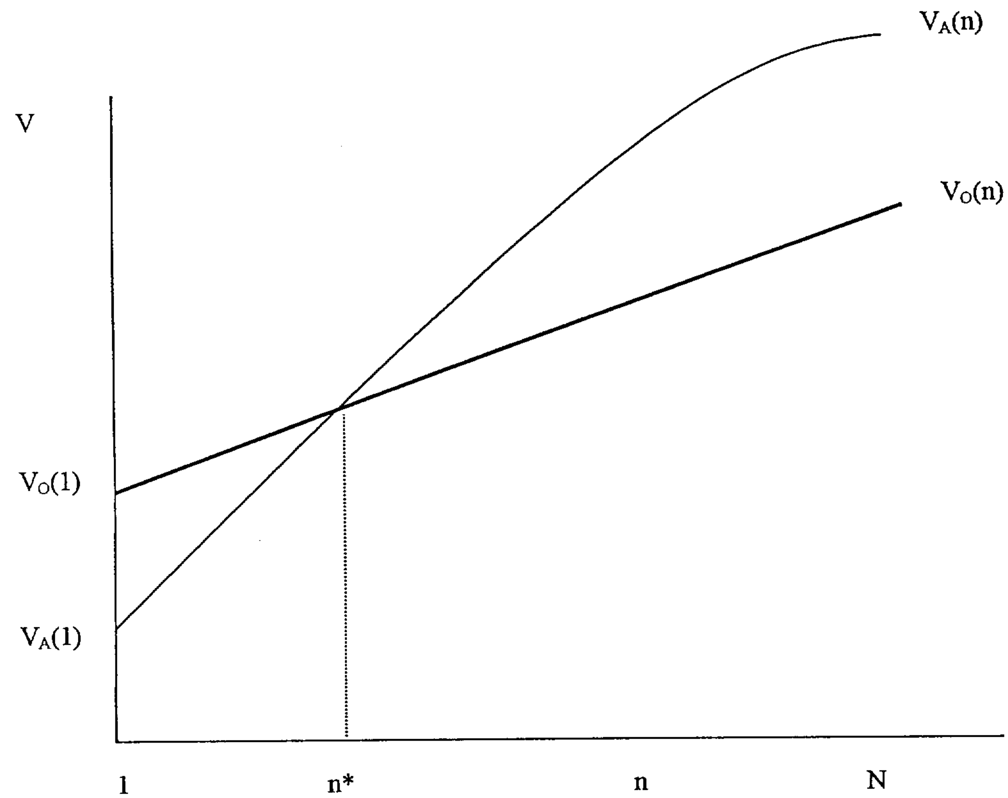
Table 7
Flexible Functional Form Estimates
Dependent variable: log(sales price/reflated original cost)
(regressions weighted by reflated original cost)

By type of buyer		By mode of sale	
Regressor	**Estimate**	**Regressor**	**Estimate**
Constant	-0.173 (0.781)	Constant	2.948 (0.783)
Log(real original cost)	-0.097 (0.063)	Log(real original cost)	-0.338 (0.063)
Dummy for rebuilds	-0.783 (0.183)	Dummy for rebuilds	-0.502 (0.202)
Age	-0.080 (0.025)	Age	-0.105 (0.031)
Age^2	0.001 (0.0005)	Age^2	0.002 (0.0006)
Aerospace dummy	1.526 (0.432)	Private liquidation dummy	0.694 (0.443)
Aerospace*Age	-0.186 (0.048)	Liquidation*Age	0.018 (0.039)
Aerospace*Age^2	0.004 (0.001)	Liquidation*Age^2	-0.0009 (0.0007)
Number of observations	125	Number of observations	125
$\bar{R}^2$	0.575	$\bar{R}^2$	0.554
P-value on joint significance of aerospace terms	0.0007	P-value on joint significance of liquidation terms	0.009

Table 8
Implied Depreciation Rates by Age
(Flexible functional form model)

	By Buyer		By Mode of Sale	
Age	**Aerospace**	**Outsiders**	**Private Liquidation**	**Public Auction**
1	0.225	0.074	0.081	0.096
5	0.192	0.063	0.073	0.082
10	0.148	0.050	0.063	0.063
15	0.102	0.037	0.052	0.045
20	0.053	0.023	0.041	0.026

Figure 1: Value Functions from the Model



n = the number of units left to sell

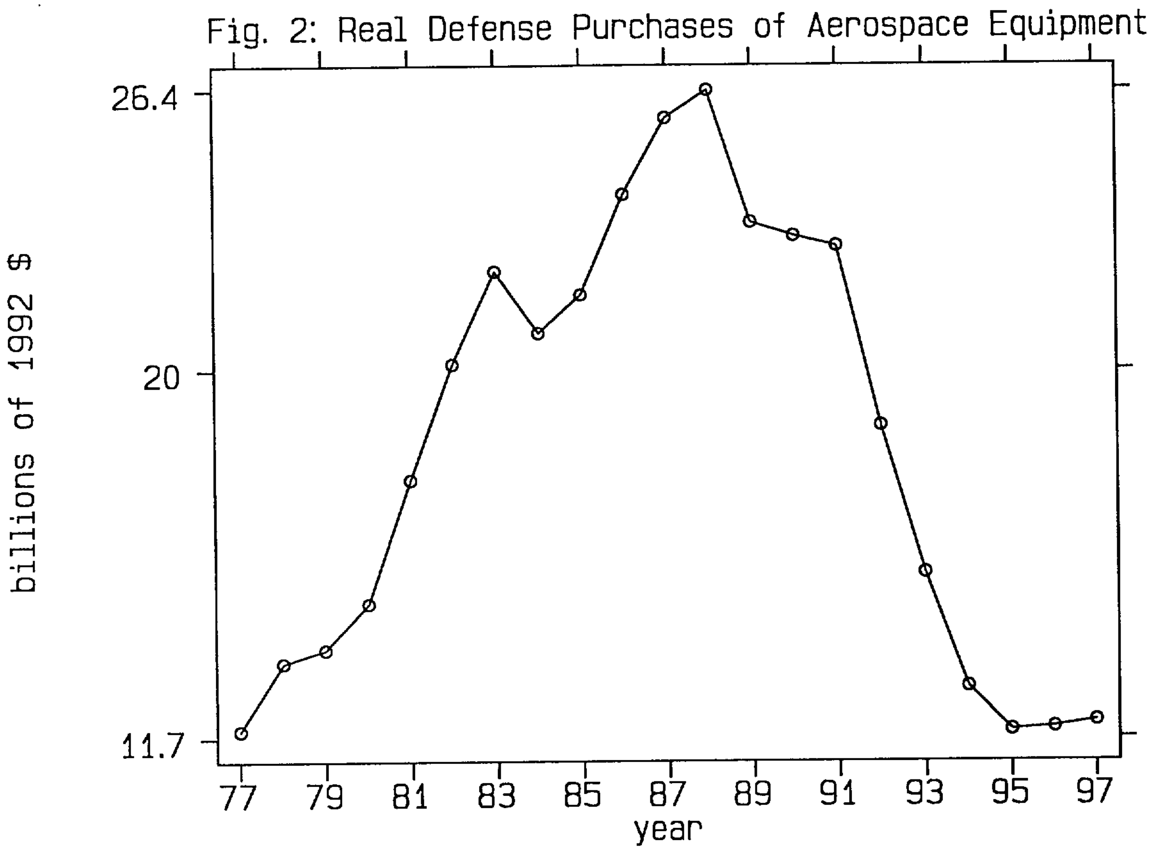


Fig. 2: Real Defense Purchases of Aerospace Equipment
26.4
20
11.7
billions of 1992 $
77
79
81
83
85
87
89
91
93
95
97
year

Fig. 3: Ratio of Sales Price to Reflated Original Cost
(Circle size is proportional to original cost)

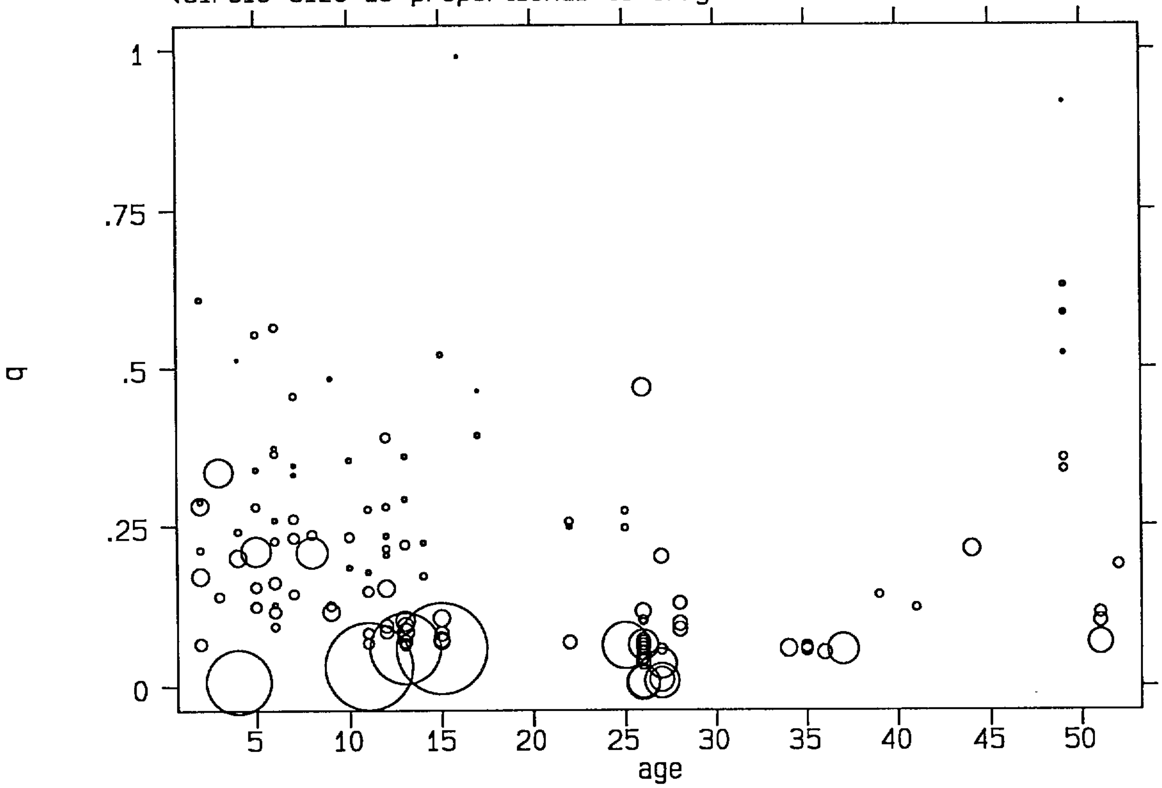


Fig. 4: Fitted q's by Type of Buyer
(A = aerospace; O = other)

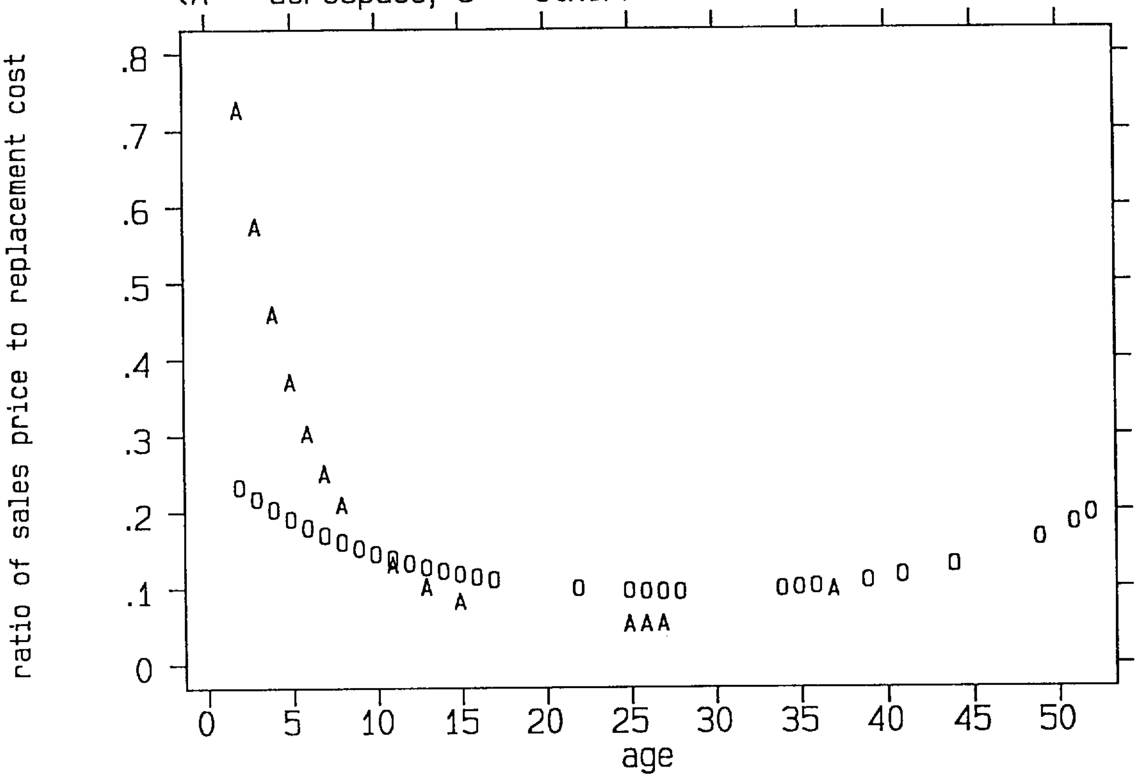


Fig. 5: Fitted q's by Mode of Sale
(L = private liquidation, X = public auction)