THE BUSINESS CYCLE, FINANCIAL PERFORMANCE, AND THE RETIREMENT OF CAPITAL GOODS

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Working Paper **6392**

NBER WORKING PAPER SERIES

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Working Paper 6392
http://www.nber.org/papers/w6392

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

I wish to thank Olivier Blanchard, Ricardo Caballero, Boyan Jovanovic, Pete Klenow, Jim Poterba, Robert Pindyck, Bob Solow, two anonymous referees, and seminar participants at the NBER Summer Institute for comments and to thank the MIT Center for Energy and Economic Policy Research and the National Science Foundation for financial assistance. Any opinions expressed are those of the author and not those of the National Bureau of Economic Research.

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NBER Working Paper No. 6392
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ABSTRACT

The neoclassical investment literature assumes that capital is homogenous, lives forever and has a constant depreciation rate. More recent theories of investment have shown that when there are distinct capital vintages with embodied technologies, depreciation and capital retirement become economic decisions and this raises important problems with existing empirical work. Direct testing of these issues, however, has been rare because of the lack of micro data. This paper uses new data on the service lives of individual capital goods in the airline industry to empirically examine the impact that economic factors have on capital retirement. The results strongly support the view that retirement is fundamentally an economic decision. Retirement is much more likely in recessions, when the cost of capital is low, or when a firm has good financial performance. Factor prices and industry regulation are also important. Since many of these factors also influence capital expenditures, the results imply that estimates from the conventional investment literature such as the effect of the cost of capital or financial performance may substantially overstate the case since their impact on *net* investment may be much more modest than their impact on gross investment. The results also have implications for the measurement of productivity.

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1. INTRODUCTION

In order to establish a theory which can be tested empirically with existing macroeconomic data, the neoclassical investment literature assumes that a firm's capital stock is homogenous, lasts forever and depreciates at a constant rate which is unrelated to economic conditions. These assumptions--homogeneity, stability, and exogeneity--are critical for estimating the determinants of investment and are by no means innocuous. In practice, investment data concern only capital expenditures--*gross* investment--rather than the theoretically appropriate *net* investment. The difference is depreciation and capital retirement. To the extent that the conventional literature is correct to assume depreciation and capital retirement are exogenous and constant, fluctuations in gross investment are the same as fluctuations in true net investment. If, however, the assumptions about depreciation are not valid and economic factors matter, especially if the factors are the same ones that influence capital expenditures, then the impact that they have on *gross* investment (estimated in the conventional literature) may be quite different from their impact on true, *net* investment. This problem will also influence measured productivity.

When capital is heterogeneous it is difficult to believe that depreciation or retirement are constant and exogenous. As discussed in an early literature by Feldstein and Rotschild (1974) and Feldstein and Foot (1971), constant depreciation with differing rates across goods can create "lumpiness" in investment and "echoes" of past investment in future decisions. Boddy and Gort (1971) noted early that there is evidence of capital heterogeneity across sectors and more recent work by Goolsbee and Gross (1997) has demonstrated how important capital heterogeneity for the study of investment at the micro level.

In the area of capital retirements, recent advances in macroeconomics have shown that in vintage capital models with embodied technological progress, the depreciation and obsolescence of capital become economic decisions rather than consequences of physical decay. Firms must decide when it makes sense to replace old machines and this non-representative agent situation has important predictions of what should influence capital retirement and also has some key macroeconomic implications.

Cooper and Haltiwanger (1993) and Caballero and Hammour (1994, 1996) present models with vintages where firms concentrate retirements and "destruction" during recessions when the opportunity cost of reallocation is lowest. This implies that, empirically, the retirements of existing capital should be negatively correlated with the business cycle. Cooley, Greenwood, and Yorukoglu (1995) show that firms should replace existing capital when the price of new capital is low, i.e., retirements should be negatively related to prices and positively related to financial performance if it lowers the cost of funds. Other authors have shown the importance of vintage capital for measurements of productivity growth (Greenwood, Hurcowitz, and Krusell, 1997), learning by doing (Bahk and Gort, 1993 or Klenow, 1998), and firm survival (Agarwal and Gort, 1997).

Direct testing of these theories at the micro level is important for our understanding of investment but a lack of data has made capital retirement the invisible twin of capital expenditure. Nonetheless, given the right data, these new theories are testable against the neoclassical model because the neoclassical model makes a very clear prediction: economic factors should not matter for retirement. In the neoclassical view, depreciation and retirement are physical, exogenous processes and, strictly interpreted, capital should last forever. While this may seem a rather stringent model to test, these assumptions are critical for the neoclassical investment literature. If the assumptions fail, it means that changes to gross investment and net investment are not the same and the results from the empirical investment literature may not be valid. In contrast, the new theories of investment imply that the business cycle, the cost of capital, financial performance and any shocks to the relative productivity of a particular type of capital should have identifiable effects on retirements.

This paper turns to a unique micro data set on capital decisions in the airline industry from 1972-1984 in order to test these theories. The data concern decisions about one of the most common jet airplanes of all time--the Boeing 707--and follow individual capital goods where vintage and retirement are directly observed. The individual capital goods are matched to detailed data on financial performance, the business cycle, factor prices, and the cost of capital. While airlines may not be representative of the rest of the economy, the results from this micro data provide direct, unmistakable evidence that vintage is important for capital retirements and that economic factors do play an important role and of precisely the form predicted by the new investment models. The fact that many of the factors influencing retirement in this industry are the same ones normally used in the investment literature to explain capital expenditures may have important implications for our empirical understanding of true investment behavior and productivity measurement.

The paper is divided into eight sections. Section 2 presents a model of the capital retirement decision. Section 3 gives background on the airline industry, the 707, and the data. Section 4 presents the empirical methods and specifications. Section 5 presents the basic results while section 6 shows them to be robust to alternative explanations. Section 7 gives some macroeconomic implications and the final section concludes.

2 ECONOMIC RETIREMENT: AN ANALYTICAL FRAMEWORK

The literature has produced many different vintage capital models so in this section I present a simplified model of the replacement problem for a firm with a single capital good—in this case a plane—in order to illustrate the role that economic factors can play when there is capital heterogeneity.[1] In this model, there are two varieties of capital goods--the existing plane and a new type of plane and there is no uncertainty. Industry demand in each period t generates revenue, R_t, which, for simplicity, is assumed to be the same for both the new and old plane. There are two operating expenses, fuel costs and maintenance. The existing capital good has energy intensity E while the new plane has intensity E' where E'<E so the new plane is more efficient and the price of energy is p. The plane requires maintenance expenses in each period the plane flies that cost m in the first year of operation and increase at a rate δ per year for the life of the plane.[2] The net income at time t for an existing model plane of age A is then

$$R_t - pE - m(1+\delta)^A . \qquad (1)$$

The firm is trying to decide whether to replace this existing plane with a new plane. If it does so, it must pay a purchase price today of q times the cost of funds (1+f) where $f \geq 0$ and it

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[1] In reality, firms can buy or sell capital independent of replacement. Because airline fleets have continuously trended upward over the sample in this paper, I assume that all retirements are replacements and that expansion investment is made on standard net present value criteria and is unrelated to the replacement decisions.

[2] The constant revenue across planes and the putty-clay assumption about energy intensity are for simplicity and are reasonable approximations for aircraft as is the assumption of rising maintenance expenses with age. The results are basically unchanged, though, if one assumes that there are no maintenance expenses but that revenue or fuel efficiency deteriorates with age.

takes one period for the capital to become operational.[3] Once it does so, however, it will get a plane with better fuel efficiency and lower maintenance costs. Defining the discount factor θ to be 1/(1+r), where r is the interest rate, the new plane has a net present value at time s (having been purchased at time s-1) of: [4]

$$V(s) = \sum_{t=s}^{\infty} \theta^{t-s} \left(R_t - pE^{t} - m(1+\delta)^{t-s} \right). \qquad \textbf{(2)}$$

To see the effect that economic covariates have on the retirement decision, consider a firm on the margin between deciding whether to replace the existing plane this period (time zero) and start using the new plane in period 1 or wait one period to replace and start using the new plane in period 2. The value of replacing at time 0 (with plane becoming operational at time 1) is

$$\theta V(1) - q(1+f) \qquad \textbf{(3)}$$

and the value of replacing in period 1 (becoming operational at time 2) is

$$R_0 - pE - m(1+\delta)^{A} + \theta^2 V(2) - \theta q(1+f). \qquad \textbf{(4)}$$

Define the function $\Delta(t)$ to be the value in time t of waiting one period to replace the plane and q^* to be the modified purchase price $q(1+f)$. $\Delta(0)$ is the difference between (4) and (3):

$$\Delta(0) = \left[R_0 - pE - m(1+\delta)^{A} + \left(\theta^2 V(2) - \theta q^* \right) \right] - \left[\theta V(1) - q^* \right] \qquad \textbf{(5)}$$

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[3] Though the empirical work uses annual data, the periods in this model need not be an entire year for the intuition derived resulting from the model to hold.

[4] When making these calculations, I assume that a firm cannot buy a used version of the new plane, that there will not be another new capital type once the new version is purchased, and that the income of the new version is always greater than zero so they hold it forever. None of these is essential but they greatly simplify the model.

which, plugging in from (2) and rearranging terms, yields

$$\begin{aligned}\Delta(0) = R_0 - pE - m(1+\delta)^A + q^*(1-\theta) - \theta\left[\sum_{t=1}^{\infty} \theta^{t-1}(R_t - pE' - m(1+\delta)^{t-1})\right] \\ + \theta^2\left[\sum_{t=2}^{\infty} \theta^{t-2}(R_t - pE' - m(1+\delta)^{t-2})\right]\end{aligned} \qquad \textbf{(6)}$$

Appendix B shows that (6) can be rewritten more intuitively as

$$\Delta(0) = \left[R_0 - \theta R_1\right] + \left[(1-\theta)q(1+f)\right] - p\left[E - \theta E'\right] + m\left[\frac{\theta(1-\theta)}{1-\theta(1+\delta)} - (1+\delta)^A\right]. \qquad (7)$$

Intuitively, the condition says that by waiting an additional period to replace the plane, the firm earns the difference in revenues between the current and the discounted future period, saves the interest on the purchase price, but loses the discounted difference in energy costs and the properly discounted difference in maintenance expenses.

The comparative statics are straight forward since, at the margin, anything which increases the value of waiting, $\Delta(0)$, will increase the retirement age of existing capital and *vice versa*. Booms can be thought of as increasing current revenue, R_0. Consistent with the new investment theories, $d\Delta(0)/dR_0 = 1 > 0$, indicating that firms hold on to existing capital longer at the margin during booms when the opportunity cost of down time is highest.[5]

Likewise, $d\Delta(0)/dq$ and $d\Delta(0)/d(1+f) = 1-\theta > 0$, indicating that increases in the purchase price or the cost of funds makes replacement more costly and lead the firm to hold onto

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[5] The model of Klenow (1998) implies the opposite, that replacement should be greater in booms. This is because Klenow concerns learning by doing which depends on output. Firms install capital when output (and hence learning) is highest. In this model, capital always takes one period to build so the firm installs it when output (and hence opportunity cost) is lowest.

existing capital longer at the margin.

Finally, $d\Delta(0)/dp = (\theta E' - E)$, and since the new plane is more efficient than the existing plane (i.e., $E' < E$), $d\Delta(0)/dp < 0$, indicating that higher fuel prices reduce the retirement age of existing capital. This is not surprising. The existing plane is more fuel intensive so increasing energy prices gives a negative shock to its relative productivity.

This basic model of the firm's capital decision shows that with heterogeneous capital and vintages, retirement will not be exogenous to the economic environment and thus motivates the empirical work below.

SECTION 3: AIRLINES AND DATA

A. The Airlines and the 707

While vintages as well as economic forces play key roles in the new theories of capital decisions, in practice their importance is little known. For several reasons, airlines are an ideal place to examine capital retirement decisions. First, and most important, there is data on individual capital goods where vintage can be directly observed. Second, airlines take their capital decisions very seriously. A single plane can last for decades and costs tens of millions of dollars and a major carrier like United is often making decisions about hundreds of planes in the course of a year. Indeed, the attention devoted to capital decisions in airline economics textbooks indicates that they are central to airline operation.[6] Third, the demand for airline travel is highly cyclical so that business cycle fluctuations can have a substantial impact on the demand for the services of existing planes. Fourth, there have been many shocks to the variables of interest over the period of this sample (1972-1984). Demand, fuel costs, the cost of capital and firm financial performance have all fluctuated substantially during this time, allowing the results to isolate the effect of each on retirement decisions. Finally, the technology of the capital stock is largely embodied in the capital goods and different airplanes have very different operating characteristics. Although these factors make airlines a great place to find micro evidence of the economics of capital retirement, it is also important to note that these same reasons may imply that airlines are not representative of the wider economy.

The Boeing 707 was the first long range jet put into general use and by the early 1960s, the 707, the smaller B-720 and the DC-8 had almost fully replaced propeller planes in the fleets of the major carriers. The 707 was produced from 1958-1970 and there were two general types, the 100 series, whose median delivery year was 1964, and a slightly larger 300 series whose median delivery year was 1967.[7] The next generation of jets which included the 727, 737, 747, DC-10 and L-1011 first arrived in the 1960s and began replacing the older jets. In 1971, 707s comprised almost 20% of the entire fleet of all carriers but they were also the oldest planes so they were ripe to be retired as the years went on. After airline deregulation in 1978, they still made up about 10% of the fleet. By the mid-1980s they were entirely gone, hastened significantly by the fuel shocks which rapidly made the fuel-intensive 707 economically obsolete, as demonstrated in Goolsbee (1997). Noise regulations which required the complete retro-fitting of all 707s by 1985 also played a role by instituting a phase-in period requiring at least 25% compliance by 1981 and 50% compliance by 1983.

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[6] Standard references are James (1982) or O'Connor (1989).

[7] Within the 300 series, the -300 was the oldest model and had a turbojet engine. The -300B had a turbofan engine.

B. DATA AND IDENTIFICATION STRATEGY

The Aviation Data Centre's *Airliner Production List* tracks by tail and registration number each 707 ever produced, from its first flight, through all changes of ownership and operating status to its final retirement. The sample in this paper includes every 707 in the service of major carriers in 1972 excluding planes crashed, lost or destroyed in terrorist incidents.[8] The major carriers operating 707s in 1972 were American, Northwest, TWA, Pan-American, Braniff, Western and Continental. The sample includes 351 707s: 102 707-100s and 249 707-300s (107 300Bs, 125 300Cs, and 17 300s). This gives 2717 plane-year observations.

I classify a carrier as having retired a plane when the carrier takes it out of service. This includes withdrawing it, scrapping it, or selling it to another user. The aggregate stock of operating 707s in this sample is shown in figure 1. Right censoring is not a problem because there are only six planes in the final year of data and they were all removed from service. The actual first destinations of the planes when removed are listed in table 1. Since many of the planes are sold to foreign airlines and some to non-airline business in the U.S., most of the results will only identify how economic covariates affect the value of operation relative to the value of outside offers and I will usually assume that the outside demand is not related to the covariates to get around this issue. Empirically, however, this should *understate* the effect that covariates have on retirement because the high fuel prices, low aggregate demand, or low cost of

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The -300C was the same as the -300B but allowed a cargo configuration.

[8] This paper assumes that the firms own their planes. Although leasing is currently prevalent in the airline industry, the data indicate that among these carriers, leasing 707s was quite rare and was almost always a long-term capital lease when it did occur.

capital which encourages retirement probably also decrease the outside demand for used 707s. The results below will show this intuition to be true.

I match the data on the individual planes to fuel price data from the *Aircraft Operating Cost and Performance Report*, a rich data set on airline operating costs kept by the Civil Aeronautics Board (CAB) which gives the fuel cost per available seat mile (ASM) for each aircraft type in every airline-year. These cost data are then matched to the carrier's financial performance using the *Air Carrier Financial Statistics,* as well as to the state of aggregate demand and to the cost of new capital equipment from Kopcke (1985). There may be error in this cost of capital due to the tax status of the firms but some of the results will attempt to check this. Summary statistics of the data used in the sample are listed in table 2 and further details on the variables used can be found in Appendix A.

SECTION 4: EMPIRICAL SPECIFICATION AND METHODS

To estimate the effect that a vector of economic covariates, **x**, has on the decision to retire capital, this study uses a hazard model which estimates the instantaneous probability of retirement for individual planes conditional on having survived to the present.[9] Such methods are common in the labor literature using individual labor market histories. For any direct study of capital retirement, it is critical to have micro data on individual planes. A regression of the share of the 707 stock retired in a given year, for example, on a series of aggregate variables

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[9] This approach assumes that the carriers make retirement decisions on a plane by plane basis. This assumption does not preclude firms owning capital goods of multiple ages simultaneously but does imply that older planes should be retired before younger planes. In practice, this is almost always true for the airlines in this sample and when false, it probably results from some planes having had high utilization which makes their working age different from their calendar age.

without any information on the ages of the individual planes would be unidentified. Any observed pattern of retirement which could be explained by factor price changes or market conditions could also be explained by variation in the unobserved age distribution of planes in that year.

The hazard function $h(a|x_{it})$ is the probability in year t that plane i will be retired at age a conditional on having survived to that age ,

$$h(a|x_{it}) = \lim_{\Delta \to 0} \frac{P(a \leq A < a+\Delta | x_{it},\, A \geq a)}{\Delta}. \qquad \textbf{(8)}$$

I adopt the common assumption that the covariates do not change the shape of this hazard function but instead shift it (proportional hazards) so the actual hazard can be written $h(a|x_{it})=h_0(a)*\exp(x_{it}'B)$, where $h_0(a)$ is a baseline hazard function. The covariates used here are not fixed for the duration of the capital good so a model with time-varying covariates is required.

Clearly, some stochastic structure is required for the model or else the hazard is degenerate—zero until the price of oil exceeds a certain level and then certain death. For simplicity I assume that the baseline hazard follows a Weibull distribution. The probability of retirement for a plane of age a in year t is then

$$h(a|x_{it}) \;=\; \rho a^{\rho-1} \;*\; e^{(X_{it}'B)} \qquad \textbf{(9)}$$

where ρ is a shape parameter and the B's are the coefficients on the covariates. The Weibull is commonly used in practice because of its empirical flexibility. It can take on many shapes, depending on the estimated ρ. If ρ is equal to one, it becomes a simple exponential decay model. If ρ exceeds one, the hazard increases with age. Results will show that assuming the Weibull functional form does not influence the results as they are very similar to results using the semi-parametric method of Cox (1972) which makes no assumption about the baseline hazard's functional form.

While the hazard model, by its nature, can only give reduced form estimates, this is not very troubling partly because there is no agreement on a structural model in this area and partly because the neoclassical literature makes a clear, testable prediction about the reduced form: exogenous capital obsolescence means that economic covariates should have no effect on the hazard rate—only age should matter. In fact, by assuming a constant depreciation rate, the neoclassical investment literature routinely makes the even stronger assumption that even age doesn't matter.

It is important to note the key difference between the neoclassical view of investment and the neoclassical view of retirement. For investment, we think of the decision as being based on fundamentals potentially embodied in a variable like Tobin's q. If we poorly control for a firm's fundamentals, covariates correlated with fundamentals will appear to affect investment in reduced form but this correlation will be spurious. The reduced form works for retirements, though, because neoclassical theory requires that *even the fundamentals* should not influence capital retirement. Indeed, if the same fundamentals affect both investment and retirements, then neoclassical empirical work which looks only at expenditures may have serious problems. Whether economic factors matter for capital retirement in reduced form because they are correlated with a firm's fundamentals or because of their inherent importance, neoclassical theory is still rejected.

If the vintage capital models are correct, however, economic factors *should* play a role in the retirement decision. Fuel costs, by making the 707's performance worse relative to other planes should have a positive coefficient on the retirement hazard. Airline financial performance, measured by cash flow, should also have a positive effect if higher cash flow lowers financing costs or if low earnings mean firms lose their tax subsidies so their cost of capital rises. The cost of capital equipment itself should have a negative coefficient as should the business cycle, as represented by either the level or growth rate of GDP or the level of airline sales, since the opportunity cost of reallocation delays is high in booms. The regressions will also include a dummy for deregulation after 1978 and a variable representing anti-noise regulation as well as model dummies. Some specifications will also include year dummies to eliminate any unobserved aggregate factors.

5. BASIC RESULTS

Column (1) of Table 3 presents a basic Weibull hazard regression for the retirement of Boeing 707s. The results are presented in log form so that a one unit increase in the covariate with coefficient b will multiply the baseline hazard by exp(b). At the bottom of the column is the estimate of the log of the shape parameter, ρ. If the log of ρ is zero (i.e., $\rho = 1$), then the baseline hazard function is exponential and vintage is not important.

The results show clearly that vintage matters for 707s. The log shape parameter is significantly greater than zero implying that older planes are much more likely to be retired than younger planes with the same covariates. Inverting the hazard in equation (9) gives an expected lifetime for a plane with given covariates. In this equation, a 707-300B with average covariates over its service life has an expected life of 16.6 years. The results also demonstrate that economic factors are clearly important for capital retirement decisions. Fuel costs, the business cycle, the cost of capital and firm financial performance all have large and highly significant coefficients with the predicted sign.

The coefficient on GDP growth indicates that a one standard deviation decrease in GDP growth of 2.6 percentage points increases the instantaneous hazard rate by 40%. Firms are more likely to readjust their capital stocks at the trough of the business cycle. This masks the differential effect by, vintage, however. Table 4 shows the probability of surviving for three years in a boom of 4% GDP growth and a bust of zero growth for a 707-300B of different ages. The other covariates are held at their mean levels. For a ten year old plane, the probability of surviving three years falls from 81.5% to 70%. For the older planes, the impact is more dramatic. Survival probabilities for 20 year old planes fall from 34.3% to 11.9% and for 25 year old planes from 12.7% to less than 1%. In other words, during recessions, airlines do retire their capital and they concentrate the adjustment among the oldest planes—exactly as predicted.

The cost of capital and cash flow also have the predicted sign indicating that when purchasing new investment is more costly, either because of high taxes or because of poor financial performance, firms hold onto their existing capital longer. A one standard deviation decrease in the cost of capital increases the yearly retirement probability by 24% and a one standard deviation increase in the cash flow ratio increases the probability by 29%. Table 5 shows the probability of surviving for three years with covariates at the mean cost of capital and then with an additional 10% investment tax credit. There is a significant reduction in the probability of survival and the drop is greatest for the older planes. The three year survival probability for 10 year old plane falls from 78.5% to 69.3% but for a 25 year old plane from 7.1% to 0.1%. The overall expected survival time falls from 16.6 years to 14.8 years. An increase in cash flow has a similar effect.

The coefficient on cash flow does not necessarily mean that financial constraints are at work. It may be that the cost of capital is mismeasured for firms with low cash flow because the data assumes the firms can use all available investment subsidies but firms with tax losses usually cannot. It is entirely legitimate, however, to the cash coefficient as showing the importance of increasing the cost of purchasing new capital, broadly defined—either by reducing available tax subsidies or by direct financial constraints. The coefficients on the cost of capital and cash flow indicate that the cost of buying new capital influences the retirement decision significantly, a fact that is inconsistent with the neoclassical literature.

Factor prices also matter. A one standard deviation increase in fuel costs makes the yearly retirement probability of 707s more than 66% higher. The large magnitude simply confirms the results in Goolsbee (1997) which show in detail how the fuel shocks basically made the fuel-intensive 707 obsolete overnight. Noise regulations have also had an important impact on capital retirement, raising the probability of retirement significantly. Deregulation extended service lives, though not significantly.

6. ADVANCED RESULTS: CONTROLS AND ROBUSTNESS

A. Measurement Problems

There may be measurement problems with some of the independent variables in the specifications which could bias the coefficients. Columns (2)-(4) deal with exactly these issues.

First, concerning the measure of the business cycle, the theoretical explanation of the importance of the business cycle showed that the level of output, rather than the growth rate, influences the retirement age. Column (2) replaces GDP growth with the ratio of passenger revenue to property plant and equipment for the airline as a measure of the level of demand. I generally use GDP because the passenger revenue ratio may be endogenous, but the results show that using it shows the same negative and significant effect of demand on retirement and that the other coefficients are mostly unchanged except for fuel costs which becomes even more important. Here, a boom which increases passenger revenue by 4% reduces the hazard by around 20%. At the mean, a 707-300B's expected lifetime is 17.5 years but with the increase in output grows to 18.3 years.

The model further indicated that the effect of output should depend on the year. Current output should reduce retirements while future output should increase it. If, in addition, high levels of output in a previous period either increase the need for current maintenance or delay retirements to the present, past output should also increase current retirements. Column (3) includes the detrended level of real GDP as well as the level with one lag and one lead and the results show that all the coefficients have the predicted sign. Current output significantly reduces the instantaneous probability of retirement and high output in the previous year increases it. Future output increases the probability of retirement, but the coefficient is small and insignificant, perhaps meaning firms' expectations of future output are noisy. The other specifications use GDP growth rate only as a parsimonious way to characterize the effect of output. The results in (3) indicate that, if anything, this simplification biases the results downward since the coefficients on the other covariates such as the cost of capital and cash flow are larger than in the earlier specifications, though not significantly.

A second measurement issue concerns the cost of capital. The measure used in the regressions assumes that each firm can use all existing investment subsidies of the government and is paying the statutory corporate tax rate. As mentioned above, if firms have tax loss carryforwards, this may not be the case. This issue may be particularly relevant for airlines since many of these firms have large losses throughout the sample. To whatever extent the cost of capital is mismeasured at the firm level, however, this should serve to bias downward the coefficient on the cost of capital. The significant and relatively large coefficient on the cost of capital in equations (1)-(3), therefore, may be related only to the interest rate portion and not to the tax component which is mismeasured.[10]

To determine if the importance of the cost of capital comes about only from the real interest rate and not from taxes, column (4) repeats the specification but includes the tax term alone as a separate regressor. If taxes have a different effect than the rest of the cost of capital, then the tax term should have the opposite sign of the full cost of capital term. This is an imperfect measure, but the coefficient on the tax term in (4) does have a positive coefficient. The magnitude, however, is small and the coefficient is insignificant. I cannot reject that changing the cost of capital through taxes or through other components has the same effect. The coefficients on the other covariates basically remain unchanged.

B. Heterogeneity and Functional Form

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[10] Goolsbee (1998) shows that there may also be an upward sloping supply curve for new capital which reduces the effectiveness of investment tax incentives but here I assume that individual airlines are price takers.

Since the hazards are reduced form estimates which make a number of statistical assumptions, it is important to test how sensitive the results are to loosening the restrictions. First, there may be unobserved heterogeneity among different individual aircraft which Heckman and Singer (1986) and others have shown can lead to bias. If there are good planes and bad planes, for example, bad ones will retire young and the surviving planes will be of higher unobserved quality. This heterogeneity, however, will tend to bias the estimated baseline hazard away from finding that the hazard increases with age (good planes are both older and less likely to be retired). The hazard estimated here is increasing despite this bias.

If the heterogeneity is correlated with the covariates, however, it may also bias the other coefficients, particularly with the left censoring in the sample (some planes are already gone when the sample begins so the remaining sample may have selection problems). To correct for this problem and to test for the importance of heterogeneity, Diamond and Hausman (1984) advocate restricting the sample by eliminating early years of data, thereby making the problem worse, and testing whether it affects the results. Column (5) repeats the specification in column (1) but eliminates the first six years of data, restricting the sample to the 1978-84 period. This also allows a check on whether deregulation significantly changed the economic environment facing retirement decisions. None of the coefficients on the economic covariates in (5) is significantly different than in (1) indicating that heterogeneity may not be a significant problem and that deregulation did not appear to create a structural change in the retirement decision.

In addition, Han and Hausman (1990) and Sueyoshi (1992) have shown that even if unobserved heterogeneity exists, estimating the baseline hazard nonparametrically can remove most of the bias it creates. Column (6), therefore, repeats the analysis of (1) but does not assume a Weibull baseline hazard. Instead, it uses the Cox semi-parametric approach, which estimates the impact of the covariates while treating the baseline hazard as a nuisance parameter (see Kalbfleisch and Prentice, 1980 for details). Although this method eliminates the estimated shape parameter and makes it difficult to calculate the actual hazard rate, it does create a robust method to estimate the impact of the covariates on the hazard rate, no matter what form that hazard takes.[11] The coefficients are directly comparable the those in column (1). All of them have the same sign and are of similar magnitudes. Indeed, most of the coefficients are actually larger.

C. Competing Risks And Misclassification

The hazard estimates classify many different and potentially unrelated outcomes as retirements. Classifying sales to cargo companies and foreign airlines as retirements, in particular, seems to call into question whether these capital goods have truly become obsolete and whether the demand for the outside good needs to be modeled explicitly. Earlier I argued that treating sales as retirements ought to bias the estimated impact of economic factors on true retirements downward since the shocks leading an airline to retire its 707s might also reduce the price they could get for the 707 if selling it. Column (7) verifies this intuition, again using the Cox method but classifying sales to airlines, cargo companies, and private users as a separate exit state—a "competing risk" in hazard terminology—which may respond differently than true retirements. In such a case, if a plane is sold out of the country, for example, this is a type of censoring. We do not have information of how long the plane actually lived, only that it had not

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[11] Actually, it is possible to back out the implied baseline hazard using the methods in Kalbfleisch and Prentice (1980). Goolsbee (1997) does this and finds the hazard increasing in age and generally consistent with the Weibull.

yet retired at the age when it was sold. The coefficients in (7), then, estimate the effect that economic covariates have on the probability of *actual* retirement. As predicted, the magnitudes of all of the economic factors are much larger than in the other specifications indicating that economic forces play an even larger role in the pure retirement decision than in the decision to sell.

D. Spurious Macroeconomic Variation

As a final check for robustness, equation (8) includes year dummies to absorb the effect of all annual variation such as the business cycle, the cost of capital, regulations, as well as any unobserved factors. The coefficients are still identified from the cross-sectional variation in covariates between carriers and planes within a given year. This identifies the influence of the firm specific fuel cost per seat mile and the firm specific cash flow.

In this regression, the coefficient on cash flow is larger than in (1). A one standard deviation increase in cash flow increases the yearly retirement hazard by 48% versus 29% in (1). This larger values probably reflects the fact that GDP growth does not fully account for the business cycle in (1) and the unobserved component of the cycle in the regressions without year dummies are partly absorbed in the financial performance of the firms. In other words, low cash flow makes retirement much less likely and at the trough of the business cycle cash flow tends to be depressed. The trough of the business cycle itself, however, makes retirement *more* likely and thus partly reduces the coefficients on cash flow. In the regressions with year dummies, it is possible to isolate the effect cash flow from the aggregate shocks of the business cycle. Fuel costs have similar effects to the other specifications. A one standard deviation increase in fuel costs approximately doubles the yearly hazard.

7. MACROECONOMIC IMPLICATIONS

All of the results clearly support the view that capital vintages matter and that capital retirement is an economic decision. It is important to point out, though, that not all investment is replacement investment. If it were, and these results could be applied to the wider economy, the counter-cyclical nature of replacement would imply that investment should be greatest in recessions which is clearly false. Surveys of investment such as reported in Feldstein and Foot (1971) indicate that while a large fraction of investment is replacement, the majority is traditional expansion investment.

Despite this caveat, the first important implication of the results presented is their importance for thinking about the difference between gross investment (i.e., capital expenditures) and net investment. The results show that factors like the cost of capital can influence both purchases *and* retirements. Their impact on the theoretically correct measure of *net* investment is unknown.

Because the data here examine only one type of capital, it is difficult to say how large an impact this could have. For an illustrative calculation, however, we can take a large carrier like TWA in a year when 707s were still a large part fraction of airlines' capital stock such as 1978 (before the 1979 oil shock). It is possible, using the price data described in Goolsbee and Gross (1997), to calculate the market value of all planes held by TWA in that year. This amounts to around $1.42 billion. The market value of 707s was approximately one quarter of this total. The average age of 707s was about 13 years so the mean annual probability of retirement was around

9% using specification (1). A 10% ITC would increase this probability by about 3 percentage points or more than $10 million of extra retirements. If we take conventional estimates of the one year neoclassical elasticity of investment demand of somewhere between -.1 and -.66, this implies that 10% the ITC would increase TWA's capital expenditures by between $14 and $94 million. Taking out the extra retirements, though, and calculating the true elasticity using net investment indicates that the neoclassical literature might overstate the true elasticity for TWA by up to 75%.

A similar calculation would hold for analyzing the effect of cash flow on investment. Firms with low cash flow invest less but they also reduce their retirements so the effect on net investment is likely to be much smaller, mitigating the impact of financial constraints on the capital stock, for example (if that is what the cash flow coefficients represent). The evidence might also be interpreted as showing that financial constraints do not exist at all since firms do not sell their planes for cash when their cash flow is low as one might expect of a constrained firm.

The second important potential implication from the results in this paper is for the evaluation of productivity. Goolsbee (1997) shows that the fuel shocks accelerated the retirement of fuel intensive aircraft which caused the actual capital stock to be significantly smaller than the measured capital stock (which assumes constant depreciation). This mismeasurement could be one component of the apparent productivity slowdown associated with the oil shocks as suggested in Baily (1981). Similarly, in booms the results here suggest that capital lives get longer so that actual capital is greater than measured capital which could help explain part of the procyclical component to productivity, similar to the explanations centering on capacity utilization (see Basu, 1996 for a discussion).

Finally, the results raise important simultaneity issues with empirical work that uses capital vintage as an explanatory variable such as Gort, Bahk, and Wall (1993) or Bahk and Gort (1993). Bahk and Gort, for example, decompose learning by doing in manufacturing plants and find that reducing the average vintage of capital by one year increases output by 2.5% to 3.5%. This does not take into account the fact that increasing output, by reducing capital retirement, will itself tend to increase the average vintage of capital and thus make their estimate a lower bound on the effect. For 707s, for example, a 3.5% increase in sales lengthens the expected survival age of 707s in specification (2) by almost a full year. In an industry like airlines where 707s comprised up to 20% of the total fleet at certain times, this is a serious issue.

We should keep in mind, however, the argument of Denison (1964) whose evidence from 1924-1960 when capital stocks were young and new investment was a small fraction of total capital showed that even large investments could not reduce the average age of the capital stock by a large amount. Denison did not consider the effect of capital retirement in his discussion but the point probably remains valid in many industries, particularly those where capital does not last very long (so replacing old capital does not significantly reduce average age).

8. CONCLUSION

The evidence presented is quite clear that the capital decisions described in this data are much better explained by new investment theory than by the neoclassical model. Using data on the service lives of individual Boeing 707 aircraft from 1972-1984, the results clearly reject the capital homogeneity and exogeneity assumptions. Capital vintages matter a great deal in the regressions—older planes are much more likely to be retired than younger planes. Further, the business cycle, the costs of capital, the cost of funds, fuel costs, and noise regulation all have important effects and the conclusions are highly robust to alternative specifications and functional forms.

Since many of the factors which influence capital retirement are the same ones that influence capital purchases in conventional studies, the results presented here raise the intriguing possibility that much of what conventional wisdom believes to have an important effect on investment actually affects both capital expenditures *and* capital retirements and, therefore, may have little effect on true, *net* investment. They also influence our measurement of productivity. The significance of the results using this micro data warrant further looks into the empirics of new investment theory in the future.

TABLE 1: RETIREMENT FATES FOR 707 AIRCRAFT

FATE	NUMBER	PERCENTAGE
Sold to Foreign Operator	161	45.9
Withdrawn from Use	101	28.8
Sold to USAF for Parts	49	14.0
Sold to Private/Cargo Use	31	8.8
Scrapped/Cannibalized	9	2.6
TOTAL	351	100

Source: Aviation Data Centre (1984). This lists the initial fate only.

TABLE 2: DATA SUMMARY STATISTICS

VARIABLE	MEAN	STD. DEVIATON
Delivery Year	66	3.0
Retirement Year	80	2.5
Fuel Cost (Cents/ASM)	1.68	.67
Cost of Capital	20.2	1.7
Tax Term	97.1	2.7
GDP Growth	2.74	2.60
Cash Flow/Capital (%)	12.4	5.2
Passenger Revenue/Capital (%)	140.5	39.4

TABLE 3: ESTIMATES OF 707 RETIREMENT HAZARD

Vars.	(1)	(2)	(2)	(3)	(4) Cox	(5) Cox CR	(6) 78-84	(7)
Fuel costs	.756 (.180)	.840 (.188)	1.789 (.213)	.782 (.183)	.931 (.172)	1.999 (.331)	1.057 (.214)	1.090 (.329)
GDP growth rate	-.131 (.037)			-.134 (.038)	-.148 (.041)	-.318 (.053)	-.096 (.045)	
Cost of capital	-.122 (.054)	-.189 (.092)	-.093 (.043)	-.127 (.056)	-.163 (.056)	-.341 (.070)	-.113 (.057)	
CF/K	.050 (.017)	.065 (.022)	.059 (.011)	.061 (.022)	.072 (.018)	.155 (.040)	.074 (.030)	.076 (.023)
Deregulation	-.274 (.235)	-.441 (.272)	-.407 (.205)	-.172 (.261)	-.090 (.237)	2.57 (.839)	--	
Noise Reg.	.030 (.004)	.050 (.009)	.019 (.003)	.030 (.004)	.039 (.004)	.073 (.007)	.031 (.005)	
GDP Level $_{t-1}$		.007 (.002)						
GDP Level $_{t}$		-.004 (.001)						
GDP Level $_{t+1}$		.001 (.002)						
Pass. Revenue/K			-.034 (.003)					
Tax Term				.036 (.032)				
Constant	-8.501 (1.021)	-13.248 (5.441)	-9.223 (.881)	-12.399 (3.249)	--	--	-7.223 (1.622)	
Shape: ln (P)	1.211 (.064)	1.246 (.067)	1.462 (.057)	1.241 (.067)	--	--	.892 (.153)	1.251 (.075)
Dummies	M	M	M	M	M	M	M	M, Y
n	2717	2717	2717	2717	2717	2717	863	2717

Notes: Each equation estimates the hazard for 707s using maximum likelihood as described in the text. Equations (1)-(4) and (7)-(8) assume a Weibull baseline hazard. Equations (5) and (6) use the Cox semi-parametric method. The sample in each is 1972-1984 except in (7) where it is 1978-84. Equation (6) estimates the retirement hazard assuming sales to airlines and cargo companies are a competing risk. The variables are defined in the data appendix. Standard errors are in parentheses. M represents model dummies and Y represents year dummies.

TABLE 4:
ESTIMATED 3-YEAR SURVIVAL PROBABILITY (IN PERCENT)

Age	Boom: 4% Growth	Bust: No Growth
10 Years	81.5	70.3
15 Years	59.6	39.3
20 Years	34.3	11.9
25 Years	12.7	0.4

Notes: These are the estimated probabilities of surviving three years for 707-300Bs of various ages with GDP growth rates listed at the top of the column and all other covariates held constant at their mean levels. The calculations are described in the text.

TABLE 5:
ESTIMATED 3-YEAR SURVIVAL PROBABILITY (IN PERCENT)

Age	Mean	With 10% ITC
10 Years	78.5	69.3
15 Years	53.8	37.8
20 Years	26.9	10.7
25 Years	7.1	0.1

Notes: These are the estimated probabilities of surviving three years for 707-300Bs of various ages with the cost of capital at its mean level and then with an additional 10% investment tax credit. All other covariates are held constant at their mean levels. The calculations are described in the text.

APPENDIX A: DATA

The fuel cost associated with flying one available seat mile is calculated using the C.A.B. *Aircraft Operating Cost and Performance Report*. In this sample, every carrier was required to report data for each type of plane in operation on the amount of fuel used, cost paid per gallon, seat miles flown as well as many other operations data. For example, American Airlines reports sufficient information to calculate the fuel cost per available seat mile (ASM) for its 707-100Bs, 707-300s, 707-300Bs and 707-300Cs in both international and domestic use in each year of the sample. Because different carriers have different flight speeds and route structures and buy fuel in bulk, fuel costs can vary substantially between firms even for the same models in the same year. The specific measure used is calculated by taking the average available seat miles per hour for the carrier-plane-year, dividing by the average gallons of fuel consumed per hour divided by the average price paid per gallon for that carrier-plane-year to get a nominal cost (if the carrier has both international and domestic flights and the cost of fuel is different, the average price weighted by the total hours flown of each type of service is used). The nominal cost per ASM is then scaled by the GDP deflator.

If the total hours flown by one type of aircraft for a carrier in a given year is too small, the CAB does not report the data. This is usually the case when a carrier has only one or two planes of that type remaining in its fleet. For these cases I impute the cost of fuel by averaging the fuel economy of that plane type in the last three reported years and then the average fuel price per gallon for either the other types of 707s or the fuel cost for the 727-100 for the same carrier in the missing year. Testing this imputation procedure on years in which I do have data, shows that the results are almost always within 5% of the true value. This procedure was used on less than 2% of the plane-years of data.

The financial data for each company come from *Air Carrier Financial Statistics*, and the *Air Carrier Traffic Statistics*. The measure of financial performance is the ratio of cash flow to gross property plant and equipment for the airline-year. The cost of capital is a yearly average of the quarterly data from Kopcke (1985) which are listed in Berndt (1990). The tax term alone comes from Goolsbee (1998). Both the cost of capital and the tax term alone assume that firms can fully use legislated tax incentives and are paying the statutory corporate income tax rate. The variable for deregulation is a simple dummy equal to 1 after 1978. The noise regulation variable is 25 in 1981 and 1982 and 50 in 1983 and 1984 to represent the compliance schedule for noise regulations which required 25% and 50% of 707s to be retired or retrofitted by 1981 and 1983.

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APPENDIX B

We know that the value of waiting one year to replace is

$$\Delta(0) = R_0 - pE - m(1+\delta)^A + q*(1-\theta) - \theta\left[\sum_{t=1}^{\infty}\theta^{t-1}(R_t - pE' - m(1+\delta)^{t-1}\right] + \theta^2\left[\sum_{t=2}^{\infty}\theta^{t-2}(R_t - pE' - m(1+\delta)^{t-2}\right]$$

Inside the two bracketed terms, all but the energy and revenue terms in year one cancel in the two summations. The only summation terms which do not cancel are the maintenance terms:

$$\Delta(0) = R_0 - pE - m(1+\delta)^A + q*(1-\theta) - \theta R_1 + \theta pE' + \theta m + \left[\sum_{t=1}^{\infty}\frac{m(1-\theta)}{(1+\delta)}\theta^t(1+\delta)^t\right]$$

Rewriting and solving the summation,

$$\Delta(0) = R_0 - \theta R_1 - pE + \theta pE' + q*(1-\theta) - m(1+\delta)^A + \frac{m(1-\theta)\theta}{1-\theta(1+\delta)}$$

or, as listed in the text:

$$\Delta(0) = \left[R_0 - \theta R_1\right] + (1-\theta)q(1+f) - p\left[E - \theta E'\right] + m\left[\frac{\theta(1-\theta)}{1-\theta(1+\delta)} - (1+\delta)^A\right]$$

FIGURE 1: AGGREGATE STOCK OF 707s