

Fuel Costs and the Retirement of Capital Goods

by

Austan Goolsbee

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Massachusetts Institute of Technology

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Abstract

This paper explores the effect that energy prices and market conditions have on the retirement rates of capital goods using new micro data on aircraft lifetimes and fuel costs. The oil shocks of the 1970s made fuel intensive capital like the Boeing 707 a prime target for retirement. The results, based on retirements of 707s from the fleets of the major airline carriers from 1972-1984 are quite robust and show that the oil shock of 1979-1981 made the probability of retirement for a 707 between 5 and 15 times higher. The estimated probability that a 15 year old 707-300C in 1981 would retire before 1982 was 96%. If the oil shock had not occurred this probability of retirement would have been between 8 and 14%. The potentially large effect of energy taxes on capital retirement has important implications for their usefulness and for their potential impact on current airline fleets.

Classification: E22 Capital; Investment; Capacity
L93 Air Transport
Q43 Energy and Macroeconomics

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When economists consider policies like energy or pollution taxes, they often assume that these policies change energy and pollution intensities by altering the utilization of assets at the micro level. In a world with different types of capital goods and different energy or pollution intensities embodied in those goods, however, this traditional view may be quite inaccurate. In such a world, marginal changes in aggregate intensity may come about primarily from discrete decisions to retire inefficient capital so the determinants of capital retirement are extremely important. This view could have a substantial impact on our understanding of these market based instruments. Small increases in energy taxes, for example, may have no effect on pollution or energy intensity in the short run because they are not large enough to lead to capital retirement. Capital retirement also plays an important role in net capital formation. The level of replacement investment depends critically on the rate of capital retirement and Feldstein and Foot (1971) have noted that about half of total investment is really for replacement. Despite its importance, there are remarkably few studies of capital retirement and scrappage. Traditional studies of capital assume constant depreciation over time or a fixed service life as in Jorgenson (1989) or Hulten (1990) and there is little work on the retirement of actual capital goods.¹ A major difficulty has been identifying shocks to the relative productivity of old versus new capital.²

The price of fuel in the 1970s provides just such a set of shocks for the airline industry. At their height, fuel expenses made up almost 60% of the direct operating costs for airlines and the energy intensity of capital was embodied in the capital goods themselves (the Boeing 707 flew about 42 seat miles to the gallon while the 747, 767 and MD-80 averaged almost 70) so the retirement of 707s is an ideal place to look for the effects of fuel prices on retirement. This paper, using a new data set on 707 life cycles and detailed carrier specific fuel cost data, shows that higher fuel costs

¹ Some examples of such work are Das (1991,1992), Cockburn & Frank (1992) and Rust (1987).

² Cockburn & Frank (1992) is an exception.

dramatically increased the probability of retirement of 707s and increased them more for fuel intensive 707s than for the less intensive ones.

The paper is divided into five sections. The first presents a simple theory of the optimal retirement age of capital when there is embodied technical progress. The next section gives background on the 707 and the airline industry (section 2). The following section describes the specification and the data (section 3). The next presents the estimation results (section 4) and the final section uses the results to simulate the total effect of the oil shocks on retirement (section 5). It concludes with a brief consideration of pertinent issues raised by these findings and some directions for further research.

SECTION 1 Economic Retirement: An Analytical Framework

Since market forces alter the stream of quasi-rents to an asset, it is natural to believe that they influence the decision to retire capital. This is an old idea and there are several theoretical models of the role of fuel prices and taxation on the optimal retirement age of capital.³ Here, the coverage will be quite stylized. In this model, there are two types of capital, the 707 and an alternative plane. There is no uncertainty. All changes are permanent. The demand for air services is fixed and the only costs of operation are fuel expenses. The firm currently owns one 707, with energy intensity E which yields R in revenue in the first period and declines at rate δ each period after that because of physical decay. The price of energy is p . The alternative technology has the same revenue R which declines at rate δ starting the period after it is purchased and has energy intensity E' where $E' < E$. The interest rate is r and the price of capital is q . In each period the firm must decide whether to fly its 707, retire it or replace it. The firm receives from the 707 a stream worth current value $V(t) = RV(t) - CV(t)$ where

³ Some early discussions of obsolescence can be found in Solow, Tobin et al. (1966) and Phelps (1963). Some excellent presentations of the theory of endogenous retirement are in Feldstein and Rothschild (1974), Nickell (1975) and Malcomson (1978).

$$RV(t) - CV(t) = \sum_{j=t}^{\infty} [(1-\delta)^j / (1+r)^{-j} \cdot R - (1+r)^{-j} \cdot pE] \quad (1)$$

The 707 will remain in service until $V(t)=0$ at age T and then the plane is retired. The plane may be retired before age T , however, because the airline can always replace it with the alternative plane.

This new plane will have higher revenues and lower costs, but also a purchase price of q . The firm will switch planes if $[RV(t)' - RV(t)] - [CV(t)' - CV(t)] - q > 0$ --in words, if the gains in revenue plus the savings in cost from switching to a new plane exceed its purchase price. $RV(t)'$ and $CV(t)'$ are for the new plane. The purchase price, q , subtracted from the net present value of the new plane, $V'(t)$, is plotted with $V(t)$ in Figure 1. The two curves cross before T so the firm retires the 707 and switches planes at age $T' < T$.

Figure 1 also allows us to explore the effect that various factors should have on the retirement age of the 707. When the price of new capital increases, the $V' - q$ curve falls to V'^* so that the optimal retirement age increases to T'' . In Figure 2 I show that when the price of energy changes, both V and $V'-q$ will shift to V^* and V'^* because the costs for both types will increase, but since $E' < E$, the V' curve will shift by less--the costs of the new plane increase less because it is more fuel efficient--so the retirement age falls. The magnitude depends on the difference between E and E' . The larger the difference in energy intensities, the more the age falls.

These simple results motivate empirical work on the actual role that input prices and capital costs have on retirement decisions. Before presenting the estimation, however, the nature of the industry and the good itself will be discussed.

SECTION 2: The 707 and the airlines

The cost structure of the airlines makes them particularly sensitive to market fluctuations in capital and fuel prices. Fuel is a major factor in airline operation. With the increase in costs, fuel

went from about 20% of operating expenses in 1971 to almost 60% in 1981. The real price of a gallon of jet fuel for the airlines is shown in Figure 3.

Purchasing and retiring capital is also critical to carrier performance because a single plane can last for decades and is extremely expensive. One DC-10, for example, cost about \$60 million in 1980. The airlines themselves are aware of how important the timing of capital decisions is and airline economics textbooks give substantial coverage to the issues of replacement and expansion investment.⁴ The textbooks stress the importance of forecasting future unit costs per seat mile for various planes as well as future demand in deciding when to purchase capital. The fuel cost increases forced airlines to rethink logistical issues--slower cruise speeds, lighter carpets and seats, shorter taxi times--in order to reduce fuel consumption but they also raised a major question about the viability of some capital equipment. As Table 1 shows, different types of aircraft have very different fuel intensities. This is mainly due to the number of engines on the plane and the age of the engine technology. The 707 had four old engines and most other planes had two or three newer ones. The 707 was produced from 1958-1970 as shown in Table 2 and there were two general types, the 100 series which started first and a slightly larger and generally less fuel intensive 300 series whose production began shortly after.⁵ The 707 was the first long range jet put into general use by airlines and by the early 1960s the 707, the smaller B-720 and the DC-8 had replaced propeller planes in the fleets of the major carriers. The next generation of jets including the 727, 737, 747, DC-10 and L-1011 first arrived in the 1960s and began replacing the older jets. Most of the first generation jets were retired rapidly but the 707 remained in service for many years. In 1971, the 707 comprised

⁴ For examples see Mandell (1979), James (1982) or O'Connor (1989).

⁵ The 707-100B held 134 passengers. There were three types of 707-300 series. The original 707-300 held 149 passengers and had a turbojet engine (the JT4). The newer types, the 707-300B and -300C, had 147 passengers and replaced the turbojet with a turbofan engine (the JT3D). The -300C was the best selling of the models and had a cargo door for easier loading. In practice it often had fewer seats than the -300B.

almost 20% of the entire fleet of all carriers. In 1979 they still made up almost 9% of the fleet. By 1985, they were all gone. A dramatic increase in the retirements occurred around 1979-1981, and the drop was more pronounced for the 707-100s than for the 707-300s.

The airlines had several options when retiring their 707s: they could sell them to a foreign country, cannibalize them for parts, sell them to a cargo company, sell them to the Air Force or withdraw them from use and put them "out to pasture" in the desert. Table 3 gives the retirement destination for the 707s in this sample. Note that the table shows the fate of 707s when they are first removed from the fleet only. For example, many planes were withdrawn from use and then later sold to the Air Force for the engines but they still appear in Table 3 as withdrawn from use. One might wonder about classifying withdrawals as retirements when airlines might have been mothballing them until more profitable conditions arose. In no case, however, in the entire 12 year sample was a 707 brought back into major airline service and this has been a common way to dispose of planes. In addition, results presented later indicate that fuel prices affect both types of retirement identically.

SECTION 3: Data and empirical specification

3.1 Empirical Specification

To estimate the effect that the covariates, x , have on the decision to retire capital, this study uses a hazard model which estimates the time to failure (retirement) of an individual plane. It is absolutely critical to have micro data on individual planes to study retirement. A standard regression of the share of the 707 stock retired in a year on a series of annual variables 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 could also be explained by basic physical decay. The covariates used here are not fixed for the duration of the capital good so a model with time-varying covariates is required. The hazard function $h_i(a|x_i)$ is the probability that plane i will be retired at age a in time t conditional on not having retired yet

$$h_{it}(a|x_{it}) = \lim_{\Delta \rightarrow 0} \frac{P(a \leq T < a + \Delta | x_{it}, T \geq a)}{\Delta} \quad (2)$$

I adopt the common assumption that the covariates do not change the shape of this hazard function but instead just shift it (proportional hazards). 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. Future work will place the stochastic structure in a structural model as discussed in Rust (1987) and Das (1992) but to do so requires strong assumptions about functional forms. Instead, I use the Cox (1972) semiparametric hazard model to estimate the effect of the covariates on service life, treating the baseline hazard $h_0(t)$ as a nuisance parameter (in the results a standard Weibull parametric form for the baseline hazard is also used for comparison to these semiparametric estimates). β can be estimated by maximizing the partial likelihood function

$$L(\beta) = \prod_{i=1}^n \left(\frac{\exp[x_i' \beta]}{\sum_{j \in R(t)} \exp[x_j' \beta]} \right) \quad (3)$$

(see Kalbfleisch & Prentice, 1980 for a detailed discussion of the Cox model). The x matrix here includes the following covariates: the cost of fuel for the year, the real cost of capital times the real price of durable goods for the year, gdp growth for the year, a dummy for deregulation after 1978, a dummy indicating whether the firm took a loss in the year, a variable for anti-noise regulation, and a general measure of the intensity of use (the average flight length for the carrier in the year).

3.2 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 changes of ownership and operating status to its final retirement. The sample here includes every 707 in the service of major carriers in 1972 excluding planes crashed, lost or destroyed in terrorist incidents. The carriers operating 707s in 1972 were American, Northwest, TWA, Pan-American, Braniff, Western and Continental. The sample includes 354 707s: 96 707-100s and 258 707-300s (107 300Bs, 130 300Cs, and 21 300s). This gives 2717 plane-years of observation. Since there were some planes retired before 1972, there could be sample selectivity problems, i.e. the inferior planes were gone before 1972, but this is not as important here as it is in other contexts.⁶ Since no planes survived past 1984, censoring is not an issue. Retirement occurs when the plane is taken out of the service of a major carrier. Actually, many of the planes are sold to foreign airlines and some to non-airline business in the U.S. Technically this prevents identification of a pure, fuel induced change to the absolute level of quasi-rent on the old asset and instead shows the change in relative levels of quasi-rent streams for the airlines and the next best use.⁷ I will assume that this outside demand is not related to the price of fuel to get around this issue but this should actually understate the effect fuel has on retirement because the high fuel prices probably decreased the demand for used 707s.

The hazard estimation also requires fuel price data. This study uses both the annual price of fuel for the industry and a very rich data set kept by the Civil Aeronautics Board called the *Airline Operating Cost and Performance Report*. Every carrier was required to report, for each type of plane in operation, data on the amount of fuel used, cost paid per gallon, seat miles flown and many other facts. In other words, American Airlines in 1981 reported 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

⁶ See Heckman & Singer (1986) for a detailed view of possible problems. The current analysis is not concerned with estimating whether there is duration dependence in 707 hazards the way it might be for unemployment durations and which would clearly be biased by selection problems.

⁷ I owe this observation to Dick Schmalensee.

international and domestic use. Because different carriers have different flight speeds and route structures and buy fuel in bulk, costs can vary substantially between firms even for the same models in the same year. This gives us an excellent source of variation to identify the role of factor prices on retirement. The actual construction of the fuel cost per available seat-mile data is described in Appendix 1. Table 4 lists the average fuel cost (in 1987 cents) per available seat mile for the four aircraft types in selected years. There is also substantial variation between carriers among the same planes. Take the 300C as an example, Figure 4 plots the fuel costs for carriers operating the 300C. Some of the specifications will use only the annual price of fuel in case the variation between carriers in the detailed fuel cost data does not reflect the marginal cost facing the carriers or is caused for some other reason than fuel price changes. Because there are other potential factors correlated with this simple time-series variation, I also explore alternative explanations for accelerated retirement in the oil shock period and use the inherent fuel intensity differences between the plane types to show that oil matters more for the fuel intensive planes than for the others controlling for other effects. The other specifications use the detailed fuel price data and allow for identification of the effect of fuel costs on retirement but remain robust to alternative explanations.

SECTION 4: Results

4.1 Kaplan-Meier Hazard Estimates

Figure 5 shows the Kaplan-Meier estimate of the hazard rate for 707-100s and 707-300s. It is simply the percentage of planes alive at a given age which retire at that age. Figure 6a and 6b show the integrated Kaplan-Meier hazard but split each group into early and late delivery years. Clearly the hazard rates shift over time. The planes delivered later have shorter life spans. For 707-100s, the median retirement age of planes built before 1965 was about 18 years and after 1965 only 14 years. For -300s the ages were 15 and 11.

The means of the variables used in the analysis are listed in Table 5 for the full sample and

then for planes in the year they were retired and years they were not. The most pronounced differences at first glance between retirement and non-retirement years is that the cost of fuel in retirement years is much higher.

4.2 Cox Hazard Model Estimation: Industry Oil Price

Table 6 lists a series of Cox hazard model estimates using covariates and the annual price of oil in the industry. This does not use the variation between carriers, only between models and over time. The coefficients are not in hazard rate form so a one unit increase in the covariate with coefficient b will multiply the baseline hazard by $\exp(b)$. The price of oil is scaled by the fuel intensity in Table 1 for each type of 707. In column (1), oil is the only factor that shifts the hazard rate. Its effect is large, very significant and positive indicating an increase in the instantaneous probability of retirement. Column (2) is a more inclusive specification including the cost of capital times the price of durable goods, gdp growth, a deregulation dummy, a noise regulation variable and the average stage length of the carrier in the year, but the cost of capital is not significant. Column (3) then adds a dummy variable indicating whether the carrier took a loss in the year. The cost of capital variable is now significant and important. The loss dummy may indicate cash flow considerations or a tax loss carryforward position but these issues will not be pursued here.⁸ When a lagged value of the cost of capital was included, the coefficient was insignificant, very close to zero and did not affect the other coefficients so I exclude it. In (3), a one percent increase in the price of oil in 1981 would increase the hazard by 2.8% for a 707-100 or 2.6% for a 707-300B. Since the Cox estimation eliminates the baseline hazard as a nuisance parameter, we cannot calculate the actual probability of retirement in a given year. To do that, Equation (5) estimates the same model but fitting a Weibull parametric form for the hazard. Using the estimates from (5) and plugging into the

⁸ For a detailed analysis of the role of carrier financial factors on retirement, including cash flow, tax-loss carryforward positions and the cost of capital, see Goolsbee (1993).

Weibull hazard formula gives an estimate of the hazard rate in 1981. At age 10 in 1981, a 707-100 had a hazard of .43, a 300B had a hazard of .26. If we take these estimates as the true hazard in 1981, the coefficients from the Cox estimation in (3) imply that a 10% increase in the price of oil in 1981 would have increased the hazard of 100s from .43 to .56 and for the 300B from .26 to .33. Equation (4) includes dummies for the model type to account for model fixed effects. In this case the price elasticities of the hazard were slightly smaller than in (3), 2.4 and 2.2, indicating that the 10% increase in 1981 would have increased the 100's hazard from .43 to .54 and the 300B's from .26 to .32. A higher cost of new capital lowers the hazard. Faster gdp growth, meant to proxy for airline demand, also reduces the probability of retirement of 707s because high demand forces firms to use whatever capital they have on hand. Deregulation has no effect on retirement rates.

4.3 Potential Alternative Causes of Retirement

The two main potential problems with the specifications above are the Air Force purchase program and anti-noise regulations. After a discussion of these two alternatives are specifications which remove their effects.

HYPOTHESIS I: AIR FORCE PURCHASE PROGRAM

The USAF operated (and continues to operate) many derivatives of the 707 including KC-135 stratotankers, E-3A (AWACs) for radar detection and VC-137s for transporting VIPs. In the 1980s, the Air Force decided to put JT3D turbofan engines on its KC-135 tankers which were using less powerful J57 turbojets. To do so, the Air Force simply bought a large number of former airline 707s and cannibalized them for their engines and parts. This could potentially bias the results since estimation of the effects of covariates on retirement assumes that airlines would sell no plane before its time. If the Air Force exogenously bought 707s before they were at a 'ripe' retirement age and purchased them at the same time the price of fuel was high, fuel might erroneously seem important.

The engine retrofit program, however, did not begin until 1982 and the airlines, generally,

did not retire the planes just because the Air Force was buying. The Air Force was buying because the airlines were getting rid of the planes and they thought it would be a less inexpensive way to get the engines for their planes. It was certainly cheaper than purchasing an entirely new plane like the proposed 707-700 which was never developed.⁹ A large fraction of the planes bought in the KC-135E program were already withdrawn from use when they went to the USAF.

A simple way to see that the Air Force is not driving the results is to compare the retirement rates of USAF versus non-USAF 707s. If the USAF had purchased planes before their natural retirement age, then the survival probabilities of the non-USAF planes should be higher than the USAF ones. Yet the two rates are basically the same. The USAF bought 101 planes, 65% by 1982 and 93% by 1983. Of the non-USAF planes, 79% were retired by 1982 and 95% by 1983. More formal evidence is presented in Table 6 column (6) where the specification of equation (3) is repeated but without the planes that ended in the USAF program. The fuel coefficient is even larger than in (3) but is not significantly different. The results are basically identical so I treat the Air Force as a standard type of retirement.

HYPOTHESIS II: ANTI-NOISE REGULATION

During the same period as the oil shocks of the late 1970s and early 1980s, stringent anti-noise regulations went into effect which could have caused the accelerated retirement of 707s.¹⁰ The 707 with its four large engines was an extremely loud airplane. New York Idlewild airport (now JFK) first instituted noise limits and monitoring systems in the 1960s because of complaints from surrounding communities about the 707's loud whine. Using measurements of the noise level on the dB scale (where the threshold of human pain is at 120 dB, a diesel freight train around 100 dB and

⁹ For some discussion of the KC-135E program and of the various military and civilian 707 models see Lloyd (1987) or Wright (1990).

¹⁰ For a summary of all domestic and international noise regulation as well as a history of their enactment, see Smith (1989) or Panzarella (1979).

someone yelling at about 85 dB) the take off noise of a 707 is around 104 dB. The 727, 737, DC-10 and L-1011, on the other hand, are all below 90 dB. Only the Concorde is louder.

The first major federal regulation reducing airplane noise was F.A.R. 36, passed in 1969. It limited the production of new aircraft whose noise exceeded federal standards. The regulation spelled the end of the main production line of 707s. The next important regulation that affected the 707 was the F.A.R. 91-136 compliance rule, passed in 1976 which extended the standards to existing aircraft and meant the end of the 707 in US airline fleets. A compliance schedule was drafted which required 25% of the 707s to be removed from service by 1981, 50% by 1983 and 100% by 1985. To account for FAR 91-136, a variable which rises to 25 in 1981 and 50 in 1983 to represent the noise regulation is included in the specifications below. The variable is significant, but it should be noted that in fact, 50% of the planes were gone by 1981, and almost 90% were gone by 1983 even though only 25% and 50% were required.

4.4 Natural Experiment with Year Dummies

One way to remove the effects of noise regulation and of air force purchases would be to include year dummies. If the alternative hypotheses affect all the planes equally, their influence would be washed out in the dummies. Unfortunately, this is impossible if the price of oil is also an annual variable. To get around this without simply using the carrier fuel cost data, I use the inherent difference in fuel economy between the different 707 models to indicate the role of fuel in retirement. The 707-100B and -300 were generally more fuel intensive than the 707-300B and -300C. By dividing the sample into these two groups and then interacting the group dummies with year dummies, this estimation allows comparison of the two groups' retirement behavior over time. Since the noise regulation affected all the 707s, the year dummies of the two groups should not be systematically different on its account. If oil is the cause, however, the year dummies for the fuel intensive group should be larger than for the other group following the oil shock in 1979 indicating that fuel intensive

707s are more likely to retire in those years than non-intensive ones. There is clear evidence that fuel intensive planes retired more rapidly than non-fuel intensive ones. The average year dummy for the fuel intensive group was -1.35 from 1972-1979 and 1.72 after 1979 while the less fuel intensive group averaged -0.10 from 1972-79 and 1.43 after (the same pattern holds when vintage dummies are included in the estimation). Using only annual variation in fuel costs, this is the strongest evidence possible showing that factor price changes accelerated retirement.

4.5 Robust Results: Detailed Fuel Cost Data

There are, of course, many potential problems with using only the annual variation in fuel costs. It may not reflect the actual prices paid by the major carriers who often face different prices from one another. Further, since the planes' fuel intensities may change over time, the adjustments using 1975 fuel intensities may be inappropriate for other years. Fortunately, if the more detailed data set on fuel costs is used, robust identification of the fuel effect on retirement is possible. Table 7 presents estimation using this real cost of one seat mile in 1987 cents. Column (1) presents a specification allowing only the fuel cost to shift the hazard. It is large and highly significant. (2) presents the full specification. Because the stage length is not exogenous to the plane's fuel cost per mile the way it was to the average price of jet fuel, these specifications exclude it. The results are larger than the previous ones. The real price elasticities for the 100 and 300Bs' hazards in 1981 were 2.8 and 2.6 using the annual oil price. Using fuel cost per mile, the fuel price elasticities are both 3.3. In equation (4) I again do a Weibull specification to get a baseline hazard to compare to. Here, the 1981 hazard of a 10 year old 707 is .44 for the 100 and .38 for the 300B. A 10% increase in the price of fuel in 1981 would raise the instantaneous probability of retirement from .44 to .61 for the 100 and from .38 to .52 for the 300B. Column (3) excludes the withdrawn from use planes to determine if this is a different kind of retirement. None of the coefficients are significantly different so we treat the withdrawn planes as standard retirements.

The cost of capital is also important. In a world of no property taxation, a corporate income tax rate of 35% and full depreciation deductions on investment over the life of the good, introducing an investment tax credit would reduce the effective rate of taxation on capital income by $ITC / (1 - \tau_c)$. So a 10% tax credit would increase the 707 hazard, at the mean cost of capital, by 72%. A 10 year old 300B's hazard, for example, would increase from .38 to .66 in 1981.

The most important results, however, using the new fuel prices come from (5) and (6). Including year dummies to take out all annual variation still allows estimation of fuel cost on retirement. Equation (5) includes model dummies and year dummies. Equation (6) also includes vintage dummies. In both cases, the role of fuel costs is much larger than before. The price elasticities of the hazard for the 100 and 300B in 1981 are now between 3.8 and 5.0 rather than around 3. These results are robust to the problems of excluded hazard shifters like noise regulation and USAF purchases. This is extremely important. The year dummies will take into account all factors which influence retirement of 707s generally. To spoil the estimates of (5) and (6) requires an omitted factor which is correlated with the price of fuel, causes more fuel intensive planes to retire faster than less fuel intensive planes and also causes 707 models of high fuel cost carriers to retire faster than identical models of low fuel cost carriers. I will use the estimates from (5) and (6) in the simulations below.

One consideration to note about the fuel results presented is that airlines can change utilization of their planes as well as retire them so the coefficients on fuel are probably underestimated. For example, a carrier might have retired a 707 in 1980 if used on a full route structure but by reducing utilization, retirement could wait until 1982.¹¹ The CAB data shows this quite clearly. For instance, In 1973, the average 707-100 flew 8.39 hours per day at 463 miles per hour. In 1981, the same plane flew 4.75 hours a day at 444 mph. Similarly, the 300B flew 9.36 hours a day at 481 mph in 1973 and

¹¹ Berndt and Wood (1985) discuss the issue of energy induced changes in utilization in detail.

4.62 hours at 450 mph in 1981. As a result, the fuel economy for the 100 and 300B planes increased from 33.8 and 37.9 ASM per gallon in 1973 to 42.2 and 48.0 ASM per gallon in 1981. To give an idea of the effect this has on retirement rates, consider a reduction in the fuel economy of 707-300Bs in 1981 to their 1973 level. This would have increased the fuel cost per seat mile from 2.69 cents to 3.41 cents. The hazard would be more than two and a half times larger.

SECTION 5: Oil Shock Simulations

To consider the role that the oil shocks of 1974-5 and 1979-81 had on retirement rates, I take the hazard estimates from the Weibull specification as the actual retirement probabilities in 1975 and 1981 and ask what would have happened to the hazard rate if the price of oil had returned to its 1973 or 1978 pre-shock level, according to the Cox estimates above. The results in Table 8 show how decisive the price of oil was. The estimates indicate that the oil shock made retirement in 1974 about 2 to 3 times more likely and in 1981 about 5 to 15 times more likely. Take the example of the 707-300C. A plane that reached age 15 in 1981 had a 96% chance of retiring before 1982. Without the oil shock, the hazard would have been about 12%. These results say that the fuel shocks made 707s an obsolete vehicle basically overnight. As might be expected, the magnitude of this effect was well known to the airline industry. *Air Transport World*, the trade publication for Airline managers, ran several editorials on the fact that 707s had become obsolete and in 1981 claimed that fuel economy had "become an obsession" and was leading to the rapid retirement of 707s. American Airlines took out full page advertisements offering their 707s for sale and the owner of the first 707 even offered to sell it as a museum piece.

Another way to simulate the effect of fuel increases on retirement is to consider the effective service life of an airplane under different fuel prices. It is common in empirical work to assume that aircraft have a useful service life that is fixed at 14 or 18 years. If, however, the true service life changes substantially when factor prices change, then this empirical work can be quite inaccurate. The

service life calculation is particularly easy using the Weibull specification even though the results are smaller than for the Cox specification. The Weibull indicates that a plane facing constant gdp growth of 2.5% per year and a constant cost of capital at the average level would have an expected service life of 22 years at the 1973 fuel price. At the 1978 fuel price, though, the expected service life would be 16 years and at the 1981 price only 8 years.

The sheer magnitude of fuel's effect on retirement has important implications for the fleets of current airlines. Although planes as fuel intensive as the 707 are gone, Table 1 showed that there were equally large differences in intensity among existing planes. A common plane with poor fuel economy today is the 727. The difference in 1975 between the 707-300, the most fuel intensive plane in the sample, and the 727-200 was about the same as the difference between the 727-200 and the 737 today. If the 727 behaved exactly as a 707-300, for example, a 5% energy tax in 1994 could lead to as much as a 15% increase in the retirement hazard, creating unexpected capital replacement costs for the airlines forced to retire their fuel intensive capital. This also means that some carriers could be more susceptible to such a tax than others. Table 9 shows the share of 727s in the total fleet size (including planes on order). An energy tax on airlines might cause large windfall losses for some carriers, particularly TWA, Continental and United who would suddenly find a large fraction of their capital stock obsolete. The effect of fuel on retirement might also be important in areas like pulp mills, steel mills, generators and automobiles, where energy intensities are embodied in the capital goods themselves and are not easy to change ex post.

CONCLUSION

This study has shown that the price of fuel has a substantial effect on the decision to retire jet aircraft. The oil shocks increased the probability of retirement for 707s dramatically--between 5 and 15 times in 1979-81. Reducing the cost of capital also accelerates retirement. A natural modelling extension for this research would be to include uncertainty as in Dixit & Pindyck (1993) or Das

(1992) and to estimate a structural model of the retirement decision.

More important, however, the large effects of fuel on retirement found here have important implications for the other areas of research. If the oil shocks increased obsolescence in other industries the way they did for the airlines, then the measured capital stock is too large and this could help explain the productivity slowdown (see Baily 1981). Further, large effects of factor prices on retirement rates of inefficient capital could change our view of market based instruments like energy or pollution taxes. Since the capital stock of the economy is not homogenous but is instead filled with many different types of capital assets, the most important mechanism that market instruments have may be their effect on discrete decisions to purchase or retire assets rather than on marginal changes in utilization as is most commonly assumed. Understanding this adjustment mechanism of price based policies is vital for their practical use.

**Table 1: Fuel Efficiency of Aircraft Models
(Available Seat Miles per Gallon)**

Aircraft Type	1983	1975
B-767-200	71.1	--
B-757-200	70.9	--
MD-80	68.4	--
B-747	64.6	52.9
DC-10-10	61.6	51.8
A300-B4	60.2	--
B-737-200	58.3	41.1
L-1011	55.1	47.8
B-727-200	50.2	39.7
DC-8-61	50.0	44.8
707-300B	42.5	40.2
B-707-300C	--	38.5
B-707-100B	--	37.2
B-707-300	--	35.2

Source: *Airline Operating Costs and Performance Report*

Table 2: Production of 707s

YEARS	707-100s	707-300s
1958-61	30	22
1962-64	24	36
1965-67	36	109
1968-70	6	91

Source: *Airliner Production List*, Aviation Data Centre

Table 3: Retirement Fates of 707 Aircraft

FATE	NUMBER	PERCENTAGE
Sold to Foreign Operator	152	42.8 %
Withdrawn from Use	101	28.4 %
Sold directly to USAF	49	13.8 %
Sold to Private/Cargo Use	42	12.1 %
<u>Scrapped/Cannibalized</u>	<u>10</u>	<u>2.8 %</u>
TOTAL	354	100%

Table 4: Fuel Cost in 1987 cents/seat-mile for plane types

<u>Year</u>	<u>300</u>	<u>100</u>	<u>300c</u>	<u>300b</u>
1972	1.10	.88	.82	.82
1975	1.90	1.53	1.68	1.71
1978	1.86	1.67	1.70	1.64
1981	3.69	3.02	3.22	2.89
1984	--	2.11	--	2.02

Table 5: Variable Summary
(standard deviation in parentheses)

Variable Name	Full Sample	Retirement Years	Non-retirement years
Delivery Year	1965.6 (3.0)	1965.3 (3.1)	1965.7 (2.9)
Exit Year	1980.1 (2.5)	1978.7 (3.2)	1980.3 (2.3)
Duration (years)	14.4 (3.6)	13.4 (3.9)	14.6 (3.5)
Industry Price of Oil Index (707-100 in 1978 = 1.00)	.91 (.40)	1.29 (.47)	.86 (.36)
Fuel cost of 1 seat mile (1987 cents)	1.69 (.68)	2.30 (.73)	1.60 (.62)
Loss dummy	.40 (.49)	.41 (.49)	.40 (.49)
GDP growth	2.74 (2.60)	1.84 (2.53)	2.88 (2.58)
Capital Price Index (1987 = 100)	117.0 (6.0)	113.2 (5.6)	117.5 (5.8)
Cost of capital in %	20.2 (1.73)	21.6 (2.0)	20.0 (1.6)
Average Stage Length	991 (471)	962 (405)	995 (480)

**Table 6: Estimates of Cox Model for 707 retirement hazard--using industry oil price
(Standard errors in parentheses)**

Vars.	(1)	(2)	(3)	(4)	(5)¹² Weibull	(6) No usaf
Price of oil	1.612 (.1577)	1.428 (.3291)	1.452 (.3272)	1.276 (.3415)	1.560 (.4698)	1.705 (.3368)
Cost of capital * price		-.0003 (.0005)	-.0014 (.0005)	-.0015 (.0006)	-.0033 (.0002)	-.0009 (.0006)
Loss dummy			-1.136 (.1429)	-.9519 (.1464)	-1.300 (.2106)	-.7904 (.1451)
GDP growth rate		-.0461 (.0322)	-.1496 (.0357)	-.1530 (.0363)	-.2444 (.0306)	-.0941 (.0378)
Deregulation dummy		-.2624 (.2808)	.2173 (.2690)	.1913 (.2790)	.3149 (.2953)	-.0656 (.2862)
Noise regulation variable		.0277 (.0053)	.0277 (.0054)	.0255 (.0056)	.0177 (.0070)	.0201 (.0063)
Stage length		.0005 (.0002)	.0006 (.0002)	.0004 (.0002)	.0005 (.0010)	.0004 (.0002)
Sigma					.4300 (.0421)	
Model Dummies	No	No	No	Yes	No	No
Pseudo-R2	.0331	.0047	.0644	.0791		.0568
Log Likl.	-1704.8	-1659.2	-1649.7	-1623.7	-889.3	-1391.1

¹² The Weibull coefficients listed are in fact the estimated coefficients divided by the estimated σ scale parameter so as to be comparable with the Cox estimates. Since the scale parameter is estimated itself these standard errors are underestimated.

**Table 7: Estimates of Cox Model for 707 retirement hazard—using ASM fuel cost
(Standard errors in parentheses)**

Vars.	(1)	(2)	(3) No wfu	(4)¹³ Weibull	(5)	(6)
Price of oil	.9989 (.0923)	1.083 (.1692)	1.041 (.1943)	1.143 (.2560)	1.232 (.3539)	1.629 (.3823)
Cost of capital * price		-.0015 (.0005)	-.0012 (.0006)	-.0033 (.0002)		
Loss dummy		-1.133 (.1461)	-1.163 (.1817)	-1.297 (.0193)	-1.261 (.1699)	-1.171 (.1727)
GDP growth rate		-.1396 (.0364)	-.0963 (.0401)	-.2310 (.0301)		
Deregulation dummy		-.0503 (.2576)	-.2462 (.3360)	.1552 (.2629)		
Noise regulation variable		.0331 (.0051)	.0339 (.0065)	.0252 (.0075)		
Sigma				.4286 (.0401)		
Model Dummies	No	No	No	No	Yes	Yes
Year Dummies	No	No	No	No	Yes	Yes
Vintage Dummies	No	No	No	No	No	Yes
Pseudo-R2	.0361	.0684	.0543		.0884	.0543
Log Likl.	-1699.5	-1642.5	-1110.0	-877.0	-1607.3	-1110.0

¹³ The Weibull coefficients listed are in fact the estimated coefficients divided by the estimated σ scale parameter so as to be comparable with the Cox estimates. Since the scale parameter is estimated itself these standard errors are underestimated.

Table 8: Effect of Oil Shocks on Estimated Retirement Probabilities

<u>Airplane and Age</u>	<u>Est. Retirement Probability</u> 1975		<u>Est. Retirement Probability</u> 1981	
	Actual	No oil shock	Actual	No oil shock
<u>707-100</u>				
Age 5	.06	.02 - .03	.18	.02 - .03
10	.16	.06 - .07	.44	.05 - .08
15	.27	.10 - .12	.75	.08 - .14
<u>707-300B</u>				
Age 5	.08	.02 - .03	.15	.02 - .03
10	.19	.05 - .07	.38	.05 - .08
15	.33	.09 - .12	.65	.09 - .14
<u>707-300C</u>				
Age 5	.08	.02 - .03	.22	.02 - .03
10	.19	.05 - .07	.56	.05 - .09
15	.33	.09 - .13	.96	.08 - .15
<u>707-300</u>				
Age 5	.10	.03 - .04	.38	.02 - .05
10	.24	.06 - .08	.95	.05 - .10
15	.42	.11 - .15	--	--

Table 9: Fuel Efficiency of Current Fleets

Carrier	727s (%)	Fleet Size
TWA	35.2	210
Continental	28.6	325
United	26.1	482
Delta	23.2	660
American	21.9	750
Northwest	13.8	515
USAir	6.7	436
Southwest	0.0	162

Appendix 1: Data Sources

The real price of jet fuel comes from the PPI and the Oil and Petroleum Statistical Annual. First it is scaled to equal 1.00 for a -100 in 1978. Then the price of fuel for the other types of 707s are adjusted by using their relative fuel intensity in Table 1, dividing by 1.081 for -300B, 1.035 for the -300C, and .946 for the -300. The price index of durable goods is the durable goods deflator divided by the gdp deflator in the Economic Report of the President. The financial data for each company and the average flight stage length come from Air Carrier Financial Statistics, and the Air Carrier Traffic Statistics of the Civil Aviation Board (CAB). The cost of capital is a yearly average of the quarterly data from Kopcke which is listed in Berndt (1990).

The fuel cost of one available seat mile is derived by taking the average available seat miles per hour for the given carrier and plane type in a given year, dividing by the average gallons of fuel consumed per hour divided by the average price paid per gallon for that plane (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 statistics. This is usually the case when a carrier has one or two of a given type of plane remaining. To impute the cost of fuel it is necessary to have the fuel intensity of the plane and the average price paid for fuel. An average is taken of the last three reported years for the fuel economy and then the average fuel price for either the other types of 707, if available for that carrier in that year or else the fuel cost for a similar plane like the 727-100 is used. 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. Further, by definition this is only relevant when there are few planes remaining and their effect on the results is negligible.

It might be natural to question the use of Available Seat Miles (ASM) rather than Revenue Passenger Miles (RPM) for the fuel economy calculations. It is standard practice among airlines, however, to use ASM because of the variability in revenues and passengers. A detailed demonstration that ASM is a better measure is given in James (1982). Just to make sure, though, I have done the same estimation above but taking the average load factor before and after deregulation (about 53% and then 60%) and scaled the fuel costs into passenger miles but the fuel estimates are almost exactly the same and not statistically different at all.

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Figure 1

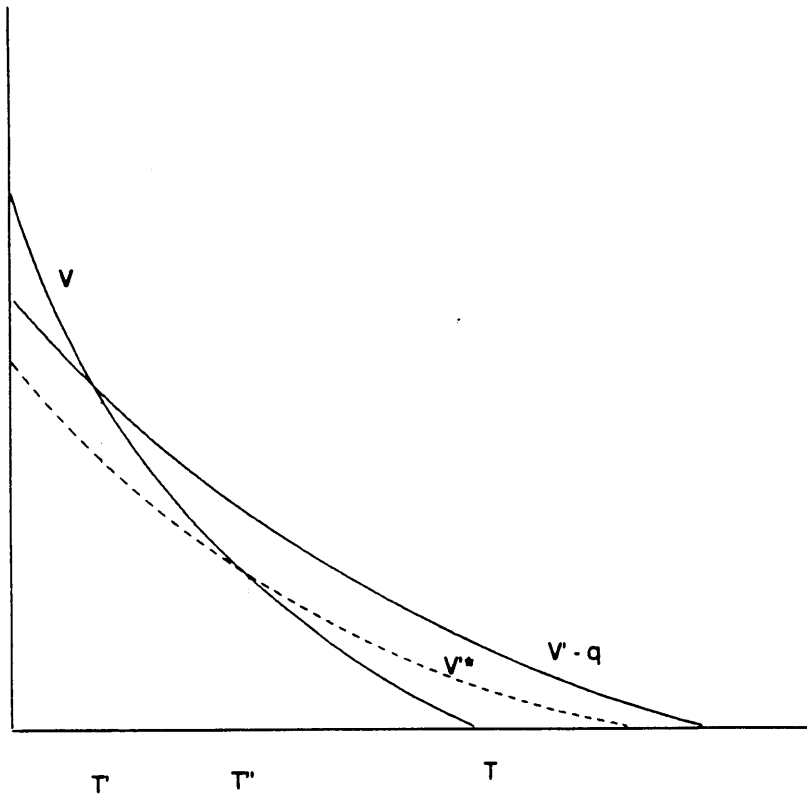


Figure 2

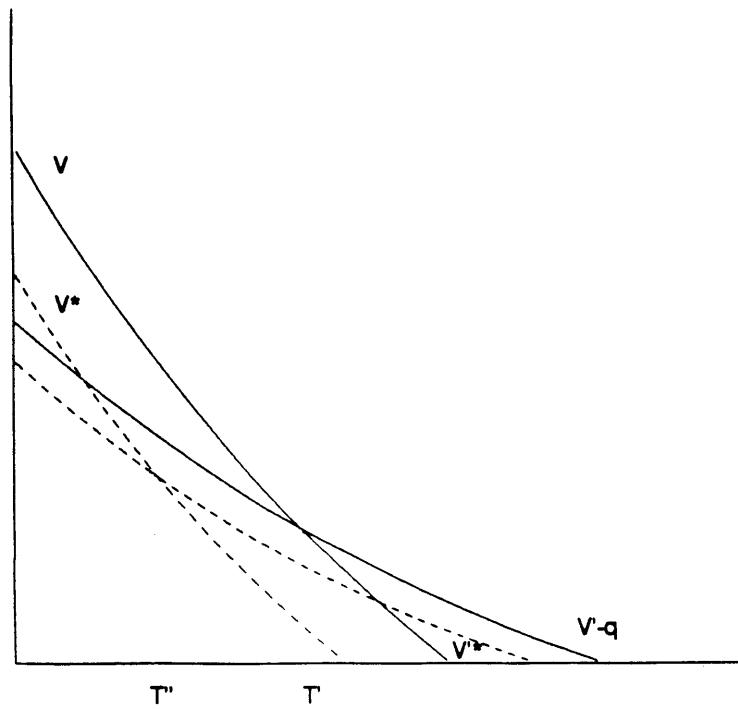


Figure 3: Real Price of Jet Fuel

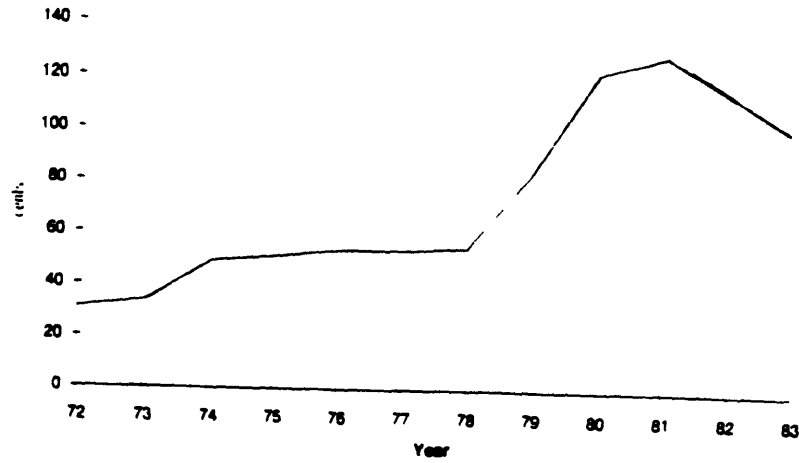


Figure 4: Carrier Fuel Costs for 300C

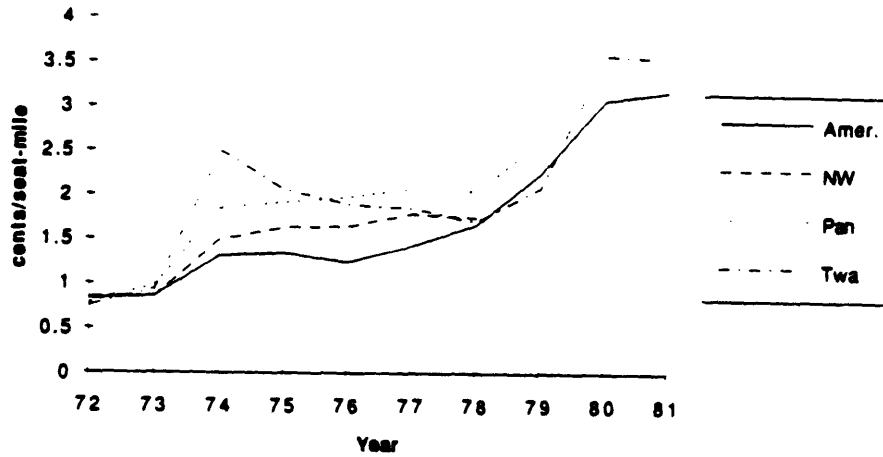


Figure 5: Kaplan-Meier Hazard Rates

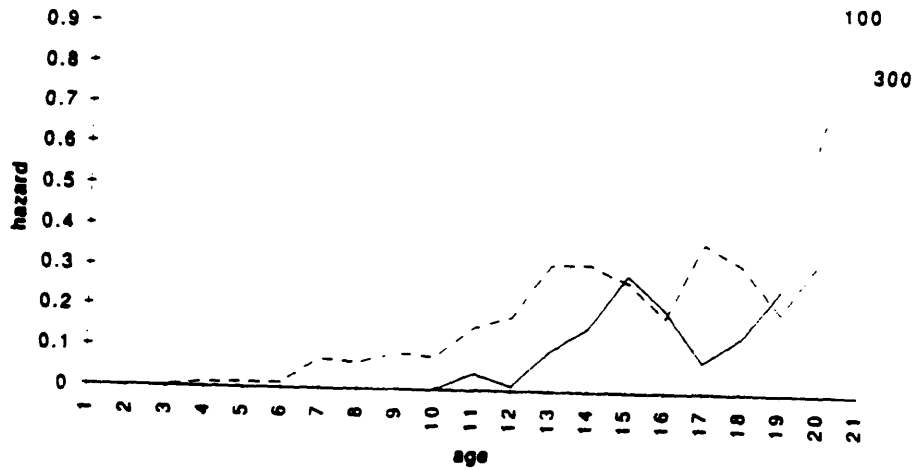


Figure 6a: Integrated Hazard for 100

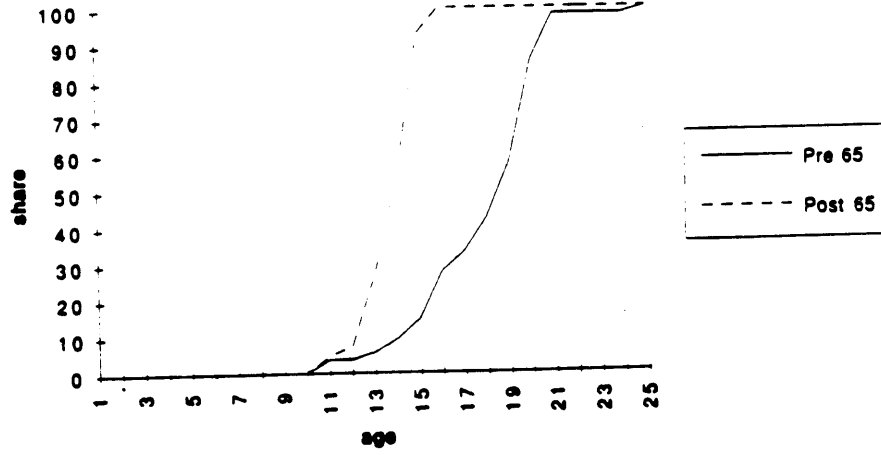


Figure 6b: Integrated Hazard for 300

