Lemons and Leases in the Used Business Aircraft Market

Thomas W. Gilligan

USC Center for Law, Economics & Organization
Research Paper No. C03-4

CENTER FOR LAW, ECONOMICS AND ORGANIZATION RESEARCH PAPER SERIES

Sponsored by the John M. Olin Foundation

University of Southern California Law School
Los Angeles, CA 90089-0071

Lemons and Leases in the Used Business Aircraft Market

Thomas W. Gilligan*

Department of Finance and Business Economics
Marshall School of Business
University of Southern California
Los Angeles, CA 90089-1427

April 1, 2003

Abstract

Given adverse selection, durable goods that trade infrequently depreciate quickly. Consistent with this prediction I find an inverse relationship between depreciation and trading volume for less reliable brands of used business aircraft. Additionally, recent theoretical analyses suggest that leasing, by increasing the average quality of used goods, may reduce adverse selection in durable goods markets. Indeed, I find a direct relationship between depreciation and trading volume for aircraft models with relatively high lease rates. Together these findings suggest that adverse selection is a prominent feature of the contemporary used business aircraft market and that leasing mitigates the consequences of adverse selection. (JEL C23, C33, D82, L15, L62)

Keywords: Industrial organization, adverse selection, durable goods, leasing, business aircraft.

---

* I wish to thank Adam Goldberg and Rishika for their able research assistance and the Marshall School of Business for their generous financial support. Many of my colleagues, particularly Joe Chen, Harry DeAngelo, Winand Emons, John Matsusaka, Lior Menzly, Oguzhan Ozbas, Ivan Png and Frank Wykoff provided useful suggestions. Kevin Murphy supplied some of the data used in this paper as well as sharing his insights on the evidence for adverse selection in modern labor markets. Seminar participants at the University of Arizona, Claremont McKenna College, City University of Hong Kong and the Hong Kong University of Science and Technology supplied many helpful comments. Barney Byard of Aviation Data Services, Inc., Paul Wyatt of Intertec Books Aviation Bluebook Price Digest and Bob Breiling of Robert E. Breiling Associates, Inc., were generous with their time and knowledge of the business aircraft market. This work is preliminary and comments are welcomed. All opinions, errors and omissions are mine.

Lemons and Leases in the Used Business Aircraft Market

This paper presents evidence of adverse selection in the market for used business aircraft. That is, for at least parts of this market the data suggest that quality is an essential characteristic of business aircraft, that uncertainty about quality is an important feature of aircraft transactions, that sellers are often better informed than buyers about aircraft quality, and that the asymmetric distribution of information about quality is reflected in the depreciation rates and trading intensities of used business aircraft. This paper also contains evidence that leasing mitigates adverse selection in the used business aircraft market.

These findings are important for at least three reasons. First, evidence of the insights contained in Akerlof's (1970) seminal work are mixed and inconclusive in contemporary durable goods markets. Bond (1984) finds weak evidence of adverse selection among older trucks only. Genesove (1993) finds only slight evidence of adverse selection in dealer auction markets for used cars. Fabel and Lehmann (2000) and Emons and Sheldon (2002) find stronger support for the existence of adverse selection in used automobile markets. However, the results of Porter and Sattler (1999) are inconsistent with adverse selection in used automobile markets. In as much as the used vehicle market represents the canonical example in Akerlof's (1970) seminal paper and the natural and compelling intuitive illustration of the issues that arise given asymmetric information about product quality, the failure to detect either uniform or compelling evidence of adverse selection constitutes a nettlesome part of the literature. And the focus of extant empirical work on used cars and trucks, while understandable, is constricting. Can evidence be found for adverse selection in other than used automotive markets? The results contained in this paper address these limitations.

Second, in a series of recent papers Hendel and Lizzeri (1999, 2002) develop a dynamic theoretical model of a durable goods market and use this model to, among other things, explore the relationship between durable good price declines (i.e., the difference between new and used durable prices; durable good price depreciation) and trading intensities (i.e., the percentage of the stock of a given type or brand of durable good traded in a period; durable good trading volume). Hendel and Lizzeri (1999) show that price declines and trading intensities are directly and inversely related under complete and asymmetric information about durable good quality, respectively. Hendel and Lizzeri (2002) also show that leasing, by increasing the average quality of durable goods transacted in used markets, may mitigate the consequences of adverse selection.[1] The results contained in this paper show how these predictions constitute a framework for assessing the relevance of adverse selection and, when proxies for qualitative uncertainty are present, for testing broader classes of theory pertaining to patterns of trade in used durable goods. These results validate the insights provided by Hendel and Lizzeri (1999, 2002) and illustrate a simple yet powerful method for testing theories of trade in used durable goods.

And third, counteracting or extra-market institutions are often understood as solving or mitigating problems of qualitative uncertainty and the asymmetric distribution of information. The market for business aircraft exhibits many of these features. For example, it is common for transactions of used business aircraft to carry some form of guarantee or warranty of serviceability and performance. Brand names of aircraft manufacturers, dealers and brokers are prominent features of this market. Certification and licensing practices are very intense and administered by agencies with sweeping regulatory and legal authority. Indeed, it is difficult to

[1] Waldman (1999) and Johnson and Waldman (2001) also show that leasing can reduce adverse selection in competitive markets by promoting the sale of used goods without regard to quality.

think of a durable goods market with more numerous and extensive counteracting institutions. The results contained in this paper illustrate that adverse selection can survive the types of counteracting institutions present in the market for business aircraft. Adverse selection can be a pervasive feature of even mature, active and institutionally rich durable goods markets. These results also show that innovative counteracting institutions such as leasing contracts can mitigate adverse selection.

I test the predictions provided by Hendel and Lizzeri (1999, 2002) using pricing and trading and leasing frequency data from the market for business aircraft in North America over the period 1980-1999. To be sure, quality is important feature of aircraft generally and business aircraft specifically. Performance, expense and safety are the major dimensions of business aircraft quality. Potential proxies for uncertainty about quality are readily available and based on the regulatory safety histories of aircraft. Market participants, chiefly aircraft brokers and sales agents, believe these proxies affect buyer perceptions of reliability, the inverse of qualitative uncertainty, and aircraft resale values. I use these proxies of aircraft qualitative uncertainty to sharpen the predictions provided by Hendel and Lizzeri (1999, 2002).

To illustrate the nature of my results, I find that relatively reliable aircraft, those exhibiting low qualitative uncertainty based on regulatory measures of safety, from models with high leasing frequencies exhibit a direct and statistically significant relationship between depreciation and trading intensity. This result illustrates that complete information models are adequate for explaining the trading patterns of used durables exhibiting low qualitative uncertainty. Conversely, relatively unreliable aircraft, those exhibiting high qualitative uncertainty based on regulatory measures of safety, with low leasing frequencies have an inverse and statistically significant relationship between depreciation and volume of trade. This result shows that asymmetric information models are necessary to explain trading patterns in a population of used durable goods that exhibits variation in qualitative uncertainty. I also find that these results are quantitatively more important for older aircraft but nonetheless statistically meaningful in subsets of the data that include only younger aircraft. The results contained in this paper highlight the importance of conditioning tests of adverse selection on measures of qualitative uncertainty and the presence and magnitude of potentially counter-acting institutions like leasing.

Section I of this paper is a brief survey of the empirical literature. Section II summaries the relevant theoretical results and identifies the key empirical predictions that I test in Section IV. Section III contains an introduction to the business aircraft market and describes the data used in the empirical analysis. Section V is a conclusion.

I. Related Empirical Literatures

The primitive lemons model has many implications, several of which form the basis for empirical attempts to document the relevance of adverse selection and counteracting institutions in used durable goods markets. I provide a brief survey these studies in this section of the paper.

If adverse selection exists, durable goods sold in used markets should be lower in quality than goods retained by their original owners and may require more frequent or costly repair or be more likely to fail relevant performance assessments. Bond (1984) analyzes a U.S.-based data set and shows that pickup trucks in excess of ten years in age recently acquired in the used market require more maintenance. Emons and Sheldon (2002) examine the automobile market in the Swiss canton of Basle-City and show that the probability of finding a defect at government mandated safety inspections is greater for recently sold used cars. Taken together these studies suggest that the quality of goods traded in used markets is lower than the average quality of durable goods *in toto*. Bond (1984) also speculates that since trucks sold by brokers are probably less than ten years old, independent used truck dealers may act as an effective counteracting institution. Emons and Sheldon (2002) also find that used cars sold by dealers are less likely to have defects and, like Bond (1984), interpret this finding as evidence that third-party brokers of used transactions can serve as effective counteracting institutions in markets with asymmetric information. Both suggest that the reputation or certification activities of dealers may serve to ameliorate the effects of adverse selection.

Another implication of the lemons hypothesis is that used durable good prices are more heavily discounted in the presence adverse selection. Genesove (1993) shows that the wholesale auction prices of used cars sold by new cars dealers who have a greater propensity to sell their used cars (i.e., the "trade-ins" associated with new car purchases) without regard to quality are slightly greater than the wholesale auction prices of used cars sold by used car dealers. Fabel and Lehmann (2000) argue that internet used car markets, while lowering search costs, are generally bereft of the types of counteracting institutions designed to address adverse selection and show that the average price of used cars traded electronically are, all else equal, lower than those traded in traditional markets. These studies suggest that durable good prices are lower given the potential for adverse selection.

Another implication of adverse selection is that the probability that a used durable good is sold declines with the duration of ownership. According to the basic lemons story, low quality goods are discounted and resold quickly while current owners retain higher quality durables. It is reasonable to assume that learning about used durable good quality occurs fairly earlier in the ownership cycle. Emons and Sheldon (2002) show that the probability of re-selling a used car falls considerably with the length of ownership. When combined with their other empirical findings, Emons and Sheldon (2002) provide direct evidence that used cars trade in adversely selected markets.

Another direct implication is that adverse selection retards trade and reduces the prices of used durable goods. In the presence of adverse selection, new and used durable good price differentials should be negatively correlated with the level of activity in used markets. Using a large data set of automobile title transfers from Illinois over the 1986 to 1994 period, Porter and Sattler (1999) show that the total number of owners of a particular automobile, whether individual vehicles are traded at all, and the duration of ownership, all measures of the trading activity, are positively associated with durable good price depreciation. They interpret their results as inconsistent with the predictions of the adverse selection model. The analysis I conduct below is most closely related to theirs, with the exception that I allow the price depreciation, trading activity relationship to depend on measures of qualitative uncertainty and leasing frequency.

If leasing mitigates adverse selection by increasing the qualities of goods available for resell, used durables that were previously leased should on average trade at a premium over those that were previously sold. Desai and Purohit (1998) show that this pattern holds for at least one popular automobile model. More generally, Hendel and Lizzeri (2002), Waldman (1999) and Johnson and Waldman (2001) show that the stylized facts of leasing in contemporary automobile markets are consistent with asymmetric information models of trade in used durable goods.[2] For example, the facts that only a fraction of lessees exercise their option to purchase their now-used

[2] Indeed, Hendel and Lizzeri (2002) produce an "irrelevance result" illustrating that leasing affects neither market allocations nor producer profits under complete information. The obvious implication of their result is that asymmetric information models are necessary for understanding the patterns and consequences of leasing in durable goods markets.

car and that the option or "buy-back" price exceeds the average used car price are explicable within the context of models of durable goods markets that assume that sellers are better informed than potential buyers. These studies offer at least strong preliminary evidence that leasing may mitigate adverse selection, a proposition I explore further below.

II. Theoretical Predictions and Empirical Implications

Hendel and Lizzeri (1999, 2002) formalize the essential logic of selling and leasing contracts in durable goods markets. They also derive some testable implications of the effects of asymmetric information and adverse selection for patterns of trade in such markets. The empirical framework used in this paper is based on their comparative statics exercises. In this section I summarize their arguments and describe how I implement their empirical predictions.

Consider a model in which durable goods last for two periods. The quality of new durable goods is deterministic and given by v. The quality of used durable goods is (potentially) stochastic and equals w_l (for low) or w_h (for high) according to some distribution function. Since $v > w_h$, durable goods depreciate with certainty over time. Consumers are heterogeneous and differ in their valuations of durable good quality and demand at most one unit of a durable good in any period. Consumers make transactions in the durable good market to maximize their discounted flow of net utility (i.e., the utility of owning a durable good net of acquisition costs). The economy lasts forever with consumers born in the first period of the model. No new consumers enter the economy over time and a constant flow of new durable goods arrives each period. The flow of new units is sufficiently small so that some consumer types do not purchase durable goods, either a new or used (i.e., types with low valuations of quality). Hendel and Lizzeri (1999) analyze the steady state, rational expectations equilibria of this economy.

In the relevant parts of their analysis Hendel and Lizzeri (1999) establish the relationship between two variables under alternative assumptions about the distribution of information in the used durable goods market. These variables are the difference between the prices of a given new and used durable good - the durable good's price decline - and the fraction of units of a particular type or brand of durable good traded in the used market - the durable good's volume of trade. I test these predicted relationships below.

A. Trade Under Complete Information

Under complete information, buyers and sellers of used durable goods are symmetrically informed about quality which is assumed deterministic and equal to w. The quantity $v - w$ represents durable good quality deterioration and is directly related to the durable good's price decline. When quality deterioration is small some buyers of the new durable retain ownership of their unit rather than incur the costs associated with used durable good transactions. When durable good quality deterioration is large relative to the transaction costs of the used durable good market, however, more owners of the durable good wish to sell their unit and purchase a new unit in the current period. Thus, the durable good's volume of trade is also directly related to $v - w$.

To elaborate, consider two brands of a durable good, brand X and brand Y, such that $v_x > v_y > w_y > w_x$. Brand X exhibits higher new and lower used durable good quality than does brand Y; that is, brand X deteriorates more than brand Y. Hendel and Lizzeri (1999) show that under these circumstances and assuming that the transactions costs of the used durable good market are sufficiently low so that trade occurs in both brands, the price decline is larger and the volume of trade is greater for brand X than for brand Y. Given complete information in a used durable goods market, price declines and trading volumes across brands with varying rates of deterioration are directly related.

B. Trade Under Asymmetric Information

Under asymmetric information, the quality of the used durable good is a random variable whose realization is known only to the seller and not to potential buyers. This information structure creates adverse selection and lowers the quality of durable goods traded in the used market. Moreover, more buyers of new durable goods retain ownership in the second period rather than sell their units at a price equal to the average quality of a traded used durable. When uncertainty about durable good quality is large, price declines are larger and volumes of trade are lower than under deterministic used good quality.

To elaborate, consider two brands of a durable good, brand R (for reliable) and brand U (for unreliable), such that $v_r = v_u$, $w_l^r = w_h^r = E(w^r)$, $w_l^u < E(w^u) < w_h^u$, and $E(w^r) = E(w^u)$. That is, the only difference is that brand U used durable goods exhibit random quality. Hendel and Lizzeri (1999) show that under these circumstances the price decline is greater and the volume of trade is smaller for the unreliable brand. Given incomplete information in a used durable goods market, price declines and trading volumes across brands of varying reliability are inversely related.

C. Asymmetric Information and Leasing

In many durable goods markets new units are leased rather than sold to buyers. Apart from a standard first-period rental payment, the typical leasing contract specifies an option or buy-back price that the lessee must pay to retain possession of the durable good in its second and last period of life. Hendel and Lizzeri (2002) show that the percentage of durable good units returned to the lessor exceeds the percentage of units traded in the used market under standard selling contracts and, thus, that leasing contracts increase the volume of trade in used durable goods markets. They also show that returned units are of higher average quality than units sold in the used market under selling contracts and, therefore, that price declines are lower under leasing. Both of these effects indicate that leasing ameliorates the consequences of adverse selection in durable goods markets; that is, leasing mitigates both the reductions in trading volume and used prices caused by adverse selection. Given asymmetric information, price declines and trading volumes for models with relatively high leasing frequencies more closely resemble the direct relationship found when information in complete. Leasing, by mitigating the adverse selection problem, promotes the standard direct relationship between the price decline and volume of trade of used durable goods predicted under complete information.

D. Empirical Implications of the Alternative Theories

Assuming complete information, price declines and trading volumes are directly related and unaffected by qualitative uncertainty or leasing frequency. Under asymmetric information, the relationship between price declines and trading volumes are channeled through variation in qualitative uncertainty and leasing frequency. Unreliable durables exhibit an inverse relationship between the price decline and volume of trade. Durables with relatively high leasing percentages have a direct relationship between price decline and volume of trade. In theory, the relevance of the competing informational assumptions and the existence of adverse selection as well as the role of leasing can be assessed by observing the relationship between price declines and volumes of trade conditional on variation in durable good reliability and leasing frequency.

While the contemporary theoretical work on adverse selection in durable goods markets is elegant and constitutes a significant contribution to the literature, its use for guiding empirical research is limited in at least one important respect. Most, if not all, durable goods live for more than two periods and, indeed, transit the used durable goods market several times before obsolescence or destruction. This observation raises two immediate questions. First, can the intuition obtained from models employing the assumptions described above be expected to hold for situations in which durable goods are traded more than once and possibly often over relatively long periods of time? And second, how might one operationalize the idea of a price decline in such a multi-period environment?

I employ three key assumptions in my empirical design. First, I assume that the intuitions of two period models extend fully to many period settings. That is, what is true about the behavior and outcomes in the first (new) and second (used) periods of the models described above are also true for models with a potentially large and arbitrary number of periods. Second, I assume that depreciation or decay rates in durable good prices are suitable proxies for price declines in multi-period settings. And third, I assume that the predicted effects of the alternative hypotheses are reflected by the way in which trading volumes, qualitative uncertainty and leasing frequencies affect a continuous and constant rate of depreciation.

Given these assumptions, the alternative theories suggest that $r = f(V, Q, L)$ where r is the constant and continuous durable good depreciation rate and V, Q and L are measures of trading volume, qualitative uncertainty and leasing frequency, respectively. Under complete information, the relationship between depreciation and volume of trade is direct and unaffected by qualitative uncertainty and leasing frequency, implying that $f_1 > 0$ and $f_{12} = f_{13} = 0$. Under asymmetric information, the relationship between depreciation and volume of trade should also be channeled at least partly and indirectly through qualitative uncertainty and directly through leasing frequency, implying that $f_1 \geq 0$, $f_{12} < 0$ and $f_{13} > 0$. Thus, the alternative hypotheses can be assessed by exploring the properties of $f(\bullet)$.

The relationships of interest can be estimated given some additional data and structure. Let P_t^{it} represent the price in period t of a durable i manufactured in period t. Obviously, $t \leq t$ and $t - t$ is the durable good's age in periods. Assuming a constant rate of continuous depreciation r^{it}, the price in period t of the durable i manufactured in t is given by $P_t^{it} = A_t^{it} P_t^{it} e^{-r^{it}(t-t)}$ where A_t^{it} is a shift parameter depending on, among other things, economy-wide and industry-specific factors (i.e., supply and demand shifters). Define $RV_t^{it} = P_t^{it} / P_t^{it}$ as the residual value of the durable good in period t. Rearranging terms yields $\log(RV_t^{it}) = \log(A_t^{it}) - r^{it}(t-t)$. Assuming a quadratic form for $f(V, Q, L)$ and making the obvious substitution produces the residual value function

$$\log(RV_t^{it}) = \log(A_t^{it}) - AGE_t^{it}\Big(a_0 + a_1 V_t^{it} + a_2 Q_t^{it} + a_3 L_t^{it} + a_4 (V_t^{it})^2 + a_5 (Q_t^{it})^2$$

$$+ a_6 (L_t^{it})^2 + a_7 V_t^{it} Q_t^{it} + a_8 V_t^{it} L_t^{it} + a_9 Q_t^{it} L_t^{it}\Big) + e_t^{it} \qquad (1)$$

where V_t^{it}, Q_t^{it} and L_t^{it} are contemporaneous measures of trading volume, qualitative uncertainty and leasing frequency, respectively, $AGE_t^{it} = (t-t)$ and e_t^{it} is a random variable with zero expected value and constant variance. For concreteness, I refer to the terms in brackets pre-multiplied by aircraft age as the depreciation rate function and $\log(A_t^{it})$ as the shift parameter of the residual value function.

Inspection of equation (1) illustrates that, given complete information, the relationship between depreciation and trading volume is direct and unaffected by qualitative uncertainty and leasing frequency; $a_1 + a_4 V_t^{it} > 0$ and $a_7 = a_8 = 0$. Given asymmetric information, the relationship between depreciation and trading volume is, in part, channeled indirectly through qualitative uncertainty and directly through leasing frequency; $a_1 + a_4 V_t^{it} \geq 0$, $a_7 < 0$ and $a_8 > 0$. Evaluating the depreciation rate function within equation (1) permits direct test of the alternative theories of trade in used durable goods.

Inspection of equation (1) further illustrates that a positive relationship between depreciation and trading volume does not justify rejection of asymmetric models of trade in used durable goods. It is clearly possible for the derivative of the estimated depreciation rate with respect to trading volume evaluated at specific values of the independent variables to be positive (i.e., $a_1 + a_4 V_t^{it} + a_7 Q_t^{it} + a_8 L_t^{it} > 0$) at the same time that qualitative uncertainty and leasing frequency are statistically and theoretically meaningful for explaining variation in the depreciation/trading volume relationship (i.e., $a_7 < 0$ and $a_8 > 0$). In a population of durable goods that varying in terms of qualitative uncertainty and leasing frequency, a positive relationship between depreciation and trading volume can be found even when asymmetric information and adverse selection are important features of the trading environment.

Inspection also reveals that equation (1) can be used to assess the effects of adverse selection on both estimated depreciation rates and the relationship between depreciation and trading volume evaluated at different values of the independent variables. These analyses help quantify the consequences of asymmetric information in used durable goods markets. For example, do durables with abnormally high levels of qualitative uncertainty or leasing frequencies depreciate more or less quickly than their more reliable counterparts? What are the quantitative effects of qualitative uncertainty and leasing frequency on durable good depreciation rates? Is the elasticity of depreciation with respect to trading volume greater for durables that exhibit above average reliability and leasing frequencies and, if so, by how much? Estimation of equation (1) provides not only a direct and fairly parsimonious vehicle for testing hypotheses regarding the informational structure of used goods trading environments, but also for quantifying the effects of adverse selection in durable goods markets.

III. Data Definitions and Descriptions

Business aircraft are used for a variety of purposes. Some aircraft are utilized to promote commercial objectives on a spontaneous, non-scheduled basis. Examples of such uses include the transport of personnel or materials to distant locations, the carriage of customers to plant or other commercial facilities, or the use of aircraft by sales or medical personnel to cover predetermined territories. Airplanes used for such purposes are deemed business aircraft and are regulated as such by relevant administrative bodies across various political jurisdictions. Most companies, corporations or individuals that operate business aircraft employ modern, multi-engine, turbine-powered jets or turboprops to conduct their business. Business aircraft are alleged to enhance the productivity of key corporate personnel.[3]

The National Business Aviation Association (NBAA) represents over 6,100 mostly U.S.-based member companies that own, operate or support over 8,200 aircraft used for business

[3] Andersen Consulting, *Business Aviation in Today's Economy: A Shareholder Value Perspective*, White Paper Series Number 4, Spring 2001. Lou Harris and Associates, *Survey of Companies Using Turbine-Powered General Aviation Aircraft for Business Transportation*, June 24, 1997. See Hersch and McDougall (1992) for an alternative, agency-theoretic view of the demand for business aircraft.

purposes.[4] More than half of these companies utilize a single aircraft in their flight operations and employ, on average, less than three aviation professionals on a full-time basis. Corporate Members, companies with flight departments and large professional aviation staffs operating a fleet of aircraft, constitute roughly twenty-five percent of the NBAA. NBAA members operate over 2,900 light and medium jets (i.e., jets weighing less than 30,000 pounds such as the Cessna Citation and Learjet series), 1,350 large jets (i.e., jets weighting more than 30,000 pounds such as the Gulfstream, Dassault, Falcon and Challenger series), and 1,800 turboprop aircraft (e.g., Beech King Airs). According to the Federal Aviation Administration (FAA), the 5,254 twin-engine turbojet aircraft in corporate or business use in the U.S. during 1999 logged over 1.3 million flight hours while the 2,817 twin-engine turboprop aircraft in corporate or business use in the U.S. logged more than 730,000 flight hours over this same period of time.

A. Business Aircraft Residual Value and Trading Volume

According to the General Aviation Manufacturers Association (GAMA), just under 1,000 new U.S. manufactured turbine business aircraft were sold in 2000 (315 turboprop and 588 jet aircraft). In addition, a significant number of used business aircraft change hands every year. For buyers wishing to compare and contrast the performance features of alternative new and used business aircraft, ARG/US, a research and analysis firm specializing in the business aircraft market, produces a product called CompAir, a data set containing nearly 170 pieces of information on more than 90 of the most popular jet and turboprop aircraft in today's business aviation market. Fields in the CompAir data set contain information on aircraft speeds, payloads, airworthiness directives, crew requirements, range, and operating and insurance costs. The CompAir data set also contains an extensive library of articles and images on aircraft and

[4] These descriptions come from *NBAA Business Aviation 2000 Fact Book*, National Business Aircraft Association, Washington, D.C.

aircraft appliances (e.g., radios, power carts, etc.). I use the CompAir data set as the basis of my sample construction exercise.

Prices in the business aircraft market are of obvious interest to buyers, sellers and brokers. The most reputable source for contemporaneous information on aircraft prices is the *Aircraft Bluebook Price Digest*. Published quarterly, the *Aircraft Bluebook Price Digest* provides information based primarily on dealer and broker surveys of the average retail price of a particular make, model and manufacture year of aircraft where average retail price is defined as the average transaction price "for a mid-time (average flight history), average aircraft (typically equipped) at the end of the previous quarter." The *Aircraft Bluebook Price Digest* also contains information on retail price trends, the high wholesale price and loan values, and estimates of the costs and frequency of periodic maintenance and overhaul of particular brands and models of aircraft.[5] Importantly for my purposes the *Aircraft Bluebook Price Digest* also publishes information on the new price of average equipped aircraft of a particular brand. The publisher of the *Aircraft Bluebook Price Digest*, Intertec Books, compiles these data into an archive entitled the *2001 Historical Value Reference*. According to the preface of this archive, "[a]ll prices . . . are considered a representative average." The preface also contains the reminder that "[t]he Bluebook data were derived from many sources, have been edited and are believed to be correct." Nearly all of the data in the *2001 Historical Value Reference* are reported on an annual frequency and represent the average of the end-of-quarter prices for each year. In order to

[5] To be clear and with admitted abuse of terminology, "brand" refers to a particular make, model and manufacture year aircraft. "Model" refers to a given make and model aircraft. Different brand aircraft can have the same model designation; such aircraft would be produced in distinct years.

estimate equation (1) I construct the residual value variable by dividing the current average retail price for a given brand of aircraft by its new price. These data exist through the year 2000.

In order to calculate the volume of trade variables necessary to test the hypotheses of interest, both transaction and stock information are required for each brand of aircraft in my sample.[6] Transaction data were obtained from Aviation Data Service, Inc. (AvData), an aviation data and research company based in Wichita, KS. For each year over the period 1980-1999, the data identify the purchaser of every used business jet and turboprop in the U.S., Canada and Mexico (i.e., North America) as well as the aircraft brand, serial number and registration mark. AvData obtained these data by inspecting the registration information filed with the relevant regulatory agencies (e.g., in the U.S., the FAA). These data were aggregated to generate the raw number of transactions for each brand of aircraft over the period 1980-1999. Stock data were obtained from Intertec's *Aircraft Bluebook Price Digest*, *Spring 2000*. Among other things, the price digest reports aircraft serial numbers which, when aggregated appropriately, identify the total number of aircraft produced and sold by brand. This number is the divisor in my volume of trade calculation.

B. Leasing in the Business Aircraft Market

Leasing contracts in the business aircraft market are virtually identical to those observed in other capital equipment or durable goods markets. The lessee pays an initial amount and sequence of rental payments to the lessor and, at the end of the lease's term, has the option of taking ownership of the aircraft by tendering the pre-specified buy-out price. Leasers of business aircraft tend to be prominent financial institutions (e.g., U.S. Bankcorp., G.E. Capital, etc.).

[6] Naturally, the volume of trade variable is simply, for each year over the 1980-1999 period, the number of transactions divided by the number of aircraft of a given brand.

While there is some variation in the terms and conditions of aircraft leases, most tend to follow a standard format with initial lease periods in the four-to-six year range.

Table 2 reports some summary statistics of the model lease numbers and percentages for data in my sample. The lease number reports, for each model, the number of aircraft operated under a leasing contract in a given year. The model lease percentage is simply this number divided by model fleet size, the number of aircraft of a given model leased and registered in North America in a given year. Once again, I obtained these data from AvData. It is important to note that this variable aggregates lease and fleet size numbers across brands of aircraft produced in different years and, fittingly, captures the interdependence of aircraft brands for assessing the effects of airworthiness directive histories and leasing percentages. It is also useful to note that data on leasing frequencies are not available at the level of aircraft brand.

The average percentage of leased aircraft, by model, is slightly less than 13 percent over the 1980-1999 period. Jets are leased more frequently than turboprops. Figure 1 shows that the use of leasing contracts became more prominent over the sample period. The average model lease percentage at the beginning and end of the sample period is less than 4 and greater than 13 percent, respectively. As can be surmised by inspecting the maximum and minimum lease percentages in the figure, the standard deviation of model lease percentages more than doubles over the sample period (from 4.5 to 11.75 percent).

C. Measure of Qualitative Uncertainty

Quality is a complex and important feature of any business aircraft. Performance is one aspect of quality. Performance is often related to the size (e.g., useful payload or seating capacity), speed (e.g., climb and cruise) and range of an aircraft (e.g., maximum distance under various aircraft loadings and safety parameters). Another dimension of quality is expense.

Aircraft expenses are categorized as variable or operating (e.g., fuel, crew and consumable parts), fixed (e.g., hull and liability insurance and maintenance items such as software and manuals), periodic (e.g., inspection, engine overhaul, interior refurbishment, and aircraft modernization and upgrade), training (e.g., for crew and maintenance personal) and facilities costs (e.g., hangar and maintenance office expenses). And finally, safety is yet another, and perhaps the most important, aspect of aircraft quality. Safety is related to many factors and is sometimes measured, *ex post*, by the number of incidents or accidents involving a particular brand or model of aircraft.

Qualitative uncertainty is obviously important for a durable as complex as business aircraft. For example, aircraft that suffer frequent mechanical problems or whose performance is limited by weather or other physical factors have diminished utility and reliability. Questionable is the reliability of aircraft that often experiences unanticipated repairs or insurance charges. And aircraft with unfortunate accident histories are of evident unreliability.

One potential measure of qualitative uncertainty for a particular brand of used aircraft is its regulatory safety history. The use of aircraft for commercial purposes is one of the most heavily regulated activities in any modern economy. In the United States, for example, there are a set of regulations, Title 14 Code of Federal Regulations (14 CFR), as well as an administrative regulatory agency, the Federal Aviation Administration (FAA), dedicated to the establishment and promotion of the safety of civil (non-military) aviation. Toward this end, the FAA issues a set of rules called *airworthiness directives*.[7] The purpose of this regulatory process is to

[7] According to the *Airworthiness Directives Manual* (FAA-AIR-M-8040.1, U.S. Department of Transportation, Federal Aviation Administration, May 1994), "Airworthiness directives (AD's) are substantive regulations issued by the Federal Aviation Administration in accordance with part 39 of the Federal Aviation Regulations (14 CFR part 39). Airworthiness directives are issued when (1) an unsafe condition has been found to exist in particular aircraft, engine,

disseminate information about aircraft safety in a timely and useful fashion. To the extent that compliance with aircraft airworthiness directives entails significant costs or imposes limitations on aircraft use, an aircraft's airworthiness directives history can have implications for all three dimensions of aircraft performance. Appendix I contains an example of one such airworthiness directive.

Distinct brands of aircraft exhibit considerable variation in their respective regulatory safety histories. Table 2 reports some descriptive statistics of the cumulative number of airworthiness directives for brands of aircraft in my sample. The cumulative number of airworthiness directives for all brands of aircraft ranges from 0 to 42. The average and median cumulative numbers of airworthiness directive in the sample are 9.27 and 7, respectively. The average cumulative number of airworthiness directives for jet aircraft is slightly less than that of turboprop aircraft (7.80 versus 11.18). Roughly two-thirds of all aircraft in my sample exhibit a value of cumulative number airworthiness directives between 1 and 17.

Aircraft brands with substantial and complex airworthiness directives histories are subject to more qualitative uncertainty and present potential buyers with several unique challenges, such as more extensive and complicated pre-purchase and recurring inspections, issues regarding regulatory compliance, and questions pertaining to subsequent aircraft utility. Aircraft with substantial airworthiness directives histories often raise issues regarding aircraft quality and reliability. I will use the cumulative number of airworthiness directives as a proxy for aircraft qualitative uncertainty to estimate equation (1) in the analysis that follows.

---

propellers, or appliances installed on aircraft, and (2) that condition is likely to exist or develop in other aircraft, engines, propellers, or appliances of the same type design. Once an AD is issued, no person may operate a product to which the AD applies except in accordance with the requirements of that AD."

A narrow and simple count variable such as the cumulative number of airworthiness directives is, at best, a crude (inverse) proxy for aircraft reliability. Airworthiness directives can vary substantially in terms of the costs they impose on aircraft owners and the limitations they imply for aircraft use. Substantial concerns about an aircraft's reliability can be associated with the issuance of nominally minor and costless airworthiness directives. Indeed, one may even argue that airworthiness directives have the net effect of reducing uncertainty about aircraft quality by forcing current owners to undertake necessary repairs and corrective actions and by generating and publicizing information relevant for assessing aircraft utility.

There are several reasons to believe that the cumulative number of airworthiness directives may, indeed, serve as a suitable proxy for aircraft qualitative uncertainty. First, industry participants and experts in the market for used business aircraft acknowledge that the regulatory history of a particular aircraft is an important indicator of its potential quality uncertainty. For example, the preface to the *Residual Value Guide* (Intertec Books, 1997) contains the following statement.

> Many have found that used aircraft behave somewhat like securities traded on the stock market. A multitude of external factors influence change. For example, interest rates, airworthiness directives and government-induced incentives (or lack thereof) all weigh heavily on the aircraft market.

The regulatory safety history of an aircraft can affect values in a variety of ways and may proxy for more fundamental information about aircraft reliability.

Second, aircraft accidents are complex events. Any generalization based on a simple count of such accidents can be misleading. However, it is generally appreciated and easy to document that the cumulative number of airworthiness directives and the cumulative number of accidents associated with any aircraft brand are highly correlated.[8] Since it is reasonable to think of the accident generating process as following a Poisson distribution, it is also easy to see that brands of aircraft with substantial accident histories raise broader safety concerns and exhibit greater qualitative uncertainty.[9] If brands of aircraft prone to accidents are less reliable than other aircraft, than the cumulative number of airworthiness directives is, indeed, a viable proxy for qualitative uncertainty.

And third, Hendel and Lizzeri (1999) suggest an independent test of the *lemons* hypothesis and, implicitly in my framework, the ancillary assumption that the cumulative number of airworthiness directives proxies for qualitative uncertainty. Using their theoretical framework they show that the effect of adverse selection on the price of used durables is unambiguous; the price of used durables in the presence of adverse selection is lower than when there is no qualitative uncertainty (pp. 1104). Thus, if the cumulative number of airworthiness directives is an acceptable proxy for qualitative uncertainty and such uncertainty is a precursor to adverse selection in the business aircraft market, a negative and statistically significant relationship between the cumulative number of airworthiness directives and aircraft residual

[8] To support this claim, I gathered accident and incident data for all of the jet aircraft in my sample. These data come from the *Business Jet Aircraft Accident Summary: Aircraft Introduction Through* 2001compiled by Robert E. Breiling Associates, Inc., Boca Raton, FL. (Similar data exist for turboprop aircraft but formatting differences prevented easy comparisons.) The mean correlation coefficient between the cumulative number of airworthiness directives and the cumulative number of accidents across jets in the sample is .84. *A* simple regression of the cumulative number of airworthiness directives against the cumulative number of jet aircraft accidents adjusting for brand factors (i.e., including fixed effects) and correlated model errors (i.e., allowing for clustering effects on aircraft model) yields a positive and statistically significant coefficient (.20, p-value less than .01) and a R-squared statistic of .85, suggesting a positive correlation coefficient exceeding .90. This later method of computing a correlation coefficient adjusts for between-brand heterogeneity and for variation in the number of time-series observations available for different brands aircraft.

[9] Recall that the Poisson is a one-parameter distribution function in which the mean and variance are equal.

values should be evidenced. Indeed, I find such a relationship and report the results of this test in the tables that follow.

D. Control Variables and Data Summary

Several industry-level and macroeconomic variables are included as controls in the estimations presented below. At the industry level I include the number of new business aircraft delivered and estimated aircraft use for each year from 1980-1999. These data were obtained from General Aviation Manufacturers Association's (GAMA) Statistical Databook 2000. At the economy level I include standard measures of economic activity (i.e., gross domestic product and gross private domestic investment). Table 2 reports some descriptive statistics for these control variables.

The marriage of the data provided by ARG/US, Intertec, AvData, and the FAA resulted in an unbalanced panel with time-series data for 218 jet and 146 turboprop brand aircraft. The data begin in 1980 and end in 1999. Aircraft made after 1994 are excluded from the analysis owing to their paucity of time-series observations. Table 1 identifies the sample and some additional relevant information such as the number of time-series available for each model aircraft, the aircraft manufacturer, and the terminal CompAir new price of each aircraft model.

Table 2 contains some descriptive statistics of the residual value, age, and trading volume variables for aircraft brands in my sample. The residual value for observations in my sample ranges from 31 to 238 percent. On average, the residual value for jets is slightly higher than it is for turboprops (88.88 versus 72.21 percent) due somewhat to the older average age of turboprop aircraft. Two-thirds of all observations exhibit residual values between approximately 60 and 100 percent. The age of aircraft ranges from 0 (i.e., aircraft allegedly resold in their first year of life) to 41 years. The average age of jet aircraft is slightly less than that of turboprop aircraft

(9.10 versus 11.06 years). Roughly two-thirds of all aircraft in my sample are between 3 and 17 years of age. Trading volume ranges from 0 (no trade in a particular brand aircraft) to 600 percent.[10] On average, the trading volumes associated with jet and turboprop aircraft are roughly equal and slightly below 15 percent. Approximately 80% of all observations on aircraft trading volume are less than 40%. Table 2 also reports the number of distinct aircraft brands and time-series observations in the data set.

Figure 2 presents a visual summary of the data by aircraft age. Percentages and numbers are represented on the left and right vertical scales, respectively, while aircraft age runs along the horizontal dimension. Note that the volume of trade variable is exceptionally high (low) for used transactions involving relatively new (old) aircraft (i.e., those less (greater) than three (thirty) years of age). The leasing percentage is fairly constant in the data over the age of aircraft. Real and nominal residual values are also depicted in Figure 2, as is the number of observations for each age of aircraft.

IV. Empirical Analysis

This section presents estimations of the aircraft depreciation rate function. For all of the estimations I assume that the shift parameter $\log(A_t^{it})$ in the residual value function is a linear

[10] Less than one percent of the observations in the sample (38, to be precise) exhibit trading volumes greater than 100 percent. These observations typically occur in the first year of an aircraft's life and for brands and model years of aircraft with small production runs. Moreover, Intertec's *Aircraft Bluebook Price Digest*, *Spring 2000*, notes that "The listed serial numbers . . . are by model year when the manufacturer cooperates in giving them. Otherwise, they are approximated by calendar year as registered at the FAA." They further caution that "[t]he date of manufacture and model year should be determined by aircraft records." Thus, there may be some downward bias is the stock number for relatively new aircraft (i.e., aircraft manufactured in one year but not sold and registered with FAA until the following year) and, therefore, some upward bias in the volume of trade variable for aircraft in their first year of life.

function of economy-wide (gross domestic product and gross private domestic investment) and industry-specific (new aircraft shipments and total aircraft usage) variables. I also assume that this shift parameter may depend on both brand and model fleet sizes, aircraft type (i.e., jet versus turboprop) and brand fixed effects.[11] A deflator is added to account for changes in the relevant price level. Whenever relevant, variables used to estimate the depreciation rate (e.g., volume of trade, the cumulative number of airworthiness directives, and the number of lease-operated aircraft) are also added as controls. I also assume that the variance of the error term in the residual value function may differ for distinct brands and that the error terms may be correlated for particular models of aircraft. Thus, all of the estimations reported below employ a robust covariance approach that yields heteroskedastic-consistent standard errors and permits correlated (i.e., clustered) errors for given models of aircraft (White, 1980 and Moulton, 1986). Errors for different models of aircraft are assumed independent.

A. Single Equation Estimations of Aircraft Residual Value

Equations (3.1) through (3.5) in Table 3 are estimations of the aircraft depreciation rate function assuming that all of the independent variables in the residual value function are fixed and pre-determined. Equations (3.1) and (3.2) assume that only aircraft age is relevant for explaining variation in depreciation rates. These equations indicate that the estimated depreciation rate is slightly less that 40 percent and, rather than being constant, diminishes with aircraft age. New aircraft depreciate more quickly than their seasoned counterparts. The parameters on all of the control variables in the residual value function, which are not reported in the table, are different from zero at conventional levels of statistical significance (i.e., p-values

[11] Trading information may be more complete for aircraft with larger brand and model runs minimizing transaction costs and depreciation rates. Moreover, recall from above that the annual average usage rates differ for jet and turboprop aircraft.

less than .05) and these variables, brand fixed effects, and aircraft age explain nearly 75 percent of the variation in aircraft residual value (i.e., the adjusted R-squared in (3.2) is 0.7464).

Equation (3.3) adds brand fleet size, model fleet size and aircraft type variables as additional determinants of the depreciation rate function and control variables in the residual value function. Again, all of the controls are statistically significant (p-values less than .01 in this case) and a high portion of the variation in aircraft residual values is explained. Both brand and model fleet sizes have a small but significantly negative effect on estimated depreciation rates. All else equal, aircraft produced in larger numbers depreciate more slowly than their more sparsely produced alternatives. Aircraft type does not affect depreciation in this specification.

Equation (3.4) adds volume of trade as both a control variable in the residual value function and a determinant of the depreciation rate function. This specification assumes that neither qualitative uncertainty nor leasing frequency affect depreciation rates. Consistent with trade under complete information and the results contained in Porter and Sattler (1999), trading volume and depreciation rates are directly related in the market for business aircraft. The coefficient on the trading volume variable is positive and, statistically speaking, marginally different from zero (i.e., a p-value associated with a one-tailed test less than .10). Evaluated at the mean of the relevant variables (e.g., estimated depreciation rate and average trading volume), a one percent increase in trading volume is associated with approximately a .001 percent rise in the depreciation rate. Quantitatively, trading volume has a small direct impact on aircraft depreciation.

Equation (3.5) is the single-equation estimation for the most complete specification of the aircraft residual value and depreciation rate functions. The cumulative number of airworthiness directives, my measure of qualitative uncertainty, and the number of lease operated aircraft are added both as control variables in the residual value function and determinants of the depreciation rate in this estimation.[12] Moreover, squared terms and all possible interactions of the volume of trade, the cumulative number of airworthiness directives, and the number of lease operated aircraft variables are added to complete the quadratic specification of the depreciation rate function. Several findings emerge from this estimation. To begin, as can be seen in the bottom panel of Table 3, the addition of these variables increases the explanatory power of the regression and provides a better model of aircraft depreciation rates. Additionally, exclusion restrictions on the cumulative number of airworthiness directives, the number of lease operated aircraft, and both variables are rejected at conventional levels suggesting that, contrary to the complete information model, both variables are important for explaining variation in aircraft depreciation rates.[13]

More importantly, the estimated parameters reported in (3.5) provide direct support for the asymmetric model of trade in used durable goods and the proposition that leasing mitigates adverse selection. The parameter on the interaction between the volume of trade and cumulative number of airworthiness directives variables is statistically less than zero (p-value less than .01). All else equal, aircraft brands with higher levels of qualitative uncertainty (i.e., larger values of the cumulative number of airworthiness directives variables) exhibit an inverse relationship between trading volume and estimated depreciation. The parameter on the interaction between

[12] Notice that since both the brand and model fleet sizes are entered as control variables in the estimation of the depreciation rate function, the coefficients on the cumulative number of airworthiness directives and the number of lease operated aircraft measure the effects of qualitative uncertainty and leasing frequency conditional on brand and model fleet sizes.

[13] The exclusion restrictions test the hypotheses that the coefficients on variables composed of the cumulative number of airworthiness directives and the number of lease operated aircraft in the estimated aircraft depreciation rate function, both respectively and jointly, equal zero.

the volume of trade and the number of lease operated aircraft variables is statistically greater than zero (p-value less than .01). All else equal, aircraft models with higher leasing frequencies exhibit a direct relationship between trading volume and depreciation rates. Both of these findings are consistent with the notion that asymmetric information is a prominent feature and that leasing mitigates adverse selection in the used aircraft market. These findings are also inconsistent with complete information models that predict that measures of qualitative uncertainty and leasing frequency should not affect the relationship between trading volume and depreciation rates.

Panel A in Table 4 provides a quantitative assessment of the impact of qualitative uncertainty and leasing frequency on the estimated aircraft depreciation rate function. The parameter estimates reported in column (3.5) of Table 3 are used to calculate estimated depreciation rates and elasticities of depreciation with respect to trading volume at the mean and at intervals of one standard deviation above and below the mean of the key independent variables. For low values of qualitative uncertainty and high leasing frequency (i.e., entries toward the northeast corner of each panel), estimated trading patterns should more closely reflect the predictions of complete information models. For high values of qualitative uncertainty and low leasing frequencies (i.e., entries toward the southwest corner of each panel), estimated trading patterns should reflect the predictions of asymmetric information models. The purpose for presenting results in this manner is to further ascertain if used aircraft trading patterns reflect the predictions of both the complete and asymmetric information models.

To begin, the first row of each entry in Panel A of Table 4 reports the estimated depreciation rates. Notice that rates tend to rise with decreases in both qualitative uncertainty and leasing frequency. The difference between the highest and lowest reported rates in Panel A is approximately 2.12 percent. To illustrate the magnitude of these differences, after five years the used prices for aircraft with such differences in estimated depreciation rates would differ by more than eleven percent.

To continue, the second row of each entry in Panel A reports the elasticity of the estimated depreciation rate with respect to trading volume. The number in parenthesis below this computation is the F-statistic associated with null hypothesis that the derivative of the estimated depreciation rate with respect to trading volume equals zero.[14] When qualitative uncertainty is low (i.e., one standard deviation below the mean in the sample) and leasing frequency is high (i.e., one standard deviation above the mean), the elasticity of the estimated depreciation rate with respect to trading volume is positive (0.0115) and statistically distinct from zero (p-value less than .05) as predicted by complete information models. On the other hand, when qualitative uncertainty is high (i.e., one standard deviation above the mean in the sample) and leasing frequency is low (i.e., one standard deviation below the mean), the elasticity of the estimated depreciation rate with respect to trading volume is negative (-0.0045) and statistically distinct from zero (p-value less than .10) as predicted by asymmetric information models. Consistent with the results presented in (3.4) this key elasticity is positive (0.0035) and statistically significant (p-value less than .05) when evaluated at the mean of the independent variables in the sample.

Both the estimated parameters of equation (3.5) in Table 3 and the computations and statistical tests reported in Panel A of Table 4 provide strong support for the importance of

[14] As always, this elasticity is simply the derivative of the estimated depreciation rate with respect to trading volume times mean trading volume divided by the estimated depreciation rate. Note that both the estimated derivative and depreciation rate are functions of the qualitative uncertainty and leasing frequency variables.

asymmetric information in understanding patterns of trade in the used business aircraft market. Qualitative uncertainty and leasing frequency are important determinants of the estimated aircraft depreciation rate function. Comparing equation (3.4) with the elasticity computations reported in Panel A illustrates that pooling aircraft with varying degrees of qualitative uncertainty and leasing frequency can lead to unwarranted conclusions about the presence or relevance of adverse selection.

B. Instrumental Variables Estimations of Aircraft Residual Value

In rigorous models of trade in used durable goods, price declines (i.e., embedded depreciation rates) and trading volumes are jointly determined by, among other things, the distribution of buyer tastes, rates of durable good quality deterioration, and realizations of used durable good quality. These models suggest that measures of trading volume are neither fixed nor pre-determined, but rather endogenous. As such, single equation estimations presented above may produce asymptotically biased estimates and potentially dubious conclusions regarding the relationship between depreciation and trading volume. In this section of the paper I perform instrumental variables (IV) estimations to better evaluate the structural relationship between depreciation and trading volume.

I use two variables as instruments for trading volume in estimations of the aircraft residual value function; aggregate pre-tax corporate profits and median cash compensation for executives among U.S. corporations over the 1980-1999 period. Both of these instruments reflect, at least in part, the value marginal product of executives and other senior personnel and, therefore, should affect the level of activity in the used business aircraft market and not aircraft depreciation. The corporate profits instrument is adjusted for inventory valuation and capital consumption and is taken from the Department of Commerce's Bureau of Economic Analysis.

The executive compensation instrument excludes options and other contingent payments and is taken from and described more fully by Murphy (1999). Together, these instruments should explain some of the exogenous variation in my volume of trade variable and provide consistent estimates of the relationship between aircraft depreciation and trading volume.[15]

Equation (5.1) in Table 5 is an IV estimation where the predicted volume of trade is added as both a control variable and a determinant of the depreciation rate in the residual value function. As is the case in (3.4), this specification assumes that neither qualitative uncertainty nor leasing frequency affect depreciation rates. The parameter values on all of the variables in the residual value function are very similar across both equations. Unlike the results presented in (3.4), however, and inconsistent with the complete information model, trading volume and depreciation rates are not even marginally statistically related in (5.1). Accounting for the endogeniety of trading volume eliminates the direct relationship between depreciation and trading volume found at the mean of the data and reported in (3.4).

Equation (5.2) in Table 5 is the IV estimation for the most complete specification of the aircraft depreciation rate function. As before, the cumulative number of airworthiness directives and lease percentage are added as control variables in the residual value function and, in a quadratic form, as determinants of the aircraft depreciation rate function. Again, the addition of these variables increases the explanatory power of the regression and provides a better model of aircraft depreciation rates. Exclusion restrictions of the cumulative number of airworthiness

[15] Valid exclusion from the residual value function is one requirement of a proper instrument in this setting. Such exclusion is invalid if other variables that affect both aircraft residual value and trading volume are omitted from the residual value function. For example, increases in aggregate economic activity might reasonably be expected to increase overall asset values and the flow of new aircraft into the market. Adding measures of aggregate economic activity, total aircraft usage, and new aircraft shipments control for such factors and strengthen the plausibility of my instruments.

directives, the number of lease operated aircraft, and both variables in the estimated aircraft depreciation rate function are easily rejected (p-values less than .01). These variables are clearly important for understanding depreciation rates even after accounting for the endogeniety of aircraft trading volumes.

The estimated parameters reported in (5.2) provide additional and more compelling support for the importance of asymmetric information and the proposition that leasing mitigates adverse selection in the used aircraft market. The parameter on the interaction between the volume of trade and cumulative number of airworthiness directives variables is statistically less than zero (p-value less than .01) and over three times larger than the same estimate in (3.5). The parameter on the interaction between the volume of trade and lease percentage variables is statistically greater than zero (p-value less than .01) and over three times larger than the same estimated parameter in (3.5). Accounting for the endogeniety of trading volume enhances the importance of measures of qualitative uncertainty and leasing frequency for explaining patterns of trade in the used business aircraft market.

Panel B in Table 4 replicates the exercise performed in Panel A using the IV estimation reported in (5.2). As indicated in the panel, estimated depreciation rates grow with increasing leasing frequency and decreasing qualitative uncertainty. The largest computed depreciation rate is over three and a quarter percent higher than the lowest calculated rate, a greater spread than the one exhibited in Panel A. To illustrate the magnitude of these differences, after five years the used prices for aircraft with such differences in estimated depreciation rates would differ by more than seventeen percent. Moreover, and consistent with the results show in (5.1), the elasticity of depreciation with respect to trading volume is positive (.0046) but indistinguishable from zero for aircraft exhibiting an average number of lease operated aircraft and cumulative number of airworthiness directives. Accounting for potential endogeniety eliminates the relationship between depreciation and trading volume evaluated at the mean of the data.

The numbers reported in Panel B do indicated, however, that for aircraft with a leasing frequency one standard deviation above and a cumulative number of airworthiness directives one standard deviation below the mean, the elasticity of deprecation with respect to trading volume is positive (0.0294) and statistically different from zero (p-value less than .05). This elasticity is over two and an half times larger than the one computed under the assumption that trading volume is exogenous. For aircraft with a leasing frequency one standard deviation below and a cumulative number of airworthiness directives one standard deviation above the mean, the elasticity is negative (-0.0222), statistically significant (p-value less than .05), and nearly five times greater than the comparable figure calculated presuming fixed trading volume. Comparing the two panels in Table 4 illustrate that accounting for the endogeniety of aircraft trading volumes yields additional and more compelling quantitative support for the asymmetric information model and the idea that leasing mitigates adverse selection.

Figure 3 is a visual depiction of the effects of qualitative uncertainty and leasing frequency on the relationship between the estimated aircraft depreciation rate and the volume of trade. The relationships in this figure are based on the IV estimations reported in equation (5.2). The consequences of qualitative uncertainty and leasing frequency are evident in the figure. For low values of qualitative uncertainty and high lease frequency, the relationship between depreciation and trading volume is statistically positive. For high values of qualitative uncertainty and low lease frequency, the relationship between depreciation and trading volume is statistically less than zero. Figure 3 also illustrates both of the main findings of my analysis. Asymmetric information is an important determinant of trade and leasing mitigates adverse selection in the used business aircraft market. Figure 3 further reveals the quantitative importance of qualitative uncertainty and leasing frequency to aircraft depreciation rates.

C. Consistency and Included Instruments

Columns (5.3) and (5.4) in Table 5 are IV estimations based on using only executive compensation and corporate profits, respectively, as an instrument to account for the endogeniety of volume of trade. These estimations are conducted to assess the relative validity of the alternative instruments for aircraft trading volume. Comparison of these two columns with (5.2) illustrates the overall similarity of the key estimated parameters with respect to the use of both or either instruments. The parameters on the interaction of volume of trade with cumulative airworthiness directives and volume of trade with the number of lease-operated aircraft are virtually identical across all three equations. At first glance it would appear as if my main findings are unaffected by inclusion of subsets of the available instruments.

However, the null hypotheses that both instruments are equally valid and that the key parameters in the depreciation rate function are consistently estimated are rejected for three of the four parameters of interest. Using the results reported in (5.2)-(5.4), I perform Hausman (1978) tests on the consistency of the two parameters on the key interaction terms. These tests are based on the assumption that the differences in parameters across estimations using both versus alternative instruments for trading volume are distributed normally with mean zero and variance equal to the difference in variances of the estimated parameters.[16] While the parameter estimates across all three equations are remarkably identical, so too are the estimated standard errors resulting in rejection of the null hypothesis.

[16] The relevant variances are taken from estimations that do not employ either robust or clustered standard errors.

Panels A and B in Table 6 mimic those of Table 4 and report the estimated depreciation rates and elasticities of depreciation with respect to trading volume based on equations (5.3) and (5.4), respectively. The purpose for these panels is to gauge the economic or substantive importance of the statistically inconsistently estimated parameters of the key interaction terms in the depreciation rate function. Comparisons of Panels A and B in Table 6 to Panel B in Table 4 illustrates the overall similarity of the results. Importantly, both confirm that the elasticity of depreciation with respect to trading volume is positive (negative) for aircraft with low (high) qualitative uncertainty and high (low) leasing frequency. I conclude that my main findings are unaffected by inclusion of only subsets of the instrumental variables.

D. Effects of Aircraft Age

Table 7 reports IV estimations of the depreciation rate function for various subsets of the data. The first of these subsets truncates the data by aircraft age. Recall that, owing to the determination of model year reported in Intertec's *Aircraft Bluebook Price Digest*, transactions of relatively young aircraft may in fact represent new rather than used sales. An estimation excluding transactions involving relative young aircraft should expose any bias caused by this classification error. Moreover, recall that previous authors found more evidence for adverse selection among older durables (Bond, 1984). An estimation excluding transactions involving older aircraft should reveal the importance of age to my findings.

Equation (7.1) is an IV estimation based on a subset of the data that excludes aircraft less than five years in age. Comparing the parameter estimates reported in this equation to (5.2), the benchmark estimates based on all of the data, illustrates several important facts. The bulk of the parameter estimates are remarkably stable across both equations. Brand and model fleet sizes reduce depreciation rates and jet aircraft depreciate more slowly. However, the consequences of age on aircraft depreciation are insignificant when younger aircraft are excluded from the estimation. This is consistent with the existence of a substantial new aircraft premium and the concern that some of the early transactions in my panel are for new aircraft that are heavily discounted from list price to find an initial owner. More importantly, the parameters of interest for evaluating the alternative hypotheses are consistent in magnitude with those reported in (5.2) and statistically significant. The parameters on the interaction of the predicted volume of trade and cumulative number of airworthiness directives variable are stable and significantly less than zero. The parameters on the interaction of the predicted volume of trade and leasing frequency variable are stable and significantly greater than zero. And tests of the exclusions restrictions illustrate that both the cumulative number of airworthiness directives and leasing frequency variables are important for understanding variation in aircraft depreciation. The familiar patterns heretofore reported hold even when over one quarter of the data containing the youngest aircraft are excluded from the estimation. The potential improper classification of transactions early in an aircraft's life has no affect on my chief findings.

Equation (7.2) is an IV estimation that excludes aircraft greater than twenty years old. As before, when compared to the benchmark estimation (5.2) it can be seen that most of the qualitative conclusions heretofore reported hold even when older aircraft are excluded. Excluding older aircraft increases the sensitivity and precision of the estimated depreciation rate to aircraft age confirming the conclusion that declines in depreciates rates with age occur mostly for younger aircraft in the sample. Again, brand and model fleet sizes reduce estimated depreciation rates and jet depreciation less quickly. The parameters important for evaluating the alternative hypotheses are consistent in sign with those reported in (5.2) and statistically significant. Interestingly, estimations of the depreciate rate function that exclude nearly ten percent of the observations involving aircraft older than twenty years of age reveal that the parameters on the relevant interactions terms are smaller in magnitude - roughly half - than those estimated using all of the data. These findings are consistent with the idea that the predicted consequences of qualitative uncertainty and leasing frequency are evident even among relatively younger aircraft (i.e., those less than twenty years of age) and become quantitatively more important when older aircraft are added to the estimations. Tests of the exclusions restrictions or the significance of relevant parameters illustrate that both the cumulative number of airworthiness directives and lease percentage variables are important for understanding variation in aircraft depreciation.

Panel A in Table 8, again, mimics the exercises conducted in Tables 4 and 6 using these estimates reported in (7.2). Inspection of these results confirms the interpretation that the basic patterns heretofore reported can be found even when older aircraft are excluded from the estimation. These results also show that the sensitivity of estimated depreciation rates to trading volume is diminished when older aircraft are excluded. Like Bond (1984), these results suggest that the consequences of asymmetric information and adverse selection are particularly evident in populations of seasoned durable goods.

E. Exclusion of Extreme Trading Volume Observations

Equation (7.3) in Table 7 is an IV estimation of the aircraft depreciation rate function for a subset of the data that excludes observations with trading volumes more than one standard deviation from the sample mean (i.e., roughly thirty eight percent). Recall that some of the observations in the data exhibit abnormally large values for the volume of trade variable (e.g., in excess of one hundred percent) that may depend, among other things, on inaccurate calculations of the stock of a particular brand of aircraft. Again, the results are very similar to those obtained from the benchmark case. Aircraft brands with high qualitative uncertainty exhibit an inverse relationship between trading volume and depreciation. Aircraft models with high lease frequencies exhibit a direct relationship between depreciation and trading volume. And both the cumulative number of airworthiness directives and leasing rates are important for explaining variation in estimated depreciation rates. The results are robust with respect to the exclusion of over six percent of the observations with the largest trading volumes in the sample.

F. Endogeniety of Lease Operated Aircraft

Equation (7.4) is an IV estimation of equation (1) in which the number of lease operated aircraft is replaced by an estimated value based on supply and demand shifters (i.e., gross domestic product, gross private domestic investment, the total number of business aircraft shipped, and total business aircraft usage) and model fleet size. This estimation is designed to assess the robustness of my results with respect to the assumption that leasing frequency is a fixed and pre-determined variable. Inspection reveals that all of the key parameters remain largely the same and that the major conclusions remain unchanged. Panel B in Table 8 used the estimates reported in (7.4) to quantify the key values and relationships of interest. This panel shows that the main findings are unaffected even presuming the endogeniety of lease operated aircraft.

G. Proxy for Quality Variation

Tables 3, 5 and 7 all contain a row entitled "Effect of Qualitative Uncertainty on Aircraft Residual Value." This row reports the parameter (and t-statistic) value on the cumulative number of airworthiness directives when it is entered as a control variable in the aircraft residual value function. Recall that Hendel and Lizzeri (1999) show that asymmetric information about quality reduces the price of used durables. Aircraft residual values should be lower for aircraft with larger values of the cumulative numbers of airworthiness directives if this variable is a suitable proxy for qualitative uncertainty. Inspection of these three tables illustrates that my measure of qualitative uncertainty has a negative independent effect on aircraft residual values and is statistically significant for all but two cases; when trading volume is assumed fixed and pre-determined and when the number of lease operated aircraft is considered endogenous. In general, the evidence supports my proxy for qualitative uncertainty as well as the insight that the value of any potential proxy can be independently assessed by exploring its effect on the price of used durable goods.

V. Conclusions and Discussion

The empirical analysis contained in this paper focuses on the relationship between depreciation and trading volume for used business aircraft. Under complete information, this relationship should be direct and unaffected by brand qualitative uncertainty or model leasing frequencies. These later predictions are easily rejected in the data. Indeed, I find that less reliable brands exhibit an inverse while models with higher leasing frequencies have a direct relationship between depreciation and trading volume. Both of these correlations are consistent with the predictions of the alternative models of trade in used durable goods. The results of this paper strongly support the propositions that asymmetric information is an important factor and that leasing mitigates adverse selection in the market for used business aircraft.

How do my results fit within the extant empirical literature? Like Genesove (1993), Emons and Sheldon (2002) and Fabel and Lehman (2000), I find support for adverse selection independent of durable good age. Like Bond (1984), I find that the evidence is quantitatively stronger for older durables. Consistent with the evidence contained in Desai and Purohit (1998), I find that leasing mitigates adverse selection. However, my results are nominally inconsistent with those contained in Porter and Sattler (1999) who find a direct relationship between various measures of used automotive trading volume and depreciation. Upon closer inspection I conjecture that these seemingly disparate results may be reconcilable. Note that while Porter and Sattler (1999) do add measures of qualitative uncertainty as control variables in their estimations, they do not condition the trading volume and depreciation relationship on variation in these key measures. I too find a direct relationship between trading volume and depreciation when evaluated at the mean value of the independent variables, including quality variation, in the sample for single equation estimations. However, my paper differs from theirs in that I allow durable good depreciation rates to depend on the interactions of trading volume with potential measures of adverse selection, and it is only when evaluated for above average qualitative uncertainty and below average leasing frequency that I uncover a negative and statistically significant relationship between trading volume and depreciation. The comparison of my results to those contained in Porter and Sattler (1999) suggests that asymmetric information theories of trade in used durable goods provide predictions *conditional* on the presence of qualitative uncertainty or counter-acting institutions like leasing contracts. In markets where such uncertainty or institutions are likely to vary substantially across brand or models, any productive empirical design must condition on these key factors.

It is perhaps useful to point out that this paper contains a methodological contribution by developing a simple framework for detecting adverse selection in trading patterns of used durable goods. This framework involves exploring how the estimated relationship between used durable good depreciation rates and trading intensities depend on measures of durable good qualitative uncertainty and leasing frequencies. I offer various ways to verify the validity of proxies for reliability, including correlations between the proxies and obvious external qualitative measures (e.g., accident rates) and the impact of the proxies on used durable good prices. This framework suggests that, given a suitable candidate measure of qualitative uncertainty, adverse selection is easily detectable in the trading patterns of used durable goods.

Other, more recent research may provide additional methods for testing alternative theories of trade in used durable goods. For example, Stolyarov (2002) examines a complete information framework with positive transaction costs to explore patterns of durable good resale over time. His model yields a "double-hump" pattern, equilibria in which the probability of resale peaks twice in a durable good's life, which he argues is consistent with much of the observed variation in U.S. automotive markets. Emons and Sheldon (2002), on the other hand, examine Swiss automotive markets and find that the probability of resale falls considerably with the length of ownership independent of automobile age. They argue that this pattern is consistent with the idea that buyers of high quality used durables retain ownership while buyers of low quality durables resale them immediately and draw again from the potential replacement pool. It might be interesting to amend Stolyarov's (2002) model for period-by-period qualitative uncertainty, compute the equilibrium inter-temporal trading given this adjustment, and test the implications of such a model in a market where adverse selection is known to affect important trading patterns.

In conclusion, the market for used business aircraft is vibrant, institutionally rich and characterized by adverse selection. The evidence from this market suggests that active trading in used durable goods, substantial counteracting institutions such as leasing, and measurable adverse selection can coexist in ways consistent with the recent theoretical analyses of Hendel and Lizzeri (1999, 2002), Waldman (1999), and Johnson and Waldman (2001). While much of the extant empirical literature is a search for supporting evidence, it may be better to think of adverse selection as a force that defines the qualitative contours or boundaries of a market rather than as an impediment to market trade or efficiency. Rather than inquiring about the existence of adverse selection in markets plagued by obvious qualitative uncertainty, perhaps it is time now to focus on questions regarding the size, growth, efficiency and evolution of counteraction institutions in such markets.

References

Akerlof, George A. "The Market for Lemons: Qualitative Uncertainty and the Market Mechanism." *Quarterly Journal of Economics*, August 1970, 84(3), pp. 488-500.

Bond, Eric W. "Test of the Lemons Model: Reply." *American Economic Review*, September 1984, 74(5), pp. 801-04.

Desai, Preyas and Purohit, Devavrat. "Leasing and Selling: Optimal Marketing Strategies for a Durable Good Firm," *Management Sciences,* November 1998, 44(11), pp. S19-S34.

Emons, Winand and Sheldon, George. "The Market for Used Cars: A New Test of the Lemons Model." Manuscript, University of Bern, April 2002.

Fabel, Oliver and Lehmann, Erik E. "Adverse Selection and the Economic Limits of Market Substitution: An Application to E-Commerce and Traditional Trade in Used Cars." Manuscript, University of Konstanz, February 23, 2000.

Genesove, David. "Adverse Selection in the Wholesale Used Car Market." *Journal of Political Economy*, August 1993, 101(4), pp. 644-65.

Hausman, Jerry A. "Specification Tests in Econometrics." *Econometrica,* 46(6), pp. 1251-70.

Hendel, Igal and Lizzeri, Alessandro. "Adverse Selection in Durable Goods Markets." *American Economic Review*, December 1999, 89(5), pp. 1097-1115.

____________________________________. "The Role of Leasing Under Adverse Selection." *Journal of Political Economy,* February 2002(110), pp.113-143.

Hersch, Philip L. and McDougall, Gerald S. "Separation of Ownership from Control and the Demand for Corporate Aircraft." *Journal of Economics and Business,* June 1992, 44(3), pp. 223-236.

Johnson, Justin P. and Waldman, Michael. "Leasing, Lemons, and Buy-Backs." Manuscript, Cornell University, June, 2001.

Moulton. B.R., "Random Group Effects and the Precision of Regression Estimates." *Journal of Econometrics*, 1986, 32(3), pp. 385-397.

Murphy, Kevin J. "Executive Compensation," in O. Ashenfelter and D. Card, ed., *Handbook of Labor Economics*, Vol. 3. Elsevier Science B.V., 1999, pp. 2485-2563.

Porter, Robert H. and Sattler, Peter. "Patterns of Trade in the Market for Used Durables: Theory and Evidence." NBER Working Paper No. 7149, May 1999.

Rust, John. "Stationary Equilibrium in a Market for Durable Assets." *Econometrica*, July 1985, 53(4), pp. 783-805.

Stolyarov, Dmitriy. "Turnover of Used Durables in a Stationary Equilibrium: Are Older Goods Traded More?" *Journal of Political Economy*, December 2002, 110(6), pp. 1390-1413.

Waldman, Michael. "Leasing, Lemons, and Moral Hazard." Manuscript, Cornell University, August, 1999.anuscript. Ithaca, N.Y.: Cornell University, December 2001.

________________. "Durable-Goods Theory for the Real-World." *Journal of Economic Perspectives*, Winter 2003, 17(1), pp. 131-154.

White, Halbert. "A Heteroskedasticity-Consistent Covariance Matrix and a Direct Test for Heteroskedasticity," *Econometrica* 1980, 48(5), pp. 817-838.

Aircraft Bluebook Price Digest, Various Volumes. Overland Park, KS: Intertec Publishing.

Airworthiness Directives Manual. FAA-AIR-M-8040.1. U.S. Department of Transportation, Federal Aviation Administration, May 1994.

Business Aviation in Today's Economy. Andersen Consulting White Paper Series Number 4, Spring, 2001.

CompAir: The Ultimate Aircraft Evaluation Tool. Cincinnati, OH: Aviation Research Group/U.S., Inc., 2000.

NBAA Business Aviation 2000 Fact Book. National Business Aircraft Association, Washington, D.C.

Survey of Companies Using Turbine-Powered General Aviation Aircraft for Business Transportation. New York: Louis Harris and Associates, Inc. June 24, 1997.

Residual Value Guide. Overland Park, KS: Intertec Publishing, 1997.

Appendix I

Example of an Airworthiness Directive

88-06-02 CESSNA: Amendment 39-5900. Applicable to Model 550 series airplanes, serial numbers (S/N) 550-0561, -0562, -0564, -0565, -0566, -0568, and -0569; and Model S550 series airplanes, S/N S550-0140 through -0146, -0148, and -0149; certificated in any category.

Compliance is required as indicated, unless previously accomplished.

To preclude wiring failure, which could result in smoke and/or fire in the cabin, accomplish the following:

A. For Cessna Model 550 series airplanes: Prior to next activation of the airplane's electrical power, disconnect the electrical power to the indirect lighting system, in accordance with Cessna Alert Service Letter SLA550-33-02, dated March 14, 1988. Electrical power may be reconnected to the indirect lighting system following replacement of the affected wiring harness described in, and in accordance with, Cessna Service Bulletin SB550-33-9, dated March 17, 1988, or later FAA-approved revisions.

B. For Cessna Model S550 series airplanes: Prior to next activation of the airplane's electrical power, disconnect the electrical power to the indirect lighting system, in accordance with Cessna Alert Service Letter SLAS550-33-01, dated March 14, 1988. Electrical power may be reconnected to the indirect lighting system following replacement of the affected wiring harness described in, and in accordance with, Cessna Service Bulletin, SBS550-33-5, dated March 17, 1988, or later FAA-approved revisions.

C. An alternate means of compliance which provides an acceptable level of safety may be used when approved by the Manager, Wichita Aircraft Certification Office, FAA, Central Region.

All persons affected by this directive who have not already received the appropriate service documents from the manufacturer, may obtain copies upon request to Cessna Aircraft Company, P.O. Box 7706, Wichita, Kansas 67277.

These documents may be examined at the FAA, Northwest Mountain Region, 17900 Pacific Highway South, Seattle, Washington, or the FAA, Central Region, Wichita Aircraft Certification Office, 1801 Airport Road, Room 100, Mid-Continent Airport, Wichita, Kansas.

This amendment 39-5900 becomes effective May 10, 1988.

It was effective earlier to all recipients of Priority Letter AD 88-06-02, issued March 16, 1988.

Figure 1:
Lease Rates by Year for
Aircraft Models in the Sample

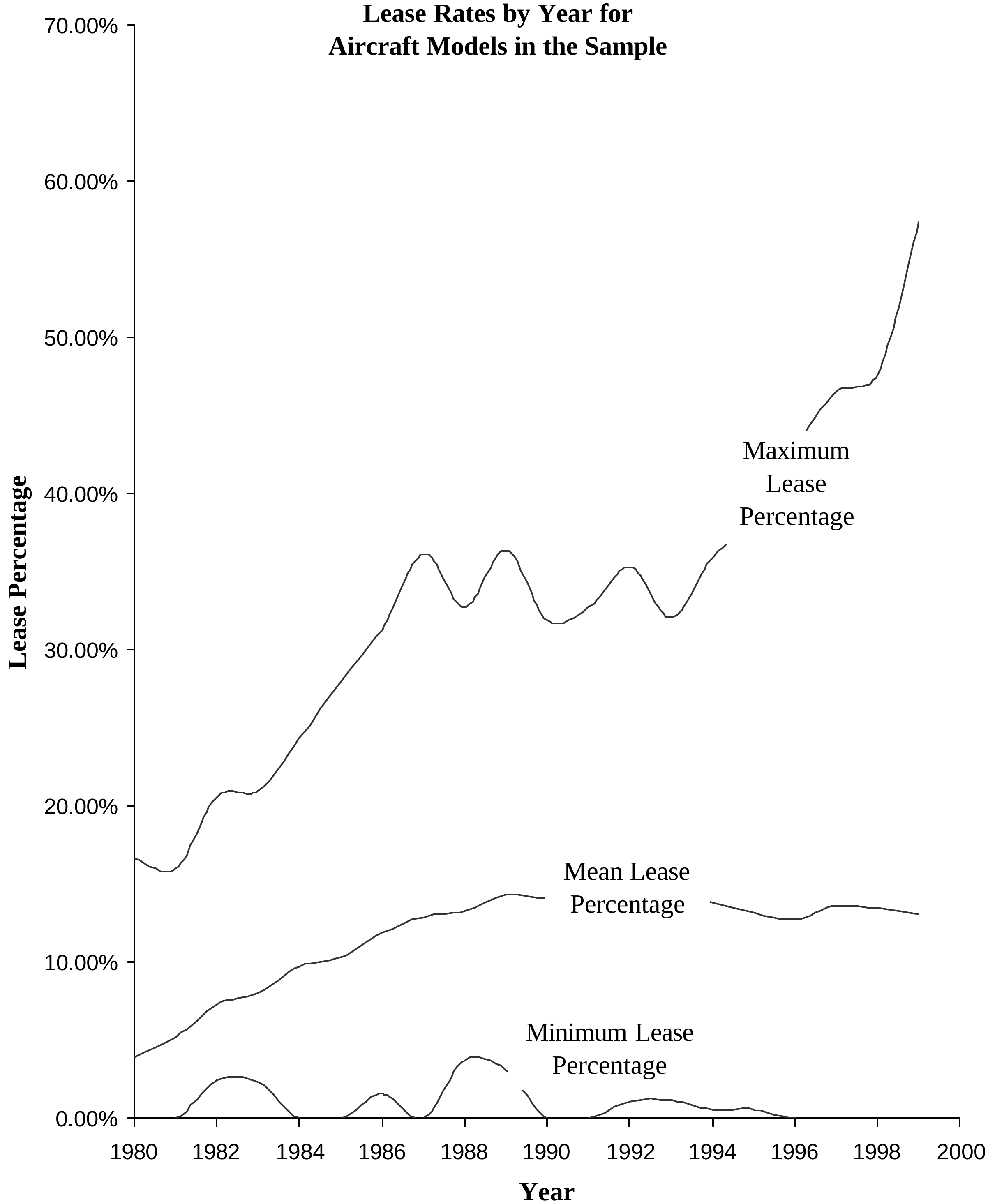

Figure 2:
Data Characteristics by Aircraft Age

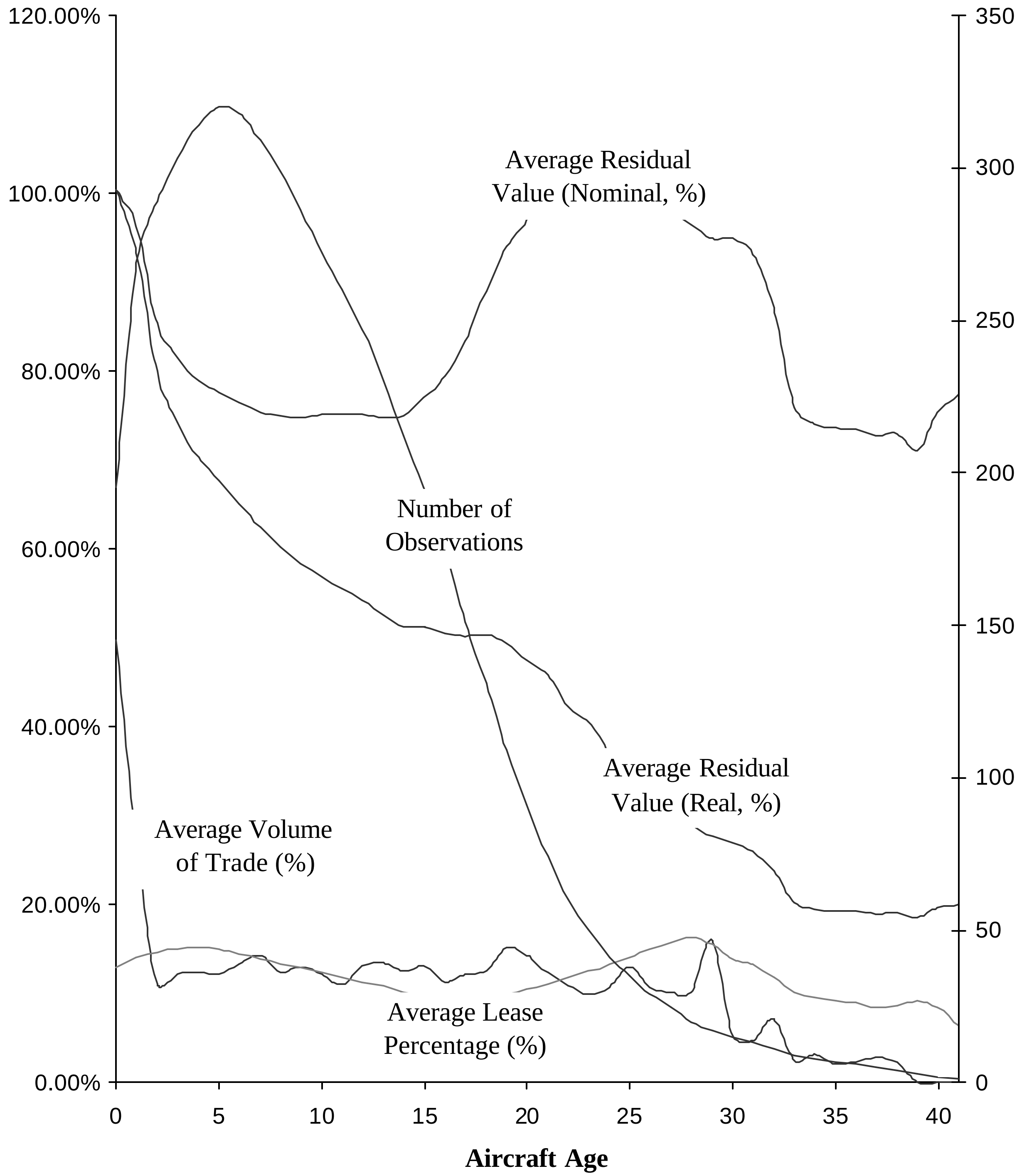

Figure 3:
Relationship Between Depreciation Rate and Volume of Trade
(Based on IV Estimation (5.2))

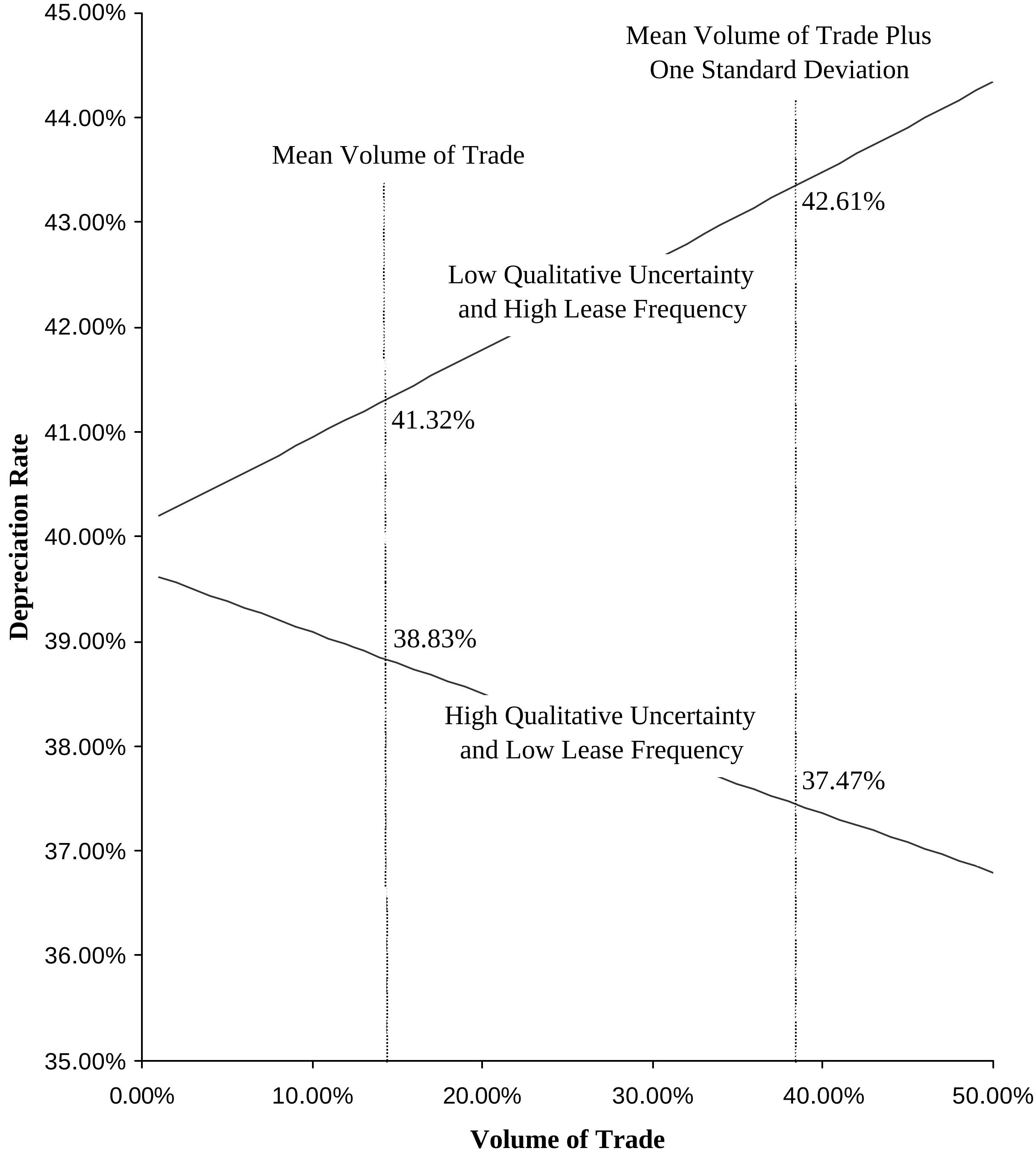

Table 1
Sample of Aircraft*

MODEL	MANUFACTURER	CATEGORY	MODEL YEARS	# MADE	NEW PRICE
Astra SP, IA-1125	Israel Aircraft (ISR)	Large Jet	1990 – 1992 (3)	36	$9,800,000
Beechjet, BE-400A	Raytheon (US)	Small Jet	1990 – 1994 (5)	212	$6,332,840
Challenger 600, CL-600	Bombardier (CN)	Large Jet	1981 – 1983 (3)	85	$8,400,000
Challenger 601, CL-601-1A	Bombardier (CN)	Large Jet	1983 –1987 (5)	66	$13,500,000
Challenger 601, CL-601-3A	Bombardier (CN)	Large Jet	1987 – 1993 (7)	134	$17,600,000
Challenger 601, CL-601-3R	Bombardier (CN)	Large Jet	1993 – 1994 (2)	59	$18,800,000
Cheyenne 400LS, PA-42-1000	Piper (US)	Small Turboprop	1983 – 1991 (6)	44	$1,780,000
Cheyenne I , PA-31T-500 I	Piper (US)	Small Turboprop	1978 – 1985 (8)	153	$630,000
Cheyenne II, PA-31T-620 II	Piper (US)	Small Turboprop	1974 – 1983 (10)	539	$657,308
Cheyenne IIIA, PA-42-720	Piper (US)	Small Turboprop	1980 – 1990 (9)	60	$1,545,000
Citation I, CE-500	Cessna (US)	Small Jet	1972 – 1983 (12)	689	$1,740,000
Citation II, CE 550	Cessna (US)	Small Jet	1978 – 1993 (14)	729	$3,700,000
Citation II SP, CE-551	Cessna (US)	Small Jet	1978 – 1988 (9)	94	$2,990,000
Citation S/II, CE-S550	Cessna (US)	Small Jet	1984 – 1988 (5)	159	$3,450,000
Citation III, CE-650	Cessna (US)	Large Jet	1983 – 1991 (9)	202	$6,900,000
Citation V, CE-560	Cessna (US)	Small Jet	1989 – 1994 (5)	262	$4,850,000
Citation VI, CE-650	Cessna (US)	Large Jet	1991 – 1993 (3)	24	$7,350,000
Citation VII, CE-650	Cessna (US)	Large Jet	1992 – 1994 (3)	114	$11,414,000
Citationjet, CE-525	Cessna (US)	Small Jet	1993 – 1994 (2)	359	$3,695,000
Conquest I, CE-425	Cessna (US)	Small Turboprop	1981 – 1986 (6)	236	$1,290,000
Conquest II, CE-441	Cessna (US)	Small Turboprop	1978- 1986 (9)	362	$1,725,000
Diamond IA, MU-300	Mitsubishi (JP)	Small Jet	1982 – 1983 (2)	93	$1,870,000
Falcon 100, DA-100	Dassault (FR)	Small Jet	1983 – 1989 (7)	43	$3,875,000
Falcon 20F, DA-20F	Dassault (FR)	Large Jet	1970 – 1983 (14)	230	$4,000,000
Falcon 50, DA-50	Dassault (FR)	Large Jet	1980 – 1994 (15)	252	$15,200,000
Falcon 900, DA-900	Dassault (FR)	Large Jet	1986 – 1991 (6)	103	$21,250,000
Falcon 900C, DA-900B	Dassault (FR)	Large Jet	1991 – 1994 (4)	68	$27,810,000
GI-C, G-159	Gulfstream (US)	Large Turboprop	1958 – 1969 (12)	200	$885,000
G-II, G-1159	Gulfstream (US)	Large Jet	1967 – 1979 (13)	256	$7,000,000
G-III, G-1159A	Gulfstream (US)	Large Jet	1979 – 1986 (8)	202	$13,500,000
G-IV, G-1159C	Gulfstream (US)	Large Jet	1986 – 1995 (10)	225	$23,900,000
HS 125-700	Hawker Siddeley (UK)	Large Jet	1977 – 1983 (7)	215	$4,900,000
HS 800A, BAe 125-800	Hawker Siddeley (UK)	Large Jet	1984 – 1994 (11)	243	$9,350,000
King Air 300, BE-300	Raytheon (US)	Large Turboprop	1984 – 1990 (7)	219	$2,450,000
King Air B100, BE-100	Raytheon (US)	Small Turboprop	1976 – 1983 (8)	135	$1,040,000
King Air B200, BE-200	Raytheon (US)	Small Turboprop	1974 – 1994 (21)	792	$4,285,370
King Air C90, BE-C90	Raytheon (US)	Small Turboprop	1971 – 1983 (13)	498	$940,000
King Air C90A, BE-C90A	Raytheon (US)	Small Turboprop	1984 – 1992 (9)	236	$1,420,000
King Air C90B, BE-C90B	Raytheon (US)	Small Turboprop	1992 – 1994 (3)	199	$2,810,170
King Air E90, BE-E90	Raytheon (US)	Small Turboprop	1972 – 1981 (10)	347	$930,000
King Air F90-1, BE-F90	Raytheon (US)	Small Turboprop	1979 – 1985 (7)	237	$1,495,000
Learjet 25, LR-25D	Gates Learjet (US)	Small Jet	1976 – 1984 (9)	161	$1,485,000
Learjet 35A, LR-35A	Gates Learjet (US)	Small Jet	1976 – 1992 (17)	635	$4,610,000
Learjet 55, LR-55	Gates Learjet (US)	Large Jet	1981 – 1986 (6)	119	$5,100,000
Solitaire, MU-2B-40	Mitsubishi (JP)	Small Turboprop	1979 – 1981 (3)	56	$855,000
Westwind II, IA-1124A	Israel Aircraft (ISR)	Large Jet	1982 – 1987 (6)	90	$2,700,000

***** The manufacturer's country is noted in parenthesis. Small and large jets are those with maximum gross weights below and above 20,000 pounds, respectively. Small and large turboprops are those with maximum gross weights below and above 12,500 pounds, respectively. The number in parenthesis in the **MODEL YEARS** column represents the number of time-series observations for a given model included in the sample. The amount in the **NEW PRICE** column represents the aircraft's list price, in current dollars, for the last year in which it was manufactured.

Table 2
Descriptive Statistics*

Variable Name	Mean	Maximum	Minimum	Standard Deviation	# of Observations
Panel Data					
Residual Value (%)	81.64	238.00	31.00	21.42	364/5410
Jet Aircraft Only	88.88	238.00	37.30	21.02	218/3062
Turboprop Aircraft Only	72.21	149.18	31.00	16.94	146/2348
Aircraft Age (Years)	9.95	41.00	0.00	7.08	364/5410
Jet Aircraft Only	9.10	32.00	0.00	6.32	218/3062
Turboprop Aircraft Only	11.08	41.00	0.00	7.82	146/2348
Brand Fleet Size	32.36	197.00	1.00	28.91	364/5410
Jet Aircraft Only	26.71	114.00	0.00	21.33	218/3062
Turboprop Aircraft Only	39.74	197.00	1.00	35.17	146/2348
Brand Yearly Transactions	4.31	114.00	0.00	5.94	364/5409
Jet Aircraft Only	3.46	62.00	0.00	5.18	218/3061
Turboprop Aircraft Only	5.43	114.00	0.00	6.63	146/2348
Model Fleet Size	184.04	489.00	0.00	116.46	364/5410
Jet Aircraft Only	163.30	456.00	4.00	109.63	218/3062
Turboprop Aircraft Only	211.21	489.00	0.00	119.51	146/2348
Cumulative Airworthiness Directives	9.27	42.00	0.00	7.70	364/5410
Jet Aircraft Only	7.80	42.00	0.00	7.16	218/3062
Turboprop Aircraft Only	11.20	31.00	0.00	7.95	146/2348
Model Lease Number	21.09	107.00	0.00	19.79	364/5407
Jet Aircraft Only	28.14	107.00	0.00	22.88	218/3062
Turboprop Aircraft Only	11.88	39.00	0.00	8.34	146/2345
Volume of Trade (%)	14.45	600.00	0.00	23.98	364.5409
Jet Aircraft Only	13.84	600.00	0.00	24.25	218/3061
Turboprop Aircraft Only	15.25	500.00	0.00	23.60	146/2348
Model Lease Percentage (%)	12.77	57.35	0.00	9.00	364/5400
Jet Aircraft Only	17.66	57.35	0.00	8.32	218/3062
Turboprop Aircraft Only	6.36	36.36	0.00	4.91	146/2338
Time Series Data					
Gross Domestic Product (Billions of dollars)	5702.33	9268.6	2795.6	1917.44	20
Gross Private Domestic Investment (Billions of dollars)	890.82	1578.20	484.20	302.57	20
Corporate Profits (Billions of dollars; adjusted for inventory valuation and capital consumption)	458.56	833.80	197.70	206.02	20
Murphy's Median Cash Executive Compensation (Thousands of dollars)	935.28	1640.43	431.50	334.61	20
U.S. Manufactured Aircraft Shipments (Number of units)	556.00	1307.00	348.00	244.28	20
Estimated Aircraft Use by Type (1,000s of hours flown)	3486.80	4549.00	2313.00	615.89	20

* The column entitled "# of Observations" reports the number of distinct aircraft (i.e., aircraft of a unique brand and manufacturer year) and time-series observations in the sample, respectively.

Table 3
Single Equation Estimations of the Aircraft Depreciate Rate Function*

Independent Variables	**(3.1)**	**(3.2)**	**(3.3)**	**(3.4)**	**(3.5)**
Constant	0.3963 (7.63)	0.3775 (7.29)	0.4290 (8.81)	0.4259 (8.46)	0.4297 (9.04)
Aircraft Age	-	-0.0011 (2.39)	-0.0011 (2.85)	-0.0011 (2.74)	-0.0009 (3.56)
Model Fleet Size	-	-	$-4.900*10^{-5}$ (2.63)	$-4.880*10^{-5}$ (2.63)	$-9.080*10^{-5}$ (5.71)
Brand Fleet Size	-	-	$-1.673*10^{-4}$ (3.36)	$-1.641*10^{-4}$ (3.36)	$-1.287*10^{-4}$ (4.78)
Aircraft Type (Jet=1)	-	-	-0.0034 (0.74)	-0.0032 (0.70)	-0.0106 (2.21)
Volume of Trade	-	-	-	0.0037 (1.50)	0.0083 (1.89)
Cumulative Number of Airworthiness Directives	-	-	-	-	-0.0005 (0.72)
Number of Aircraft Operated Under Leasing Contract	-	-	-	-	0.0004 (1.41)
Squared Volume of Trade	-	-	-	-	0.0004 (0.71)
Squared Airworthiness Directives	-	-	-	-	$6.210*10^{-6}$ (0.36)
Squared Leased Aircraft	-	-	-	-	$-1.140*10^{-6}$ (0.54)
Interaction of Volume of Trade and Cumulative Airworthiness Directives	-	-	-	-	-0.0012 (2.23)
Interaction of Volume of Trade and Number of Lease Operated Aircraft	-	-	-	-	0.0006 (2.17)
Interaction of Airworthiness Directives and Leased Operated Aircraft	-	-	-	-	$7.680*10^{-6}$ (0.65)
Effect of Qualitative Uncertainty on Aircraft Residual Value	-	-	-	-	-0.0098 (1.50)
Number of Observations	364/5410	364/5410	364/5410	364/5409	364/5406
Adjusted R-Squared	0.6987	0.7464	0.7744	0.7747	0.7910
Exclusion Restrictions:					
Cumulative Airworthiness Directives	-	-	-	-	3.91**
Number of Lease Operated Aircraft	-	-	-	-	4.94**
Both Cumulative Directives and Lease Operated Aircraft	-	-	-	-	4.99**

***** Control variables and fixed effects are included, but not reported, in these estimations of the aircraft residual value function (equation (1) above). Robust and clustered (by model) standard errors are employed. The numbers reported in parentheses below the parameter estimates are t-statistics. Double (single) asterisks on the F-Statistics are associated with p-levels less than .01 (.05). The row marked "Effect of Quality Variation on Aircraft Residual Value" is a test of my proxy for qualitative uncertainty; it contains the parameter estimate and t-statistic for the cumulative number of airworthiness directives variable in the residual value function. Recall that a negative coefficient is predicted provided the cumulative number of airworthiness directives is a useful proxy of qualitative uncertainty

Table 4
Estimated Depreciation Rates and Elasticities with Respect to Volume of Trade*

Panel A: Calculations Based on Single Equation Estimation of Equation (1) (Equation (3.5))

Value of Cumulative Number of Airworthiness Directives Variable	Value of Lease Number Variable	Mean Minus One Std. Deviation	Mean Number of Leased Aircraft	Mean Plus One Std. Deviation
	Mean Minus One Standard Deviation	39.32 0.0072* (3.42)	38.69 0.0070** (6.09)	37.97 0.0115** (5.85)
	Mean Value of Cumulative Directives	39.73 -0.0009 (0.40)	38.22 0.0035** (5.22)	37.62 0.0079** (5.69)
	Mean Plus One Standard Deviation	38.08 -0.0045* (2.93)	37.68 -0.0002 (0.01)	37.20 0.0043* (4.01)

Panel B: Calculations Based on Instrumental Variables Estimation of Equation (1) (Equation (5.2))

Value of Cumulative Number of Airworthiness Directives Variable	Value of Lease Number Variable	Mean Minus One Std. Deviation	Mean Number of Leased Aircraft	Mean Plus One Std. Deviation
	Mean Minus One Standard Deviation	39.32 0.0016 (0.09)	40.37 0.0158** (4.77)	41.24 0.0294** (7.57)
	Mean Value of Cumulative Directives	38.66 -0.0101** (4.59)	39.92 0.0046 (0.82)	40.99 0.0187** (5.04)
	Mean Plus One Standard Deviation	37.97 -0.0222** (9.07)	39.44 -0.0067 (1.39)	40.72 0.0076 (1.09)

* The first row of each entry is the calculated depreciation rate based on the estimated parameters and identified values of the independent variables (the mean value is used for variables other than airworthiness directives and lease numbers). The second row reports the elasticity of the estimated depreciation rate with respect to volume of trade; i.e., the derivative of the function with respect to trading volume multiplied by the ratio of mean trading volume to the calculated depreciation rate. The number in parenthesis below the elasticity calculation is an F-statistic based on the null hypothesis that the derivative of the depreciation rate function with respect to trading volume equals zero. Double (single) asterisks are associated with p-levels less than .05 (.10).

Table 5
Instrumental Variables Estimations of the Aircraft Depreciate Rate Function*

Independent Variables	**Use of Both Instruments**		**Use of Single Instruments**	
	Compensation & Corp. Profits		**Compensation**	**Corp. Profits**
	(5.1)	**(5.2)**	**(5.3)**	**(5.4)**
Constant	0.4239 (9.04)	0.4290 (9.19)	0.4235 (9.49)	0.4484 (8.92)
Aircraft Age	-0.0011 (2.89)	-0.0009 (3.80)	-0.0010 (3.95)	-0.0010 (4.17)
Model Fleet Size	$-4.880*10^{-5}$ (2.64)	$-8.380*10^{-5}$ (5.91)	$-8.200*10^{-5}$ (5.72)	$-8.200*10^{-5}$ (5.65)
Brand Fleet Size	$-1.720*10^{-4}$ (3.62)	$-1.581*10^{-4}$ (4.95)	$-1.616*10^{-4}$ (4.92)	$-1.623*10^{-4}$ (4.77)
Aircraft Type (Jet=1)	-0.0035 (0.75)	-0.0111 (2.38)	-0.0111 (2.36)	-0.0112 (2.39)
Volume of Trade	-0.0042 (0.40)	0.0071 (0.45)	0.0043 (0.27)	-0.0020 (0.12)
Cumulative Number of Airworthiness Directives	-	0.0003 (0.38)	0.0003 (0.39)	-0.0003 (0.41)
Number of Aircraft Operated Under Leasing Contract	-	$2.695*10^{-4}$ (0.91)	$2.627*10^{-4}$ (0.88)	$2.792*10^{-4}$ (0.95)
Squared Volume of Trade	-	0.0031 (0.38)	0.0057 (0.67)	0.0105 (0.1.18)
Squared Airworthiness Directives	-	$-3.120*10^{-6}$ (0.20)	$-2.570*10^{-6}$ (0.17)	$-6.46*10^{-6}$ (0.00)
Squared Leased Aircraft	-	$-2.330*10^{-6}$ (1.12)	$-2.130*10^{-6}$ (1.03)	$-1.750*10^{-6}$ (0.88)
Interaction of Volume of Trade and Cumulative Airworthiness Directives	-	-0.0041 (2.80)	-0.0041 (2.61)	-0.0039 (2.20)
Interaction of Volume of Trade and Number of Lease Operated Aircraft	-	0.0020 (3.20)	0.0019 (3.18)	0.0016 (2.89)
Interaction of Airworthiness Directives and Leased Operated Aircraft	-	$1.370*10^{-5}$ (1.33)	$1.330*10^{-5}$ (1.28)	$1.170*10^{-5}$ (1.08)
Effect of Qualitative Uncertainty on Aircraft Residual Value	-	-0.0115 (1.90)	-0.0115 (1.88)	-0.0111 (1.80)
Number of Observations	364/5409	364/5406	364/5406	364/5406
Adjusted R-Squared	0.7746	.7981	0.7976	0.7961
Exclusion Restrictions:				
Cumulative Airworthiness Directives	-	7.71**	7.56**	6.30**
Number of Lease Operated Aircraft	-	6.44**	6.32**	6.34**
Both Cumulative Directives and Lease Operated Aircraft	-	7.00**	6.90**	6.50**

***** Control variables and fixed effects are included, but not reported, in these estimations of the aircraft residual value function (equation (1) above). Robust and clustered (by model) standard errors are employed. The numbers reported in parentheses below the parameter estimates are t-statistics. Double (single) asterisks on the F-Statistics are associated with p-levels less than .01 (.05). The row marked "Effect of Quality Variation on Aircraft Residual Value" is a test of my proxy for qualitative uncertainty; it contains the parameter estimate and t-statistic for the cumulative number of airworthiness directives variable in the residual value function. Recall that a negative coefficient is predicted provided the cumulative number of airworthiness directives is a useful proxy of qualitative uncertainty.

Table 6
Estimated Depreciation Rates and Elasticities with Respect to Volume of Trade:
Sensitivity of Main Findings to Included Instruments*

Panel A: Calculations Based on Use of Executive Compensation as Instrumental Variable (Equation (5.3))

		Value of Lease Number Variable		
		Mean Minus One Std. Deviation	**Mean Number of Leased Aircraft**	**Mean Plus One Std. Deviation**
Value of Cumulative Number of Airworthiness Directives Variable	**Mean Minus One Standard Deviation**	38.74 0.0007 (0.02)	39.76 0.0147** (3.98)	40.62 0.0280** (6.78)
	Mean Value of Cumulative Directives	38.08 -0.0113** (4.86)	39.30 0.0032 (0.39)	40.36 0.0168** (4.43)
	Mean Plus One Standard Deviation	37.38 -0.0237** (8.15)	38.80 0.0086 (1.92)	40.06 0.0055 (0.62)

Panel B: Calculations Based on Use of Corporate Profits as Instrumental Variable (Equation (5.4))

		Value of Lease Number Variable		
		Mean Minus One Std. Deviation	**Mean Number of Leased Aircraft**	**Mean Plus One Std. Deviation**
Value of Cumulative Number of Airworthiness Directives Variable	**Mean Minus One Standard Deviation**	41.11 -0.0010 (0.04)	42.08 0.0101 (2.11)	42.92 0.0208** (4.38)
	Mean Value of Cumulative Directives	40.47 -0.0116** (5.10)	41.62 -0.0001 (0.00)	42.64 0.0108 (2.54)
	Mean Plus One Standard Deviation	39.38 -0.0226** (6.68)	41.16 -0.0105* (2.86)	42.36 0.0008 (0.02)

* The first row of each entry is the calculated depreciation rate based on the estimated parameters and identified values of the independent variables (the mean value is used for variables other than airworthiness directives and lease numbers). The second row reports the elasticity of the estimated depreciation rate with respect to volume of trade; i.e., the derivative of the function with respect to trading volume multiplied by the ratio of mean trading volume to the calculated depreciation rate. The number in parenthesis below the elasticity calculation is an F-statistic based on the null hypothesis that the derivative of the depreciation rate function with respect to trading volume equals zero. Double (single) asterisks are associated with p-levels less than .05 (.10).

Table 7
Robustness Checks of Instrumental Variables Estimations of the Aircraft Depreciate Rate Function*

Independent Variables	Include Aircraft of Age 5-41 Yrs. (7.1)	 0-20 Yrs. (7.2)	Volume of Trade Less Than 38% (7.3)	Use Predicted # of Leased Aircraft (7.4)
Constant	0.3498 (6.34)	0.4143 (9.03)	0.4195 (8.40)	0.4228 (8.90)
Aircraft Age	-0.0001 (0.55)	-0.0020 (8.18)	-0.0009 (3.62)	-.0010 (4.46)
Model Fleet Size	$-6.330*10^{-5}$ (3.55)	$-4.910*10^{-5}$ (2.06)	$-8.340*10^{-5}$ (5.70)	$-9.400*10^{-5}$ (5.10)
Brand Fleet Size	$-1.513*10^{-4}$ (3.51)	$-1.571*10^{-4}$ (5.00)	$-1.555*10^{-4}$ (5.00)	$-1.738*10^{-4}$ (5.53)
Aircraft Type (Jet=1)	-0.0079 (1.51)	-0.0105 (1.87)	-0.0102 (2.13)	-0.0149 (2.66)
Volume of Trade	0.0286 (1.61)	-0.0005 (0.03)	0.0005 (0.02)	-0.0156 (1.11)
Cumulative Number of Airworthiness Directives	0.0003 (0.34)	-0.0004 (0.60)	-0.0003 (0.40)	-0.0004 (0.53)
Number of Aircraft Operated Under Leasing Contract	0.0001 (0.48)	0.0003 (0.96)	0.0003 (0.88)	0.0007 (1.46)
Squared Volume of Trade	0.0048 (0.31)	0.0032 (0.43)	-0.0041 (0.26)	0.0137 (1.51)
Squared Airworthiness Directives	$-1.380*10^{-5}$ (0.86)	$-6.400*10^{-6}$ (0.33)	$-3.020*10^{-6}$ (0.20)	$2.680*10^{-5}$ (0.17)
Squared Leased Aircraft	$-1.460*10^{-6}$ (1.07)	$-2.870*10^{-6}$ (1.12)	$-2.530*10^{-6}$ (1.20)	$-6.870*10^{-6}$ (2.30)
Interaction of Volume of Trade and Cumulative Airworthiness Directives	-0.0041 (3.31)	-0.0020 (2.42)	-0.0043 (2.64)	-0.0031 (2.17)
Interaction of Volume of Trade and Number of Lease Operated Aircraft	0.0018 (3.46)	0.0010 (2.30)	0.0023 (2.93)	0.0021 (2.11)
Interaction of Airworthiness Directives and Leased Operated Aircraft	$9.090*10^{-6}$ (1.24)	$1.530*10^{-5}$ (1.29)	$1.300*10^{-5}$ (1.29)	$2.040*10^{-5}$ (1.23)
Effect of Qualitative Uncertainty on Aircraft Residual Value	-0.0203 (3.44)	-0.0110 (1.83)	-0.0123 (1.99)	-0.0058 (0.79)
Number of Observations	363/4036	357/4972	364/5062	364/5406
Adjusted R-Squared	0.8695	0.8275	0.8056	0.7972
Exclusion Restrictions:				
Cumulative Airworthiness Directives	11.71**	6.07**	7.69**	4.79**
Number of Lease Operated Aircraft	6.25**	2.22*	5.83**	3.67**
Both Cumulative Directives and Lease Operated Aircraft	9.36**	4.85**	6.67**	6.41**

***** Control variables and fixed effects are included, but not reported, in these estimations of the aircraft residual value function (equation (1) above). Robust and clustered (by model) standard errors are employed. The numbers reported in parentheses below the parameter estimates are t-statistics. Double (single) asterisks on the F-Statistics are associated with p-levels less than .01 (.05). The row marked "Effect of Quality Variation on Aircraft Residual Value" is a test of my proxy for qualitative uncertainty; it contains the parameter estimate and t-statistic for the cumulative number of airworthiness directives variable in the residual value function. Recall that a negative coefficient is predicted provided the cumulative number of airworthiness directives is a useful proxy of qualitative uncertainty.

Table 8
Estimated Depreciation Rates and Elasticities with Respect to Volume of Trade: Sensitivity of Main Findings to Age and Endogenous Leasing*

Panel A: Calculations Excluding Aircraft Over Twenty Years Old (Equation (7.2))

		Value of Lease Number Variable		
		Mean Minus One Std. Deviation	**Mean Number of Leased Aircraft**	**Mean Plus One Std. Deviation**
Value of Cumulative Number of Airworthiness Directives Variable	**Mean Minus One Standard Deviation**	37.40 -0.0056 (0.01)	38.18 0.0066 (0.87)	38.74 0.0136 (2.24)
	Mean Value of Cumulative Directives	36.78 -0.0065 (1.95)	37.32 0.0009 (0.07)	37.64 0.0082 (1.09)
	Mean Plus One Standard Deviation	36.08 -0.0127** (6.72)	36.39 -0.0051 (1.10)	36.47 0.0025 (0.27)

Panel B: Calculations Assuming Endogenous Number of Leased Aircraft (Equation (7.4))

		Value of Lease Number Variable		
		Mean Minus One Standard Deviation	**Mean Number of Leased Aircraft**	**Mean Plus One Standard Deviation**
Value of Cumulative Number of Airworthiness Directives Variable	**Mean Minus One Standard Deviation**	37.93 -0.0052 (1.25)	39.58 0.0101 (1.62)	40.70 0.0245* (3.05)
	Mean Value of Cumulative Directives	37.33 -0.0145** (8.60)	39.30 0.0014 (0.05)	40.73 0.0161 (1.63)
	Mean Plus One Standard Deviation	36.77 -0.0241** (9.04)	39.05 -0.0074 (0.95)	40.79 0.0076 (0.39)

* The first row of each entry is the calculated depreciation rate based on the estimated parameters and identified values of the independent variables (the mean value is used for variables other than airworthiness directives and lease numbers). The second row reports the elasticity of the estimated depreciation rate with respect to volume of trade; i.e., the derivative of the function with respect to trading volume multiplied by the ratio of mean trading volume to the calculated depreciation rate. The number in parenthesis below the elasticity calculation is an F-statistic based on the null hypothesis that the derivative of the depreciation rate function with respect to trading volume equals zero. Double (single) asterisks are associated with p-levels less than .05 (.10).