Leasing and Secondary Markets: Theory and Evidence from Commercial Aircraft

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Leasing and Secondary Markets: Theory and Evidence from Commercial Aircraft*

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Abstract

I construct a dynamic model of transactions in used capital to understand the role of leasing when trading is subject to frictions. Firms trade assets to adjust their productive capacity in response to shocks to profitability. Transaction costs hinder the efficiency of the allocation of capital, and lessors act as trading intermediaries who reduce trading frictions. The model predicts that leased assets trade more frequently and produce more output than owned assets, for two reasons. First, high-volatility firms are more likely to lease than low-volatility firms, since they expect to adjust their capacity more frequently. Second, ownership's larger transaction costs widen owners' inaction bands relative to lessees'.

Using data on commercial aircraft, I find that leased aircraft have holding durations 38-percent shorter and fly 6.5-percent more hours than owned aircraft. Additional tests indicate that most of these differential patterns in trading and utilization arise because owners have wider inaction bands than lessees, and carriers' self-selection into leasing plays a minor role.

1 Introduction

In this paper, I study the link between the efficiency of secondary markets for firms' inputs and the efficiency of production of final output, with a special focus on the market for commercial aircraft and the airline industry. In particular, I study how a contract that has recently become popular in the aircraft market—the operating lease—increases the efficiency of aircraft transactions and, as a result, increases capacity utilization in the airline industry.

Several markets for used capital equipment are active. For example, more than two thirds of all machine tools sold in the United States in 1960 were used (Waterson, 1964); more than half of the trucks traded in the United States in 1977 sold in secondary markets (Bond, 1983); and active markets exists for used medical equipment, construction equipment, and aircraft. Figure 1 plots the number of transactions in the primary and the secondary markets for commercial aircraft. Since the mid-1980s, trades in the secondary market for aircraft have grown steadily, and the number of transactions on used markets today is about three times the number of purchases of new aircraft.

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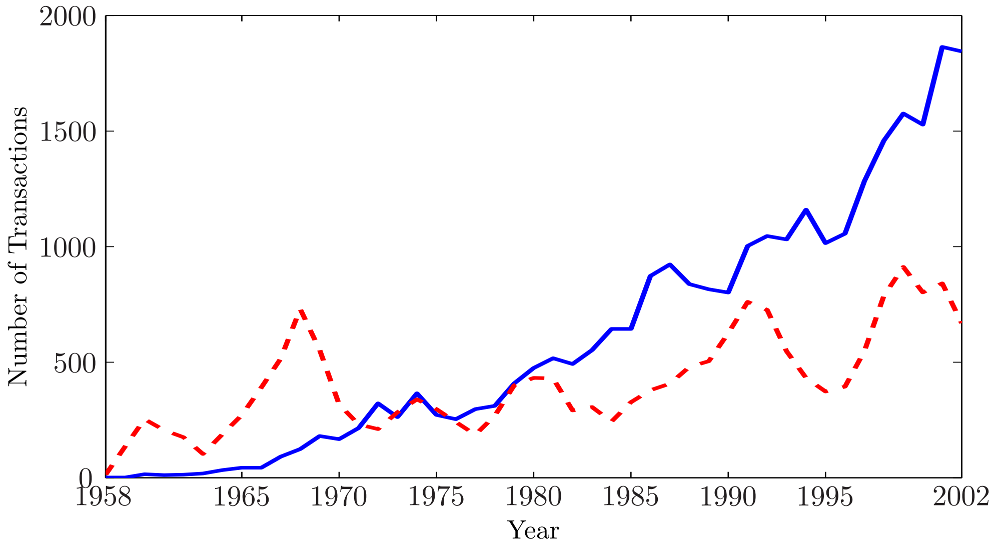


FIG. 1: Transactions in the primary (dashed line) and secondary (solid line) markets for narrow-body and wide-body aircraft, 1958-2002.

A large share of these transactions is due to leasing. About one third of the aircraft currently operated by major carriers are under an operating lease—a rental contract between a lessor and an airline for use of the aircraft for a period of four to eight years (See Section 3 and Appendix A for more details on aircraft leasing). Figure 2 plots the annual share of new commercial aircraft purchased by operating lessors. It shows that lessors are active buyers on the primary market, and that their acquisitions have increased rapidly in recent years.[1] Moreover, lessors are also active participants in secondary markets, as they frequently buy used aircraft and, more importantly, lease out each aircraft several times during their useful lifetime.

In this paper, I construct a model of aircraft transactions to understand the role of lessors when trading is subject to frictions—i.e., transaction costs and search costs for potential buyers. The model combines five key factors: 1) Carriers have heterogeneous stochastic productivity; 2) carriers have heterogeneous volatility; 3) aircraft can be bought or leased; 4) carriers incur costs to sell aircraft; and 5) lessors incur per-period costs of monitoring their assets.

In this world, secondary markets play a fundamental allocative role since carriers trade aircraft to adjust their productive capacity. When either cost or demand shocks adversely affect profitability, carriers shrink and sell aircraft. Conversely, when shocks positively affect profitability, carriers expand and acquire aircraft.

If there is no leasing, trading frictions and stochastic productivity prevent capital goods from being efficiently allocated. Efficiency requires that only the most productive carriers operate aircraft. However, transaction costs create a wedge between the price the buyer pays and the price the seller receives—a wedge that is a barrier to trade. This implies that some carriers operating aircraft are less productive than some carriers not operating aircraft.

If carriers can buy or lease aircraft, they trade off ownership's lower per-period rental rates and leasing's lower transaction costs. This trade-off generates two striking differences between leased and owned aircraft in equilibrium: 1) Leased aircraft trade more frequently, due to two effects. The first

[1] In 1981 and 1986, the United States implemented important taxation reforms, which may have spurred the entry of lessors. Section 6.1.4 discusses the role of taxation.

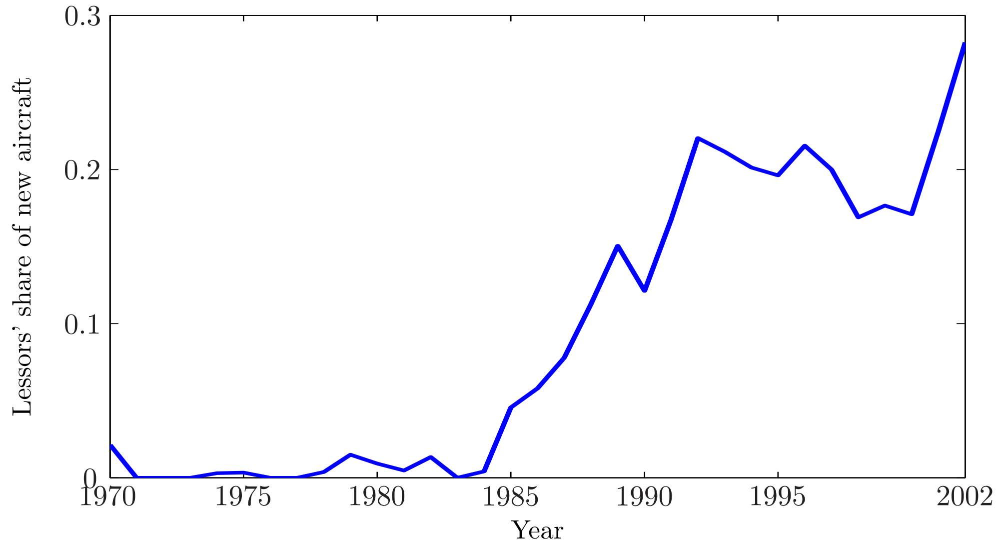


FIG. 2: Share of new narrow-body and wide-body aircraft acquired by lessors, as a fraction of total narrow-body and wide-body aircraft produced, 1970-2002.

is selection: High-volatility carriers lease and low-volatility carriers own aircraft. Since high-volatility carriers expect to adjust their capacity more frequently, they value leasing's benefits more than low-volatility carriers do. The second is that owners have wider inaction bands than lessees due to transaction costs. Thus, amidst profitability shocks, the level of profitability that triggers carriers to reduce capacity is lower for owned than for leased aircraft. 2) Leased aircraft have higher utilization, due to the same two effects. First, when acquiring aircraft, high-volatility carriers (i.e, lessees) are more productive than low-volatility carriers (i.e., owners). Second, owners' wide inaction bands generate a long left tail in their productivity distribution. Instead, leasing's lower trading frictions truncate the left tail of lessees' productivity distribution.

I use a rich dataset on commercial aircraft to provide evidence on the model's qualitative implications. I find that leased aircraft have: 1) holding durations 38-percent shorter than owned aircraft; and 2) flying hours 6.5-percent higher than owned aircraft. The empirical analysis shows that leased aircraft are parked inactive less frequently than owned aircraft, and that, conditional on being in use, leased aircraft have a higher capacity utilization than owned aircraft. Moreover, I find evidence in favor of both effects highlighted by the model, but their empirical relevance is lopsided: Most of the differential patterns in trading and utilization arise because ownership's larger transaction costs widen owners' inaction bands relative to lessees', and carriers' self-selection into leasing plays a minor role. Finally, I calibrate the model to investigate whether it is quantitatively consistent with the data. Interestingly, the calibration shows that small differences in carriers' volatilities can lead to the observed larger differences in trading and utilization between leased and owned aircraft, and confirms that self-selection of carriers does not play the dominant role.

I argue that the growth of trade in the secondary markets for aircraft since the mid-1980s is consistent with the model. The Airline Deregulation Act of 1978 dramatically reduced entry costs, thereby increasing the competitiveness of airline markets.[2] This increase in competitiveness amplified the volatility of firm-level output, implying that carriers needed to adjust their fleets more frequently. The volume of trade

[2]The airline industry was governed by the Civil Aereonautics Board (CAB) from 1938 to 1984. Under the Airline Deregulation Act of 1978, the industry was deregulated in stages. In January 1, 1982, all controls on entry and exit were

on secondary markets increased due to higher inter-firm reallocation of inputs.[3] Therefore, the entry of lessors in the mid-1980s, as documented in Figure 2, coincided exactly with a period of expansion of trade in secondary markets, when the need for market intermediaries to coordinate sellers and buyers became stronger.[4] Variations of the operating lease have evolved, but the key point is that, when carriers want to shed excess capacity, the lessor has taken over the job of finding a new operator. The logic is that specialists can do this job more efficiently, while carriers focus on operating the aircraft and servicing the passengers.

This paper identifies lessors as intermediaries who reduce frictions in secondary markets. Thus, I highlight a role for leasing in capital equipment that has been ignored in the literature.[5] I believe that the mechanisms identified in this paper are not unique to aircraft markets, but may help clarify the role of leasing for a wide range of capital equipment. Moreover, this paper is one of the few that try to empirically quantify the gains from intermediation and institutions that enhance the efficiency of trading. This is important in the context of capital goods because frictions in secondary markets are a key factor in determining an industry's aggregate productivity growth (Bailey, Hulten, and Campbell, 1992; Foster, Haltiwanger and Syverson, 2008) or an industry's speed of adjustment after a shock or a policy intervention (Melitz, 2003).

The paper is organized as follows. Section 2 discusses the related literature. Section 3 describes key features of commercial aircraft markets and of aircraft leasing. Section 4 lays out the model. Section 5 presents the empirical analysis. Section 6 considers alternative hypotheses and performs robustness checks. Section 7 concludes. Appendix A offers additional details on the contractual aspects of aircraft leasing. Appendices B and C collect omitted mathematical derivations and all proofs of Propositions.

2 Related Literature

This paper is related to several strands of the literature. First, a series of papers studies the reallocation of capital across firms (Pulvino, 1998; Ramey and Shapiro, 1998, 2001; Maksimovic and Phillips, 2001; Schlingemann et al., 2002; and Eisfeldt and Rampini, 2006). These papers document the importance of gross capital flows in determining capital accumulation (Ramey and Shapiro, 1998); study the cyclical properties of reallocations (Maksimovic and Phillips, 2001; Eisfeldt and Rampini, 2006); or investigate some frictions in the capital reallocation process (Pulvino, 1998; Ramey and Shapiro, 2001; Schlingemann et al., 2002; Eisfeldt and Rampini, 2006). However, none of these papers studies the role of leasing in reallocating capital and alleviating frictions.

Second, a strand of the literature in financial economics examines the corporate decisions to lease. Several papers focus on the tax advantages of leasing, following Miller and Upton (1976) and Myers, Dill and Bautista (1976). However, as I discuss in detail in Section 6.1.4, taxes cannot explain all the empirical patterns documented in Section 5. Thus, the current paper contributes to a small but

removed, while airfares were deregulated in January 1, 1983. The actual changes were implemented rather more rapidly. Finally, on January 1, 1985, the governance of the airline industry was transferred from the Civil Aereonautics Board to the Department of Transportation.

[3]Ramey and Shapiro (1998) analyze Compustat data and also find a significant increase in capital reallocation across firms and industries in the 1980s and 1990s.

[4]Steven F. Udvar-Hazy, Chairman and CEO of ILFC, one of the largest aircraft lessors, declares: "The inevitability of change creates a constant flow of upswings and downturns in air transportation. But one thing does not change – the continuous need for rapid, economical deployment of high performance aircraft. ILFC understood this reality as early as 1973 when we pioneered the world's first aircraft operating lease." Available at http://www.ilfc.com/ceo.htm.

[5]Smith and Wakeman (1985) analyze the determinants of corporate leasing policies and notice an incentive to lease if the lessor has a comparative advantage in disposing of the asset.

growing literature that shows that the economics of leasing go well beyond tax-minimization strategies. In particular, following the thoughtful discussion of Smith and Wakeman (1985), a few authors have focused on some financial contracting aspects of leasing (see Krishnan and Moyer, 1994; Sharpe and Nguyen, 1995; Eisfeldt and Rampini, 2009; Gavazza, 2010). Particularly related to the current paper are Sharpe and Nguyen (1995) and Eisfeldt and Rampini (2009), both of which investigate the effect of financing constraints on the leasing decision. Sharpe and Nguyen (1995) use Compustat data and find that the share of total annual fixed capital costs that is leased is higher for firms that are more likely to face relatively high premiums for external funds—i.e., firms that are lower-rated, non-dividend-paying, and/or cash-poor. Eisfeldt and Rampini (2009) construct an insightful model in which firms differ in their internal funds, and capital is bought or leased. On one side, leasing enjoys stronger claims than secured lending, and, thus, allows lessors to extend more credit than secured lenders can. On the other side, leasing is subject to agency or monitoring costs and is, thus, more expensive for borrowers. As a result of this trade-off, Eisfeldt and Rampini show that more-financially-constrained firms lease more of their capital than less-constrained firms do. They also provide extensive empirical evidence consistent with this prediction. Hence, the primary focus of Sharpe and Nguyen (1995) and Eisfeldt and Rampini (2009) is on firms' decision to lease, while my main focus is on leasing's effects on trading and allocation of assets. In Section 6.1.3, I will compare more thoroughly the implications of leasing theories based on financing constraints—in particular, Eisfeldt and Rampini (2009)—with the implications of my model.

Third, the literature on consumer durable goods has investigated the role of secondary markets in allocating new and used goods (Rust, 1985; Anderson and Ginsburgh, 1994; Hendel and Lizzeri, 1999a; Porter and Sattler, 1999; Stolyarov, 2002; Esteban and Shum, 2007). In all these papers, the gains from trade arise from the depreciation of the durables, while in this paper, the gains from trade arise from the stochastic evolution of firms' efficiency (See, also, House and Leahy, 2004). In this strand of the literature, Waldman (1997) and Hendel and Lizzeri (1999b, 2002) analyze manufacturers' incentives to lease and show that leasing may allow manufacturers to gain market power in the used market. Hendel and Lizzeri (2002) and Johnson and Waldman (2003, forthcoming) show that manufacturers' leasing ameliorates the consequences of information asymmetries about the quality of used goods. Gilligan (2004), using data on business jets, finds empirical evidence consistent with the theoretical results of Hendel and Lizzeri (2002) and Johnson and Waldman (2003). Further, Bulow (1982) shows that a durable-goods monopolist prefers to lease in order to solve the Coasian time-inconsistency problem. Thus, the current paper differs from this strand of the literature by focusing on a novel role of leasing that, I argue, captures the main empirical facts of commercial aircraft markets. In Section 6, I discuss in more detail the empirical implications of some of these models, highlighting the predictions that distinguish them from the model presented in Section 4.

Fourth, a long series of papers has analyzed the passenger-airline industry. Most of the literature has analyzed carriers' product market decisions (entry, scheduling of flights, pricing of tickets, etc.), and only a few papers have focused on aircraft transactions. Using data on aircraft transactions, Pulvino (1998, 1999) finds that airlines under financial pressure sell aircraft at a 14-percent discount. He further shows that distressed airlines experience higher rates of asset sales than non-distressed airlines do, which is consistent with the results of my model. Goolsbee (1998) studies how carriers' financial performance, the business cycle, factor prices, and the cost of capital affect carriers' decision to sell/retire a specific aircraft type, the Boeing 707. However, none of these papers considers the role of aircraft leasing.

Lastly, this paper is broadly related to the literature on intermediaries. Spulber (1999) presents a thorough analysis and surveys the literature. This paper presents one of the first empirical analyses that quantifies the gain from intermediation in the market for capital goods.

3 Background: Aircraft Markets and Aircraft Leasing

The purpose of this section is to shed light on four key economic issues: 1) the existence and nature of frictions in the secondary markets for aircraft; 2) the role of operating lessors as intermediaries in the trading and redeployment of aircraft; 3) carriers' main trade-off between leasing and owning aircraft; and 4) why intermediaries are organized as lessors—i.e., why intermediaries own aircraft rather than trading them as brokers/dealers. Appendix A provides additional information on the contractual aspects of aircraft leasing.

3.1 Trading Frictions

The market for used commercial aircraft may seem relatively active compared to the market for other more-specialized equipment. In particular, aircraft are the only form of capital equipment that can be delivered to a buyer or an operator anywhere in the world within a day and get there under their own power. Thus, the secondary market for aircraft is a single, worldwide market.

However, several facts suggests that trading frictions are important. First, aircraft are traded in decentralized markets, organized around privately negotiated transactions.[6] Thus, there is no centralized exchange providing immediacy of trade and pre-trade price transparency. To initiate a transaction, a prospective seller must contact multiple potential buyers. Comparing two similar aircraft for sale is costly since aircraft sales involve the material inspection of the aircraft, which could be located in two different countries. In addition, a sale involves legal costs, which increase substantially if there are legal disputes over the title or if the local aviation authority has deregistered the aircraft. In some cases, there could also be outstanding bills for maintenance, fuel, and parking that have to be paid before the aircraft is released by the local authority to be sold. Thus, aircraft are seldom sold at auctions. Pulvino (1998) reports that in one of the first auctions, organized in 1994 to enhance the liquidity of the market, only nine of the 35 aircraft offered for sale were sold. Some subsequent auctions ended without even a single sale. Hence, aircraft markets share many features with other over-the-counter markets for financial assets (mortgage-backed securities, corporate bonds, bank loans, derivatives, etc.) and for real assets (real estate), in which trading involves material and opportunity costs (Duffie, Gârleanu and Pedersen, 2005 and 2007). As a result, most major carriers have staff devoted to the acquisition and disposition of aircraft, which suggests that trade is not frictionless.

Second, compared to financial markets and other equipment markets, aircraft markets are "thin." The absolute number of transactions in the aircraft market is small. For example, in the 12 months between May 2002 and April 2003, of the total stock of 12,409 commercial aircraft used for passenger transportation and older than two years, only 720 (5.8 percent) traded.[7] Moreover, aircraft are differentiated products. Each type of aircraft requires human-capital investments in specific skills—for pilots, crew and mechanics—that increase the degree of physical differentiation. Product differentiation also implies that aircraft are imperfect substitutes for one another, as different types are designed to serve different markets and ranges. For example, a Boeing 747 is suited to markets in which both demand and distance are large. For a given type, the number of annual transactions can be small: Only 21 used units of the Boeing 747 traded in the 12-month period ending April 2003.

[6] This is one characteristic that Rauch (1999) uses to measure asset-specificity. The idea is that if an asset is sold on an organized exchange, then the market for this asset is thick and, hence, the asset is less specific to the transaction.

[7] The comparison with other capital goods is complicated because of the heterogeneity of capital goods. In a cross-industry study of corporate asset sales, Schilngemann et al. (2002) report a cross-industry average turnover of assets (measured in dollar values) of five percent. In their sample, more than ten two-digit industries have an average value of turnover higher than ten percent, and in some two-digit industries, the average value of turnover is as high as 23 percent.

In thin markets, the search costs to find high-value buyers are usually large (Ramey and Shapiro, 2001). Industry experts and market participants consider these frictions a fundamental characteristic of aircraft markets. For example, according to Lehman Brothers (1998): "The ratings agencies require an 18-month source of liquidity because this is the length of time they feel it will take to market and resell the aircraft in order to maximize value." Hence, transaction prices are sensitive to parties' individual shocks, and the bargaining power of sellers and buyers is an important determinant of transaction prices. For example, Pulvino (1998) finds that sellers with bad financial status sell aircraft at a 14-percent discount relative to the average market price.

3.2 Lessors as Intermediaries

In response to trading frictions, almost all over-the-counter markets have intermediaries. Indeed, starting with Demsetz (1968), trading frictions have been used to explain the existence and behavior of intermediaries. In the aircraft market, operating lessors play the role of marketmakers/dealers, and a fringe of smaller companies operate as independent brokers that are sometimes hired to match buyers and sellers. Habib and Johnsen (1999) describe the origin and nature of the leasing business as follows: "[Lessors] appear to have invested substantial resources through the 1980s and early 1990s to establish general knowledge of secondary market redeployment opportunities for used aircraft. They also appear to have invested, ex ante, to establish specific knowledge of redeployment opportunities for particular used aircraft." In its 2003 Annual Report, ILFC—the founder of the aircraft-leasing business—describes its business as follows: "International Lease Finance Corporation is primarily engaged in the acquisition of new commercial jet aircraft and the leasing of those aircraft to airlines throughout the world. In addition to its leasing activity, the Company regularly sells aircraft from its leased aircraft fleet to third party lessors and airlines." Similarly, AWAS, another operating lessor, states: "At AWAS we pride ourselves in our ability to optimise return on investment through the effective management and remarketing of our assets."

Thus, lessors are trading specialists. Indeed, Barrington (1998) notes that "the business of owning aircraft on real operating leases is similar to the business of trading in commodities."

3.3 The Trade-off between Leasing and Owning

For carriers, the key point is that, if they are leasing an aircraft and they no longer need it, the job of finding a new operator has been taken over by another party, the lessor. Leasing companies extensively advertise this advantage for carriers. For example, GECAS cites the following benefits of an operating lease: "Fleet flexibility to introduce new routes or aircraft types" and "Flexibility to increase or reduce capacity quickly." Similarly, AWAS mentions that "AWAS' customers gain operating flexibility." This focus on operational flexibility suggests that trading costs are lower on leased than on owned aircraft.

On the other hand, leasing companies have their own technical, legal and marketing teams that accumulate extensive knowledge of the market, keep track of carriers' capacity needs and monitor the use of their aircraft. These "monitoring" costs, as in Eisfeldt and Rampini (2009) and Rampini and Viswanathan (2010), imply that per-period rates are higher on leased than on owned aircraft.[8] Indeed, Gavazza (2010), using data on aircraft prices and aircraft lease rates, documents that lease rates are, on average, 20-percent higher than implicit rental rates.

[8]The model focuses on monitoring costs, but the exact reason why leasing per-period costs are higher is not critical. The thrust of the argument is that carriers trade off leasing's higher per-period costs against ownership's higher transaction costs.

Hence, carriers face a trade-off between leasing's higher per-period costs and ownership's higher transaction costs. For example, Barrington (1998) notes: "The airlines that use operating leases consider that the flexibility such leases provide makes up for the fact that the cash costs of the leases can be greater than the cost of acquiring the same aircraft through ownership." Similarly, Morrell (2001) lists "no aircraft trading experience needed" as one of the advantages of leasing for the carriers, and "a higher cost than, say, debt finance for purchase" as one of the disadvantages.

3.4 Why Lessors own Aircraft

Having documented the role of lessors as trading intermediaries, the natural question to ask is why lessors do not simply trade aircraft as brokers/dealers. The explanations combine two slightly distinct, but related issues: 1) why aircraft owners are the intermediaries—i.e., what are the efficiency gains if aircraft intermediation is performed by the same firms that own aircraft? and 2) why carriers would rather not own aircraft—i.e., what are the efficiency gains if companies that are not carriers own aircraft?

First, leasing enjoys stronger claims than secured lending. In particular, in the event of default on a lease prior to bankruptcy, a lessor can seize the aircraft more easily than a secured lender can in both U.S. and non-U.S. bankruptcies (Krishnan and Moyer, 1994; Habib and Johnsen, 1999). In U.S.-based Chapter 7 bankruptcies and in most non-U.S. bankruptcies, a lessor can repossess the asset more rapidly than a debt holder (Littlejohns and McGairl, 1998). In U.S.-based Chapter 11 bankruptcies, Section 1110 treats lessors and all other secured lenders equally in allowing foreclosure on an aircraft in the event of bankruptcy. However, the bankruptcy code establishes that other claims of secured creditors are diluted considerably more than comparable claims of lessors. For example, in an interesting case, Continental Airlines sought to have over $100 million of its lease obligations treated as debt during its reorganization under Chapter 11 bankruptcy in 1991 (Krishnan and Moyer, 1994). The lessors did not agree, and the court ruled in their favor. This episode suggests that, in a U.S.-based Chapter 11 bankruptcy, aircraft lessors enjoy stronger claims than secured lenders do. Since defaults and bankruptcies are frequent in the airline industry, leasing enhances the efficiency of redeployment by exploiting its stronger ability to repossess assets. Moroever, Eisfeldt and Rampini (2009) argue that leasing's stronger claims make it particularly attractive to financially constrained operators. Such operators are often young, have often volatile capacity needs, and are more likely to default on their leases. Hence, lessors frequently get aircraft returned, which leads them to further specialize in redeployment.

Second, Shleifer and Vishny (1992) note that "[t]he institution of airline leasing seems to be designed partly to avoid fire sales of assets." The airline industry is traditionally cyclical, with large swings. Hence, both airline profits and aircraft values carry substantial financial risk, and they are almost perfectly correlated. Leasing allows carriers to transfer some of the aircraft-ownership risk to operating lessors. The price discounts estimated by Pulvino (1998) show that even the idiosyncratic risk of aircraft ownership can be large. Lessors are better suited to assuming the risk of aircraft ownership through their specific knowledge of secondary markets, their economies of scale, and their broader diversification of aircraft types and lessees operating in different geographic regions. Moreover, the largest lessors (GECAS and ILFC) belong to large financial conglomerates, which allows them to diversify the aggregate risk of aircraft ownership and to have a lower cost of funds, thanks to a higher credit rating.

4 Model

In this section, I introduce a simple model that illustrates the effects of leasing on aircraft trading and utilization. The theoretical framework will guide the empirical analysis of Section 5. I discuss only the results of the model in the text, relegating the analytic details to Appendix C.

4.1 Setup

Time is continuous and the horizon infinite. All firms are risk-neutral and discount the future at rate $r > 0$.

Aircraft - There is a mass $X < 1$ of homogeneous capital goods, and I refer to them as aircraft. For simplicity, aircraft do not depreciate. Aircraft can be bought or leased. The (endogenous) mass $X_L \in [0, X]$ of aircraft is leased, and the mass $X - X_L$ is owned.

Firms - There are two types of firms, carriers and lessors. Carriers operate aircraft to produce flights, and lessors supply leased aircraft to carriers.

There is a unit mass of carriers, and I refer to the carriers collectively as the *industry*. Carriers are infinitesimal—i.e., each carrier can operate, at most, one aircraft. Carriers' instantaneous output y (and revenues, since the price of output is normalized to one) is given by $y(z, s) = zs$, where the parameter z is a carrier's "long-term" productivity, and the parameter s is a "short-term" shock. The parameter z is distributed in the population according to the cumulative distribution function $F(z)$, and it follows an independent stochastic process: A mass ω of carriers receives a new draw from $F(z)$ at rate α_h, whereas the complementary mass $1 - \omega$ receives a new draw at rate $\alpha_\ell < \alpha_h$. The heterogenous parameter $\alpha \in \{\alpha_\ell, \alpha_h\}$ is constant over time for each carrier and, thus, measures the volatility of long-term productivity.

The shock s follows a Markov process on the finite state space $\{0, 1\}$, with transition intensity μ from state one to state zero, and transition intensity λ from state zero to state one. The rates λ and μ satisfy $\lambda > \alpha_h > \alpha_\ell > \mu$, so that the parameter s is an infrequent, short-term profitability shock.[9] For simplicity, I assume that carriers' long-run productivity z does not change while the temporary shock s is equal to zero.

Lessors acquire aircraft at the market price p and rent them at a per-period lease rate l. In addition, lessors have to spend mp on each unit of capital in monitoring costs (Eisfeldt and Rampini, 2009; Rampini and Viswanathan, 2010). Hence, their instantaneous profits are proportional to $l - (r + m)p$: On each leased unit, the lessor's revenues are equal to the lease rate l; their costs $(r + m)p$ are equal to the opportunity cost rp of owning an aircraft of price p when the interest rate is r, and the monitoring costs mp. Lessors are competitive, and, thus, in equilibrium they earn zero profits—i.e., $l = (r + m)p$.

Trade and Transaction costs - In each period, after carriers know their current parameters z and s, they can trade aircraft. On owned aircraft, the buyer pays the endogenous price p, but the seller receives $p(1 - \tau)$, $\tau \in [0, 1]$. Hence, τp are the transaction costs. On leased aircraft, the lessee pays the endogenous per-period lease rate l to the lessor, and there are no transaction costs when trading (No transaction costs on leased aircraft are just a normalization. All that matters is that transaction costs on leased aircraft are lower than on owned aircraft).

4.2 Benchmark: No Frictions ($\tau = 0$ and $m = 0$)

Before considering the effects of frictions, I analyze the benchmark case of no frictions. In this setting, I show that leasing has no effect on the equilibrium allocation of aircraft.

Secondary markets play a fundamental allocative role, since carriers trade aircraft to adjust their productive capacity: When shocks adversely affect their efficiency zs, carriers shed aircraft that smoothly

[9]The results derived in the paper depend only on the stochastic nature of the parameters z and s, and not on the particular processes assumed, as it will become clear. The specific processes make later derivations more tractable.

reallocate to carriers who enter the industry. When there are no frictions, Proposition 1 shows that carriers trade aircraft such that, in equilibrium, only the most efficient carriers operate them.

Proposition 1 *When there are no frictions (i.e., no transaction costs and no monitoring costs), there exists a threshold value z' such that only carriers $z \geq z'$ and $s = 1$ operate an aircraft. Thus, z' satisfies*

$$X = \frac{\lambda}{\mu + \lambda} \left(1 - F\left(z'\right)\right).$$

The equilibrium lease rate l and the equilibrium price p satisfy:

$$l = z' \text{ and } p = \frac{z'}{r}$$

Moreover, there is no difference in the allocation of leased and owned aircraft. All carriers are indifferent between leasing or owning aircraft.

The equilibrium has two features that do not survive once trading and monitoring costs are present.

1. The set of carriers is partitioned. No carrier with temporary shock operates an aircraft, and only the most productive carriers with no temporary shock operate an aircraft. Hence, the equilibrium allocation maximizes the total industry output.

2. The equilibrium allocation, the equilibrium price, and the equilibrium lease rate are independent of the volatility parameters α_h and α_ℓ. The equilibrium allocation is exactly the same for high- and low-volatility carriers, even though assets' holding periods are obviously shorter for high-volatility carriers.

Proposition 1 also says that the allocation of leased and owned aircraft is identical. As a result, the following Corollary obtains:

Corollary 2 *When there are no frictions, leased aircraft and owned aircraft have the same holding duration, and fly the same number of hours.*

In Section 5, I show that the data clearly reject these implications.

4.3 The Effects of Frictions

The presence of transaction costs on owned aircraft and of monitoring costs on leased aircraft modifies the previous benchmark in a significant way. Specifically, if carriers own aircraft, the transaction costs act naturally as a barrier to selling. The next Proposition characterizes how carriers' capacity adjustment differs depending on whether they lease or own aircraft.

Proposition 3 *(i) (Owned aircraft) A carrier that acquires an owned aircraft has productivity $z \geq z^*(\alpha)$ and $s = 1$. A carrier that sells an owned aircraft has either a temporary shock ($s = 0$) and productivity below the threshold $z^{**}(\alpha)$, or has productivity z below the threshold $z^{***}(\alpha)$. If transaction costs satisfy $\tau > \frac{r}{\lambda + r}$, then $z^*(\alpha) > z^{**}(\alpha) > z^{***}(\alpha)$.*

(ii) (Leased aircraft) A carrier that acquires a leased aircraft has productivity $z \geq l$ and $s = 1$. A carrier that returns a leased aircraft has either a temporary shock ($s = 0$), or has productivity z below the threshold l.

Transaction costs generate an option value of waiting for owners. Since efficiency z is stochastic, the option value means that owners have wider bands of inaction than lessees.

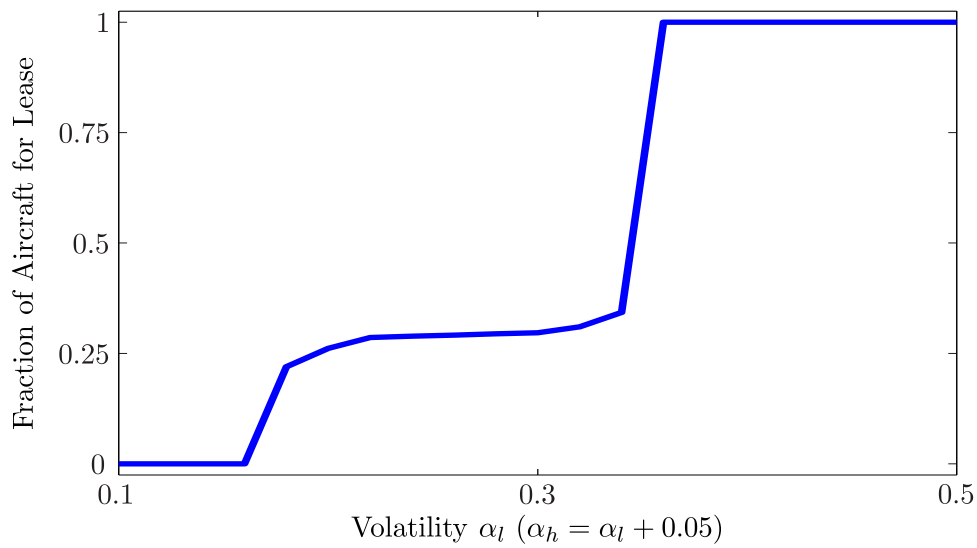


FIG. 3: Aircraft for lease as a function of the volatilities α_l and α_h of carriers' efficiency z. Baseline parameters are $X = .3$, $\mu = .03$, $r = .03$, $\lambda = .95$, $\tau = .035$, $\omega = .4$, $m = .0075$ and z is normally distributed with mean equal to 2000 and standard deviation equal to 1000.

4.3.1 Equilibrium

Lower transaction costs on leased aircraft make leasing attractive for carriers. However, monitoring costs imply that the lease rate l is pushed higher than rp, the implicit rental rate on ownership if there were no transaction costs. Hence, carriers trade off the lower implicit rental rate on owned aircraft and the lower one-time transaction cost on leased aircraft. If transaction costs are sufficiently high, leasing clearly dominates ownership for all carriers. If transaction costs are sufficiently small, owning dominates leasing for all carriers. The interesting case (and the empirically relevant one) is if transaction costs are of intermediate value.

Intuitively, the lower transaction costs of leasing are particularly attractive to high-volatility carriers since they expect to adjust their capacity more frequently. Hence, leased and owned aircraft can coexist, with high-volatility carriers leasing and low-volatility carriers owning. An analytic characterization of how the volatility of carriers' productivity affects their choice between leasing and owning cannot be provided because their choice depends on the equilibrium allocation and price, which cannot be solved for in closed form. Thus, I compute numerical solutions to illustrate carriers' choice between leased and owned aircraft. Appendix C.7 reports all equilibrium conditions.

Figure 3 shows that, in accordance with the intuition, the fraction of aircraft for lease increases monotonically as carriers' volatilities increase. If α_ℓ and α_h are low, expected transaction costs are low, and owning dominates leasing for all carriers. Similarly, if α_ℓ and α_h are high, then leasing dominates owning for all carriers. When volatilities are of intermediate values, then high-volatility carriers choose to lease and low-volatility carriers choose to own aircraft.

The comparative statics depicted in Figure 3 can be useful to understand the entry of lessors in the mid-1980s. Figure 2 documents that the aircraft-leasing business started just a few years after the 1980 Airline Deregulation Act removed controls on entry and exit and deregulated fares. Habib and Johnsen (1999) note: "Anticipating the effect of deregulation, [lessors] appear to have invested substantial resources throughout the 1980s and early 1990s to establish general knowledge of secondary market redeployment opportunities for used aircraft." The Deregulation Act increased competition in airline markets, thereby spurring the entry and exit of carriers, and increasing the volatility of output/profits.[10] Hence, Figure 3 suggests that a more competitive airline industry increases the demand for intermediaries that specialize in the reallocation of aircraft, and this may help explain why the leasing business started when the Deregulation Act was passed.

When leased and owned aircraft coexist in equilibrium, striking differences between them emerge. Specifically, the transaction costs on owned aircraft act naturally as a barrier to selling. Hence, the first testable implication follows:

Proposition 4 *In an equilibrium in which low-volatility carriers own and high-volatility carriers lease aircraft, the distribution function of holding durations of owned aircraft first-order stochastically dominates the distribution function of holding durations of leased aircraft.*

The result of the Proposition is the combination of two effects. The first is the selection of high-volatility carriers into leasing. The second is that the level of productivity that triggers owners to reduce capacity is lower than lessees'—i.e., leased aircraft have higher utilizations than owned aircraft before trading. Hence, owned aircraft trade less frequently. The same two effects also shape the equilibrium cross-sectional distributions of utilizations of leased and owned aircraft. Thus, the second set of testable implications follows:

Proposition 5 *In an equilibrium in which low-volatility carriers own and high-volatility carriers lease aircraft, the distribution function of flying hours of leased aircraft first-order stochastically dominates the distribution function of flying hours of owned aircraft. Hence:*

(i) (Extensive margin) Leased aircraft are parked inactive less frequently than owned aircraft.

(ii) (Intensive margin) Conditional on not being parked, leased aircraft fly more than owned aircraft.

The two effects act as follows. First, in equilibrium, lessee carriers have a higher entry threshold than owners—i.e., in terms of Proposition 3, $z^* \leq l$. Second, owners' wide inaction bands generate a long left tail in their productivity distribution. Instead, leasing's lower trading frictions truncate the left tail of lessees' productivity distribution. In this sense, the transaction cost acts here as, for example, the cost of firing labor acts in the general equilibrium model of Hopenhayn and Rogerson (1993). As a result, Proposition 5 shows that, on average, lessees are more efficient than owners, and, thus, leased aircraft fly more. This difference in efficiency affects both the extensive margin (whether aircraft fly or not) and the intensive margin (conditional on flying, aircraft flying hours). Furthermore, the difference in the lower tails of the productivity distributions also implies that the dispersions of the productivity distributions of owners and lessees differ.

4.4 Discussion

The model focuses in a simple way on a stark trade-off. On one side, the costs of trading leased aircraft are lower than the costs of trading owned aircraft. On the other side, leasing per-period costs are higher. The model generates sharp qualitative insights into the differences in trading and utilization between leased and owned aircraft, distinguishing carriers' selection into leasing and the effects of leasing.

[10] The higher the competition a firm faces, the flatter the marginal revenue curve is. Hence, for a given shock to marginal cost, each firm's output change is bigger in more-competitive markets.

Nonetheless, the model has set aside at least two important aspects of carriers' fleet decisions: vintage effects/replacements of aircraft and carriers' fleet-size choice.

The model assumes that all aircraft are identical and do not depreciate. Hence, carriers trade aircraft because their productivity changes over time. Aircraft depreciation introduces another motive for trade: When the quality of the capital depreciates over time, carriers sell old aircraft to acquire new, more-productive ones. Gavazza (2007) considers an extension to the current model with two aircraft vintages. Under the assumption that the quality of an aircraft and the productivity of a carrier are complements in the production function, Gavazza (2007) shows that more-efficient carriers choose higher-quality aircraft, and they choose to lease in order to replace aircraft at a lower cost when they depreciate. However, Gavazza (2007) also shows that the quantitative importance of these effects is negligible.

Furthermore, the model assumes that each carrier operates, at most, one aircraft. In the literature on aircraft differentiation (Benkard, 2004; and Irwin and Pavcnick, 2005), the assumption of independent purchases by the same carrier is common. This assumption delivers a tractable model, with clear empirical predictions. A more realistic setup would have a carrier with average productivity z and i.i.d. shocks ϵ_j and s_j on each route j it flies, so that a carrier's total output is $\sum_j (z + \epsilon_j) s_j$. Unfortunately, this version of the model is much more complicated to solve analytically, but intuitively it would deliver the additional predictions (confirmed by the data) that more-efficient carriers—i.e., carriers with a higher z—operate more aircraft, and they lease a lower fraction of their fleets, as they can reallocate their aircraft internally without paying transaction costs. However, once we take into account the fundamental indivisibilities involved in long flights and wide-body aircraft—i.e., a flight from New York to London cannot be broken down into two flights—this version of the model would still deliver the main predictions that leased aircraft trade more frequently and fly more than owned aircraft, even within a single carrier.

5 Empirical Evidence: Commercial Aircraft

In this section, I first use data from commercial aircraft to test the main qualitative implications of the model. This analysis closely follows Propositions 4 and 5: Section 5.2 investigates the differences in trading patterns between leased and owned aircraft, and Section 5.3 analyzes the differences in capacity utilization. Finally, Section 5.4 investigates whether the model of Section 4 is quantitatively consistent with the data, calibrating it to match key moments of the data.

5.1 Data

The empirical analysis uses a rich database of commercial aircraft compiled by a producer of computer-based information systems. The database is organized in several different files that classify aircraft and carriers according to different characteristics. I use two files:

1. *Current Aircraft Datafile.* This file has detailed cross-sectional data on all aircraft active in April 2003. This dataset (henceforth, cross-sectional data) reports detailed characteristics of aircraft, such as the type (Boeing 737), the model (Boeing 737-200), the engine, the age, cumulative flying hours, etc.; information related to the period with the current operator, such as the operational role of the aircraft (passenger transportation, freighter, etc.), the date on which the current operator acquired the aircraft, total flying hours, annual flying hours (for the 12-month period between May 2002 and April 2003), etc.; and whether the aircraft is leased or owned by its current operator. If the aircraft is leased, the dataset reports whether the lease is an operating or a capital lease.

The cross-sectional data are complemented by a second file:

2. *Time-series Utilization Datafile.* This file (henceforth, time-series data) reports the flying hours and landings of each aircraft for each month from January 1990 to April 2003.

The data have one limitation: They report whether an aircraft is leased with an operating or a capital lease only in the *Current Aircraft Datafile.* Hence, most of the empirical analysis relies on cross-sectional data. Nevertheless, the cross-sectional data report rich details of each aircraft, including the two outcome variables that are the focus of the model: holding durations and flying hours.[11] This richness of the data implies that, in the empirical analysis, I can control for several features of the asset that are often unobserved in other studies that rely on cross-sectional variations in the data. In addition, I can use carrier fixed-effects to control for unobserved carrier-specific factors that may induce carriers to lease and, thus, distinguish carriers' selection into leasing from the effects of leasing on aircraft trading and utilization.

I apply the following restrictions to the sample. First, I restrict the analysis to wide-body aircraft operated for passenger transportation.[12] I do so because carriers employ wide-body aircraft on long-haul point-to-point flights only, and narrow-body aircraft on shorter flights where carriers' network choice (hub-and-spoke versus point-to-point) affects capacity utilization. Second, in the analysis on capacity utilization, I further restrict the sample to aircraft operated by the same carrier in the period May 2002-April 2003. This restriction is necessary because, in order to eliminate the impact of differential seasonality for different carriers, I use annual hours flown to measure capacity utilization.

Table 1 presents summary statistics, reporting simple averages, but showing stark differences between leased and owned aircraft. Leased aircraft have shorter holding durations and higher capacity utilization than owned aircraft. To appreciate the magnitudes of the differences, the left panel of Figure 4 plots the empirical distribution of the cross-sectional holding durations ongoing as of April 2003 (measured in months), and the right panel plots the empirical distribution of capacity utilization (hours flown in the period May 2002-April 2003). The dashed line represents owned aircraft, while the solid line represents leased aircraft. A standard Kolmogorov-Smirnov test of the equality of distributions rejects the null hypothesis of equal distributions at the one-percent level (the asymptotic p-values are equal to $5.8 * 10^{-37}$ and $1.5 * 10^{-10}$, respectively). Moreover, I also test for first-order stochastic dominance, applying the non-parametric procedures proposed by Davidson and Duclos (2000) and Barrett and Donald (2003). Both tests fail to reject the null hypothesis of first-order stochastic dominance, at least at the one-percent level. Appendix B presents the details of the procedures and the formal results of the tests.[13]

[11] The model assumes that revenues and output are identical, while clearly there are some differences. In any case, the data seem to confirm that they are closely related. For example, at the aggregate level, capacity utilization is highly pro-cyclical, and aircraft are parked inactive in the desert more frequently in recessions than in booms. Similarly, at the carrier level, the data reveal that Southwest has higher capacity utilization than other U.S. carriers, and that capacity utilization is substantially lower before a carrier enters into bankruptcy. Moreover, the inclusion of carrier fixed-effects in the empirical analysis implies that the difference between leased and owned aircraft is identified from variations within carriers. Thus, it is less likely that the other component of revenues—i.e., load factors and prices—vary between leased and owned aircraft within a single carrier.

[12] The database classifies a number of aircraft as "for lease," meaning that they are currently with the lessor. These aircraft are not included in my analysis, for two reasons: 1) I do not know whether these aircraft are available to be operating leased or capital leased; 2) Lessors own freighters and convertible aircraft, too, and the data do not allow me to clearly distinguish between passenger aircraft and freighters when the aircraft are with the lessor. In Subsection 6, I perform several robustness checks that take into account the potential mismeasurement due to this data-coding issue.

[13] As holding durations and utilizations may be correlated within carriers, I have also compared the distributions of the median holding duration and median utilization for each carrier. In this case, too, I accept the null hypothesis of first-order stochastic dominance.

Table 1: Summary Statistics

	Total	Leased	Owned	p-value
Panel A				
Holding Duration (Months)	97.66	61.77	108.31	0
	(76.34)	(58.19)	(77.84)	
Age (Years)	10.80	9.71	11.12	0
	(7.37)	(6.85)	(7.50)	
# Obs	3091	707	2384	
Panel B				
Hours Flown	3349	3710	3257	0
	(1377)	(1294)	(1382)	
Parked (%)	.055	.024	.063	.0002
	(.229)	(.153)	(.245)	
Age (Years)	11.01	9.87	11.30	0
	(6.75)	(6.75)	(7.29)	
# Obs	2846	578	2268	

Notes: This table provides summary statistics of the variables used in the empirical analysis. Panel A presents summary statistics for all aircraft in the sample. This full sample is used in the analysis of holding durations. Panel B presents summary statistics for all aircraft that have been operated by the same carrier during the period May 2002 to April 2003. This restricted sample is used in the analysis of capacity utilization. Holding Duration is the number of months since the carrier acquired the aircraft. Age is the number of years since the delivery of the aircraft. Hours Flown is the number of hours flown by the aircraft during the period May 2002 to April 2003. Parked is a binary variable equal to one if the aircraft has Hours Flown equal to zero, and zero otherwise. The p-value refers to the difference of means between the sample of leased aircraft and the sample of owned aircraft. Standard deviations in parenthesis.

While the evidence is clearly not conclusive, the data uncover patterns consistent with the model. I now develop more-sophisticated empirical strategies to test Propositions 4 and 5.

5.2 Leasing and Aircraft Trading

The previous tests of equality of distributions of holding durations ignore observable aircraft characteristics that could potentially explain the differences between leased and owned aircraft. For example, Table 1 shows that leased aircraft are, on average, younger. Hence, I remove the effect of observable characteristics by regressing holding durations on a set of covariates—the age of the aircraft, aircraft model fixed-effects, engine maker fixed effects, and fixed effects for each maker of the auxiliary power unit. Then, I construct residual holding durations as the regression's residuals. The left panel of Figure 5 presents the empirical distributions of residual durations. The dashed line represents owned aircraft and the solid line represents leased aircraft. Again, the cumulative distribution function of the residual holding durations of owned aircraft first-order stochastically dominates the cumulative distribution function of the residual holding durations of leased aircraft. The average residual duration of owned aircraft is about 34 months longer than the average residual duration of leased aircraft.

In order to test for first-order stochastic dominance, I could compare the distributions of residual

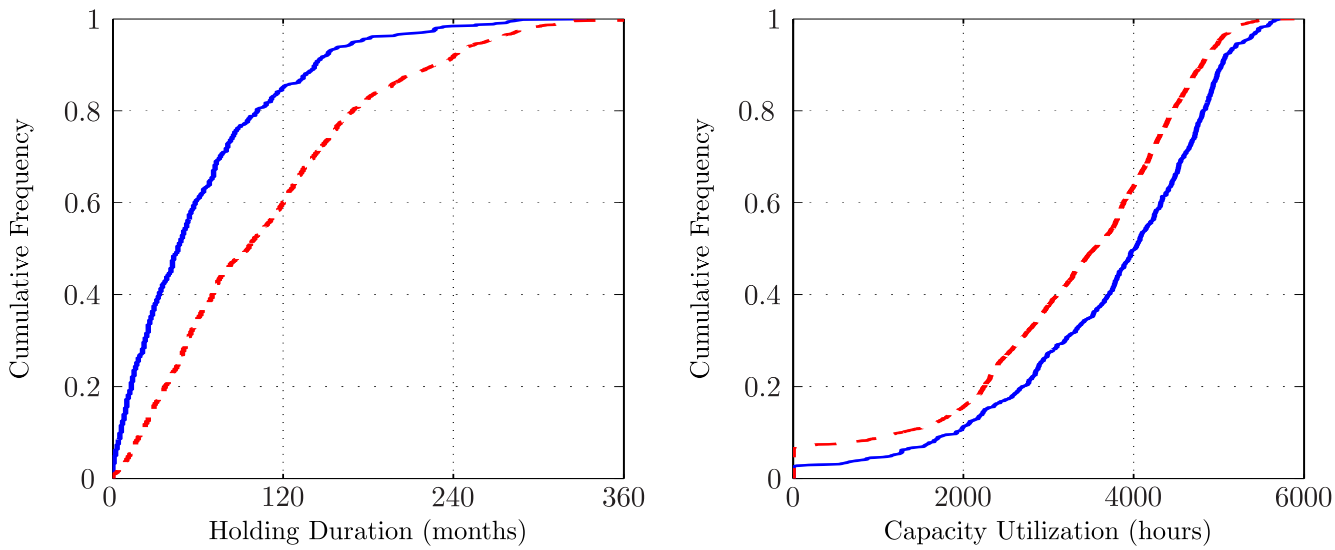


Fig. 4: Empirical cumulative distribution functions of holding durations (left panel) and capacity utilizations (right panel). The dashed line represents owned aircraft, and the solid line represents leased aircraft.

durations using the same tests used in the case of raw holding durations. However, residual durations are not directly observed but, rather, estimated. Hence, I need to take into account the sampling variability when constructing the distributions of the test statistics. Thus, I follow Abadie (2001) and use a bootstrap procedure to compute the p-values of the test statistics. The Kolmogorov-Smirnov test of equality of the distributions rejects the null hypothesis of equal distributions (the bootstrapped p-value is equal to 0). Moreover, the Davidson and Duclos (2000) and Barrett and Donald (2003) tests of first-order stochastic dominance fail to reject the null hypothesis that the distribution of residual durations of leased aircraft first order stochastically dominates the distribution of residuals of owned aircraft, at least at the one-percent level (the bootstrapped p-values are equal to .988 and 1, respectively). Practically speaking, the problem of sampling variability does not seem a major concern because of the rather large sample size of the dataset. Appendix B presents the details of the procedures and the formal results of the tests.

The right panel of Figure 5 plots similar residual durations obtained from a regression that also includes carrier fixed-effects as explanatory variables, in addition to the set of covariates previously listed. These fixed-effects controls for all unobserved carriers' characteristics, thus controlling for carriers' selection into leasing. The average residual durations of owned aircraft is now about 21 months longer than the average residual durations of leased aircraft, or 38 percent. Moreover, the bootstrapped Kolmogorov-Smirnov test of equality of the distributions rejects the null hypothesis of equal distributions (the bootstrapped p-value is equal to 0). The Davidson and Duclos (2000) and Barrett and Donald (2003) tests for first-order stochastic dominance fail to reject the null hypothesis that the distribution of residual durations of leased aircraft first-order stochastically dominates the distribution of residuals of owned aircraft, at least at the ten-percent level (the bootstrapped p-values are equal to .917 and .994, respectively). The formal results of the tests are in Appendix B.

The divergence between the left and the right panel of Figure 5, and between the estimated differences of 34 months versus 21 months when carriers fixed-effects are excluded or included in the regression, respectively, provides evidence for both forces highlighted by the model. Since the difference between leased and owned aircraft decreases when the regression controls for carrier fixed-effects, high-volatility carriers lease a higher fraction of their fleet, consistent with selection. Since the difference between leased and owned aircraft persists when the regression controls for carrier fixed-effects, leasing has an effect on

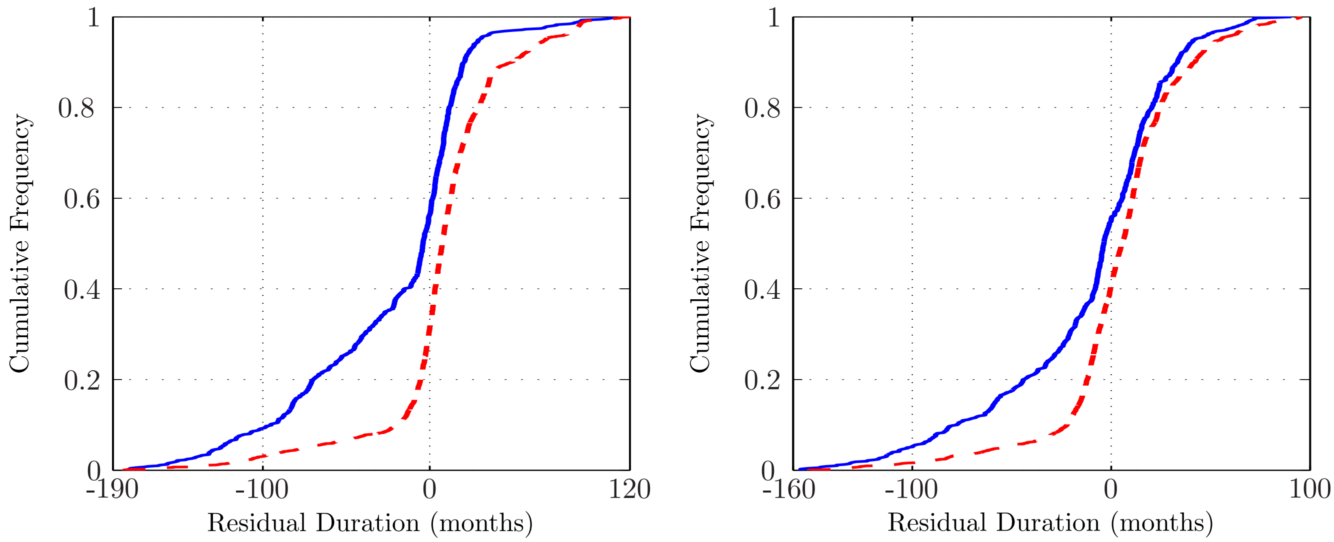


Fig. 5: The left panel depicts the empirical cumulative distribution functions of residual holding durations once observable aircraft characteristics are removed. The right panel depicts the empirical cumulative distribution functions of residual holding durations once observable aircraft characteristics and carrier fixed effects are removed. The dashed line represents owned aircraft, and the solid line represents leased aircraft.

trading independent of carriers' selection. Moreover, the magnitude of the divergence (34 months versus 21 months) suggests that carriers' selection is quantitatively less important than the effect of leasing—i.e., narrower inaction bands.

An additional way to investigate differences in trading frictions is to compare the probability of trading leased and owned aircraft as a function of the their utilization in the year prior to trade. Proposition 5 implies that leased aircraft should have a higher utilization than owned aircraft before trading. To test this implication, I employ the *Time-series Utilization Datafile* to obtain aircraft's hours flown in the period May 2001-April 2002. I then merge these hours flown with the aircraft characteristics from the *Current Aircraft Datafile.* With these merged data, I employ a linear probability model in which the dependent variable is equal to one if the aircraft traded in the period May 2002-April 2003, and zero otherwise. The independent variables are the aircraft characteristics employed in previous regressions—i.e., the age of the aircraft, aircraft model fixed-effects, and fixed-effects for each maker of the auxiliary power unit—plus the hours flown in the period May 2001-April 2002; and a dummy variable equal to one if the aircraft is leased, and zero otherwise.

Table 2 presents the results of four specifications. Specifications (1) and (2) do not include carrier fixed-effects, and specifications (3) and (4) include them. Moreover, in specifications (2) and (4), I interact the hours flown in the period May 2001-April 2002 with an indicator variable equal to one if the aircraft is leased, and zero otherwise. Thus, specifications (2) and (4) allow the previous year's utilization to differentially affect the probability of trading leased and owned aircraft.

The coefficients reported in column (1) indicate that leased aircraft are 13 percent more likely to trade, confirming the prediction of Proposition 4. The coefficients in column (2) further indicate that the difference in the probability of trading a leased aircraft versus an owned one decreases as utilization increases, and it almost disappears for aircraft that are used the most. To appreciate the magnitudes of the coefficients and to capture in a simple way the stark differences in trading probabilities, the left panel of Figure 6 displays the fitted probability of trading for an aircraft with average sample characteristics,

Table 2: Leasing and Probability of Trading

Probability of Trade	(1)	(2)	(3)	(4)
Age	.0021	.0025	.0026	.0028
	(.0011)	(.0011)	(.0011)	(.0011)
Hours Flown in t-1	−.0258	−.0111	−.0173	−.0098
	(.0043)	(.0037)	(.0047)	(.0044)
Hours Flown in t-1*Leased		−.0490		−.0249
		(.0106)		(.0106)
Leased	.1299	.2849	.1150	.1938
	(.0140)	(.0419)	(.0156)	(.0418)
Model Fixed effects	Yes	Yes	Yes	Yes
Carrier Fixed effects	No	No	Yes	Yes
R^2	.130	.145	.325	.328
# Obs	3016	3016	3016	3016

Notes: This table presents the estimates of the coefficients of four specifications of a linear probability model. The dependent variable is equal to one if the operator of the aircraft in May 2002 is no longer operating the aircraft in April 2003, and zero otherwise. Hours Flown in t-1 corresponds to the hours flown during the period May 2001-April 2002. All specifications further include a constant,
fixed-effects for the maker of the engine and fixed-effects for the maker of the auxiliary power unit. Robust standard errors in parenthesis.

obtained from specifications (2) in Table 2.

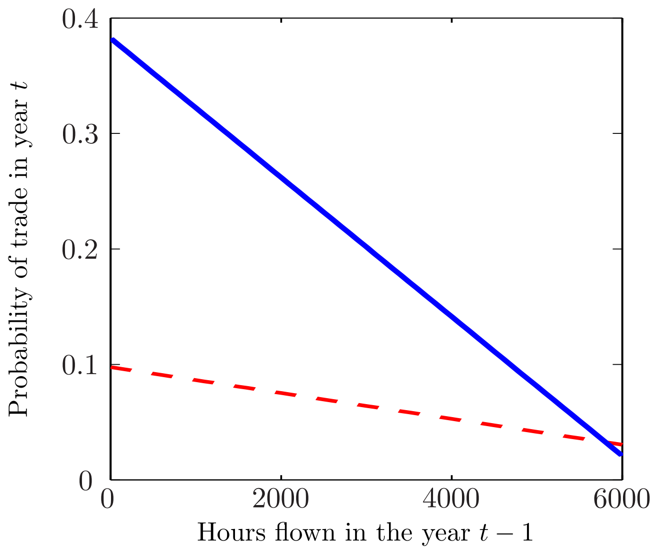
Specifications (3) and (4) indicate that the differences between leased and owned aircraft persist even if carrier fixed-effects are included. The magnitudes are smaller, though, as the right panel of Figure 6 also shows. Overall, specifications (3) and (4) confirm that selection into leasing plays a role, as predicted by the model. However, this selection does not account for all the differences in trading patterns of leased and owned aircraft, reinforcing the idea that carriers are more likely to shed leased aircraft first when their profitability declines.

Moreover, the results of Table 2 and Figure 6 show that the probability of trading an aircraft is a decreasing function of the previous year's utilization. This confirms an additional implication of the model—one that differentiates my model from alternative explanations in which depreciation and replacement are the main motives for trade, or in which differences in utilization between leased and owned aircraft are due to moral hazard. I will come back to these differential implications when I discuss alternative hypotheses and perform robustness checks in Section 6.

5.3 Leasing and Aircraft Utilization

In this section, I investigate whether leased and owned aircraft have different flying hours, directly testing Proposition 5. The empirical model controls for all observable characteristics of the aircraft reported in the cross-sectional data and then uses the residuals of aircraft flying hours as a measure of carriers' efficiency.

Specifically, let X_{ik} be the observable characteristics of aircraft i of model k—the age of the aircraft, aircraft model fixed-effects, engine maker fixed-effects, and fixed-effects for each maker of the auxiliary



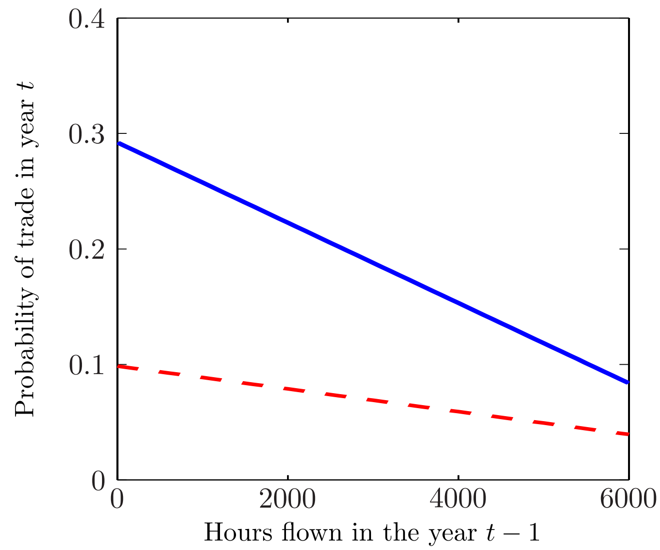


FIG. 6: Probability of trading the aircraft in year t as a function of the utilization in year $t-1$, leased aircraft (solid line) vs. owned aircraft (dashed line). The left and the right panels are based on the coefficients of specifications (2) and (4) of Table 2, respectively.

power unit— and let $z_{ik}s_{ik}$ be the (unobserved) efficiency of the operator. The observable characteristics of aircraft ik and the efficiency of its operator jointly determine flying hours y_{ik} according to:

$$y_{ik} = z_{ik}s_{ik}\exp\left(\beta X_{ik}\right). \tag{1}$$

A salient feature of the data is that aircraft are sometimes parked inactive. Hence, I let the binary variable s_{ik} describe the decision to fly the aircraft or to park it. Thus, flying hours are given by

$$\begin{aligned} y_{ik} &= z_{ik}\exp\left(\beta X_{ik}\right) \quad \text{if } s_{ik}=1 \\ y_{ik} &= 0 \quad \text{if } s_{ik}=0, \end{aligned}$$

where the binary variable s_{ik} derives from the vector of W_{ik} of observable characteristics of aircraft i of model k through the following latent process:

$$\begin{aligned} s_{ik} &= 1 \text{ if } \gamma W_{ik} + \eta_{ik} \geq 0 \\ s_{ik} &= 0 \text{ if } \gamma W_{ik} + \eta_{ik} < 0. \end{aligned}$$

Thus, I observe:

$$y_{ik} = z_{ik}\exp\left(\beta X_{ik}\right) \quad \text{if } \gamma W_{ik} + \eta_{ik} \geq 0 \tag{2}$$

$$y_{ik} = 0 \quad \text{if } \gamma W_{ik} + \eta_{ik} < 0. \tag{3}$$

The empirical model described by equations (2) and (3) is a Heckman (1979)-type selection model. Letting $\epsilon_{ik} = \log z_{ik}$, and assuming that $(\epsilon_{ik}, \eta_{ik})$ are normal random variables with mean zero and covariance matrix

$$\Sigma = \begin{pmatrix} \sigma_\epsilon^2 & \rho\sigma_\epsilon\sigma_\eta \\ \rho\sigma_\epsilon\sigma_\eta & \sigma_\eta^2 \end{pmatrix},$$

I can employ standard results for bivariate normal random variables and estimate the model using either Heckman's two-step procedure (Heckman, 1979; Amemiya, 1985) or maximum likelihood. Since the empirical model depends on σ_η only through $\frac{\gamma}{\sigma_\eta}$, the normalization $\sigma_\eta = 1$ is required.

The estimation of the empirical model given by equations (2) and (3) faces a few econometric challenges. The first concerns the separate identification of the extensive margin—whether to fly the aircraft s_{ik}—and of the intensive margin—the flying hours y_{ik}. More precisely, while the parametric assumption of normality of the error terms guarantees identification, a stronger identification requires that at least one variable included in the vector W_{ik} is excluded from the vector X_{ik}. Finding such an exclusion restriction is traditionally challenging. In the case of aircraft, this restriction requires a variable that affects the costs/benefits of parking the aircraft, but it does not affect the intensive margin of utilization. Aircraft are always parked in warm, dry locations in order to prevent damage to the fuselage and engines. Therefore, the distance of a carrier's headquarters from a warm location is a factor that plausibly affects the fixed costs/benefits of parking the aircraft, but does not affect the marginal costs/benefit of flying the aircraft one additional hour. Thus, I obtain the average latitude of the country where an operator is based. Since the latitude measures the distance from the equator, it is clearly highly correlated with the distance from a warm, dry location. However, the latitude does not vary within a country and within a carrier, so I use (the log of) the latitude interacted with the age of each aircraft ik to obtain a variable that should positively affect whether the aircraft flies, but does not affect how many hours it flies.

The second econometric challenge is a potential endogeneity concern that arises because a carrier's efficiency—the unobservable—could be correlated with the vintage of the aircraft—an observable included in the vector X_{ik}. Specifically, if the vintage of the aircraft and a carrier's efficiency are either complements or substitutes in the output function, carriers self-select and acquire different vintages according to their efficiency, with more- (less-) efficient carriers acquiring younger aircraft if they are complements (substitutes). To solve this potential concern, I use instruments that are correlated with the age of the aircraft, but arguably uncorrelated with a carrier's efficiency—i.e., the unobservable. The instruments draw upon the idea that a carrier chooses a vintage from the distribution of all vintages available at the time it acquired the aircraft. Hence, if all aircraft of a given model are young, a carrier is most likely to acquire a young aircraft. Thus, the instruments exploit two facts: 1) Heterogeneity in the time when different aircraft were acquired and, thus, in the choice set; and 2) the choice is correlated with the choice set. In practice, I use the following two instruments for the age of aircraft ik: 1) the average age of all aircraft of model k in the year in which the operator acquired aircraft ik; and 2) the total number of aircraft of model k existing in the year in which the operator acquired aircraft ik.

Specification (1) in Table 3 reports the estimates of the parameters. The point-estimate of the coefficient of aircraft age in the intensive margin equation is equal to $-.0170$, which indicates that the number of hours flown decreases slowly as aircraft age. The point-estimate of the coefficient of aircraft age in the extensive margin equation is equal to $-.1546$, which, translated into marginal effects, implies that the probability that an aircraft is parked is 0.3-percent higher for an aircraft one year older. Moreover, the interaction between the log of the latitude of the operator's country and the age of the aircraft is positive and significant, as expected. Instead, the estimate of the correlation coefficient ρ is negative, but rather imprecise in specification (1).

In the specification reported in (2), I add carrier fixed-effects to the vectors X_{ik} and W_{ik}. The point-estimate of the coefficient of aircraft age in the intensive margin equation is now equal to $-.0133$, just slightly smaller than the coefficient of specification (1): I cannot reject the hypothesis that they are identical. Similarly, the point-estimate of the coefficient of age in the extensive margin equation is now equal to $-.1827$, which is again similar to—and statistically indistinguishable from—the coefficient of specification (1).

I now use the estimated coefficients reported in Table 3 to obtain measures of carriers' efficiency.

Table 3: Estimates of the Parameters of Equations (2) and (3)

	(1)		(2)	
	Hours Flown	Fly	Hours Flown	Fly
Age	$-.0170$	$-.1546$	$-.0133$	$-.1827$
	(.0044)	(.0384)	(.0046)	(.0413)
Log(Latitude)*Age		.0186		.0222
		(.0087)		(.0094)
σ_ϵ	.5408		.5348	
	(.0476)		(.0478)	
ρ	$-.4512$		$-.9494$	
	(.5690)		(.3592)	
Model Fixed effects	Yes		Yes	
Carrier Fixed effects	No		Yes	
# Obs	2846		2846	

Notes: This table reports estimates of the parameters of equations (2) and (3), obtained using Heckman (1979) two-step procedure. Log(Latitude)*Age is the interaction between the log of the average latitude of the country of the operator of the aircraft, and the Age of the aircraft. The equations in specifications (1) and (2) further contain constant, engine-maker fixed-effects, and auxiliary-power-unit-maker fixed-effects (not reported). Standard errors in parenthesis are obtained bootstrapping the data using 1,000 replications.

More precisely, using equation (1), I calculate carriers' efficiency as:

$$\widehat{z_{ik}s_{ik}} = \frac{y_{ik}}{\exp\left(\beta X_{ik}\right)}.$$

Figure 7 shows the empirical distributions of $\widehat{z_{ik}s_{ik}}$ corresponding to owned and leased aircraft. The left panel corresponds to the efficiency $\widehat{z_{ik}s_{ik}}$ calculated using the parameters of specification (1), and the right panel corresponds to the efficiency $\widehat{z_{ik}s_{ik}}$ calculated using the parameters of specification (2)—i.e., including carriers' fixed-effects in βX_{ik}. The dashed line represents the efficiency of operators of owned aircraft, while the solid line represents the efficiency of operators of leased aircraft. Simple visual inspection shows that lessees' productivity is higher than owners'.

Since efficiency is not directly observed, but estimated, I use a bootstrap procedure to again compute the p-values of the test statistics, as I did for residual durations. Appendix B presents the formal results of the tests. The Kolmogorov-Smirnov test of the equality of distributions rejects the null hypothesis of equal distributions: The bootstrapped p-values are equal to 0 when carrier fixed-effects are not included in the empirical model, and .010 when fixed-effects are included. Moreover, the tests for first-order stochastic dominance proposed by Davidson and Duclos (2000) and Barrett and Donald (2003) fail to reject the null hypothesis that the distribution of lessees' efficiency first-order stochastically dominates the distribution of productivity of owners. The bootstrapped p-values of the Davidson and Duclos test are equal to .958 (without carrier fixed-effects) and .940 (with carrier fixed-effects), and the bootstrapped p-values of the Barrett and Donald test are equal to .989 (without carrier fixed-effects) and .973 (with carrier fixed-effects).

I now employ the estimates of carriers' efficiency to quantify the differences in utilization between leased and owned aircraft highlighted by the model. In particular, I calculate the empirical counterparts

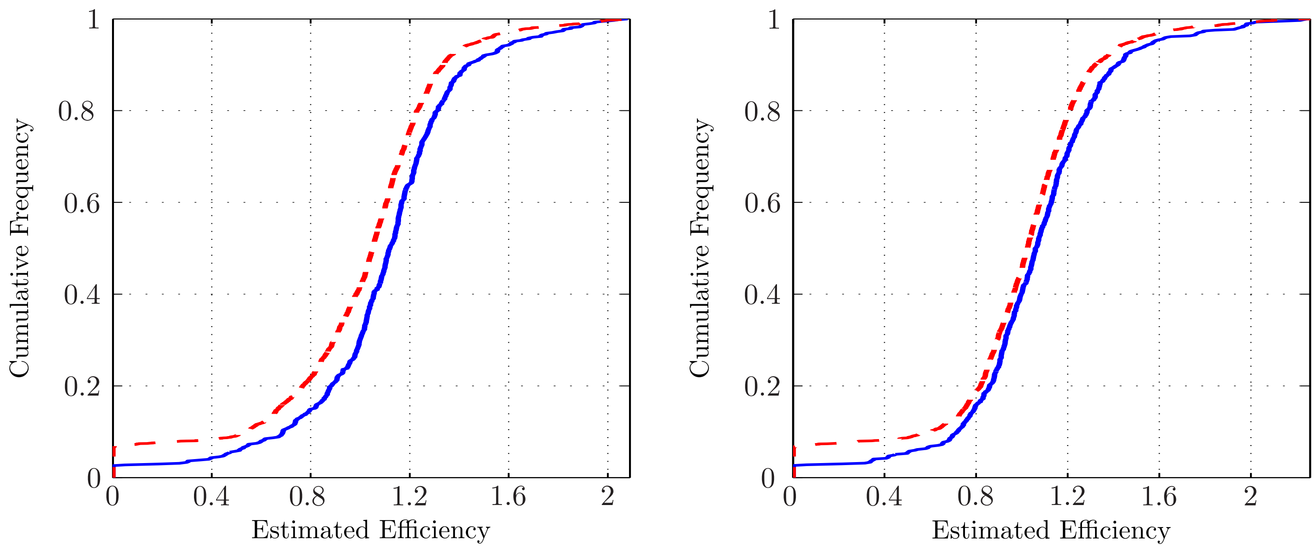


FIG. 7: Empirical cumulative distribution function of estimated efficiency, owners (dashed line) and lessees (solid Line). The left panel depicts the efficiency estimated when carrier fixed-effects are not included, and the right panel depicts the efficiency estimated when carrier fixed-effects are included.

of parts (i) and (ii) of Proposition 5 and, thus, decompose the differences between leased and owned aircraft into separate differences in the intensive and extensive margins. Specifically, let $E(s_L z_L)$ and $E(s_O z_O)$ be the average efficiency obtained from leased aircraft and owned aircraft, respectively. Taking logs, I can express the percentage difference in efficiency between leased and owned aircraft as

$$\log E(s_L z_L) - \log E(s_O z_O) = \log(\Pr(s_L = 1) E(z_L | s_L = 1)) - \log(\Pr(s_O = 1) E(z_O | s_O = 1)). \quad (4)$$

Rearranging the above equation (4), I obtain:

$$\log E(s_L z_L) - \log E(s_O z_O) = \log \Pr(s_L = 1) - \log \Pr(s_O = 1) + \log E(z_L | s_L = 1) - \log E(z_O | s_O = 1).$$

The term $\log \Pr(s_L = 1) - \log \Pr(s_O = 1)$ measures the differences in the extensive margin, and the term $\log E(z_L | s_L = 1) - \log E(z_O | s_O = 1)$ measures the differences in the intensive margin.

Table 4 quantifies and decomposes the difference between leased and owned aircraft. Columns (1) and (2) correspond to specifications (1) and (2), respectively, in Table 3.[14] Table 4 shows that the difference between leased and owned aircraft is equal to 6.5-7.8 percent of output. The intensive margin accounts for approximately 75 percent of the total difference, and the extensive margin accounts for the remaining approximately 25 percent. The divergence between columns (1) and (2) of Table 4 provides further evidence for both forces highlighted by the model. Moreover, columns (1) and (2) of Table 4 show that carriers' selection, captured by carriers' fixed-effects, accounts for a smaller fraction of the observed difference between leased and owned aircraft in capacity utilization, indicating that the effect of leasing is quantitatively more important than carriers' selection.

5.4 Calibrating the Model

In this Section, I investigate whether the model in Section 4 is quantitatively consistent with the data, calibrating it to match key moments of the data.

[14] The term $\log \Pr(s_L = 1) - \log \Pr(s_O = 1)$ is calculated as $(\log E(s_L = 1) - \log E\Phi(\gamma W)) - (\log E(s_O = 1) - \log E\Phi(\gamma W))$ to take into account the differences in observable characteristics between leased and owned aircraft.

Table 4: Differences in Utilization between Leased and Owned Aircraft

			(1)	(2)
Total	$\log E(s_L z_L) - \log E(s_O z_O)$	=	.0783	.0649
			(.0158)	(.0222)
Extensive Margin	$\log \Pr(s_L = 1) - \log \Pr(s_O = 1)$	=	.0198	.0206
			(.0056)	(.0059)
Intensive Margin	$\log E(z_L \mid s_L = 1) - \log E(z_O \mid s_O = 1)$	=	.0584	.0442
			(.0152)	(.0218)

Notes: This table reports the estimated differences in efficiency between leased and owned aircraft. The magnitudes reported in Columns (1) and (2) are calculated using the parameters of specifications (1) and (2), respectively, in Table 3. Standard errors in parenthesis are obtained by bootstrapping the data using 1,000 replications.

This calibration faces some challenges. Although the model is highly non-linear, so that all parameters affect all outcomes, the identification of some key parameters is problematic. More precisely, the mass of assets X determines the optimal buying/selling thresholds of owners and lessees (this is easy to see, for example, from the equilibrium of the frictionless benchmark—i.e., Proposition 1). In turn, for any value of the other parameters, these thresholds determine aircraft's holding durations and utilizations. Unfortunately, the data do not allow me to pin down the value of X. Similarly, the data do not provide any direct evidence on the level of monitoring costs. We can only infer that these costs belong to a certain range—i.e., they are not zero and not infinitely large—such that certain carriers choose to lease and others choose to own aircraft. For these reasons, I view this calibration as an investigation on whether the model is quantitatively consistent with the data, rather than an estimation of its structural parameters.

With the previous caveats in mind, I proceed by fixing the value of the interest rate to $r = .03$. (It is well known that the discount factor/interest rate are difficult parameters to calibrate in the data). I further assume that $F(z)$ is normal with mean $E(z)$ and standard deviation $St.Dev.(z)$ to be calibrated. Then, I choose the parameters $(X, \omega, \alpha_\ell, \alpha_h, \mu, \lambda, E(z), St.Dev.(z), \tau, m)$ so that the moments computed from the model are as close as possible to the moments in the data reported in Table 5. Panel B of Table 5 reports the implied parameters, and column (2) of Panel A reports the moments computed from the model at those parameters.

Overall, the model matches the data reasonably well: On average, the difference between the empirical and the theoretical moments is less than 13 percent. The transaction cost parameter τ is equal to approximately 15 percent—a non-trivial magnitude—and the monitoring cost parameter m is equal to approximately 2.7 percent. The parameters α_ℓ and α_h imply that the productivity of high-volatility carriers varies every 35.7 months $(\approx 12/\alpha_h)$, and the productivity of low-volatility carriers varies every 40.5 months $(\approx 12/\alpha_\ell)$. The difference is less than five months, small compared to the empirical difference in holding durations between leased and owned aircraft. This confirms that selection does not play a large role in explaining the empirical results of Section 5.2. Similarly, the parameters imply that the equilibrium entry threshold of owners is equal to $z^* = 1224$, and the entry threshold of lessees is equal to $l = 1281$. Hence, if owners had inaction bands as wide as lessees' and, thus, selection was the only difference between lessees and owners, then owners' average hours flown would be $E(y|z \geq z^*, s = 1) = 3272$, while lessees' would remain $E(y|z \geq l, s = 1) = 3329$. This small difference further corroborates that selection is a minor factor driving the empirical results of Section 5.3.

As mentioned, the parameters of Table 5 rely on several assumptions. Unfortunately, some of these

Table 5: Moments and Parameters of the Calibration

Panel A: Moments	(1) Data	(2) Model
Average Holding Duration (Months), Owned Aircraft	108.31	100.56
Average Holding Duration (Months), Leased Aircraft	61.77	55.80
St. Dev. Holding Duration (Months), Owned Aircraft	77.84	95.16
St. Dev. Holding Duration (Months), Leased Aircraft	58.19	51.24
Average Hours Flown, Owned Aircraft	3257	2728
Average Hours Flown, Leased Aircraft	3710	3329
St. Dev. Hours Flown, Owned Aircraft	1382	1827
St. Dev. Hours Flown, Leased Aircraft	1294	1610
Parked Aircraft (%), Difference Owned-Leased	3.9	3.8
Leased Aircraft (%)	22.8	23.0

Panel B: Parameters	
X	0.4958
ω	0.2835
α_h	0.3358
α_ℓ	0.2962
μ	0.0277
λ	0.4531
$E(z)$	767.42
$St.Dev.(z)$	2833.7
τ	0.1583
m	0.0267

Notes—This table contains details of the calibration of model parameters. Column (1) in Panel A reports the moments of the data that the model seeks to match. Column (2) in Panel A reports the corresponding moments computed from the model with the parameters reported in Panel B.

assumptions are not directly testable with the available data. For that reason, I view these parameters as suggestive. Nonetheless, the magnitudes of these parameters do not seem unreasonable. An interesting conclusion that emerge from the calibration is that small differences in carriers' volatilities can lead to larger differences in trading and utilization between leased and owned aircraft.

6 Alternative Explanations and Robustness Checks

The results of the previous empirical analysis provide strong evidence that the trading and utilization patterns of leased and owned aircraft differ systematically, as Propositions 4 and 5 predict. I now consider several alternative hypotheses and perform some robustness checks. The analysis confirms and strengthens the previous findings.

6.1 Selection into Leasing

In the theoretical model, high-volatility carriers lease and low-volatility carriers own aircraft. I now investigate whether different potential motives behind carriers' decision to lease could provide a coherent alternative explanation of all the empirical results.

6.1.1 Persistence of Productivity

The model assumes that, when a carrier's productivity changes over time, its new productivity is independent of the previous one. If more-productive carriers receive better productivity draws in the future, then they should have longer expected holding periods. Thus, they may choose to purchase rather than lease because they can spread the transaction costs over a longer holding period. Hence, this alternative hypothesis could explain the difference in holding durations and trading frequencies between leased and owned aircraft. However, additional patterns in the data speak against this alternative hypotheses.

The first argument against this type of selection is that the analysis in Section 5.2—Table 2 and Figures 5-6, in particular—shows that the substance of the results on holding periods is unchanged when carriers' fixed-effects are included in the estimation. Hence, an alternative hypothesis based on differences across carriers cannot explain the observed differences in holding durations between leased and owned aircraft within carriers.

Second, this alternative hypothesis suggests that owners' productivity may be higher than lessees'. However, the analysis in Section 5.3—Figure 7 and Table 4, in particular—shows that exactly the opposite is true. Moreover, the results are almost identical with or without carriers' fixed-effects.

Third, this selection based on productivity implies that the upper tails of the productivity distributions should differ, with owners' distribution first-order stochastically dominating lessees' distribution. Figure 7 shows that the two distributions move almost parallel after the initial difference at low levels of productivity, and the difference does not reverse at high productivity levels, as this alternative hypothesis requires. More formally, Appendix B shows that, when restricting the analysis to the top 15 percent of carriers' productivities, a Kolmogorov-Smirnov test of the equality of distributions does not reject the null hypothesis of equal distributions (the bootstrapped p-value is equal to .131); and the Davidson and Duclos (2000) and Barrett and Donald (2003) tests of first-order stochastic dominance reject the null hypothesis of first-order stochastic dominance (the bootstrapped p-values are equal to .474 and .455, respectively).

6.1.2 Replacement of Aircraft

An alternative hypothesis is that the most-productive carriers select leasing because it allows them to replace their aircraft at lower costs when they depreciate. This explanation acknowledges that trading frictions are lower for leased aircraft—as this paper posits—but claims that replacement is the main motive for trade. Thus, the argument is that the most-productive carriers choose to lease aircraft and trade them more frequently in order to replace them. Moreover, since productive carriers select into leasing, leased aircraft fly more than owned ones. However, several patterns in the data are inconsistent with this explanation.

First, according to this explanation, replacement is the main motive for trade. However, Table 2 and Figure 6 are inconsistent with this supposition. As noted in Section 5.2, the table and the figure show that the probability of trading an aircraft is a decreasing function of previous year's utilization. If replacement were the main motive for trade, the probability of trading an aircraft should be an increasing function of the previous year's utilization. Furthermore, if carriers selected leasing to replace aircraft, the probabilities of trading a leased and an owned aircraft should diverge as previous utilization increases, as high productivity implies high utilization. Table 2 and Figure 6 show that this is not the case.

The second argument against selection comes again from the analysis of the cumulative distribution functions of lessees' and owners' efficiency in Figure 7. This type of selection again implies that the difference in the distributions should be concentrated in the upper tail of the distribution. However, we have already highlighted that the two distributions move almost parallel after the initial difference at low productivity levels, that the difference does not grow larger as productivity increases, and that formal tests reject the null hypothesis of first-order stochastic dominance in the upper tails of the distributions.

The third argument against this type of selection is that Tables 2-4 and Figures 5-7 show that the substance of the results is identical when carriers' fixed-effects are included in the estimation. Hence, any carrier-specific factor cannot explain the observed differences between leased and owned aircraft hold.[15]

6.1.3 Financing Constraints

A few papers suggest that leasing relaxes financing constraints (Sharpe and Nguyen, 1995; Eisfeldt and Rampini, 2009). The insightful analysis of Eisfeldt and Rampini (2009) explains the key economic mechanism. Since leasing enjoys stronger claims than secured lending, lessors can extend more credit than secured lenders can. However, leasing generates agency problems because it separates ownership and control of assets. As a result of this trade-off, more-credit-constrained firms lease more of their capital.

The focus of these papers on leasing and financing frictions differs slightly from the focus here. They are interested primarily in firms' decision to lease, while this paper focuses also on the effects of leasing on aircraft trading and utilization. In aircraft markets, it is certainly true that, in the initial stages, operating lessors were mainly buying surplus second-hand aircraft from carriers and leasing them to other carriers, particularly those with poor access to debt and equity markets. Moreover, Benmelech and Bergman (forthcoming) find that airlines in countries with poor creditor rights are more likely to lease than to own aircraft, consistent with the idea that leasing allows firms to alleviate some of the financial frictions associated with debt financing. Hence, the question arises: Is it likely that financing constraints alone explain all the observed differences between leased and owned aircraft?

In my view, the answer is no, for at least two reasons. First, explanations based on financing frictions do not have joint predictions for assets' trading and utilization patterns. Instead, the data clearly show that leased aircraft trade more frequently and fly more. Second, all the empirical results are robust to the inclusion of carrier fixed-effects, while financing frictions are constant within a carrier. Hence, financing frictions do not explain the differences between leased and owned aircraft documented in Tables 2-4 and Figures 5-7, which persist once carrier fixed-effects are included in the regressions.

As emphasized in Section 3, the ideas that leasing relaxes financing constraints and that leasing facilitates asset reallocation seems complementary. Eisfeldt and Rampini (2009) suggest that leasing is particularly attractive to financially-constrained operators, and these operators often have volatile capacity needs. Hence, lessors frequently get aircraft returned, which leads them to further specialize in redeployment. This specialization explains the patterns in trading and utilization that are the focus of this paper.

[15] An additional argument comes from the comparison of two aircraft, one leased and one owned, at different points during the holding duration. If selection is driving the results, the difference in output is concentrated in the first periods of duration. Instead, if stochastic profitability is driving the results, the output difference between leased and owned aircraft increases over time as carriers operate the aircraft. The data suggest that the differences in output are negligible at the time carriers acquire the aircraft, and grow large over time, as the model predicts. See Gavazza (2007).

6.1.4 The Role of Taxation

Several papers suggest that leasing provides taxation advantages to the contracting parties, and they investigate how taxes affect corporate leasing policies (Miller and Upton, 1976; Myers, Dill and Bautista, 1976; Graham, Lemmon and Schallheim, 1998). The idea is that leases allow for the transfer of tax shields from firms that cannot fully utilize the associated tax deduction (lessees) to firms that can (lessors).

However, it is unlikely that taxes explain all the observed differences between leased and owned aircraft. First, Babcock and Bewsher (1998) note that in an operating lease, "any tax benefits are normally incidental." Second, it is not clear why there is a substantial mix of leased and non-leased assets. If leasing were so favorable from a taxation perspective, we should probably expect all aircraft to be leased. Third, if leasing gives carriers a tax advantage, then it is not clear why carriers are more likely to shed leased aircraft first. Fourth, Gavazza (2010) shows that there is considerable variation in the fraction of different aircraft types leased, and taxation advantages (if any) will not depend on aircraft type. Fifth, any tax benefit would be specific to a lessee, and would not vary within a carrier. Hence, in the empirical analysis, these advantages would have been picked up by carrier fixed-effects and would not be able to explain the observed variation between leased and owned aircraft within carriers. For these reasons, it is unlikely that taxes invalidate the tests of my hypotheses.

6.2 Quality Differentials and Adverse Selection

The literature on durable goods highlights the role of quality differentials and depreciation in explaining patterns of trade. The literature makes different predictions if parties have symmetric versus asymmetric information on the asset's quality. Hendel and Lizzeri (1999b) and Stolyarov (2002) show that, under symmetric information, lower-quality goods should trade more frequently. Since section 5.2 shows that leased aircraft trade more frequently, we must infer that leased aircraft are of lower quality. Then, however, it is difficult to explain why leased aircraft fly more than owned ones. Moreover, Pulvino (1998) clearly rejects the hypothesis that, conditional on observable characteristics such as age, lower-quality aircraft trade more than higher-quality ones. Thus, theories of quality differentials under symmetric information cannot explain the observed patterns.

Under asymmetric information, higher-quality durable goods trade more frequently (Hendel and Lizzeri, 1999a), in contrast with Akerlof's (1970) original analysis. Hence, we must conclude that leased aircraft are of higher quality. This explanation might seem to explain the empirical differences between leased and owned aircraft. In principle, adverse selection could be thought as a cost captured in a reduced-form way by the transaction costs. However, several institutional features of aircraft markets and a closer look at the data show that this explanation is unlikely to account for all observed patterns. First, the aviation authorities regulate aircraft maintenance: After a fixed number of hours flown, carriers undertake compulsory maintenance. This suggests that quality differences cannot be too high. Moreover, Pulvino (1998) rejects the hypothesis that unobserved quality differentials among aircraft explain trade patterns. Furthermore, maintenance records are readily available, and all parties can observe the entire history of each aircraft. In addition, all transactions involve a thorough material inspection of the aircraft. This suggests that asymmetries of information cannot be too large. Second, Hendel and Lizzeri (2002) present a model of leasing under adverse selection. In their framework, leased durable goods trade more frequently because high-valuation individuals select leasing, as they want to replace the durables more frequently. However, as I discuss extensively in Section 6.1.2, many patterns in the data are inconsistent with this type of selection. In particular, the data show that the main motive for trade is to reduce/increase capacity, not to replace it. Thus, the reason why individuals/firms lease an asset in

Hendel and Lizzeri's model does not seem to apply to the aircraft market. Third, from another file in the main database, I can isolate aircraft involved in sale-leaseback transactions—transactions in which the carrier initially owns the aircraft, then sells it and simultaneously leases it back from a lessor—or aircraft that were once owned by a carrier and are currently owned by a lessor. Presumably, the quality of these aircraft did not change with the type of ownership. However, these aircraft exhibit differences in trading patterns between the periods in which they were owned and the periods in which they were leased that are almost identical to the trading patterns in the cross-sectional data.

6.3 Moral Hazard

Another potential explanation of the empirical results is moral hazard: Carriers abuse leased aircraft because they do not own them (Johnson and Waldman, forthcoming). However, several other features of the data and institutional details about the aircraft market and airline business are at odds with moral hazard. First, moral hazard arises from unobservability (or non-contractibility) of actions. Here, all parties clearly observe the utilization of the aircraft: I observe how much the aircraft are used, and lessors and lessees observe utilization, too. Second, leasing contracts are contingent on aircraft utilization (hours flown and landings). Third, if moral hazard were a severe problem for aircraft, then we would probably not observe aircraft being leased at all (Smith and Wakeman, 1985; Williamson, 1988). Fourth, leased aircraft trade more frequently than owned aircraft. If carriers can abuse leased aircraft, it is not clear why they trade them more than owned aircraft. Under moral hazard, the opposite should be true—i.e., leased aircraft should trade less frequently than owned aircraft. Fifth, under moral hazard, carriers always have the incentive to fly leased aircraft more than owned ones. Thus, aircraft utilization distributions should differ in both the upper and lower tails. In contrast, Figure 7 and Appendix B show that only the lower tails differ. Sixth, the incentives to abuse a leased aircraft should be stronger if a lessee expects to return rather than keep the aircraft. However, Figure 6 shows that this not the case: Lessees are more likely to return aircraft that are used *less* than those that they keep. Similarly, Figure 6 shows that the differences in trading probabilities between leased and owned aircraft are highest for aircraft that are parked inactive and lower for aircraft that are used the most. Under moral hazard, I would expect exactly the opposite.

6.4 Time between Consecutive Lessees

One potential concern with the empirical results is that the analysis neglects the fact that leased aircraft return to the lessors between consecutive lessees. When a lease expires and the aircraft returns to the lessor, the data report this transaction. While in most cases the lessor immediately transfers the aircraft to another lessee, the aircraft sometimes might stay with its lessor for some time between consecutive lessees. If these periods between lessees were frequent and lengthy, the differences in trading patterns and the differences in utilization could be mismeasured. Similarly, the literature on investment (e.g., Cooper and Haltiwanger, 1993 and 1999; Caballero and Engel, 1999) traditionally assumes that firms must shut down operations for a fixed period when adjusting their capital stock. If there is a loss in output during this adjustment period, the estimated output gains could be overestimated.

To address this concern, I use another datafile in the database that reports the historical sequence of operators of each aircraft, with the relevant dates. From this database, I can recover the precise date on which each leased aircraft returned to the lessor before being transferred to its current operator/lessee, as reported in the cross-sectional data, and construct the time since the previous lease. Delays between leases are short—the average delay between consecutive lessees in this sample is only 28 days—which is

Table 6: Robustness check 1: Leasing and Time since Previous Operator

Time Since Previous Operator	(1)	(2)
Age	8.689	8.856
	(.292)	(.268)
Leased	−33.266	−20.208
	(2.401)	(2.319)
Model Fixed Effects	Yes	Yes
Carrier Fixed Effects	No	Yes
R^2	.589	.684
# Obs	3091	3091

Notes: This table presents the OLS estimates of a robustness check of the results on the differences in holding durations between leased and owned aircraft reported in Section 5.2. The dependent variable Time Since Previous Operator is the number of months since the aircraft was operated by a different per-passenger carrier than the carrier operating it in April 2003. The equations in specifications (1) and (2) further contain a constant, engine maker fixed effects, and auxiliary power unit maker fixed effects (not reported). Robust standard errors in parenthesis.

further evidence that lessors are quick at redeploying aircraft. As a result, the difference between holding durations (the variable reported in Table 1 and used in Section 5.2) and the time since the previous operator is less than a month for leased aircraft.

Table 6 presents the results of a regression of the time since the previous operator on a set of covariates—the year in which the aircraft was built, aircraft model fixed-effects, engine-maker fixed-effects, and fixed-effects for each maker of the auxiliary power unit. The regression is identical to those used to construct the residuals plotted in Figure 5. Table 6 shows that the results are robust to this concern. The coefficient on the leased dummy in column (1) indicates that leased aircraft have holding durations 33 months shorter than owned aircraft, only one month shorter than the 34 months reported in Section 5.2. Similarly, the specification of column (2) adds carrier fixed-effects, and the coefficients imply that leased aircraft have holding durations 20 months shorter than owned aircraft, which is, again, almost identical to the difference previously reported.

I also checked the robustness of the results on utilization to the concerns of potential mismeasurement. Specifically, the cross-sectional dataset reports each aircraft's cumulative hours flown since the delivery date, and I use the log of this variable as the dependent variable in a regression equation similar to equation (1). This regression may not perfectly measure differences between leased and owned aircraft since the dataset reports the ownership type—i.e., leased or owned—only in the cross-sectional data, and an aircraft's ownership type could change throughout its "life." Nonetheless, the regression would cast doubt on the validity of the estimated gains if owned aircraft had higher cumulative hours flown than leased aircraft. Column (1) of Table 7 shows that this is not the case: On average, leased aircraft have 6.1 percent more cumulative hours flown than owned ones. Moreover, because, as mentioned, the ownership type appears only in the cross-sectional data, I restrict the sample to aircraft younger than ten years of age in the specification of Column (2). It is more likely that these young aircraft have been leased since their first flight. Column (2) shows that the results are almost identical: In this subsample, leased aircraft have 7.6 percent more cumulative hours flown than owned ones.

Table 7: Robustness check 2: Leasing and Average Cumulative Hours Flown

log(Cumulative Hours Flown)	(1)	(2)	(3)	(4)
Age	.2265	.4769	.3286	.3369
	(.0077)	(.0157)	(.0144)	(.0153)
Age Squared	−.0044	−.0241	−.0072	−.0078
	(.0002)	(.0012)	(.0004)	(.0004)
Leased	.0610	.0764	.0660	.0627
	(.0139)	(.0166)	(.0276)	(.0319)
Model Fixed Effects	Yes	Yes	Yes	Yes
Carrier Fixed Effects	No	No	No	Yes
R^2	.833	.763	.690	.731
# Obs	2846	1434	3226	3226

Notes: This table presents the OLS estimates of a robustness check of the results on the differences in capacity utilization between leased and owned aircraft reported in Section 5. The dependent variable log(Cumulative Hours Flown) is the total number of hours flown since the delivery date of the aircraft. The sample of specification (1) is identical to the sample used in Table 3. The sample of specification (2) is restricted to all aircraft in the sample of specification (1) that are younger than ten years of age. The sample in specifications (3) and (4) additionally includes all aircraft that were acquired by a carrier between May 2002 and April 2003, and all aircraft reported available "for lease" in April 2003. See footnote 12 for a definition of "for lease" aircraft. The equations in specifications (1) to (4) further contain a constant, engine-maker fixed-effects, and auxiliary-power-unit-maker fixed effects (not reported). Robust standard errors in parenthesis.

The sample in Column (1) is identical to the sample employed in the specifications of Table 3. Hence, the sample excludes all aircraft acquired by a carrier between May 2002 and April 2003 and all aircraft that are reported available "for lease" in April 2003 (See Section 5.1 and footnote 12 for the reasons of these exclusions). To check the robustness of the results to these exclusions, I repeat the regression of Column (1) including these aircraft in the sample. The leased dummy is now equal to one if the aircraft is owned by an operating lessor, and zero otherwise.[16] Column (3) reports the results of this regression. The results are almost identical to those in Column (1), indicating that the sample restriction has no substantive effect on the estimates. Specification (4) further adds current carrier fixed-effects to the regression equation, and again the results are almost identical. In summary, Table 7 shows that the estimate of the difference between leased and owned aircraft is robust to potential biases from the sample selection, including the mismeasurement arising from periods of inactivity between consecutive lessees.

Furthermore, the results reported in Table 7 also show that the output differences between leased and owned aircraft are stable over time. The cross-sectional data correspond to a period—i.e., April 2002-March 2003—that coincides with large upheavals in the airline industry. Table 7 indicates that the empirical results are not specific to these 12 months, but are robust across different time periods.

[16]The fraction of aircraft owned by lessors that has been parked for a period longer than one year is 5.69 percent. The corresponding fraction for owned aircraft is 6.39 percent.

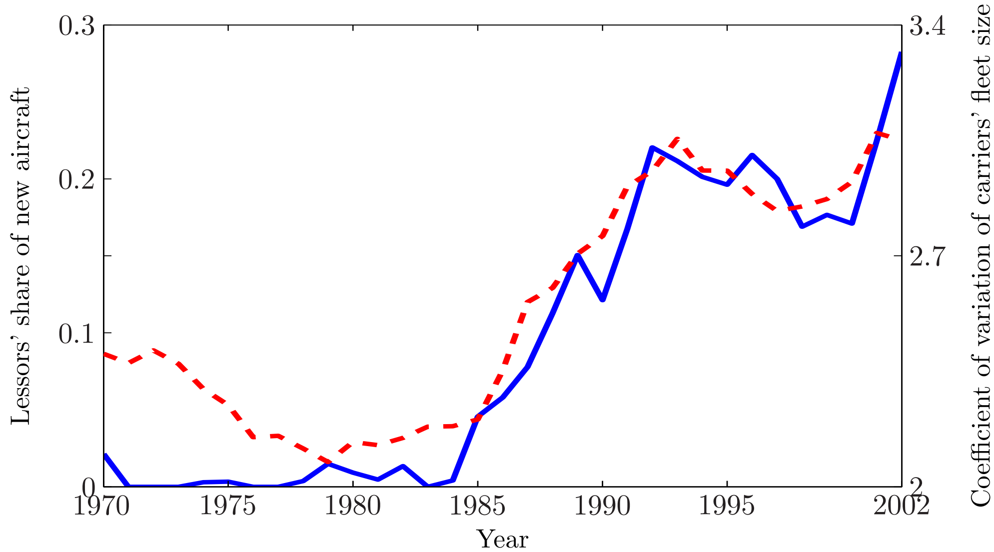


FIG. 8: Share of new narrow-body and wide-body aircraft acquired by lessors (solid line) and coefficient of variation of carriers' fleet size (dashed line), 1970-2002.

7 Concluding Remarks

The goal of this paper was to examine the link between the efficiency of aircraft transactions in secondary markets and the efficiency of production of final output—i.e., flights. I argued that aircraft lessors operate as intermediaries that reduced frictions in aircraft trading, and I constructed a model of trading in durable capital to understand the role of lessors when trading is subject to frictions. I then used a rich dataset on commercial aircraft to provide empirical evidence on the two main implications of the model: 1) leased aircraft trade more frequently than owned aircraft; and 2) leased aircraft have a higher capacity utilization than owned aircraft.

The results support the notion that when transaction costs prevent the efficiency of allocation via decentralized trade, firms have an incentive to develop institutions and adopt contractual arrangements that reduce these inefficiencies. The empirical analysis reveals a considerable gain due to the particular institution analyzed—i.e., aircraft leasing.

As noted in the Introduction, the aircraft-leasing business started just a few years after the Airline Deregulation Act. I suggested that greater competition as a result of the Act increased the importance of aircraft reallocation, and, therefore, the need for trading intermediaries became stronger. The change in market structure also had an effect on the fragmentation of airline markets, with consolidations, mergers and the emergence of a number of smaller carriers serving new markets. Aircraft leasing probably also emerged in response to the entry of these new carriers, and their entry was likely facilitated by the institution of aircraft leasing. In Figure 8, I superimpose the annual coefficient of variation of fleet size to the fraction of new aircraft bought by lessors, as in Figure 2. The two series are highly correlated. How aircraft leasing affects airline fleet compositions and airline market structures are interesting questions left for future research.

APPENDICES

A Aircraft Leasing

First used in the mid-1970s by ILFC, an aircraft lessor, the operating lease became popular in the mid-1980s after airline deregulation in the United States and Europe (Habib and Johnsen, 1999; Gavazza, 2010). The largest lessors are GECAS and ILFC, and not the aircraft manufacturers—Boeing and Airbus—even though both have recently established trading and leasing divisions.

Another type of leasing contract exists—i.e., the capital lease. In a typical capital lease, the lease terms are longer—usually over twenty years—and the lease transfers ownership of the aircraft to the lessee at the end of the lease term, so it is, in effect, a way of financing the purchase of the equipment. In the empirical analysis in Section 5, aircraft under a capital lease are pooled with owned aircraft. Gavazza (2010) empirically investigates some differences between operating and capital leases.

In a typical operating lease, the lessor rents the aircraft to a carrier for a period that is significantly shorter than the life of the aircraft—usually between four and eight years—while retaining ownership of the aircraft. The lease payments have a fixed monthly rate plus a variable fee contingent on the utilization of the aircraft (flying hours and landings). Most leases are on a "net" basis, with the lessee responsible for all operating expenses. In addition, the lessee is responsible for normal maintenance and repairs, airframe and engine overhauls, and compliance with return conditions of flight equipment on lease. Under the provisions of some leases, the lessor contributes to the cost of certain airframe and engine overhauls. Lessors require their lessees to comply with the standards of either the United States Federal Aviation Administration or its foreign equivalent. Lessors make periodic inspections of the condition of their leased aircraft. These facts suggest that informational asymmetries between lessor and lessee play a minor role in the case of aircraft.

B Tests of First-Order Stochastic Dominance (FOSD)

Let X_Z and X_W be random variables with corresponding cdfs $G_Z(\cdot)$ and $G_W(\cdot)$. $G_Z(\cdot)$ first-order stochastically dominates $G_W(\cdot)$ if

$$\begin{aligned} G_Z(x) &\leq G_W(x) \text{ for all } x \text{ and} \\ G_Z(x) &< G_W(x) \text{ for some } x. \end{aligned}$$

Let the empirical distributions be defined by

$$\widehat{G}_i(x) = N_i^{-1} \sum_{j=1}^{N_i} 1\{X_i \leq x\} \text{ for } i = Z, W$$

where $1\{\cdot\}$ denotes the indicator function, and N_i are the number of observations from distribution G_i. Using the empirical cdfs, I perform tests of the hypotheses:

$$G_Z(x) = G_W(x), \forall x \in R \tag{5}$$

and

$$G_Z(x) \leq G_W(x), \forall x \in R. \tag{6}$$

The test of (5) is conducted using the familiar Kolmogorov-Smirnov test statistics:

$$S_1 = \left(\frac{N_Z N_W}{N_Z + N_W}\right)^{1/2} \sup_a \left|\widehat{G}_Z(a) - \widehat{G}_W(a)\right|. \tag{7}$$

The test of (6) is conducted using the procedure introduced by Davidson and Duclos (2000). They show that we can make use of a predetermined grid of points a_j for $j = 1, ..., m$ and construct the t statistics

$$t(a_j) = \frac{\widehat{G}_Z(a_j) - \widehat{G}_W(a_j)}{\sqrt{\frac{\left(\widehat{G}_Z(a_j) - \widehat{G}_Z(a_j)^2\right)}{N_Z} + \frac{\left(\widehat{G}_W(a_j) - \widehat{G}_W(a_j)^2\right)}{N_W}}} \tag{8}$$

to test H_1 (dominance) against H_2 (no restriction). The hypothesis H_1 is rejected against the unconstrained alternative H_2 if any of the t statistics is significant with the positive sign, where significance is determined asymptotically by the critical values $d_{\alpha,m,\infty}$ of the Studentized Modulus (SMM) distribution with m and infinite number of degrees of freedom at the $\alpha\%$ confidence level. In practice, this implies that we fail to reject the hypothesis of $G_Z(\cdot)$ first-order stochastically dominating $G_W(\cdot)$ if

$$\begin{aligned} -t(a_j) &> d_{\alpha,m,\infty} \text{ for some } j \text{ and} \\ t(a_j) &< d_{\alpha,m,\infty} \text{ for all } j. \end{aligned}$$

An undesirable feature of the test proposed by Davidson and Duclos is that the comparisons made at a fixed number of arbitrary chosen points introduce the possibility of test inconsistency. Barrett and Donald (2003) follow McFadden (1989) and modify the Kolmogorov- Smirnov test to construct the test statistics

$$\hat{S}_1 = \left(\frac{N_Z N_W}{N_Z + N_W}\right)^{1/2} \sup_a \left(\widehat{G}_Z(a) - \widehat{G}_W(a)\right). \tag{9}$$

Barrett and Donald show that we can compute p-values by $\exp\left(-2\left(\hat{S}_1\right)^2\right)$.

I perform these tests of FOSD on the distributions of holding durations of leased and owned aircraft, and on the distributions of flying hours and efficiency of lessees and owners. I now describe the details for each case.

B.1 Holding Durations

I perform separate tests of FOSD on the pairs of distributions in each panel of Figure 5: 1) the distributions of unconditional holding durations of leased and owned aircraft (the left panel); 2) the distributions of residual durations when carrier fixed-effects are not included in the censored regression; and 3) the distributions of residual durations when carrier fixed-effects are included in the censored regression.

1. The Kolmogorov-Smirnov test rejects the null hypothesis of equality of distributions between the durations of owned aircraft and leased aircraft. The asymptotic p-value is equal to $1.4 * 10^{-38}$.

   As for Davidson and Duclos' test, I choose a grid of equally spaced percentiles of the pooled distribution of holding durations, starting from the fifth percentile, with a step of five percentiles, and ending at the 95th percentile. This results in $m = 19$ points. The critical values, tabulated in Stoline and Ury (1979), are $d_{\alpha,m,\infty} = 4.018$ for $\alpha = 1$, $d_{\alpha,m,\infty} = 3.615$ for $\alpha = 5$ and $d_{\alpha,m,\infty} = 3.425$ for $\alpha = 10$. Panel A of Table 8 presents values of the t statistics. The results clearly show that the distribution of holding durations of owned aircraft first-order stochastically dominates the distribution of holding durations of leased aircraft, as all t statistics are negative and the absolute value of the largest one is $14.97 > 4.018$.

   As for Barrett and Donald' test, the distribution of holding durations of owned aircraft lies everywhere below the distribution of holding durations of leased aircraft. Hence, the probability of rejection of the null hypothesis of stochastic dominance is zero.

Table 8: Tests of FOSD for Holding Durations

Panel A										
Percentile	5	10	15	20	25	30	35	40	45	50
duration	7	14	22	29	37	45	52	59	69	76
$t(a_j)$	-7.24	-9.36	-10.20	-11.00	-11.17	-11.90	-12.21	-12.54	-12.51	-13.16
Percentile	55	60	65	70	75	80	85	90	95	
duration	90	105	119	130	143	157	178	211	250	
$t(a_j)$	-14.94	-14.79	-14.97	-12.60	-13.49	-13.60	-12.13	-9.56	-6.65	
Panel B										
Percentile	5	10	15	20	25	30	35	40	45	50
Hours Flown	0	1473	2022	2294	2517	2771	2979	3219	3430	3681
$t(a_j)$	-4.59	-3.24	-2.86	-3.32	-5.36	-5.68	-5.06	-5.27	-5.92	-5.87
Percentile	55	60	65	70	75	80	85	90	95	
Hours Flown	3832	3972	4131	4266	4408	4554	4713	4869	5046	
$t(a_j)$	-5.52	-5.81	-6.14	-6.53	-7.07	-6.53	-7.09	-6.04	-4.70	

Notes: This table presents the results of the test of FOSD developed by Davidson and Duclos (2000). Panel A refers to the distributions of holding durations of leased and owned aircraft, and Panel B refers to the distributions of hours flown of leased and owned aircraft. Percentile corresponds to the percentile of the pooled distribution of holding durations at which the statistics in equation (8) are calculated. duration and Hours Flown are the values of the holding duration and flying hours, respectively, corresponding to the Percentile reported above them. $t(a_j)$ is the value of the statistics reported in equation (8).

2. Since residual durations are estimated rather than observed, the sampling variability of the estimated parameters must be taken into account when constructing the distributions of the test statistics. Hence, I bootstrap the p-values of the test statistics, following the procedure described in Abadie (2001). Abadie also provides a set of weak regularity conditions to imply consistency. These assumptions do not require continuity of the distributions and, in particular, are satisfied by distributions with a probability mass.

   The Kolmogorov-Smirnov test of equation (7) rejects the null hypothesis of equality of distributions between the durations of owned aircraft and leased aircraft. The p-value is equal to 0.

   As for Davidson and Duclos' test, in each repetition, I choose a grid of equally spaced percentiles of the pooled distribution of residual durations, starting from the fifth percentile, with a step of five percentiles, and ending at the 95th percentile. I compute the statistics in equation (8) at each of the $m = 19$ points. I use 1000 repetitions. The p-value is equal to .985.

   As for Barrett and Donald' test, in each repetition, I compute the statistics in equation (9) using a grid of 1000 equally spaced points between the first and the 99th percentile of the distribution of estimated residual durations. I use 1000 repetitions. The p-value is equal to 1.

3. The Kolmogorov-Smirnov test of equation (7) rejects the null hypothesis of equality of distributions between the durations of owned aircraft and leased aircraft. The p-value is equal to 0.

   As for Davidson and Duclos' test, in each repetition, I choose a grid of equally spaced percentiles of the pooled distribution of residual durations, starting from the fifth percentile, with a step of five percentiles, and ending and the 95th percentile. I compute the statistics in equation (8) at each of the $m = 19$ points. I use 1000 repetitions. The p-value is equal to .917.

As for the Barrett and Donald' test, in each repetition, I compute the statistics in equation (9) using a grid of 1000 equally spaced points between the first and the 99th percentile of the distribution of estimated residual durations. I use 1000 repetitions. The p-value is equal to .994.

B.2 Flying Hours and Efficiency

I perform separate tests of FOSD on the following pairs of distributions: 1) the distributions of flying hours of leased and owned aircraft; 2) the distributions of efficiency of operators of leased and owned aircraft estimated from the model of equations (2) and (3) when carrier fixed-effects are not included in the empirical model; 3) the distributions of efficiency of operators of leased and owned aircraft estimated from the model of equations (2) and (3) when carrier fixed-effects are included in the empirical model; and 4) the top 15 percent of the distributions of efficiency of operators of leased and owned aircraft estimated from the model of equations (2) and (3) when carrier fixed-effects are included in the empirical model. Since efficiency is estimated, I again bootstrap the p-values of the test statistics.

1. The Kolmogorov-Smirnov test rejects the null hypothesis of equality between the distributions of flying hours of owned aircraft and of leased aircraft. The asymptotic p-value is equal to $1.5 * 10^{-10}$.

   As for Davidson and Duclos' test, I choose a grid of equally spaced percentiles of the pooled distribution of flying hours, starting from the fifth percentile, with a step of five percentiles, and ending at the 95th percentile. This results in $m = 19$ points. The critical values, tabulated in Stoline and Ury (1979), are $d_{\alpha,m,\infty} = 4.018$ for $\alpha = 1$, $d_{\alpha,m,\infty} = 3.615$ for $\alpha = 5$ and $d_{\alpha,m,\infty} = 3.425$ for $\alpha = 10$. Panel B of Table 8 presents values of the t statistics. The results clearly show that the distribution of holding durations of owned aircraft first-order stochastically dominates the distribution of holding durations of leased aircraft, as all t statistics are negative and the absolute value of the largest one is $7.079 > 4.018$.

   As for the Barrett and Donald' test, the distribution of holding durations of owned aircraft lies everywhere below the distribution of holding durations of leased aircraft. Hence, the probability of rejection of the null hypothesis of stochastic dominance is zero.

2. The Kolmogorov-Smirnov test of the equality of distributions rejects the null hypothesis of equal distributions (the bootstrapped p-value is equal to 0).

   As for Davidson and Duclos' test, in each repetition, I choose a grid of equally spaced percentiles of the pooled distribution of estimated efficiencies, starting from the fifth percentile, with a step of five percentiles, and ending at the 95th percentile. I compute the statistics in equation (8) at each of the $m = 19$ points. I use 1000 repetitions. The p-value is equal to .958, so the test fails to reject the null hypothesis that the distribution of productivity of lessees first-order stochastically dominates the distribution of owners' productivity.

   The Barrett and Donald' test also fails to reject the null hypothesis of dominance. The bootstrapped p-value is .989.

3. The Kolmogorov-Smirnov test of the equality of distributions rejects the null hypothesis of equal distributions (the bootstrapped p-value is equal to .010).

   As for Davidson and Duclos' test, in each repetition, I choose a grid of equally spaced percentiles of the pooled distribution of estimated efficiencies, starting from the fifth percentile, with a step of five percentiles, and ending at the 95th percentile. I compute the statistics in equation (8) at each of the $m = 19$ points. I use 1000 repetitions. The p-value is equal to .940, so the test fails to reject the null hypothesis that the distribution of productivity of lessees first-order stochastically dominates the distribution of owners' productivity.

The Barrett and Donald' test also fails to reject the null hypothesis of dominance. The bootstrapped p-value is .973.

4. The Kolmogorov-Smirnov test of the equality of distributions does not reject the null hypothesis of equal distributions (the bootstrapped p-value is equal to .131).

   As for Davidson and Duclos' test, in each repetition, I choose a grid of equally spaced percentiles of the pooled distribution of estimated efficiencies above the 85th percentile, starting from the fifth percentile, with a step of ten percentiles, and ending at the 95th percentile. I compute the statistics in equation (8) at each of the $m = 9$ points. I use 1000 repetitions. The p-value is equal to .474, so the test rejects the null hypothesis that the distribution of productivity of lessees first-order stochastically dominates the distribution of owners' productivity.

   The Barrett and Donald' test also rejects the null hypothesis of dominance. The bootstrapped p-value is .455.

C Omitted Proofs

C.1 Value Functions

Before proving all Propositions, I introduce some general notation and derive the value functions that I use in several proofs.

Let $V_O(z, s)$ be the value of a carrier with long-term efficiency z and temporary shocks s that owns and operates an aircraft (I will drop α from the arguments of the value functions if it does not generate ambiguity); $V_L(z, s)$ the value of a carrier with long-term efficiency z and temporary shocks s that leases an aircraft; and $W(z, s)$ the value of a carrier with long-term efficiency z and temporary shocks s that does not operate (neither owns nor leases) any aircraft. $V_O(z, s = 1)$ satisfies:

$$\begin{aligned} rV_O(z, s = 1) \quad &= \quad z + \mu(\max\{V_O(z, s = 0), W(z, s = 0) + p - T\} - V_O(z, s = 1)) + \\ &\quad\ \alpha \int (\max\{V_O(x, s = 1), W(x, s = 1) + p - T\} - V_O(z, s = 1))\, dF(x) \end{aligned} \tag{10}$$

where $T = \tau p$. Equation (10) has the usual asset-pricing interpretation. A carrier in state $(z, s = 1)$ has current output/revenue equal to z. Then, in any instant, at most one of two events can happen: 1) At rate μ, the carrier receives a temporary shock, and the carrier decides whether to park the aircraft (in which case, it suffers a capital loss equal to $V_O(z, s = 0) - V_O(z, s = 1)$) or to sell it (in which case, it suffers a capital loss of $W(z, s = 0) + p - T - V_O(z, s = 1)$). 2) At rate α, the carrier receives a new draw of the efficiency parameter z, so the firm takes expectation over its optimal future actions. After learning its new efficiency, the carrier chooses between continuing to operate the aircraft it owns (in which case, it enjoys a capital gain/loss of $V_O(x, s = 1) - V_O(z, s = 1)$), or selling the aircraft and exiting (capital gain equal to $W(x, s = 1) + p - T - V_O(z, s = 1)$). (In principle, the firm could also sell the aircraft and lease another one, with capital gain equal to $V_L(x, s = 1) + p - T - V_O(z, s = 1)$. However, this, almost trivially, is never optimal, so it is omitted.)

Similarly, $V_L(z, s=1)$ satisfies:

$$\begin{aligned} rV_L(z,s=1) &= z - l + \mu\left(\max\left\{V_L(z,s=0), W(z,s=0)\right\} - V_L(z,s=1)\right) + \\ & \alpha \int \left(\max\left\{V_O(x,s=1) - p, V_L(x,s=1), W(x,s=1)\right\} - V_L(z,s=1)\right) dF(x). \end{aligned} \tag{11}$$

The interpretation of the equation (11) is now simple. The main differences between $V_L(z, s=1)$ and $V_O(z, s=1)$ are that $V_L(z, s=1)$ contains the per-period lease rate l as a flow cost, and that there are no transaction costs in the expression for $V_L(z, s=1)$.

Similarly, we can derive

$$rV_O(z,s=0) = \lambda\left(\max\left\{V_O(z,s=1), W(z,s=1) + p - T\right\} - V_O(z,s=0)\right), \tag{12}$$

$$rV_L(z,s=0) = -l + \lambda\left(\max\left\{V_O(z,s=1) - p, V_L(z,s=1), W(z,s=1)\right\} - V_L(z,s=0)\right), \tag{13}$$

$$\begin{aligned} rW(z,s=1) &= \mu\left(W(z,s=0) - W(z,s=1)\right) + \\ & \alpha \int \left(\max\left\{V_O(z,s=1) - p, V_L(z,s=1), W(z,s=1)\right\} - W(z,s=1)\right) dF(s), \end{aligned} \tag{14}$$

$$rW(z,s=0) = \lambda\left(\max\left\{V_O(z,s=1) - p, V_L(z,s=1), W(z,s=1)\right\} - W(z,s=0)\right). \tag{15}$$

C.2 Proof of Proposition 1

I first show that all carriers with no temporary shock ($s=1$) are indifferent between leasing and owning aircraft. Using the equations derived in Section C.1, we obtain that $V_L(z, s=1) - V_O(z, s=1)$ satisfies:

$$(r + \mu + \alpha)\left(V_L(z,s=1) - \left(V_O(z,s=1) - p\right)\right) = -l + rp.$$

Hence, if $l = rp$, then $V_L(z, s=1) = V_O(z, s=1) - p$. Now, I show that, indeed, $l = rp$ is the only possible equilibrium.

Suppose not, and assume that $l > rp$. Then, $V_L(z, s=1) < V_O(z, s=1) - p$ and no carrier leases aircraft. Moreover, demand for owned aircraft drives up the prices for owned aircraft until $l = rp$. The case for $l < rp$ is similar.

I now determine the equilibrium allocation, and the price and lease rate of aircraft.

Consider the case of a carrier that leases an aircraft. Using equations (11) and (14), we obtain that $V_L(z, s=1) - W(z, s=1) = \frac{z-l}{(r+\mu+\alpha)}$. This implies that all carriers with efficiency $z \geq z' = l$ operate aircraft, while carriers with $z \leq z'$ do not operate any aircraft if they have no temporary shock. Moreover, since there are no transaction costs, all carriers with a temporary shock dispose of their aircraft.

I now determine the equilibrium value of z'. Denote by S_0 the mass of carriers with a temporary shock. The cutoff value z' must satisfy

$$X = (1 - S_0)\left(1 - F\left(z'\right)\right). \tag{16}$$

Equation (16) says that the equilibrium mass of carriers operating the mass of aircraft X is equal to the fraction of carriers with no temporary shock whose efficiency is above the cutoff value z'. Moreover, in order to determine S_0, we can use the equality of stocks and flows in a small interval of time of length ϵ. S_0 satisfies:

$$S_0 = (1 - S_0)\mu\epsilon + S_0(1 - \lambda\epsilon) = \frac{\mu}{\mu + \lambda}.$$

The above equation says that, in steady state, the mass of carriers with a temporary shock S_0 is equal to the sum of the mass of carriers that had no temporary shock in the previous instant and just received a temporary shock, plus the mass of carriers whose temporary shock persists at least one more period.

The aircraft lease rate l is determined by the indifference condition of the marginal carrier z'. The marginal carrier is indifferent between operating an aircraft or not. Thus, solving equations $V_L(z', s=1) = W(z', s=1)$, the lease rate l and the aircraft price p are equal to:

$$l = z' \text{ and } p = \frac{z'}{r}.$$

C.3 Proof of Corollary 2

Since Corollary 2 is a special case of Proposition 4, I delay its proof to the Proof of Proposition 4.

C.4 Proof of Proposition 3

(i) I derive the optimality conditions for owners: There exists three values (z^*, z^{**}, z^{***}) of the efficiency parameter z that satisfy the indifference between acquiring an aircraft or not (z^*); keeping an aircraft or selling it when hit by a $s = 0$ shock (z^{**}); and keeping an aircraft or selling it when z declines (z^{***}). These three thresholds fully determine the set of carriers that operate aircraft in equilibrium. Finally, I prove that $z^* > z^{**} > z^{***}$.

I now derive the value z^* of a carrier that is indifferent between acquiring an aircraft or not. Using the value functions (11) and (14), we obtain that z^* satisfies

$$V_O(z^*, s=1) - p = W(z^*, s=1). \tag{17}$$

This implies that all carriers with efficiency $z \geq z^*$ and $s = 1$ acquire an aircraft, while carriers with $z \leq z^*$ do not acquire any aircraft.

Consider, now, a carrier that owns an aircraft and receives a temporary shock. It is indifferent between selling the aircraft and operating it if its efficiency z^{**} satisfies $W(z^{**}, s=0) + p - T = V_O(z^{**}, s=0)$, which is equivalent to:

$$\frac{\lambda W(z^{**}, s=1)}{\lambda + r} + p - T = \frac{\lambda V_O(z^{**}, s=1)}{\lambda + r}. \tag{18}$$

To understand the above equality, the left-hand side follows from the fact that if the carrier is exiting and paying the transaction cost T, it is not acquiring an aircraft and stays out once its temporary shock disappears. The right-hand side follows from the fact that if the carrier is staying in today, it stays in once his temporary shock disappears.

Finally, we can rearrange equation (18) and obtain

$$W(z^{**}, s=1) = V_O(z^{**}, s=1) - \frac{\lambda + r}{\lambda}(p - T) \tag{19}$$

Consider, now, a carrier with no temporary shock that owns an aircraft and is indifferent between selling it, and operating it. The efficiency z^{***} of this carrier satisfies $W(z^{***}, s=1) + p - T = V_O(z^{***}, s=1)$. This equality is equivalent to:

$$\begin{aligned} W(z^{***}, s=1) + p - T \quad = \quad & \frac{z^{***} + \mu \max\{V_O(z^{***}, s=0), W(z^{***}, s=0) + p - T\}}{r + \mu + \alpha} + \\ & \frac{\alpha \int (\max\{V_O(x, s=1), V_L(x, s=1) + p - T, W(x, s=1) + p - T\})\, dF(x)}{r + \mu + \alpha}. \end{aligned}$$

Since the carrier is indifferent between exiting or operating today, it must be that if it receives a temporary shock, it prefers to exit:

$$\max\left\{V_O\left(z^{***}, s=0\right), W\left(z^{***}, s=0\right)+p-T\right\} = W\left(z^{***}, s=0\right)+p-T = \frac{\lambda}{\lambda+r}W\left(z^{***}, s=1\right)+p-T.$$

Hence, $W\left(z^{***}, s=1\right)+p-T = V_O\left(z^{***}, s=1\right)$ corresponds to:

$$\begin{aligned} W\left(z^{***}, s=1\right)+p-T &= \frac{z^{***}+\mu\left(\frac{\lambda}{\lambda+r}W\left(z^{***}, s=1\right)+p-T\right)}{r+\mu+\alpha}+ \\ &\quad \frac{\alpha\int\max\left\{V_O\left(x, s=1\right), V_L\left(x, s=1\right)+p-T, W\left(x, s=1\right)+p-T\right\}dF\left(x\right)}{r+\mu+\alpha}, \end{aligned}$$

which we can rearrange as:

$$W\left(z^{***}, s=1\right) = V_O\left(z^{***}, s=1\right) - \frac{\left(r+\alpha\right)\left(p-T\right)}{r+\mu\frac{r}{\lambda+r}+\alpha}. \tag{20}$$

I now prove that, if $\tau > \frac{r}{\lambda+r}$, then $z^* > z^{**} > z^{***}$. Note that all carriers are indifferent between leasing and owning when they acquire an aircraft—i.e., $V_O\left(z, s=1\right)-p = V_L\left(z, s=1\right)$. Combining it with equation (17), we obtain:

$$V_O\left(z^*, s=1\right) - W\left(z^*, s=1\right) = p$$

Similarly, we can rearrange equations (19) and (20) to obtain:

$$\begin{aligned} V_O\left(z^{**}, s=1\right) - W\left(z^{**}, s=1\right) &= \frac{\lambda+r}{\lambda}\left(p-T\right), \\ V_O\left(z^{***}, s=1\right) - W\left(z^{***}, s=1\right) &= \frac{\left(r+\alpha\right)\left(p-T\right)}{r+\mu\frac{r}{\lambda+r}+\alpha}. \end{aligned}$$

Since $\tau > \frac{r}{\lambda+r}$, we obtain that $p > \frac{\lambda+r}{\lambda}\left(p-T\right) > \frac{(r+\alpha)(p-T)}{r+\mu\frac{r}{\lambda+r}+\alpha}$. Therefore, using equations (17), (19) and (20):

$$V_O\left(z^*, s=1\right) - W\left(z^*, s=1\right) > V_O\left(z^{**}, s=1\right) - W\left(z^{**}, s=1\right) > V_O\left(z^{***}, s=1\right) - W\left(z^{***}, s=1\right).$$

Thus, in order to prove that $z^* > z^{**} > z^{***}$ it is enough to prove that $V_O\left(z, s=1\right) - W\left(z, s=1\right)$ is increasing in z. Using equations (10) and (14), we obtain:

$$\begin{aligned} & V_O\left(z, s=1\right) - W\left(z, s=1\right) \\ = & \frac{z+\mu\left(\max\left\{V_O\left(z, s=0\right), W\left(z, s=0\right)+p-T\right\} - W\left(z, s=0\right)\right)}{\left(r+\mu+\alpha\right)} + J \end{aligned}$$

where $J = \frac{\alpha\int\left(\max\left\{V_O(x,s=1), W(x,s=1)+p-T\right\}\right)dF(x)}{r+\mu+\alpha} - \frac{\alpha\int\left(\max\left\{V_O(z,s=1)-p, W(z,s=1)\right\}\right)dF(s)}{r+\mu+\alpha}$ is a constant that does not depend on z.

Now there are two cases, depending on the value of $\max\left\{V_O\left(z, s=0\right), W\left(z, s=0\right)+p-T\right\}$.

(a) If $\max\left\{V_O\left(z, s=0\right), W\left(z, s=0\right)+p-T\right\} = W\left(z, s=0\right)+p-T$, then

$$V_O\left(z, s=1\right) - W\left(z, s=1\right) = \frac{z+\mu\left(p-T\right)}{\left(r+\mu+\alpha\right)} + J,$$

which is increasing in z.

(b) If $\max\left\{V_O(z,s=0), W(z,s=0)+p-T\right\} = V_O(z,s=0)$, we can use equation (12) to obtain

$$V_O(z,s=0) = \frac{\lambda\left(\max\left\{V_O(z,s=1), W(z,s=1)+p-T\right\}\right)}{(r+\lambda)} = \frac{\lambda V_O(z,s=1)}{(r+\lambda)}$$

since if it was optimal to keep the aircraft when $s=0$, it has to be optimal to keep it when $s=1$. Now there are two subcases, depending on the value of $W(z,s=0)$.

(b1) If $W(z,s=0) = \frac{\lambda(\max\{V_O(z,s=1)-p, W(z,s=1)\})}{r+\lambda} = \frac{\lambda(V_O(z,s=1)-p)}{r+\lambda}$, then

$$\begin{aligned} V_O(z,s=1) - W(z,s=1) &= \frac{z+\mu\left(\frac{\lambda V_O(z,s=1)}{(r+\lambda)} - \frac{\lambda(V_O(z,s=1)-p)}{(r+\lambda)}\right)}{r+\mu+\alpha} + J \\ &= \frac{z+\frac{\lambda\mu p}{(r+\lambda)}}{r+\mu+\alpha} + J, \end{aligned}$$

which is increasing in z.

(b2) If $W(z,s=0) = \frac{\lambda(\max\{V_O(z,s=1)-p, W(z,s=1)\})}{r+\lambda} = \frac{\lambda W(z,s=1)}{r+\lambda}$, then

$$\begin{aligned} V_O(z,s=1) - W(z,s=1) &= \frac{z+\mu\left(\frac{\lambda V_O(z,s=1)}{r+\lambda} - \frac{\lambda W(z,s=1)}{r+\lambda}\right)}{r+\mu+\alpha} + J \\ &= \left(\frac{z+}{r+\mu+\alpha} + J\right)\frac{(r+\lambda)(r+\alpha+\mu)}{r\alpha+r\lambda+r\mu+\alpha\lambda+r^2}, \end{aligned}$$

which is increasing in z. This concludes the proof of part (i).

(ii) The proof is contained in the proof of Proposition 1.

C.5 Proof of Proposition 4

Consider two aircraft, one owned and the other leased. The owned aircraft is traded at rate $\alpha_\ell F(z^{***}) + \mu H_O(z^{**})$, where $H_O(z,s=1)$ is the endogenous cumulative distribution function of efficiency z of owners with no temporary shock. To calculate $H_O(z^{**}, s=1)$, consider the pdf $h_O(z,s)$ and a small interval of time of length ϵ. Up to terms in $o(\epsilon)$, in the interval $z^{***} \le z < z^{**}$ the distribution $h_O(z,s=1,\cdot)$ evolves from time t to time $t+\epsilon$ according to:

$$h_O(z,s=1,t+\epsilon) = \alpha_\ell \epsilon f(z,t) + (1-\alpha_\ell\epsilon - \mu\epsilon)\, h_O(z,s=1,t)$$

Substituting and taking the limit for $\epsilon \to 0$, in steady state $H_O(z^{**}, s=1)$ satisfies:

$$H_O(z^{**}, s=1) = \frac{\alpha_\ell\left(F(z^{**}) - F(z^{***})\right)}{\alpha_\ell + \mu}. \tag{21}$$

The leased aircraft is traded at rate $\alpha_h F(z^*) + \mu$. Since the stochastic processes of z and s are Poisson processes, the resulting distribution functions of holding durations of owned aircraft and leased aircraft are exponentials with parameters $\alpha_\ell F(z^{***}) + \mu H_O(z^{**})$ and $\alpha_h F(z^*) + \mu$, respectively. Since $\alpha_h > \alpha_\ell$, $z^* > z^{***}$, $H_O(z^{**}) < 1$, the Proposition follows.

If $\tau = 0$, then $z^* = z^{***}$ and $z^{**} = +\infty$. Hence, Corollary 2 follows too.

C.6 Proof of Proposition 5

To prove part (i), note that no leased aircraft is parked. Instead, if $\tau > \frac{r}{\lambda+r}$, all owners with efficiency $z \geq z^{**}$ park the aircraft when they receive a temporary shock.

To prove part (ii), only carriers with no temporary shock fly the aircraft. I now prove that $z^* \leq l$. The marginal carrier acquiring an aircraft has efficiency z^* satisfying: $W(z^*, s=1, \alpha_\ell) = V_O(z^*, s=1, \alpha_\ell) - p$. Since this carrier could have leased instead, it must be that $V_O(z^*, s=1, \alpha_\ell) - p \geq V_L(z^*, s=1, \alpha_\ell)$. Hence, $W(z^*, s=1, \alpha_\ell) \geq V_L(z^*, s=1, \alpha_\ell)$. Using (11) and (14), we obtain that $W(z^*, s=1, \alpha_\ell) \geq V_L(z^*, s=1, \alpha_\ell)$ corresponds to $\frac{z^*-l}{r+\mu+\alpha_\ell} \leq 0$. Thus, $z^* \leq l$.

Conditional on $z \geq l$, the distributions of efficiency of owners and lessees are identical. Moreover, all operators with efficiency $z^{***} \leq z < l$ are owners. Hence, conditional on flying, the efficiency of lessees is higher than the efficiency of carriers.

Combining (i) and (ii), the first statement of the Proposition follows too.

C.7 Equilibrium

I now derive the equations that characterize an equilibrium in which all low-volatility carriers own aircraft, and all high-volatility carriers lease.

I first show that, at the time they acquire an aircraft, the choice between owning and leasing does not depend on the productivity z. A carrier chooses to lease rather than own an aircraft if and only if $V_L(z, s=1) > V_O(z, s=1) - p$, which corresponds to:

$$\begin{aligned} & \frac{z - l + \mu \max\{V_L(z, s=0), W(z, s=0)\}}{r+\mu+\alpha} + \\ & \frac{\alpha \int \max\{V_O(x, s=1) - p, V_L(x, s=1), W(x, s=1)\} dF(x)}{r+\mu+\alpha} \\ > \; & \frac{z + \mu \max\{V_O(z, s=0), W(z, s=0) + p - T\}}{r+\mu+\alpha} + \\ & \frac{\alpha \int (\max\{V_O(x, s=1), V_L(x, s=1) + p - T, W(x, s=1) + p - T\}) dF(x)}{r+\mu+\alpha} - p. \end{aligned} \tag{22}$$

Since there are no transaction costs on leasing, a carrier that is currently leasing returns its aircraft to the lessor when it receives a temporary shock—i.e., $\max\{V_L(z, s=0), W(z, s=0)\} = W(z, s=0)$. Moreover, since the carrier we are considering is acquiring an aircraft, it must be that acquiring an aircraft (either owned or leased) yields a higher value than not acquiring one—i.e., $\max\{V_O(x, s=1) - p, V_L(x, s=1)\} \geq W(x, s=1)$. In addition,

$$\begin{aligned} & \max\{V_O(z, s=0), W(z, s=0) + p - T\} \\ = \; & \max\left\{\lambda \frac{\max\{V_O(z, s=1), V_L(z, s=1) + p - T\}}{\lambda + r}, \lambda \frac{\max\{V_O(z, s=1) - p, V_L(z, s=1)\}}{\lambda + r} + p - T\right\} \\ = \; & \max\left\{\frac{\lambda V_O(z, s=1)}{\lambda + r}, \lambda \frac{V_O(z, s=1) - p}{\lambda + r} + p - T\right\} \\ = \; & \max\left\{\frac{\lambda V_O(z, s=1)}{\lambda + r}, \frac{\lambda V_O(z, s=1) + rp - (\lambda + r) T}{\lambda + r}\right\} \end{aligned}$$

Now there are two cases:

1) $\tau > \frac{r}{\lambda+r}$. In this case, $\max\{V_O(z,s=0), W(z,s=0)+p-T\} = \frac{\lambda V_O(z,s=1)}{\lambda+r}$. Hence, we can rewrite inequality (22) as:

$$\begin{aligned} &\frac{z-l}{r+\frac{r}{\lambda+r}\mu+\alpha} + \frac{\alpha\int \max\{V_O(x,s=1)-p, V_L(x,s=1), W(x,s=1)\}\,dF(x)}{r+\frac{r}{\lambda+r}\mu+\alpha} \\ > \; &\frac{z}{r+\frac{r}{\lambda+r}\mu+\alpha} + \frac{\alpha\int (\max\{V_O(x,s=1), V_L(x,s=1)+p-T, W(x,s=1)+p-T\})\,dF(x)}{r+\frac{r}{\lambda+r}\mu+\alpha} - p. \end{aligned}$$

Eliminating common terms in the above equality, we obtain

$$\begin{aligned} &\frac{-l}{r+\frac{r}{\lambda+r}\mu+\alpha} + \frac{\alpha\int \max\{V_O(x,s=1)-p, V_L(x,s=1), W(x,s=1)\}\,dF(x)}{r+\frac{r}{\lambda+r}\mu+\alpha} \\ > \; &\frac{\alpha\int (\max\{V_O(x,s=1), V_L(x,s=1)+p-T, W(x,s=1)+p-T\})\,dF(x)}{r+\frac{r}{\lambda+r}\mu+\alpha} - p \end{aligned}$$

which is independent of z.

2) $\tau \leq \frac{r}{\lambda+r}$. In this case, $\max\{V_O(z,s=0), W(z,s=0)+p-T\} = \frac{\lambda V_O(z,s=1)+rp-(\lambda+r)T}{\lambda+r}$. Hence, we can rewrite inequality (22) as:

$$\begin{aligned} &\frac{z-l}{r+\frac{r}{\lambda+r}\mu+\alpha} + \frac{\alpha\int \max\{V_O(x,s=1)-p, V_L(x,s=1), W(x,s=1)\}\,dF(x)}{r+\frac{r}{\lambda+r}\mu+\alpha} \\ > \; &\frac{z+\mu\frac{rp-(\lambda+r)T}{\lambda+r}}{r+\frac{r}{\lambda+r}\mu+\alpha} + \frac{\alpha\int (\max\{V_O(x,s=1), V_L(x,s=1)+p-T, W(x,s=1)+p-T\})\,dF(x)}{r+\frac{r}{\lambda+r}\mu+\alpha} - p. \end{aligned}$$

which is again independent of z.

Thus, in both cases, carriers' choice between leasing or owning does not depend on their productivity z.

An equilibrium in which high-volatility carriers lease and low-volatility carriers own aircraft requires that the following conditions hold:

1. Leasing rate is equal to:
$$l = (r+m)\,p. \tag{23}$$

2. The marginal lessee has productivity equal to the lease rate l :
$$V_L(l,s=1,\alpha_h) = W(l,s=1,\alpha_h). \tag{24}$$

3. All high-volatility carriers prefer to lease
$$V_L(z,s=1,\alpha_h) > V_O(z,s=1,\alpha_h) - p \tag{25}$$
and all low-volatility carriers prefer to own
$$V_L(z^*,s=1,\alpha_\ell) < V_O(z^*,s=1,\alpha_\ell) - p. \tag{26}$$

4. The marginal carrier acquiring an aircraft has efficiency z^* satisfying:
$$V_O(z^*,s=1,\alpha_\ell) - p = W(z^*,s=1,\alpha_\ell). \tag{27}$$

5. The marginal carrier selling an owned aircraft has efficiency z^{**} satisfying:

$$V_O\left(z^{**}, s=0, \alpha_\ell\right) = W\left(z^{**}, s=0, \alpha_\ell\right) + p - T. \tag{28}$$

6. The marginal carrier selling an owned aircraft has efficiency z^{***} satisfying:

$$V_O\left(z^{***}, s=1, \alpha_\ell\right) = W\left(z^{***}, s=1, \alpha_\ell\right) + p - T. \tag{29}$$

7. The mass $1-\omega$ of low-volatility carriers is composed by the mass $X - X_L$ of carriers that operate an aircraft, the mass SS_0 of carriers with no aircraft and no temporary shock, and the mass L_0 of carriers with no aircraft and a temporary shock:

$$\begin{aligned}
1-\omega &= X - X_L + SS_0 + L_0, && (30)\\
SS_0 &= SS_0\left(1-\alpha_\ell\epsilon-\mu\epsilon\right) + SS_0\alpha_\ell\epsilon F\left(z^*\right) + \lambda\epsilon L_0 + \left(X-X_L\right)\alpha_\ell\epsilon F\left(z^{***}\right) \\
&= \left(X-X_L\right)\frac{\mu H_O\left(z^{**}, s=1\right) + \alpha_\ell F\left(z^{***}\right)}{\alpha_\ell\left(1-F\left(z^*\right)\right)}, && (31)\\
L_0 &= \left(1-\lambda\epsilon\right)L_0 + \mu\epsilon SS_0 + \left(X-X_L\right)\mu\epsilon H_O\left(z^{**}, s=1\right) \\
&= \frac{\mu\epsilon SS_0 + \left(X-X_L\right)\mu\epsilon H_O\left(z^{**}, s=1\right)}{\lambda}, && (32)
\end{aligned}$$

where $H_O\left(z, s=1\right)$, the endogenous cumulative distribution function of efficiency z of owners with no temporary shock, is derived in equation (21).

8. The supply X_L of leased aircraft equates the mass of high-volatility carriers with no temporary shock and productivity above the lease rate l. Similar to the proof of Proposition 1, this corresponds to:

$$X_L = \frac{\lambda\omega}{\mu+\lambda}\left(1-F\left(l\right)\right). \tag{33}$$

Equilibrium requires that equations (23)-(33) are satisfied.

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