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. I then test the empirical implications using a dataset on commercial aircraft and carriers fleets.

Carriers trade aircraft either to replace their fleet or to reduce excess capacity. Trading frictions hinder the efficiency of the allocation of capital and lessors reduce frictions by centralizing the exchange. Thus, leased aircraft trade more frequently and produce a higher output than owned aircraft, as lower barriers to trade imply that lessees are more efficient than owners and allow a finer pairing between quality of capital and efficiency of carriers on leased aircraft.

In the empirical section, consistent with the model, we find that 1) leased aircraft have a holding duration 35% shorter than owned aircraft; 2) leased aircraft have 8% higher output than owned aircraft. The estimates imply that most of the gain in output arises because lower barriers to trade increase the average efficiency of carriers, and finer pairing contributes only to 0.14% of the gain.

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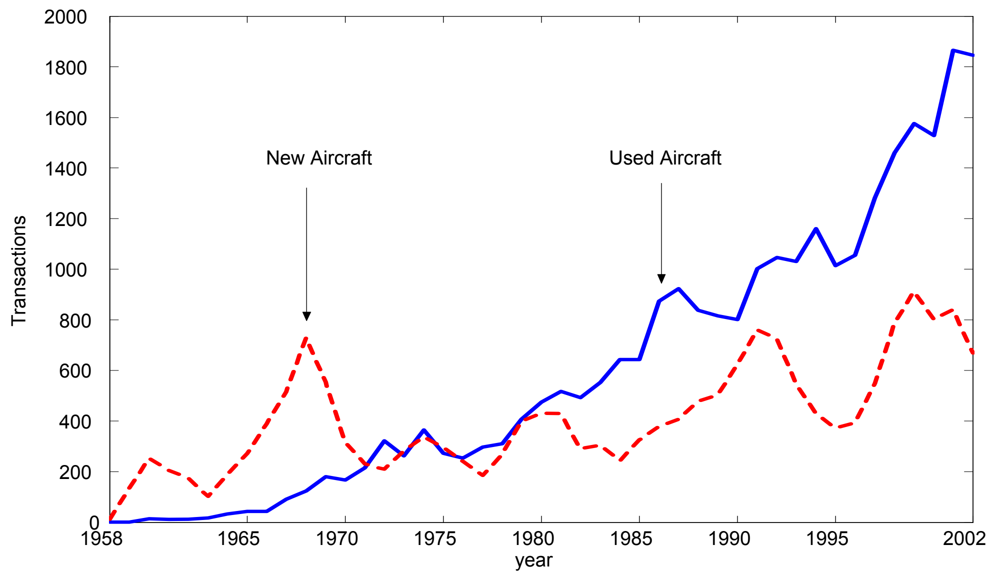

FIG. 1 - TRANSACTIONS IN THE PRIMARY (DOTTED LINE) AND SECONDARY (SOLID LINE) MARKETS FOR NARROWBODY AND WIDEBODY AIRCRAFT.

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 very popular in the aircraft market - the operating lease - increases the efficiency of transactions of aircraft and, as a result, increases the production of final output (flights) in the airline industry.

Markets for used capital equipment are rather 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 total number of trucks traded in the United States in 1977 were traded 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.[1] Since the mid 80's, trade in the secondary market for aircraft has grown steadily and today the number of transactions on the used market is about three times the number of purchases of new aircraft.

A large share of these transactions is due to leasing. A substantial number of the aircraft currently operated by major carriers is under an operating lease, a rental contract between a lessor and an airline for the use of the aircraft for a short period of time (4-5 years).[2] Figure 2 plots the fraction of new commercial aircraft delivered to lessors to total aircraft delivered by year.[3] The figure shows that lessors are actively engaged in the purchase of new aircraft and their acquisitions have increased rapidly in recent years. But lessors are also very active participants in secondary markets, as they frequently buy used aircraft and, more importantly, they lease out each aircraft several times during its useful lifetime.

In this paper, I construct a model of transactions in used aircraft to understand the role of lessors

[1] Commercial aircraft are divided in smaller Narrobody aircraft like the Boeing 737 and larger Widebody aircraft like the Boeing 747.

[2] See Section 3 for more details on the Operating Lease.

[3] In 1986 the US implemented an important taxation reform, the Tax Reform Act. The entry of lessors might have been spurred by the Act, but it is also interesting to note that deliveries of aircraft lessors started to pick up in 1985. Due to time-to-built/delivery lags, these aircraft were ordered in 1983-1984.

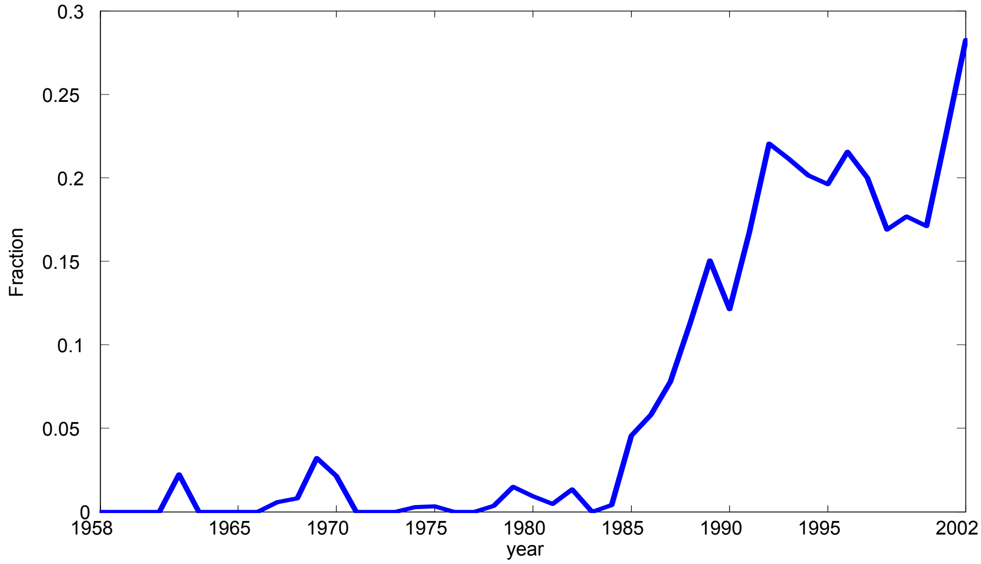

Fig. 2 - Fraction of new Narrowbody and Widebody aircraft delivered to lessors by year.

when trading is subject to frictions. The model combines four key ingredients: 1) firms have heterogeneous stochastic efficiency; 2) aircraft are produced every period and depreciate; 3) aircraft can be bought or leased; 4) used aircraft sales are subject to frictions. In this world, secondary markets play a fundamental allocative role. Because the quality of capital and the efficiency of the firm are complements, firms self select and acquire different quality of capital according to their efficiency. Thus, firms trade used capital for two reasons. The first is the replacement of old aircraft. When the quality of capital depreciates over time, firms sell their old aircraft to acquire newer ones. The second is the adjustment of productive capacity. When either cost or demand shocks adversely affect profitability, firms shrink and sell aircraft. Vice versa, when shocks positively affect profitability, firms expand and acquire aircraft.

If there is no leasing, trading frictions hinders the efficiency of the allocation of capital and the production of output. Optimality requires perfect matching between quality of the capital and efficiency of the firm. However, transaction costs create a wedge between the price paid by the buyer and the price received by the seller that acts as a barrier to trade. This implies that matching between quality and efficiency is coarse. In particular, some firms operating new aircraft are less efficient than some firms operating old aircraft; and some firms operating an aircraft are less efficient than some firms not operating any aircraft.

I argue that lessors act as intermediaries that reduce transaction costs.[4] When carriers can buy or lease aircraft, I show that leased aircraft trade more frequently. This improves the matching process between firms and capital and, as a result, leased aircraft produce a higher output than owned aircraft. This gain can be decomposed into three distinct effects. The first is a *parking effect*: leased aircraft are parked inactive less frequently than owned aircraft. The second is a *efficiency effect*: the efficiency of lessees is higher than the efficiency of owners, conditional on the aircraft being in use. The third is a *pairing effect*: the covariance between quality of the aircraft and efficiency of the carrier is higher for leased aircraft than for owned aircraft, conditional on the aircraft being in use.

In the empirical section, I find evidence consistent with the implications of the model using a detailed dataset on commercial aircraft. The data reveal that leased aircraft have holding durations 35% shorter

[4] Transaction costs are meant to include search costs for a potential buyer and other trading frictions. Since the primary activity of lessors is to rent out the fleet they own, it seems plausible that they have a cost advantage in the transactions.

than owned aircraft. I then use annual hours flown to measure output[5] and I find that leased aircraft have flying hours 8% higher than owned aircraft.

I estimate the depreciation pattern of aircraft in order to obtain measures of quality of aircraft and efficiency of the carriers. Based on the estimates, I can decompose the difference in output (hours flown) between leased and owned aircraft into the empirical counterparts of the three components identified in the theoretical model: 1.8% of the difference in output is explained by the *parking effect;* 6.2% is explained by the *efficiency effect* and .14% is due to the *pairing effect.* Moreover, the estimates reveal that leasing' lower transaction costs endogenously increase efficiency by reducing carriers' inaction regions, and selection of highly efficient carriers into leasing plays a minor role.[6]

I argue that the growth of trade in the secondary markets for aircraft since the mid 1980s is consistent with my model. The Airline Deregulation Act of 1978 dramatically reduced entry costs, thereby increasing the competitiveness of airline markets.[7] This increase in competitiveness amplified the volatility of firm level output, implying that carriers need to adjust their fleets more frequently. The volume of trade on secondary market increased substantially due to higher inter-firm reallocation of inputs.[8] The entry of lessors in the mid 1980s, as documented in Figure 2, therefore exactly coincides with a period of expansion of trade in secondary markets, when the need for market intermediaries to coordinate sellers and buyers becomes stronger.[9]

Variations of the operating lease have evolved, but for the airlines the key point is when they want to replace or reduce capacity much of the job of finding a new operator for its used capital has been taken over by another party, the lessor. In this sense, leasing can be viewed as part of a more general trend towards outsourcing of certain corporate activities. In the airline industry, some carriers now also outsource their aircraft and engine maintenance, food service, and more recently, the computer based reservation system. The logic is that specialists can do these jobs more efficiently and the carriers have enough to do just operating the aircraft and servicing the passengers.

This paper identifies lessors as intermediaries who provide liquidity and reduce frictions in secondary markets. Thus, I highlight a novel role for leasing in capital equipment that has been ignored in the literature.[10] I believe that the mechanisms identified in these paper are not unique to the aircraft markets,

[5] See Subsection 5.1 for the shortcomings and the advantages of this measure of output.

[6] We cannot fully rule out that the observed patterns in the data are due to informational asymmetries (moral hazard or adverse selection) between the parties. Informational asymmetries are definitively an important aspect of many durable goods markets, as highlighted by Hendel and Lizzeri (1999a, 2002) and Johnson and Waldman (2003, 2005). However, several characteristics of the aircraft market suggest that informational asymmetries might play a minor role here. In particular, due to a series of regulatory issues on maintenance, adverse selection and quality uncertainty do not seem an important motivation for trade, as already documented by Pulvino (1998). Moreover, moral hazard arises from unobservability or non-contractibility of actions, while in the case of aircraft all parties clearly observe how much the aircraft has been flown and, as explained in Section 3, leasing contracts are indeed contingent on the utilization (hours flown and landings) of the aircraft. For a more complete discussion of these and related arguments, see Subsection 5.6.

[7] 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. From January 1, 1982, all controls on entry and exit were removed, while airfares were deregulated from 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.

[8] Ramey and Shapiro (1998) analyze Compustat data and also find a significant increase in capital reallocation across firms and industries in the 80s and 90s.

[9] 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.`

[10] 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.

but they may help understand the role of leasing for a wide range of capital equipment. Moreover, this paper is one of the few papers that tries to empirically measure the gain due to intermediation and to institutions that enhance the efficiency of trading. This is of particular importance because the efficiency of secondary markets for capital equipment is a key factor in any industry's speed of adjustment after a shock or a policy intervention.

The paper is organized as follows. Section 2 discusses the related literature. Section 3 illustrates some institutional characteristics of secondary markets for commercial aircraft and of aircraft lessors. Section 4 lays out the model. I first analyze the benchmark case of no transaction costs and I then consider how transaction costs affect the allocation of aircraft. The empirical analysis is performed in Section 5. Section 6 concludes. Omitted mathematical derivations and all proofs of Propositions are collected in the Appendixes A to C.

2 Related Literature

The paper is related to several strands of the literature. The first important strand is the literature on durable goods. This literature has generally analyzed consumer durables, with Bond (1983) being a notable exception. Bulow (1982) shows that a monopolist manufacturer might prefer to lease durable goods to solve the Coasian time-inconsistency problem. Rust (1985), Anderson and Ginsburgh (1994), Hendel and Lizzeri (1999a), Porter and Sattler (1999), Stolyarov (2002) and Esteban and Shum (2006) concentrate on the interactions between primary and secondary markets for consumer durables such as cars. In these models, all gains from trade arise from the depreciation of the durable.[11] In this context, Waldman (1997) and Hendel and Lizzeri (1999b, 2002) have analyzed the incentive to lease for a manufacturer. These papers show that the manufacturer might prefer to lease to gain market power in the used market. In the aircraft market, however, as explained in more detail in the next Section 3, the largest lessors are not the manufacturers of the aircraft. Thus, the explanations provided by the literature do not fully apply. In contrast, in my paper lessors are intermediaries that specialize in trading.

The second is the literature on firms' investment. More relevant to my work are Cooper and Haltiwanger (1993), Cooper, Haltiwanger and Power (1998), who focus on the replacement problem, and Ramey and Shapiro (2001) and Eisfeldt and Rampini (2006) who study capital reallocations. These papers analyze a single firm's problem without explicitly solving the equilibrium in the market for capital.

A strand of the literature in corporate finance examine the corporate decisions to lease. These studies generally focus on the financial lease. Smith and Wakeman (1985) provide an exhaustive but informal overview and Sharpe and Nguyen (1995) present a detailed empirical analysis. This literature focuses primarily on financial reasons to lease, while I focus on the *effect* of leasing on secondary markets for aircraft and on the output produced by the carriers.

Further, this paper is related to the literature on intermediaries. Spulber (1999) presents a thorough analysis and surveys the literature. Here, I present one of the first empirical analysis that quantifies the gain due to intermediary firms specializing in transactions.

Lastly, a long series of papers have analyzed the airline industry. Most literature has analyzed the entry or the pricing decision of carriers, and few papers have discussed transactions of aircraft, with Pulvino (1998,1999) and Gilligan (2004) being notable exceptions. Pulvino (1998) uses transaction level data and finds that airlines under financial pressure sells aircraft at a 14% discount. He further shows that distressed airlines experience higher rates of asset sales than no distressed airlines, which is consistent with the results of my model. Gilligan (2004) uses data from the market for business jets and finds evidence

[11] See also House and Leahy (2004), where, in contrast, gains from trade arise because in each period indivduals draw a match parameter that describes how well the car they own suits their needs.

consistent with the fact that leasing ameliorates the consequences of information asymmetries about the quality of used aircraft. Hence, both my paper and Gilligan's work show empirically how leasing mitigates market imperfections.

3 Background

The market for used commercial aircraft has three main institutional characteristics.[12] First, it is a worldwide single market, where aircraft are often transferred from an operator in one country to an operator in another country. Second, the market is dominated by privately negotiated transactions. Most major carriers have staff devoted to the acquisition and disposition of aircraft and sometimes independent brokers are used to match buyers and sellers. Third, sometimes aircraft are purchased by governments and air cargo companies, but the major players are airlines and lessors.

The operating lease business was essentially founded by International Lease Finance Corporation (ILFC) in the early 1970s and today several companies are in the field. Approximately one third of all commercial aircraft worldwide is leased. The share is larger for Narrowbody (37.16%) than for Widebody Aircraft (23.07%). Interestingly, the largest lessors are not the aircraft manufacturers - Boeing and Airbus - even though both have recently established Trading/Leasing divisions. The largest lessor is GECAS, a unit of General Electric Company. GECAS today owns approximately 1200 aircraft, manages approximately 300 aircraft for others and has more than 230 airline customers. As a term of comparison, the largest carrier in the world, American Airlines, operates around 700 aircraft. The market structure for leasing is such that there are two very big lessors - GECAS and ILFC - that jointly have more than 50% of the market and a limited number of other lessors that split the rest of the market.

In its Annual Report, ILFC 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. In some cases the Company provides fleet management services to companies with aircraft portfolios for a management fee. The Company also remarkets and sells aircraft owned by others for a fee."*[13]

The picture that emerges is that lessors are trading specialists. Together with the fact that lessors are big firms that own a large number of aircraft, this suggests that economies of scale in trading are relevant and able to generate substantial differences in transaction costs between leased and owned aircraft. This is the most likely reason behind the gains estimated in Section 5.

An operating lease means that the lessor retains ownership of the asset and rents it to the airline for a period of time that in general varies between four to eight years. The rental payments are structured as two-part tariffs, with a fixed monthly lease rate plus a variable fee contingent on lessees' utilization (monthly flying hours and landings). Most leases are on a "net" basis with the lessee responsible for all operating expenses. In addition, normal maintenance and repairs, airframe and engine overhauls, and compliance with return conditions of flight equipment on lease are paid for by the lessee. 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.

[12] See Pulvino (1998).

[13] Form 10-K, International Lease Finance Corporation - ILFC. Filed on March 11, 2004.

Another type of leasing contract already existed with an older history, the capital lease. In a capital lease, the lease terms are longer, usually fifteen years to twenty years, and the airline has an option to buy the airplane 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.[14]

4 Model

In this Section, I introduce a simple model that guides the empirical analysis performed later. I do not aim at offering a full characterization of all realistic features of airlines' optimal fleet decision. My theoretical approach focuses on highlighting the major forces that motivate the trading of aircraft and the effects of leasing on patterns of trading and utilization of aircraft. We only discuss the results of the model in the text, relegating most of the analytic details to Appendix C.

I first introduce the assumptions of the model. Then, I consider the benchmark case where transaction costs on leased and owned aircraft are the same. I show that in this setting the trading and utilization patterns of leased and owned aircraft are exactly the same. I later introduce higher transaction costs on owned aircraft than on leased aircraft and generate predictions on the different behavior of leased and owned aircraft. Finally, I consider the supply of aircraft by a stylized monopolist lessor. The Section concludes with a discussion of the assumptions, the results and a summary of the empirical predictions that I then test in Section 5.

4.1 Setup

Aircraft - In each period an exogenous flow x of capital goods enters the economy. For concreteness, I refer to them as aircraft. Aircraft depreciate stochastically.[15] More specifically, a new aircraft produces a flow of service equal to q_1. At the end of each period, a quality q_1 aircraft depreciates to $q_2 < q_1$ with probability $\gamma > 0$. A quality q_2 aircraft does not depreciate but dies with probability γ. Given stochastic depreciation, the total number of aircraft of quality q_i is equal to $X_i = X = \frac{x}{\gamma}$. The total mass of aircraft is then equal to $2X$ and I assume that $2X < 1$.[16]

Aircraft can be bought or leased. For each quality q_i, a mass $0 \leq X^L \leq X$ of aircraft is leased and a mass $X - X^L$ is owned.[17]

Firms - There are two types of firms, carriers - who use aircraft to produce flights - and a lessor - who supplies leased aircraft to carriers.

There is a unit mass of carriers that differ in their efficiency parameter $z \in [\underline{z}, \overline{z}]$. Efficiency is stochastic and it evolves according to

$$\begin{aligned} z_t &\sim F(z) \text{ with probability } \alpha \\ z_t &= z_{t-1} \text{ with probability } 1-\alpha \end{aligned}$$

where $\alpha \in [0, 1)$ measures the volatility of a carrier's efficiency.[18] Carriers are infinitesimal, i.e. each carrier can operate at most one aircraft. The per-period revenue π and output Y of a carrier of efficiency

[14] In Gavazza (2006) I empirically investigate the differences between the operating and the capital lease.

[15] Aircraft depreciate stochastically to highlight in the clearest way the reasons for trade in the model. See Subsection 4.2 for a more thorough discussion of the assumption.

[16] Any $X < 1/2$ can be generated by some cost or market structure in the production of aircraft.

[17] I am assuming that the quantity of q_1 aircraft and q_2 aircraft available for lease are the same, even though in principle the lessor could choose different quantities. The assumption simplify calculations but could easily be dispensed with.

[18] The results derived in the paper depend only on the stochastic nature of efficiency and not on the particular process assumed, as it will become clear. The specific process makes later derivations more tractable.

z operating an aircraft of quality $q \in \{q_1, q_2\}$ are

$$\pi(z,q) = Y(z,q) = zq.$$

I refer to the carriers collectively as the *industry.*

The monopolist lessor[19] acquires aircraft at the market price p_i and rents them at a rental rate r_i. His per-period profits are

$$\pi_L = \sum_{i=1,2} \left(r_i - \left(p_i - \beta(1-\gamma)p_i - \beta\gamma p_{i+1}\right)\right) X^L \tag{1}$$

where $p_3 = 0$ and β is the discount factor, common to carriers and the lessor. On each leased unit, the lessor's revenue is equal to the rental rate r_i. His cost is given by the implicit rental rate on ownership - where the discount factor is adjusted to take into account that with probability γ each aircraft depreciates.

Trade and Transaction costs - In each period, carriers discover their current efficiency z and can trade aircraft. On owned aircraft, the buyer pays the endogenous price p_i, but the seller receives $p_i - T$, where $T \geq 0$ represents transaction costs and $i = 1, 2$. On leased aircraft, the lessee pays the endogenous per-period rental rate r_i to the lessor and there are no transaction costs when trading.[20]

For simplicity, I assume also that the change in the efficiency parameter z and the depreciation of the aircraft are mutually exclusive events, so that at most one of them can happen in each period.

For notational convenience, let $q_3 = 0$ denote the quality of an aircraft that just died, whose prices is equal to $p_3 = 0$. Note that a carrier with no aircraft has a q_3 aircraft.

4.2 Benchmark: no transaction costs. $T = 0$

Before considering transaction costs, I first analyze the case where there are no frictions in trading. This is a useful benchmark when considering the impact of transaction costs on trading patterns and carriers' output. I show that in this benchmark case, leasing has no effect on the equilibrium allocation of aircraft. Hence, leased and owned aircraft have exactly the same probability of being traded, the same distribution of holding durations and produce the same output. However, as I will show in Section 5, the data clearly reject these implications.

An allocation specifies which carriers operate which aircraft. Since the quality of the aircraft and the efficiency of the carrier are complements, carriers self select and acquire different qualities of aircraft according to their efficiency. Thus, secondary markets play a fundamental allocative role. Carriers trade aircraft for two distinct reasons. The first - captured by the parameter γ - is the replacement of old aircraft: when the quality of capital depreciates over time, carriers sell their old aircraft to acquire higher quality ones. The second - captured by the parameter α - is the adjustment of productive capacity: when shocks adversely affect profitability, firms exit and sell aircraft to carriers who wish to enter the industry, for example. Proposition 1 shows that in the benchmark case carriers trade aircraft such that in equilibrium perfect assortative matching always obtains. Moreover, the same assortative matching obtains for leased and owned aircraft.

Proposition 1 *When there are no transaction costs, there exists two threshold values z_1 and z_2 with $z_1 > z_2$ such that all carriers $z \geq z_1$ operate q_1 aircraft, carriers $z_2 \leq z < z_1$ operate q_2 aircraft and carriers $z < z_2$ do not operate any aircraft. Equilibrium on the market for each quality q_i requires that z_1*

[19] It is important to remind that the lessor is not the producer of aircraft, but merely an intermediary.

[20] 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.

and z_2 satisfy

$$\begin{aligned} X_1 &= 1 - F(z_1) \\ X_2 &= F(z_1) - F(z_2) \end{aligned}$$

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

Two features of this equilibrium allocation are worth noting:

1. The set of carriers is partitioned and there is perfect matching between quality of the aircraft and efficiency of the carriers. Here, perfect matching implies two things. First, only the most efficient carriers operate an aircraft, as all carriers above the z_2 threshold operate an aircraft. Second, the set of firms operating the q_1 aircraft is disjoint from the set of firms operating a q_2 aircraft. These two considerations together imply that the equilibrium allocation maximizes the total industry output.

2. The equilibrium allocation of aircraft and prices is independent of the volatility parameter α, as it can be verified from inspection of the equations determining it. The equilibrium is exactly the same in the case of deterministic efficiency $(\alpha = 0)$ and in the case of i.i.d. efficiency $(\alpha = 1)$, even though the volume of trade obviously increases as α increases.

As I will show later, none of these feature survives once I introduce transaction costs.

Proposition 1 also says that the allocation is the same for owned and leased aircraft. As a result, we obtain:

Corollary 2 *When there are no transaction costs, leased aircraft and owned aircraft have the same holding duration, the same probability of being traded and the same output.*

4.3 The Effects of Transaction Costs

In this Section I introduce transaction costs on owned aircraft to understand the way leasing affects the trade of aircraft and industry output. A precise derivation of the equilibrium conditions is found in Appendix C. Here, I simply discuss the features of the equilibrium that guide the empirical analysis performed in Section 5.

The presence of transaction costs on owned aircraft modifies the previous benchmark in a significant way. Lower transaction costs on leased aircraft makes leasing very attractive for carriers. However, market power implies that the lessor does not serve the entire market.[21] As a result, the rental rate r_i is pushed higher than $p_i - \beta(\gamma p_{i+1} + (1-\gamma) p_i)$, the implicit rental rate on ownership if there were no transaction costs. This implies that carriers trade-off the lower implicit rental rate on owned aircraft and the lower one-time transaction cost on leased aircraft. This results in most carriers being indifferent between leasing and owning aircraft when they acquire aircraft.

For owners, the quality of the aircraft that a carrier owns now becomes an additional state variable and determines jointly with the efficiency z the optimal policy of the firm. The transaction cost acts in two different ways. Logically, it acts as a barrier to sell when a firm owns an aircraft. However, it also acts as a barrier to buy when a carrier does not own an aircraft. As a result, we obtain

Proposition 3 *Leased aircraft trade more frequently. Hence, on average they have shorter holding duration than owned aircraft.*

[21] This is numerically shown in the next Subsection.

The transaction cost T creates the option value of waiting for owners. Since efficiency z is stochastic, waiting means requiring a lower z before selling their aircraft and exiting and a higher draw of z before replacing a depreciated aircraft. This force is obviously stronger the higher are transaction costs and therefore Proposition 3 follows.

The previous discussion indicates that owners have wider inaction regions than lessees. The next Proposition 4 in particular shows that owners have a lower value than lessees of the what we define as the *exit threshold*, the value of z such that a carrier is indifferent between continuing to operate the aircraft or disposing of it. This is one force (and the most important empirically, as I show later) behind the next Proposition.

Proposition 4 *The efficiency of lessees is higher than the efficiency of owners.*

Proposition 4 describes what we call the *efficiency effect:* lessees are on average more efficient than owners. The Proof of Proposition 4 shows that this is the sum of two distinct effects. The first is a *selection effect*: very efficient carriers choose to lease because leasing allows them to replace their q_1 aircraft at lower costs when it depreciates. Carriers with very high z are the only carriers that have a strict preference for leasing and the *selection effect* applies only to q_1 aircraft. The second effect is an *exit threshold effect*: the least efficient owner is less efficient than the least efficient lessee because lower transaction costs reduce inactions regions. 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). Note that there is a fundamental difference in timing and causality between the *selection* and the *exit threshold effects*. The *selection effect* unfolds at the time carriers acquire q_1 aircraft, while the *exit threshold effect* unfolds over time as carriers' efficiency evolves. I later exploit this fundamental difference in timing to decompose the *efficiency effect* empirically and separate its components. Moreover, the difference in timing are equivalent in difference in causality: causality runs from high efficiency to leasing in the *selection effect*, while causality runs form leasing to high efficiency in the *exit threshold effect.*

Empirically, the *efficiency effect* implies that the distribution of efficiency of lessees stochastically dominates the distribution of efficiency of owners.

The next Proposition shows that leasing has a positive effect on output, i.e. leased aircraft fly more than owned aircraft. However, the proposition says that the impact is different for new and old aircraft:

Proposition 5 *The average output of a leased aircraft is higher than the average output of an owned aircraft, but the effect is distinct for q_1 and q_2 aircraft. In particular, the difference in utilization between leased and owned aircraft is higher for q_1 aircraft than for q_2 aircraft.*

Leasing improves the matching between the quality of the aircraft and the efficiency of the carriers and this leads to higher output. The effect of matching can be decomposed in two distinct forces. The first is the previously described *efficiency effect,* i.e. the efficiency of lessees is higher than the efficiency of owners. The second effect is a *pairing effect.* Lower transaction costs allow firms to select more precisely the quality of the aircraft based on their efficiency. This increases output since the most efficient carriers always operate the best aircraft. Empirically, the *pairing effect* implies that the covariance between the quality q of the aircraft and the efficiency z of the carrier is higher for leased aircraft than for owned ones.

Proposition 5 also tells us that the difference in output between leased and owned aircraft unfolds in a subtle way. In particular, the difference in output is smaller for q_2 than for q_1 aircraft.[22] Adding some conditions on the depreciation of aircraft (depreciation is not too strong, i.e. the difference between q_1 and

[22] This is also equivalent to saying that the difference in output bewteen new and old aircraft is bigger for leased aircraft than for owned aircraft.

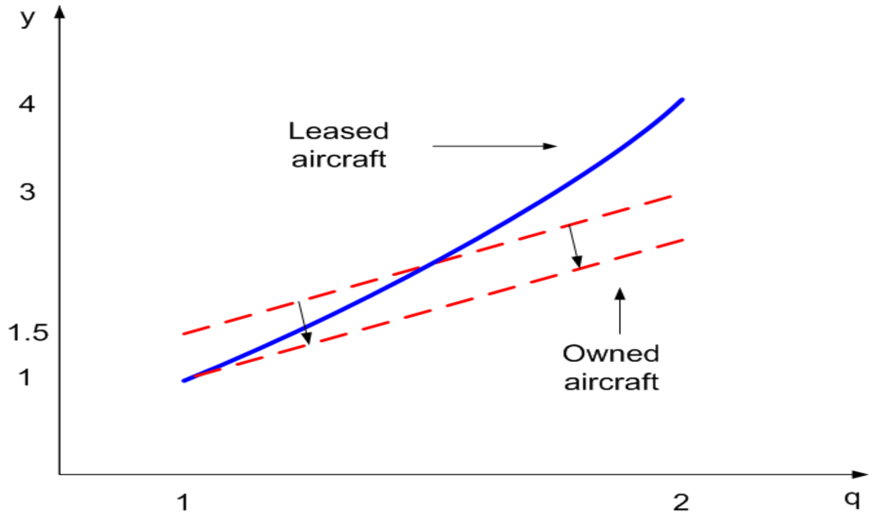

FIG. 3 - ILLUSTRATIVE EXAMPLE OF PROPOSITION 5, WHEN QUALITY q IS UNIFORMLY DISTRIBUTED ON $[1, 2]$. SEE TEXT FOR DETAILS.

q_2 is not too large) and on the efficiency distribution $F(z)$ ($F(z)$ is strictly increasing with density $f(z)$ everywhere continuous and bounded by some K), I was able to obtain an even stronger result, i.e. that the effect on output is *reversed* for old aircraft: on old aircraft, owned aircraft fly more than leased aircraft. This is because some productive carriers might end up operating old owned aircraft as they do not replace their aircraft as they do not wish to bear the transaction costs.

The results of Proposition 5 are easily understood with an example. Assume now that quality q is continuous and suppose for simplicity that efficiency z and quality q are both uniformly distributed on $[1, 2]$. Suppose also that transaction costs are so high that owned aircraft never trade, while transaction costs are zero on leased aircraft so that leased aircraft always trade. Then in equilibrium a leased aircraft of quality q is always perfectly paired to a carrier of efficiency $z = q$ and the output of leased aircraft is $y_L = zq = q^2$. On the other side, an owned aircraft of quality q is paired to a carrier whose efficiency can be any value of z and the output of owned aircraft is then $y_O = E(z)q = 1.5q$. In Figure 3, we plot the resulting output y_L and y_O as a function of quality q. For the best aircraft, leased aircraft fly more than owned aircraft, while for old aircraft owned aircraft fly more than leased aircraft. However, Proposition 5 could not establish the described "output-crossing" directly, because of the previously explained *efficiency* effect. Thus - going back to example - the efficiency z of owners ends up being distributed on $[a, 2]$ for some $a < 1$ and the average efficiency of owners $E(z)$ might be lower or higher than 1, the efficiency value of the lessee that operates the worst aircraft. As a result, the output function of owned aircraft is shifted downward in Figure 3. Hence, Proposition 5 follows: the difference in output between leased and owned aircraft is larger on new aircraft than on old aircraft.

4.3.1 Lessor's Optimal Quantity

I now discuss briefly the lessor's choice of quantity X^L. The analysis is mainly performed through a numerical analysis, but it highlights different forces at work.

The optimal quantity of aircraft X^L offered by the lessor must maximize his per-period profits because the decision to lease is static. Hence the lessor solves

$$\max_{r_1, r_2, X^L} \sum_{i=1,2} \left(r_i - \left(p_i - \beta\left(1-\gamma\right)p_i - \beta\gamma p_{i+1}\right)\right) X^L \tag{2}$$

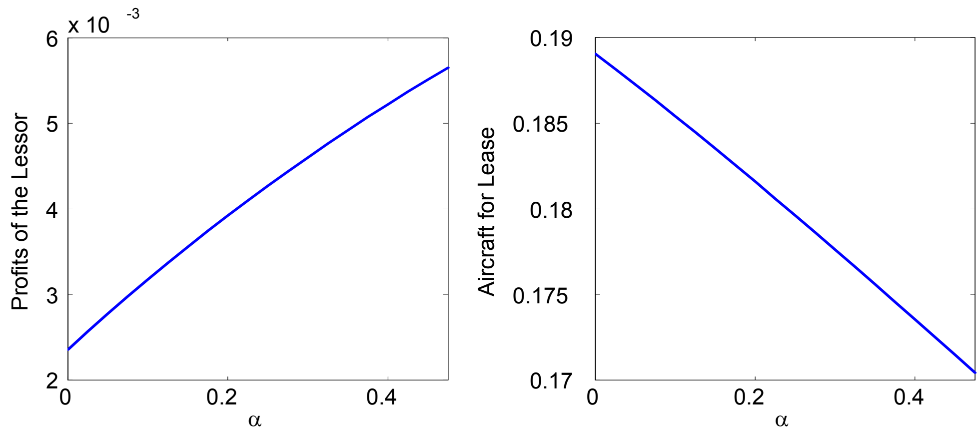

Fig. 4 - Profits of the lessor and aircraft for lease for $\alpha \in [0, 1-\gamma]$. Baseline parameters are $x = .1$, $\gamma = .5$, $\beta = .95$, $q_1 = 1$, $q_2 = .4$, $T = .025$ and z is uniformly distributed on $[0, 1]$.

subject to equilibrium conditions in the market for each quality q_i.[23]

The problem cannot be solved analytically. As any monopolist, the lessor trades off a higher markup and a higher quantity supplied. Intuitively, markup and profits are higher when transactions are more frequent. I present in Figure 4 the results of a numerical simulation and a comparative static with respect to the parameter α. In accordance with the intuition, profits increase monotonically in α, while total aircraft for lease X^L decreases monotonically in α.

I believe one major fact is worth highlighting: the change in profits due to an increase in volatility. Figure 2 showed that until the early 80s, leasing was almost nonexistent. Suddenly, around 1984 lessors started to acquire a large number of aircraft in the primary markets and the leasing business started. Note that this is just a few years after the Airline Deregulation Act removed controls on entry and exit and deregulated fares.[24] It seems natural to associate the increase in competition with an increase in volatility[25] and an increase in the turnover of firms. Hence, in terms of my model, the increase in competition makes the leasing business more profitable and this might explain why it started exactly after the Deregulation.

It is also interesting to note that two distinct form of leasing have emerged. For most consumer durables (such as cars) manufacturer leasing is the standard, while for most capital equipment (such as aircraft) third-party leasing is dominant. This difference is likely to be related to the difference in the main motivation for trade: for cars, most trades arise from replacement of the depreciated good, while for aircraft most trades arise from shocks to firm that induce expansion or reduction of assets.

4.4 Discussion and Summary of Predictions

The model presented above is highly simplified and stylized, but I argue it contains the most salient economic forces of the aircraft market. In this Section I first briefly discuss the assumptions of the model and then how the model could be enriched. The Section concludes with a summary of the empirical implications that I later test using data on commercial aircraft.

The theoretical analysis highlights that more efficient carriers choose higher quality aircraft due to complementarity and this theoretical result guides much of the empirical analysis. However, in the model

[23] More precisely, subject to equations (20), (21), (22), (23), (24), (25), (26), (27) and (28) in Appendix C.

[24] See footnote 6.

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

quality is a stochastic function of age, while in the empirical analysis aircraft quality is going to be a deterministic function of age. Given this difference, it is important to highlight the role of stochastic depreciation in the model. Stochastic depreciation is a simple "trick" to have 2 qualities, but the life of the aircraft to be longer than 2 periods without age affecting the price of the aircraft and carriers' maximization problem. This modeling assumption allows me to cleanly separate the two motives for trade in the paper: depreciation (the γ in the model) and shocks (the α in the model). However, none of the results of the model hinges upon stochastic depreciation.[26]

In the model each carrier operates at most one aircraft[27] and the only way for carriers to expand their output and profits is by operating a better aircraft. In reality, we both observe variation in carriers' size and expansion of carriers through purchase of additional aircraft. However, the assumption of infinitesimal firms is mainly done for tractability. A more realistic setup would have carriers with efficiency z and i.i.d. shocks ϵ_j on each route j they fly, so that a carrier' output is $\sum_j (z + \epsilon_j) q$. 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 operate more aircraft, their fleet is on average younger and their share of leased aircraft is lower, as they can reallocate their aircraft internally, without paying transaction costs. However, if we take into account the fundamental indivisibilities involved in long flights[28] and widebody aircraft (the focus of the empirical analysis), 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 carriers.

Moreover, the analysis hinges on one important assumption. The costs of trading leased aircraft is lower than the cost of trading owned aircraft. I suggested that economies of scale in trading might be the strongest force behind it. It seems plausible that the network of each carrier' routes affects carrier' size more than its aircraft trading activity. The degree of economies of scale in carriers' network might very well be different from economies of scale in lessors' trading and this can generate differences in transaction costs. Moreover, in the model all carriers pay the same price for the same aircraft. In reality aircraft prices are set in privately negotiated transactions between buyers and sellers and Pulvino (1998) documents that carriers under financial pressure sell aircraft at a 14% discount. Obviously, such a difference from the market price is not incurred if the carrier leased the aircraft instead. Hence, the discount could be interpreted also as a form of transaction cost that lead carriers under financial pressure to keep operating the aircraft longer than would be efficient.

The model also assumes that leased and owned aircraft coexist in equilibrium despite leasing being more efficient because market power induces the lessor to restrict output to increase profits. In Gavazza (2006) I use data on aircraft prices and aircraft lease rates and show, among other things, that lessors' market power is substantial: the mark-up of lease rates over implicit rental rates is around 20%.[29] Investigating the sources of this mark-up is an interesting question, but taken as given, it seems plausible that this

[26] In principle, I could have 2 qualities and make depreciation deterministic, i.e. an aircraft is born high quality q_1 and after T deterministic periods becomes a quality q_2 aircraft. The problem with this formulation is that the price of an aircraft would be a function of age, i.e. each aircraft of a different age has a different price. This feature complicates the analysis. Carriers would care not only about the quality of the aircraft they acquire, but also about the age, and I would then need to have age as an extra state variable to keep track. All of this does not seem important for the theoretical point I want to make.

Alternatively, I could have aircraft last 2 periods only with deterministic depreciation. But the problem now is that the quality of the aircraft depreciates in every period, so I have no way to cleanly separate the two motives for trade in the paper: depreciation (the γ in the model) and shocks (the α in the model).

[27] In the literature on aircraft differentiation (Benkard (2004) and Irwin and Pavcnick (2005)), the assumption of independent purchases by the same carrier is commonly made.

[28] A flight from New York to London cannot be generally broken down to 2 flights.

[29] If there were no frictions of any type - and in particular, frictions of trading aircraft -, probably leasing would not survive since it is 20% more expensive than owning.

mark-up implies that not all aircraft are leased, but some aircraft are owned. In this paper market power is a convenient way to obtain coexistence of leased and owned aircraft in equilibrium. However, I am not claiming this is the only reason for why lessors do not serve the entire market. The focus of the model is to obtain clear empirical predictions on the *effects* of leasing on the allocation and utilization of leased versus owned aircraft and a monopolist lessor was the easiest way to obtain the coexistence of leased and owned aircraft. Other plausible reasons for the coexistence of leased and owned aircraft are: 1) heterogenous transaction costs, as in Gehrig (1993) and Johnson and Waldman (2003, 2005), or stochastic transaction costs, as in Stolyarov (2002); 2) aggregate shocks that affect the prices of aircraft. Carriers and lessors might thus share the risk of price fluctuations; 3) carriers' financial constraints, as in Eisfeldt and Rampini (2005). All these additional explanations, however, do not explain the empirical patterns of transactions and utilizations that are the main focus of the paper.

The model highlights some forces that push carriers to self select into leasing and owning when not all units are leased. In particular, the model shows that more efficient carriers prefer to lease in order to replace their aircraft when it depreciates. I assumed that the stochastic process governing the evolution of efficiency and the transaction cost are common to all carriers. However, it is easy to extend the model to accommodate heterogeneous volatility and heterogeneous transaction costs. Higher volatility and/or higher transaction cost carriers would have wider inaction bands, be on average less efficient and more willing to lease. Higher volatility increases the probability of having to sell the aircraft and therefore of paying the transaction cost. Hence, higher volatility carriers are willing to pay more than lower volatility carriers to lease their aircraft.

The model could also easily be enriched to capture other features of the data. For example, one important feature of the airline market is that frequently aircraft are parked inactive in the desert. In a previous version of this paper I explicitely showed that a simple extension with two additional assumptions can capture this fact. The first is a fixed cost of operation f that the carrier pays if it operates the aircraft. The second is a temporary shock that each carrier receives with probability μ and lowers the output of the current period only. It is easy to show that, when hit by a temporary shock, some carriers now choose not to sell the aircraft but keep it inactive to operate it in the future. Clearly, this phenomenon is stronger the higher are the transaction costs. Thus the model would have the additional prediction that leased and owned aircraft are parked with different frequency. This effect is very similar in spirit to the *efficiency effect* previously described, but empirically creates a discontinuity in distribution of output. Hence, I call it *parking effect,* i.e. leased aircraft are parked less frequently than owned aircraft.

In summary, the model shows how the (in)efficiency of transactions translates into (in)efficiency of production. It illustrates the effects of leasing's lower trading frictions on the production of final output, i.e. flights. In the next Section, I present empirical evidence consistent with the implications of the model. The model predicts a direct link between the holding duration of each aircraft and the efficiency of its operator. To summarize, the model predicts that:

1. leased aircraft trade more frequently and have shorter holding durations than owned aircraft.

2. As a result, leased aircraft are allocated more efficiently and therefore produce a higher output than owned aircraft. The model suggests that this is the result of distinct forces, which can easily be understood decomposing the output equation in its components

$$\begin{aligned} E(Y) &= \Pr(Y>0)\,E(Y|Y>0) = \Pr(zq>0)\,E(zq|zq>0) \\ &= \underbrace{\Pr(Y>0)}_{\textit{Parking}}\left(\underbrace{E(z|Y>0)}_{\textit{Efficiency}}E(q|Y>0)+\underbrace{Cov(z,q|Y>0)}_{\textit{Pairing}}\right) \end{aligned} \tag{3}$$

Hence leased aircraft fly more than owned aircraft for three main effects:

- *Parking effect*: leased aircraft are parked less frequently.
- *Efficiency effect*: conditional on the aircraft being in use, the efficiency of lessees is higher than the efficiency of owners. This is the sum of two forces: a *selection effect* (high efficiency carriers choose to lease q_1 aircraft) and an *exit threshold effect* (lessees have narrower inaction regions).
- *Pairing effect*: conditional on the aircraft being in use, the covariance between quality of the aircraft and efficiency of the carrier is higher for leased aircraft.

In the empirical section, I also provide evidence that shows that empirically the *exit threshold effect* is the most significant component of the *efficiency effect.*

5 Empirical Evidence: Commercial Aircraft

In this Section I present empirical evidence of the main implications of the model using data from commercial aircraft, presented in the next Subsection. The empirical analysis then proceeds in two different ways, each with its pros and cons. First, I test the predictions of the model without imposing any additional structure: I present evidence consistent with the fact that transaction costs are significantly different between leased and owned aircraft. In particular, I compare holding durations, probability of parking the aircraft, probability of trading the aircraft and hours flown between leased and owned aircraft. Second, I adopt some functional form assumptions that allow me to perform a more quantititave analysis. In particular, I estimate the depreciation pattern of aircraft to obtain estimates of quality of capital and efficiency of carriers. Based on these estimates, I quantify the relevance of the *parking,* the *efficiency* and the *pairing effects.*

In the concluding part of the Section, I discuss alternative explanations, presenting additional evidence against them and in favor of the current model.

5.1 Data

The source of information used in this paper is a detailed database for the aviation market compiled by a producer of computer based aviation market information systems and safety management software. The database is organized in several different files that classify aircraft and operators according to different characteristics of interest. In my analysis I use one main file:

1. *Current Aircraft Datafile.* This file contains data on the characteristics of each aircraft, such as the type (e.g. Boeing 747, Airbus A-340), the model (e.g. Boeing 747-200), the engine, the noise stage. It reports the delivery date, the annual flying hours and landings, the cumulative flying hours and landings with the current operator, the operational role (ex: per passenger transportation, freighter, ...). It specifies if the aircraft is owned by the current operator or leased, and in this case, the type of lease (Financial vs. Operating) and length of the contract. The reference date for this file is April 2003.

   I occasionally complement this main file with a second datafile:

2. *Time-series Utilization Datafile.* This file contains the flying hours and landings of each aircraft for each month since January 1990 to April 2003.

Table 1
Summary Statistics

	Total Aircraft	Hours Flown	Parked	Holding Duration	Age
Leased	579	3709	.024	6.19	8.90
		(1293)	(.153)	(4.75)	(6.80)
Owned	2269	3255	.064	9.46	10.31
		(1383)	(.245)	(6.34)	(7.29)

Notes: Standard deviations in parenthesis.

I focus my analysis on Widebody aircraft used for passenger transportation.[30,31] I keep in my sample only those aircraft operated by the same carrier in the last 12 months.[32]

Table 1 presents summary statistics. Leased aircraft represent approximately 20% of the observations in my sample. As predicted by the model, leased aircraft have shorter holding durations, lower fraction of parked aircraft and higher hours flown (the measure of output y I am using[33]) than owned aircraft. On average, leased aircraft have a holding duration 35% shorter than owned aircraft, are parked inactive 2.5 times less frequently and fly 14% more hours.

5.2 Preliminary Evidence

Holding durations - Figure 5 presents the empirical distribution of the current holding durations.[34] The dotted line represents owned aircraft, while the solid line represents leased aircraft. It is readily apparent that on average the holding duration of owned aircraft is higher than the duration of leased aircraft, consistent with theoretical predictions of Proposition 3. A standard Kolmogorov-Smirnov test of the equality of distributions rejects the null hypothesis of equal distributions at the 1% level (the asymptotic p-value is equal to $3.2465 * 10^{-27}$). 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 accept the null hypothesis that the distribution of holding durations of owned aircraft first order stochastically dominates the distribution of holding durations of leased aircraft at the 1% level. Appendix A presents the details of the procedures and the formal results of the tests.[35]

[30] The choice of Widebody aircraft is motivated by the choice of instruments in the estimation of the quality of the aircraft, as it will become clear in Subsection 5.3. I performed similar analysis on Narrowbody aircraft obtaining similar qualitative results. In particular, I found evidence consistent with the *parking, productivity* and *pairing effects*.

[31] The database classifies a number of aircraft as "for lease", meaning that they currently with the lessor. These aircraft are not included in my analysis, since lessors lease a large number of freighters too and the data do not allow me to distinguish between the two when the aircraft is with the lesssor. See Subsection 5.6 for a robustness check that takes into account this fact.

[32] This is because I measure each aircraft' output as the total hours flown in one year. The data report hours flown also for the last month and the last 3 months. The choice of annual output however reduces the impact of different seasonality for different carriers. One concern is that this selection might cause a bias similar to the one analyzed in the literature on the estimation of production function (e.g. Olley and Pakes, 1996) as a carrier might be less likely to trade a young aircraft, since the carrier could expect larger future returns for any level of the current productivity. However, in my case this concern seems minor since results reported in Table 4 show that age of the aircraft does not significantly predict the probability of trading it.

[33] I am thus measuring output (and input) using physical units and not revenues. Here I cannot measure revenues because I do not observe neither prices nor load factors.

[34] Hence, all durations are right-censored.

[35] As holding durations might be correlated within carriers, I also compare the distributions of the median holding duration for each carrier and again I accept the hypothesis that the distribution of holding durations of owned aircraft first order

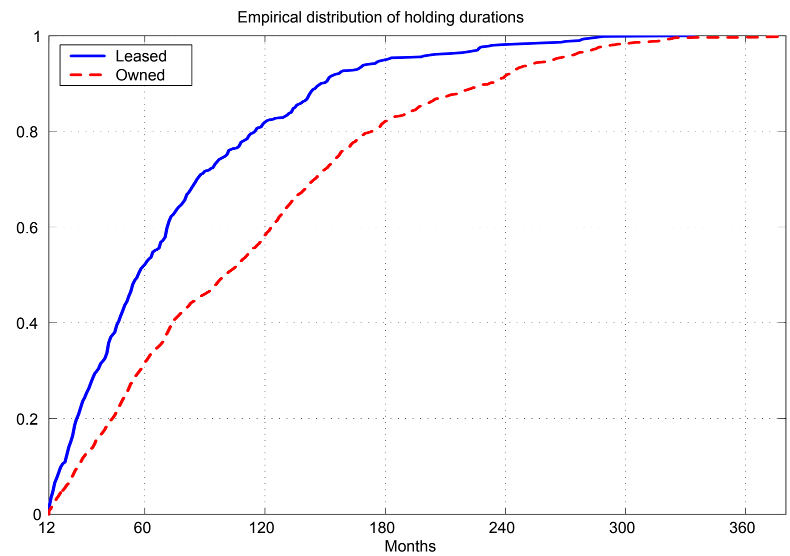

Fig. 5 - Empirical cumulative distribution functions of holding durations, owned aircraft (dotted line) vs. leased aircraft (solid line).

One potential concern is that the shorter holding duration of leased aircraft might just reflect the effect of age, as Table 1 shows that leased aircraft are on average younger. In Table 2 we present the coefficients of a truncated[36] regression of the (log of the) holding duration in months on the (log of) age of the aircraft, aircraft model fixed effects and a dummy equal to one if the aircraft is leased. Table 2 shows that, even conditioning on age, leased aircraft have a holding duration which is on average 31% shorter than the duration of owned aircraft.[37]

Table 2
Truncated Regression. Holding Durations

Log(Holding Duration)	(1)
Constant	.620
	(.194)
Log(Age)	.798
	(.010)
Leased	−.304
	(.031)
Model Dummies	Yes
Log Likelihood	−1792.9
Observations	2848

Notes: Robust standard errors in parenthesis.

stochastic dominates the distribution of holding durations of leased aircraft.

[36] I am considering aircraft that have been operated by the same carrier in the last 12 months of the database, so holding durations are truncated from below to 12 months.

[37] We also estimated the regression including carrier fixed effects and found similar results, although the coefficient on the leased dummy is slightly smaller.

TABLE 3
LEASING AND PARKED AIRCRAFT

PROBABILITY OF PARKING	(1)	(2)
CONSTANT	−.0660	.0583
	(.006)	(.045)
AGE	.0125	.0071
	(.0009)	(.0011)
LEASED	−.0219	−.0181
	(.0077)	(.009)
MODEL DUMMIES	NO	YES
R^2	.160	.278
OBSERVATIONS	2848	2848

Notes: Robust standard errors in parenthesis.

Output - The model highlights three forces that explain the higher output of leased aircraft versus owned ones: the *parking, efficiency and pairing effect.* I now present evidence that all three effects capture salient features of the data.

Parking effect - To investigate the *parking effect,* I compare the probability of being parked inactive of two observationally equivalent aircraft, one leased and one owned. Table 3 presents the results of a linear probability model[38] where the dependent variable is equal to one if the aircraft has been parked for the entire 12 months between May 2002-April 2003, and zero otherwise. The results in Column (1) show that, conditional on age, the probability that a leased aircraft is parked is 2.19% less than an owned aircraft. Since the fraction of owned aircraft parked is 6.3%, the coefficient of -.0219 represent a sizable decrease of approximately one third in the probability of parking the aircraft. Moreover, the result in Column (2) shows that result is robust to conditioning on aircraft model.

Efficiency effect - One way to understand barriers to trade and to investigate the relevance of the *efficiency effect* is to compare the probability of trade between leased and owned aircraft as a function of the utilization of the aircraft in the year prior to trade. One implication of Proposition 4 is that leased aircraft should have a higher utilization before being traded than leased aircraft. For this reason, I merged the *Current Aircraft Datafile* with the *Time-series Utilization Datafile* and obtained the hours flown in the period between May 2001-April 2002.

Table 4 reports the coefficients of a linear probability model where the dependent variable is equal to one if the aircraft has been traded in the period May 2002-April 2003, and zero otherwise. The results in Column (1) indicate that, conditional on age and utilization in the previous year, leased aircraft are 13% more likely to be traded. This is consistent with the result of Proposition 3 and reinforces the previous analysis of holding durations. In Column (2), the utilization of the aircraft is interacted with the indicator variable for leased aircraft to analyze the impact of previous utilization differently for leased and owned aircraft. Figure 6 depicts the fitted values from the results of Column (2). For any level of hours flown, the probability of trading a leased aircraft is always higher than the probability of trading an owned one. The difference is particularly stark when the aircraft was parked in the previous period. The difference

[38] I use a linear probability model instead of a probit or logit because the aircraft model fixed effects create the well known problem of perfect classification (Ruud (2000), pag.754) in the maximum likelihood estimation of probit or logit, as some aircraft model are never parked. When aircraft fixed effects are removed, the results of probit/logit and linear probability model are very similar.

Table 4
Leasing and Trade

Probability of Trade	(1)	(2)
Constant	.1056	.0405
	(.046)	(.041)
Age	−.00008	−.00003
	(.0012)	(.0012)
Hours Flown in t-1	−.0413	−.0214
	(.0056)	(.0050)
Hours Flown in t-1*Leased		−.0662
		(.012)
Leased	.1382	.3538
	(.0145)	(.048)
Model Dummies	Yes	Yes
R^2	.156	.171
Observations	2888	2888

Notes: Robust standard errors in parenthesis.

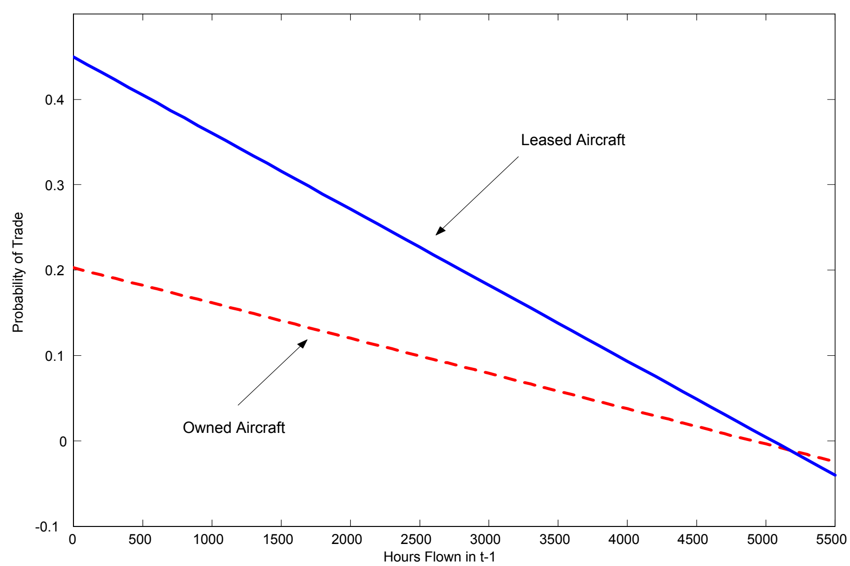

Fig. 6 - Probability of trade as a function of utilization in previous year, leased aircraft (solid line) vs. owned aircraft (dotted line). Based on coefficients of Column (2) of Table 4.

Table 5
Leasing and Hours Flown

Hours Flown	(1)
Age	-60.6
	(11.58)
Leased	333.09
	(74.67)
Age*Leased	-9.88
	(5.50)
Model Dummies	Yes
R^2	.4622
Observations	2689

Notes: Robust standard errors in parenthesis.

of probabilities reduces as utilization increases and it disappears completely for aircraft that are used the most.

It is also important to note that Figure 6 shows that the probability of trading an aircraft is a decreasing function of previous utilization. Thus, in terms of the model, trading is driven more by shocks to efficiency (α) than by replacement of aircraft (γ). We will come back to this distinction later when we decompose the *efficiency effect*.

Pairing effect - To investigate the presence of the *pairing effect*, I construct a test motivated by Proposition 5 and the discussion thereafter. Proposition 5 shows that the output gain due to leasing unfolds in a subtle way. In particular, conditional on the aircraft being in use, we should observe a higher difference in utilization between owned and leased aircraft for high quality aircraft than for low quality aircraft. Moreover, the discussion after Proposition 5 explains that actually on low quality aircraft owned aircraft could have a higher utilization than leased aircraft. As quality and age are inversely related, I can explore the *pairing* effect using only aircraft that were not parked to estimate the following equation:

$$y_{il} = \beta_l + \beta_1 Age_{il} + \beta_2 Leased_{il} + \beta_3 Age_{il} * Leased_{il} + \epsilon_{il} \tag{4}$$

where β_l is an aircraft model fixed effect. The dependent variable y_{il} is the hours flown in the last 12 months and $Leased_{il}$ is an indicator variable equal to 1 if the aircraft is leased and zero otherwise. As in the literature on the estimation of production functions (e.g.: Olley and Pakes, 1996), simple OLS estimation of equation (4) is plagued by a simultaneity problem generated by the relationship between efficiency and quality of capital. However it is exactly this bias that informs about the *pairing effect*. The Age_{il} variable for leased aircraft should be more correlated with the residual than the Age_{il} variable for owned aircraft. This should bias the coefficient on Age_{il} variable for leased aircraft more than the coefficient on Age_{il} variable for owned aircraft, and therefore β_3 should be negative. The specification used in equation (4) allows to explore the correlations between efficiency and quality of capital differently between leased and owned units.

OLS estimates of the coefficients are reported in Table 5. As predicted by the model, the coefficient β_3 is found to be negative. Moreover, the estimates mean, as implied by Proposition 5, that the difference in output between leased and owned aircraft is higher on new aircraft than on old ones.[39] This is true both in

[39] Proposition 5 also implies that the regression should fit the data for leased aircraft more precisely than for owned aircraft.

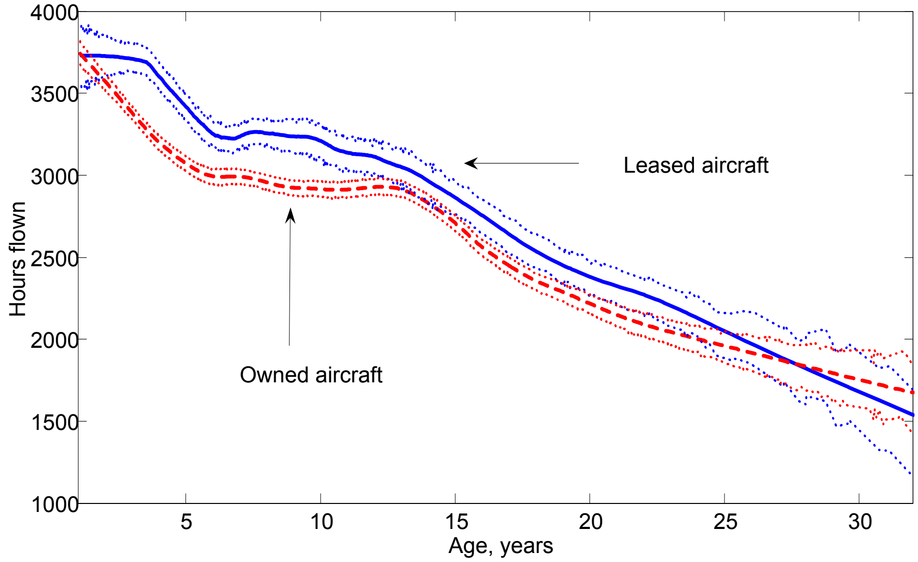

FIG. 7 - HOURS FLOWN AS A FUNCTION OF AGE, LEASED (SOLID LINE) VS. OWNED AIRCRAFT (DOTTED LINE). WITH 90% BOOTSTRAPPED CONFIDENCE BANDS.

levels (absolute difference between leased and owned aircraft) and in relative terms (percentage difference between leased and owned aircraft).

To allow for a more flexible specification, we also estimated a semi-parametric version of equation (4). More specifically, we regressed $y_{ijl} - \hat{\beta}_l$ - aircraft flying hours netted out of the aircraft fixed effect $\hat{\beta}_l$ estimated on equation (4) - on Age_{il} separately for leased and owned aircraft employing robust locally weighted scatterplot smoothing (*lowess*).[40] Figure 7 plots the estimated functions. The solid line represents leased units while the dotted line represents owned units. Again, we clearly observe the pattern predicted by Proposition 5 and by the *pairing effect*: the difference in output between leased and owned units is higher on new aircraft than on old aircraft. Moreover, we also observe a "hint" of the stronger form of the *pairing effect,* as owned aircraft fly more than leased aircraft for very old aircraft. However, the 90% confidence bands in Figure 7 indicate that the difference is statistically weak.

Combined, the evidence is consistent with the hypothesis that leasing increases capacity utilization reducing the barriers to trade between carriers. The data reveal patterns consistent with the three distinct effects highlighted by the theoretical model. The goal of the next subsection is to estimate the depreciation pattern of aircraft and obtain measures of the quality q of aircraft and efficiency z of carriers to precisely quantify the magnitude of each of the three effects.

Indeed, this is exactly what happens, as the value of the R^2 when equation 4 is estimated on leased aircraft alone is higher then when equation 4 is estimated on owned aircraft (.49 against .45).

[40] For each observation n on a dependent and an independent variable, say $(y_n,\, x_n)$, *lowess* consists in running a regression of variable y on variable x using data around x_n. Here y correspond to each aircraft flying hours netted out of the aircraft fixed effect and x is the *Age* of the aircraft. The fitted value of this regression evaluated at x_n is used as the value in constructing the nonparametric curve linking y and x. The procedure is repeated for each observation $(y_n,\, x_n)$. Hence, the number of regressions is equal to the number of observations. The procedure involves two arbitrary choices: the choice of a bandwidth (the fraction of data around x_n that is used in each regression) and a weighing scheme (the weight given to each observation in each regression). I choose bandwidth of .35 and tricubic weighting.

5.3 Quantifying the effects

The discussion of subsection 4.4 provides a natural empirical framework to estimate the depreciation patterns of aircraft and hence the efficiency of each carrier. Let

$$q_{il} = \exp\left(\beta_0 + \beta_1 Age_{il}\right)$$

be the quality of aircraft i of model l and let

$$z_{il} = \exp \epsilon_{il}$$

be the efficiency of the operator.[41] I assume that the log of potential output y^*_{il} and operating cost f_{il} of aircraft il are given by the following two equations

$$\begin{aligned} y^*_{il} &= \log q_{il} + \log z_{il} + \epsilon_l && (5) \\ f_{il} &= \lambda Z_{il} + \eta_{il} && (6) \end{aligned}$$

where $\lambda Z_{il} = \lambda_0 + \lambda_1 Age_{il}$ and ϵ_l are aircraft model fixed effects. Hence we observe

$$\begin{aligned} y_{il} &= y^*_{il} \quad \text{if } y^*_{il} \geq f_i \\ y_{il} &= 0 \quad\ \ \text{if } y^*_{il} < f_i \end{aligned}$$

so observed output is equal to potential output when potential output is higher than the fixed cost of operation, while the aircraft is parked otherwise.[42] I assume that $(\epsilon_{il}, \eta_{il})$ are normal random variables, with mean zero and covariance matrix

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

This is a censored regression model with unobserved stochastic threshold. Using standard results for bivariate normal random variables, the log-likelihood function can easily be constructed.[43] This model was introduced by Nelson (1977) to study the individual labor supply decision. Maddala (1983, pag. 174-178) and Ridder and Van Monfort (2001) discuss the identification of the model.[44]

As pointed out in the previous section, an endogeneity problem arises as efficiency z_{il} and Age_{il} of aircraft are likely to be correlated. To solve this issue, I use instruments that are correlated with the age of the aircraft, but arguably uncorrelated with the error term. The instruments exploit two ideas. First,

[41] It is important to note that there is no unobserved quality term. It would be impossible to separately identify unobserved quality and unobserved productivity. In Section 5.6 I explain why I think that quality differences among different aircraft of the same model/age are not relevant when I talk about adverse selection/moral hazard. Overall, it does not seem that unobserved (either to carriers or to the econometrician) quality differences play an important role in this market.

[42] As some aircraft are parked and have zero hours flown, I modify as log (Hours Flown)=0 when this is the case.

[43] Let $\beta X_{il} = \log q_{il} + \epsilon_l$ and let $\zeta = (\beta, \lambda, \sigma_\epsilon, \sigma_\eta, \rho)$ be the parameters' vector. The log-likelihood is:

$$\begin{aligned} L(\zeta) = & -N_1 \log \sigma_\epsilon - \frac{1}{2\sigma^2_\epsilon} \sum_{y^*_{il} \geq f_i} \left(y_{il} - \beta X_{il}\right)^2 + && (7) \\ & \sum_{y^*_{il} \geq f_i} \log \Phi \left(\frac{y_{il} - \lambda Z_{il} - \frac{\rho\sigma_\eta}{\sigma_\epsilon}\left(y_{il} - \beta X_{il}\right)}{\sqrt{\sigma^2_\eta\left(1-\rho^2\right)}} \right) + \sum_{y^*_{il} < f_i} \log \Phi \left(\frac{\lambda Z_{il} - \beta X_{il}}{\sqrt{\sigma^2_\eta + \sigma^2_\epsilon - 2\rho\sigma_\epsilon\sigma_\eta}} \right) \end{aligned}$$

[44] In particular, Ridder and Van Monfort (2001) show that the assumption of normality of the disturbances is sufficient for identification and no exclusion restrictions is needed. As equations (5) and (6) show, I used aircraft model fixed effects only in the output equation (5). I have also estimated the model including aircraft model fixed effects in the cost equation, obtaining almost identical results.

different aircraft models are not perfect substitutes for one another, but fundamental characteristics such as the flying range, the number of seats and the engine make each type of aircraft a different type of capital suited to serve specific routes.[45] This suggest to include own aircraft attributes (dummies for the maker of the engine, dummies for seats categories, manufacturers dummies) in the set of instruments for aircraft of model l. Second, the correlation between Age_{il} and efficiency z_{il} comes from carriers' demand of aircraft of model l, so I also use instruments that come from the supply side of aircraft of model l. Different models are introduced at different time. The year of introduction shifts the entire distribution of available qualities/ages of aircraft of model l. Thus, for each aircraft il I include the average serial number of aircraft of the same type as model l operated by all carriers different from the operator of aircraft il in the set of instruments.[46] I also include all interaction terms between own aircraft attributes and the average serial number of aircraft of the same type as model l operated by all other carriers in the set of instruments.[47]

Instrumenting in a non-linear model involves including both the fitted values and the residuals form the first stage in the likelihood function, as shown by Newey (1987). Table 6 reports the estimates of the parameters that uses this procedure. The coefficient β_1 on age is estimated to be equal to $-.0114$, indicating that the potential output an aircraft can produce decreases very slowly with age. The estimates of λ_1 equal to .0643 indicates that the cost of operating an aircraft increases faster with age than the decrease in potential output.[48]

I have also estimated the parameters using a pairwise difference estimation inspired by Honore and Powell (2005) that does not need instruments. The estimation exploits the fact for any two aircraft i and j of the same model l with $y_{il} > 0$, $y_{jl} > 0$ we have

$$\frac{y_{il} - y_{jl}}{Age_{il} - Age_{jl}} = \beta_1 + \frac{\epsilon_{il} - \epsilon_{jl}}{Age_{il} - Age_{jl}}.$$

The details of this procedure are in Appendix B and the results are very similar to those reported in Table

[45] This is clearly seen by inspecting Figure 2 of Benkard (2004), which shows in a Range-Seats diagram the degree of product differentiation for Widebody aircraft.

[46] Note that the model partition is finer than the type partition, as described in the Data Subsection 5.1. For example, aircraft models Boeing 747-100, 747-200, 747-300, 747-400 and 747-S all correspond to the aircraft type Boeing 747. Hence, I am using as instrument for the age of aircraft Boeing 747-100 operated by carrier l the average fuselage number of all Boeing 747 operated by carriers different than l.

[47] Note that the average serial number of the same model used by other carriers vary within model between different carriers, but not within carrier. Similarly, the interactions of this instrument with dummies for seats categories and manufacturers dummies vary within model but not within carriers. However, some models can come with different engines, so engine maker alone varies within model and the interaction engine maker times average serial number of other carriers' aircraft vary within model and within carrier. And again, different engine makers entered the market at different points in time, so this is a supply shifts that affect the entire distribution of aircraft ages of a given model. Moreover, evidence form the aircraft engine market shows that engine makers do not vertically segment the market. Thus it is not possible that the most productive carriers all choose the same engine maker and low productivity carriers choose a different one. Instead, anecdotal evidence reveals that carriers choose an engine maker versus another because, among other reasons, they want to reduce the number of engine makers to minimize maintenance costs and the number of different configurations.

The use of serial number requires some additional explanations. The serial number is a sequential number, and I think it has one additional advantage over the use of the average age of aircraft of the same model used by other carriers, that might seem a more natural instrument. Let me explain it with an example. Suppose that we have 1 model only and 3 aircraft produced sequentially, the first has age equal to 1, the second age is equal to 2, the third age is equal to 5. The serial numbers are 3, 2 and 1, respectively. Now, it is likely that the difference in the productivity of the users of aircraft of age 2 and age 5 is bigger than the difference in the productivity of the users of aircraft of age 1 and 2. However, note that this stronger correlation disappears if we instrument age using the serial number. Indeed, using age or serial number as described above as the instruments has a difference in the point estimates, and this difference is exactly as the previous discussion suggests: the point estimate using serial number of others is lower in absolute value than using age of others. However, the difference between the two is not statistically significant.

[48] I have also estimated the model with a full set of carriers fixed effects in the output equation and aircraft model fixed effects in the cost equation. The results were almost identical and, hence, omitted.

Table 6
Estimates of equations (5) and (6)

		Output Equation		Cost Equation
Constant	β_0	8.009 (.195)	λ_0	5.2229 (.3895)
Age	β_1	$-.0114$ (.006)	λ_1	.0643 (.0155)
σ_ϵ		.5412 (.099)		
σ_η		1.1385 (.105)		
ρ		0.4863 (.056)		
Observations		2848		

Notes: Bootstrapped standard errors in parenthesis. Aircraft model fixed effects not reported.

6.

I now use the estimated coefficients reported in Table 6 to obtain measures of quality of the aircraft and efficiency of the carrier. Quality is

$$\widehat{q}_{ijl} = \exp\left(\widehat{\beta}_0 + \widehat{\beta}_1 Age_{ijl}\right)$$

while efficiency is the residual of the output equation, i.e.

$$\hat{z}_{ij} = \exp\left(y_{ijl} - \log \widehat{q}_{ijl} - \epsilon_l\right) = \frac{\exp(y_{ijl})}{\widehat{q}_{ijl} \exp\left(\epsilon_l\right)}.$$

The empirical distributions of owners and lessees productivities are shown in Figure 8. The dotted line represents the efficiency of carriers when operating owned aircraft (owners), while the solid line represents the efficiency of carriers when operating leased aircraft (lessees). Simple visual inspection shows that lessees' efficiency is higher than owners'. If efficiency was directly observed, I could use the same tests already employed in Subsection 5.2 to compare the distribution of efficiency of lessees and owners. However the efficiency is not directly observed but rather estimated and the sampling variability of the estimated parameters must be taken into account when constructing the distributions of the test statistics. Hence, I follow Abadie (2001) and use a bootstrap procedure to compute the p-values of the test statistics. The Kolmogorov-Smirnov test of the equality of distributions rejects the null hypothesis of equal distributions (the bootstrapped p-value is equal to 0). Moreover, the tests for first order stochastic dominance proposed by Davidson and Duclos (2000) and Barrett and Donald (2003) accept the null hypothesis that the distribution of efficiency of lessees first order stochastically dominates the distribution of efficiency of owners (the bootstrapped p-values are equal to 0.98 and 1, respectively). Practically speaking, the problem of sampling variability does not seem a major concern because of the large sample size of the dataset. Appendix A presents the details of the procedures and the formal results of the tests.

I now use the estimates of efficiency in order to decompose the total gain due to leasing in the *parking, efficiency and pairing effects*.

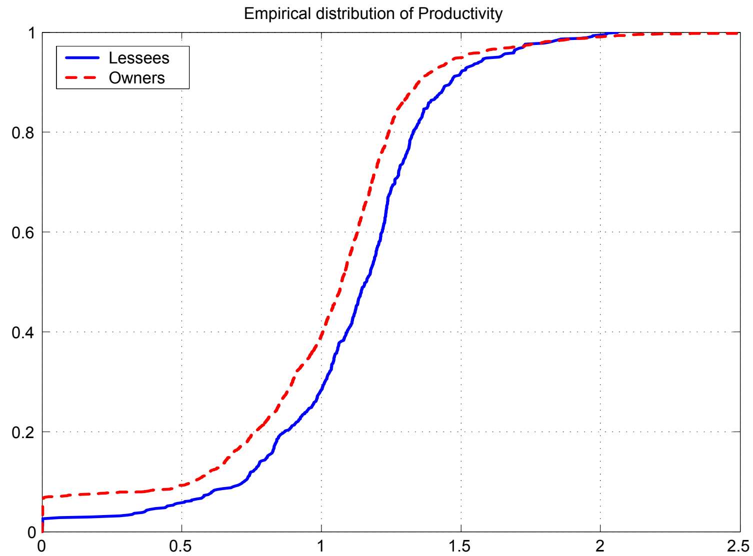

FIG. 8 - EMPIRICAL CUMULATIVE DISTRIBUTION FUNCTIONS OF EFFICIENCY, OWNERS (DOTTED LINE) VS. LESSEES (SOLID LINE).

5.4 Decomposing the gains

Having obtained measures of quality of the aircraft q and efficiency of the carrier z, in this Subsection we use equation (3) to decompose the gains due to leasing into the empirical counterparts of three effects described in the theoretical model.

Let Y_L and Y_O be the average output of a leased aircraft and an owned aircraft, respectively. Taking logs in equation (3), we can express the percentage difference in output between leased and owned units as

$$\begin{aligned}\log Y_L - \log Y_O &= \log\left(\Pr\left(Y_L > 0\right)\left(E\left(z_L|Y_L > 0\right)E\left(q_L|Y_L > 0\right) + Cov\left(z_L, q_L|Y_L > 0\right)\right)\right) - \\ &\quad \log\left(\Pr\left(Y_O > 0\right)\left(E\left(z_O|Y_O > 0\right)E\left(q_O|Y_O > 0\right) + Cov\left(z_O, q_O|Y_O > 0\right)\right)\right)\end{aligned}$$

Rearranging, we obtain

$$\begin{aligned}\log Y_L - \log Y_O &\approx \log \Pr\left(Y_L > 0\right) - \log \Pr\left(Y_O > 0\right) + \\ &\quad \log\left(E\left(z_L|Y_L > 0\right)E\left(q_L|Y_L > 0\right)\right) - \log\left(E\left(z_O|Y_O > 0\right)E\left(q_L|Y_L > 0\right)\right) + \\ &\quad \frac{Cov\left(z_L, q_L|Y_L > 0\right)}{E\left(Y_L|Y_L > 0\right)} - \frac{Cov\left(z_O, q_O|Y_O > 0\right)}{E\left(Y_O|Y_O > 0\right)}\end{aligned}$$

where the last passage follows from a Taylor expansion of $\log E\left(Y_i|Y_i > 0\right)$ around $E\left(z_i|Y_i > 0\right)E\left(q_i|Y_i > 0\right)$.[49]

As I desire to obtain the effect of leasing for observationally *identical* aircraft, I condition on the quality

[49] As it will become clear later, the approximation is justified since $Cov\left(z_i, q_i|Y_i > 0\right)$ is small compared to $E\left(z_i|Y_i > 0\right)E\left(q_i|Y_i > 0\right)$.

of aircraft[50] and further approximate the expression above as

$$\begin{aligned}\log Y_L - \log Y_O \approx\ & \log \Pr(Y_L > 0|q_L) - \log \Pr(Y_O > 0|q_O) + \\ & \log E(z_L|Y_L > 0) - \log E(z_O|Y_O > 0) + \\ & \frac{Cov(z_L, q_L|Y_L > 0) - Cov(z_O, q_O|Y_O > 0)}{E(Y|Y > 0)}\end{aligned}$$

Therefore we obtain the total effect of leasing as the sum of the empirical counterparts of the three effects outlined in the theoretical model. The term $\log \Pr(Y_L > 0|q_L) - \log \Pr(Y_O > 0|q_O)$ measures the *parking effect*. The term $\log E(z_L|Y_L > 0) - \log E(z_O|Y_O > 0)$ measures the *efficiency effect*. The term $\frac{Cov(z_L,q_L|Y_L>0)-Cov(z_O,q_O|Y_O>0)}{E(Y|Y>0)}$ measures the *pairing effect*.

Based on the estimates reported above, I can then decompose the total effect of leasing as follows

$$\log \Pr(Y_L > 0|q_L) - \log \Pr(Y_O > 0|q_O) = .0181 \tag{8}$$

$$\log E(z_L|Y_L > 0) - \log E(z_O|Y_O > 0) = .0618 \tag{9}$$

$$\frac{Cov(z_L, q_L|Y_L > 0) - Cov(z_O, q_O|Y_O > 0)}{E(Y|Y > 0)} = .0014 \tag{10}$$

The estimates reveal that the biggest effect (6.18%, approximately 80% of the total difference) is due to difference in efficiency for aircraft that are in use. 1.8% can be attributed to the difference with which aircraft are parked and .14% can be attributed to differences in the covariances between the estimated efficiency and the estimated quality of capital for aircraft in use.

5.4.1 Decomposing the *efficiency effect*

The estimates reveal that the *efficiency effect* explains 6.18% of the observed difference in output. As discussed in Section 4.3, the model says that the efficiency effect is the combination of two distinct forces. The first is the *selection effect*: high efficiency carriers decide to lease because leasing allow them to replace the aircraft without bearing transaction costs. The second is the *exit threshold effect*: the efficiency value z such that a carrier is indifferent between continuing to operate the aircraft or disposing of it is higher for lessees than for owners since higher transaction costs increase the option value of waiting. I now show that several arguments point against the results being mainly driven by selection.

The first argument comes from inspection of Figure 6. The depicted patterns are inconsistent with selection being the largest effect. If selection was dominant, we should observe the difference between leased and owned aircraft to increase with previous utilization, as high efficiency implies high utilization. This is clearly not the case.

A second argument comes from analysis of the distribution functions of lessees' and owners' productivities in Figure 8. The selection argument says the difference in the distributions should be concentrated in the upper tail of the distribution, while the higher exit threshold effect says that the difference should be concentrated in the lower tail of the distribution. The two distributions move almost parallel after the initial difference at low levels of productivities and the difference does not grow larger as efficiency increases. More formally, Appendix A shows that, when restricting the analysis to the top 15% of carriers'

[50] The model has nothing to say about the mix of aircraft qualities (ages) in lessor's portfolio, and I do not want to count differences in ages/qualities in the effect of leasing on aircraft allocation. For this reason, I disregard differences in the terms $E(q_i|Y_i > 0)\ i = O, L$. Moreover, older aircraft are more likely to be parked and since empirically leased aircraft are on average younger (Table 1), unconditional differences in parking probabilities between leased and owned aircraft reflect also differences in aircraft ages. Hence, I take the conditional (on quality/age) expectation of being parked.

TABLE 7
FLYING HOURS AND DURATION

LOG(FLYING HOURS)	(1)
AGE	$-.01$ (.008)
LEASED	.011 (.038)
HOLDING	$-.018$ (.008)
HOLDING*LEASED	.016 (.007)
MODEL DUMMIES	YES
R^2	.23
OBSERVATIONS	1351

Notes: Robust standard errors in parenthesis.

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 0.608). Also the Davidson and Duclos (2000) and Barrett and Donald (2003) tests for first order stochastic dominance reject the null hypothesis of first order stochastic dominance (the bootstrapped p-values are equal to 0.302 and 0, respectively).

A third (and the strongest) argument comes comparing two high quality aircraft, one leased and one owned, at different points during the holding duration spell. Under the selection effect, the difference in output is concentrated in the first periods of duration, while under the higher exit threshold effect the output difference between leased and owned aircraft increase over time as carriers operate the aircraft. Hence, we can separate the two forces investigating the correlation between efficiency z_{il} and holding duration $Holding_{il}$ separately between leased and owned aircraft. In particular, letting

$$\log z_{il} = \beta_2 Leased_{il} + \beta_3 Holding_{il} + \beta_4 Holding_{il} * Leased_{il} + \epsilon_{il}$$

we can estimate the output equation $\log y_{il} = \log q_{il} + \log z_{il} + \epsilon_l$ on young aircraft with positive flying hours only.[51] The model predicts that $\beta_2 > 0$ (selection effect), $\beta_3 < 0$ (efficiency decreases with duration), $\beta_4 > 0$ (efficiency decreases less for leased aircraft). Moreover, the difference in magnitude between β_2 on one side and β_3 and β_4 on the other side can tell us the relative importance of the *selection* and *exit threshold effects*.

Table 7 reports the results. As predicted by the model we find that $\beta_2 > 0$, $\beta_3 < 0$ and $\beta_4 > 0$. The point estimate of β_2 is only .011, which seems to suggest that the selection effect might be minor, but the large standard errors on the estimated β_2 suggests caution in interpreting the point estimate. Moreover, the estimate of β_3 equal to -.018 (and significantly different from zero) says that for owned aircraft efficiency declines an average of 1.8% for every year of holding duration, while it is remarkable to note that for lessees the decline in efficiency is found to be statistically different from the decline for owners and equal to only $-.018 + .016 = .002$, i.e. 0.2% per year (but indistinguishable from zero).

Together, the evidence indicates that the efficiency of lessees is higher then the efficiency of owners mainly *because* lower barriers to trade on leased then on owned aircraft increase the efficiency of lessees

[51] We defined young aircraft as aircraft with age less than 8.5 years, as this is the age that divides the sample of aircraft with positive flying hours in approximately half.

TABLE 8
GAINS FROM PERFECT PAIRING

	PERFECT PAIRING
ACTUAL OUTPUT	+0.67%
ALL OWNED	+0.71%
ALL LEASED	+0.56%

Notes: see text for explanations.

versus the efficiency of owners. Moreover, the point estimates of Table 7 imply that around 5% of the 6.18% *efficiency effect* reported in equation (9) is due to the lower exit threshold of lessees.

5.5 Perfect pairing

In this section, I evaluate the gain that would arise if there was perfect pairing between quality and efficiency. This is an important benchmark to compare the estimated .14%. Thus, aircraft model by model, I assign the highest quality of capital to the highest efficiency carrier, the second highest quality of capital to the second highest efficiency carrier and so on. I then compute the total output that would ensue and compare it with different alternative scenarios.

Mathematically, assigning to the most efficient carrier the best aircraft, to the second most efficient carrier the second best aircraft, and so on, generates a new covariance between quality and efficiency, let us call it $Cov(z_c, q_c)$. Equation (10) shows that the change in output due to this new assignment is proportional to $Cov(z_c, q_c) - Cov(z, q)$, where $Cov(z, q)$ is the empirical covariance in the data, with the current mix of leased and owned. We can also calculate $Cov(z_c, q_c) - Cov(z_O, q_O)$ where $Cov(z_O, q_O)$ is the covariance for owned aircraft only. Similarly, we can calculate $Cov(z_c, q_c) - Cov(z_L, q_L)$, where $Cov(z_L, q_L)$ is the covariance for leased aircraft only.

Table 8 presents the result of these comparisons. In the first line I evaluate the gain of perfect pairing with respect to actual output, i.e. the gain proportional to $Cov(z_c, q_c) - Cov(z, q)$. In the second line, I calculate the output gain of perfect pairing compared to the case when all aircraft are owned, i.e. the gain proportional to $Cov(z_c, q_c) - Cov(z_O, q_O)$. In the third line I compute the gain compared to the case when all aircraft are leased, i.e. the gain proportional to $Cov(z_c, q_c) - Cov(z_L, q_L)$. This table shows, then, that the .14% gain in pairing when moving from ownership to leasing is remarkable, as it represents $\frac{0.14}{0.71} = 20\%$ of all possible gains due to pairing. All three lines of the table show very small gains, ranging from a minimum of .56% to a maximum of .71% only.

The results are indicative of the relative magnitudes of the effects at work. The output gains due to perfect pairing are far smaller than the gains obtained from a higher average efficiency. This might seems surprising at first, but a careful inspection of the data explains the reason. Assume for simplicity that the correlation between quality and efficiency is zero on owned units while it is equal to one in the case of leased aircraft. Assume further that there is no difference in average efficiency and average quality between leased and owned aircraft. The percentage gain in output due to pairing is

$$\begin{aligned} \frac{Y_L - Y_O}{Y_O} &= \frac{E\left(z_L q_L\right)}{E\left(z_O q_O\right)} - 1 = \frac{E\left(z_L\right) E\left(q_L\right) + Cov\left(z_L, q_L\right)}{E\left(z_O\right) E\left(q_O\right)} - 1 \\ &= \frac{Cov\left(z_L, q_L\right)}{E\left(z_L\right) E\left(q_L\right)} = \frac{\rho \sigma_{z_L} \sigma_{q_L}}{E\left(z_L\right) E\left(q_L\right)} = \frac{\sigma_{z_L}}{E\left(z_L\right)} \frac{\sigma_{q_L}}{E\left(q_L\right)} \end{aligned}$$

The data show that $\frac{\sigma_{z_L}}{E(z_L)} \approx .1$ and $\frac{\sigma_{q_L}}{E(q_L)} \approx .3$ so that the gain of moving form no pairing at all to perfect pairing is around 3%, so very small. This figure represents an extreme upper bound of the total gains form pairing. From it, we need to substract the effect of the imperfect pairing of ownership, and the fact that different aircraft models are differentiated products. As I explained when I motivated the choice of instruments, the quality/age of the aircraft likely enters in the second stage of a carrier's decision to acquire an aircraft, after the choice of the model of the aircraft. The small gain of .71% are then explained.[52]

5.6 Alternative Hypotheses and Additional Evidence

The evidence and the estimates obtained in the previous subsections all points towards a positive causal effect of leasing on efficiency due to a reduction in transaction costs. In this Section we discuss the alternative theories of leasing proposed by the literature and describe patterns in the data that are inconsistent with these alternatives.

Moral Hazard - A possibility for the finding that leased aircraft fly more than owned aircraft could be moral hazard, as in Johnson and Waldman (2005). Carriers abuse of leased aircraft because they do not own them. However, several other features of the data and institutional details about the aircraft market and airline business seem to be inconsistent with moral hazard. First, moral hazard arise from unobservability (or non-contractibility) of actions. Here, all parties clearly observe the utilization of the aircraft: we do observe how much the aircraft are used, lessors and lessees observe utilization too.[53] Second, as explained in Section 3, leasing contracts are contingent on the utilization (hours flown and landings) of the aircraft. Third, if moral hazard was a severe problem for aircraft, then probably we should not observe aircraft being leased at all (Smith and Wakeman (1985) and Williamson (1988)). Forth, we showed that leased aircraft trade more frequently than owned aircraft. If carriers could abuse of 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, moral hazard does not explain the patterns associated with the *pairing effect*, i.e. the differences in utilization arise for new aircraft but not for older ones as shown in Figure 7.

Adverse selection - Hendel and Lizzeri (2002) and Johnson and Waldman (2003) present models of leasing under adverse selection. In principle, adverse selection could be thought as a cost captured in a reduced-form way by the transaction cost T. However, it seems unlikely that adverse selection could explain our results. First, aircraft maintenance is heavily regulated by the aviation authorities. After a certain number of hours flown, carriers have to do compulsory maintenance. This seems to suggest that quality differences cannot be too high. Also, under general adverse selection models, lower quality aircraft are traded more frequently. Here, it implies that leased aircraft are lower quality. However, it is then hard to reconcile why leased aircraft fly more than owned ones. In addition, Pulvino (1998) clearly rejects the hypothesis that lower quality aircraft trade more than higher quality ones and suggest that quality differentials among commercial aircraft of the same model/vintage are negligible. Moreover, in Hendel and Lizzeri (2002) and Johnson and Waldman (2003) frameworks, leased aircraft trade more frequently because high efficiency carriers select into leasing as they want to replace the aircraft more frequently. However, as we highlighted in particular in Section 4.3, the observed efficiency differences would then show up at the time carriers acquire the aircraft. But the data reject this implication. In Subsection 5.4.1 and in table 7,

[52] McAfee (2002) shows that using two classes obtains at most 50% of all gains due to matching.

[53] An interesting example of full observability and contractibility is found in a recent edition of Airline Fleet & Network Management, a specialized magazine:

"Our fictional leasing company, LeaseCo, has just purchased a new narrowbody jet and already has a lease contract in place with BMXAir, a new low-cost, US-based operator. As part of the contract, LeaseCo provides access for BMXAir to obtain all configuration information and required maintenance programme information for the aircraft in a digital format. (...) Once in operation, BMXAir updates actual flight information (cycles, hours, and landings) for its leased aircraft on a daily basis into the LeaseCo application. As these results are added, the solution tracks current flight hours and cycles against upcoming required maintenance activities." (Airline Fleet & Network Management, March/April 2006, pag. 28)

TABLE 9
CUMULATIVE HOURS FLOWN AND LEASING

$\log\left(\frac{\text{Cumulative Hours Flown}}{\text{Age}}\right)$	(1)	(2)
CONSTANT	7.835	7.739
	(.099)	(.063)
AGE	−.0061	−.0062
	(.001)	(.002)
LEASED	.0599	.0816
	(.010)	(.018)
MODEL DUMMIES	YES	YES
R^2	.2075	.3282
OBSERVATIONS	2847	1183

Notes: Robust standard errors in parenthesis.

we show that there is basically no difference in productivities between lessees and owners in the first years of utilization, but the difference shows up as the holding spells increase, as differences in transaction costs imply. Similarly, the data show that most trades arise because carriers want to get rid of excess capacity (in the model: the effect of α), not by replacements (in the model: the effect of γ). Thus, the details of the models of Hendel and Lizzeri (2002) and Johnson and Waldman (2003) exactly related to unobservable quality and adverse selection are not supported by the data.

Robustness check 1- One concern is that the gain is estimated on aircraft that have been with their current operator for an entire year. If there is a sizable loss in output during the trading period, the estimated gain could be overestimated. The literature on investment (e.g. Cooper and Haltiwanger, 1993 and Caballero and Engel, 1999) traditionally assumes that firms must shut down operations for a fixed period of time when trading capital. As I documented that leased units trade more frequently, the associated loss in output could potentially be substantial and invalidate my results. In the same spirit, it could also be that aircraft remain a long time with the lessor once a carrier returns it, so that the efficiency gains while in use are offset by a loss of output when returned. Hence, to check the robustness of my results to these issues, I calculate for each aircraft the average annual hours flown since the delivery date and compare the values of leased aircraft with the values for owned aircraft. This measure is not perfect since lessors buy several aircraft on secondary markets and therefore for those aircraft the average annual hours flown mixes periods of ownership with periods of leasing. However, the measure would cast doubt on the estimated gains if owned aircraft were found to have a higher average annual hours flown than leased aircraft. Table 9 shows that this is not the case. Column (1) shows that leased aircraft have 6% more average hours flown than owned ones.[54] Moreover, in order to try to partially control for the incomplete historical status of the aircraft (leased vs. owned) I resort to one institutional characteristic of the leasing business. Specifically, in Column (2) I restrict the sample to aircraft with General Electric engine only. Since General Electric is both a large lessor and a large engine maker, it is more likely that leased aircraft with General Electric engine have been owned by a lessor (GECAS) and leased out since their original delivery date. Column (2) shows that in this subsample leased aircraft have 8.16% more average hours flown than owned ones. Hence, the results in Table 9 indicate that the output gain for leased aircraft holds also for different periods of time. Both columns show that the gain of leasing is only slightly attenuated

[54] One observation was dropped since it was such a large outlier to change completely the estimated coefficients.

TABLE 10
PRODUCTIVITY AND MARKET THICKNESS

EFFICIENCY z	(1)
CONSTANT	.7617
	(.095)
%LEASED	.9533
	(.342)
TOTAL AIRCRAFT	.0007
	(.00024)
TOTAL AIRCRAFT FOR LEASE	−.0030
	(.0009)
R^2	.2675
OBSERVATIONS	27

Notes: Weighted Least Squares Regression. Weights are the total number of aircraft for each model. Robust Standard errors in parenthesis.

and still rather large.[55]

Robustness check 2 - An interesting additional robustness check of my results is to compare the estimated difference in efficiency across different aircraft models. It seems logical to expect that transaction costs are higher for less popular models that have been produced in fewer units, for a market thinness argument. In terms of my model, the efficiency of operators should be higher when they operate more popular aircraft. To verify this comparative static with respect to transaction costs intuition, I calculate the average operators' efficiency for each aircraft model and then regress it on the percentage of leased aircraft, the total number of aircraft and the product of the two, which corresponds to the total number of aircraft for lease. Table 10 presents the results. The signs of the coefficients are exactly as predicted. The more aircraft are available for each model and the higher the percentage of aircraft available for lease, the larger is the efficiency of the carriers. The sign of the coefficient on the cross product shows also that the positive impact of leasing decreases the more popular a model is. Note also that all coefficients are significantly different from zero at the 1% level despite the fact the number of observations is very small, as there are only 27 models of Widebody aircraft.

All these additional results reinforce our previous findings. To summarize, we have presented a very large number of empirical facts consistent with the idea that lessors increase the efficiency of the airline industry facilitating the trade of aircraft among carriers. All alternative hypothesis might explain some of the empirical patterns documented, but do not seem to be able to rationalize all of them.

6 Concluding Remarks

The purpose of this paper has been to examine the link between the efficiency of transactions of used capital in secondary markets and the efficiency of production of final output. I argued that lessors act as intermediaries that reduce the transaction costs and I constructed a model of trade in used capital to understand the role of lessors when trading is subject to frictions. In the empirical section, I used a dataset

[55] One fact to take into account is that the period of observation (April 2002-March 2003) coincides with an extremely unfavorable period for the airline industry, in which, for example, the number of aircraft parked was larger than usual.

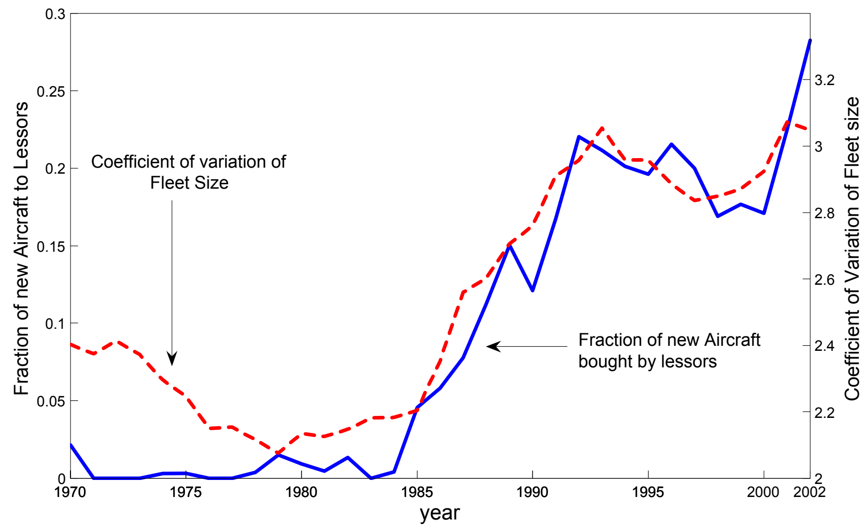

FIG. 9 - FRACTION OF NEW AIRCRAFT LEASED AND COEFFICIENT OF VARIATION OF FLEET SIZE, 1970-2002.

on aircraft and carriers' fleets to offer empirical evidence of the main implications of the model concerning the differences in holding duration and output between leased and owned aircraft.

The results support the notion that when transaction costs prevent the efficiency of allocation via decentralized trade, firms have incentive to develop institutions and adopt contractual arrangements that reduce the inefficiencies resulting from transaction costs. The empirical analysis reveals a considerable difference in output (8% in 2002-2003) due to the particular institution analyzed - aircraft leasing.

This paper has focused on the *effect* of leasing on the efficiency of secondary markets without discussing the optimality of the observed leasing contract. In particular, one natural question arises: why lessors own their aircraft? I believe three facts are important in understanding the observed contract. First, bankruptcy is a very important phenomenon in the airline industry and by owning the aircraft lessors can easily repossess their aircraft or renegotiate the terms of the contracts in case of bankruptcy. Second, aircraft cost millions of dollars and carriers are also frequently financially constrained, so that a rental contract might be attractive for carriers and lessors might be able to add financial services to increase their profits.[56] Third, there might be some taxation advantages.

As noted in the introduction, the entry of lessors is observed just a few years after the Airline Deregulation Act. I suggested that the increase in competition brought by the Act made reallocation of aircraft more important, and therefore the need for intermediaries stronger. But 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 of the entry of these new carriers, and the entry of these new carriers was likely facilitated by the institution of aircraft leasing. In Figure 9 we superimpose the annual coefficient of variation of fleet size to the fraction of new aircraft bought by lessors as in Figure 2. We clearly see that the variables are very highly correlated. To analyze theoretically and empirically the evolution of carriers in recent years and its relationship with aircraft leasing seems an interesting question left for future research.

[56] It is interesting to note that the largest lessors belong to large conglomerate firms, with apparently "big pockets" and easy access to capital. The largest lessor is GECAS, a unit of Genearl Electric; the second largest lessor is ILFC, a unit of AIG, the insurance company; another big lessor is AWAS, owned by Morgan Stanley, the investment bank.

A 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 test of the hypothesis:

$$G_Z(x) = G_W(x), \forall x \in R \tag{11}$$

and

$$G_Z(x) \leq G_W(x), \forall x \in R \tag{12}$$

The test of (11) is conducted using the familiar Kolmogorov-Smirnov test statistics

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

The test of (12) 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

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

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 accept 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

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

Barrett and Donald show that we can compute p-values by $\exp\left(-2\left(\hat{S}_1\right)^2\right)$, so that if $\widehat{G}_Z(a) - \widehat{G}_W(a) \leq 0$ for all a, then asymptotically the probability of rejection of the null hypothesis of stochastic dominance is zero.

Table 11
Test of FOSD for Holding Durations

Holding Durations										
months	13	29	44	60	76	92	108	124	139	155
$t(a_j)$	-.57	-1.79	-2.58	-3.31	-4.04	-4.53	-5.01	-5.46	-5.87	-7.09
months	171	187	203	218	234	250	266	281	297	313
$t(a_j)$	-7.40	-7.67	-7.06	-6.62	-6.86	-5.83	-4.76	-5.14	-5.10	-3.87

Table 12
Test of FOSD for Productivity Distributions

efficiency										
efficiency	.094	.19	.28	.37	.46	.56	.65	.75	.84	.94
$t(a_j)$	-5.17	-5.19	-5.26	-3.67	-3.24	-3.33	-4.00	-4.75	-3.52	-5.03
efficiency	1.03	1.13	1.22	1.31	1.41	1.50	1.59	1.69	1.78	1.87
$t(a_j)$	-5.32	-6.13	-7.22	-5.76	-3.92	-2.45	-1.52	-1.44	-0.30	0.22

I apply these tests to the distributions of holding durations of leased and owned aircraft, to the distributions of efficiency of lessees and owners and to the distributions of efficiency of lessees and owners in the top 15% of the pooled efficiency distribution. I now describe the details for each case.

Holding durations - The Kolmogorov Smirnov test rejects the null hypothesis of equality of distributions between owned aircraft and leased aircraft. The asymptotic p-value is equal to $3.2465 * 10^{-27}$.

As for Davidson and Duclos' test, I choose a grid with $m = 20$ equally spaced points between the first and the 99th percentile of the distribution of pooled holding durations. The critical values, tabulated in Stoline and Ury (1979), are $d_{\alpha,m,\infty} = 4.043$ for $\alpha = 1$, $d_{\alpha,m,\infty} = 3.643$ for $\alpha = 5$ and $d_{\alpha,m,\infty} = 3.453$ for $\alpha = 10$. Table 11 presents values of the t statistics. 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 $7.67 > 4.043$.

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

Efficiency - Since efficiency is 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 probability mass at zero.

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 the Davidson and Duclos' test, I choose a grid with $m = 20$ equally spaced points between the first and the 99th percentile of the distribution of pooled productivities. Table 12 presents values of the t statistics. The bootstrapped p-value is .98, so the test accepts the null hypothesis that the distribution of efficiency of lessees first order stochastically dominates the distribution of efficiency of owners. The Barrett and Donald' test also accepts the null hypothesis of dominance. The bootstrapped p-value is 1.

Table 13
Test of FOSD for Productivity Distributions, Upper tail

	efficiency, Top 15%									
efficiency	1.37	1.43	1.49	1.55	1.61	1.67	1.73	1.79	1.85	1.91
$t(a_j)$	.81	.07	.22	.73	.45	.87	2.27	.93	1.29	.23

Efficiency, upper 15th percentile - In this case, efficiency is restricted to be in the top 15% of the pooled efficiency distribution, which correspond to all values of efficiency above 1.309. The procedures are exactly as described above. 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 .608). As for the Davidson and Duclos' test, I choose a grid with $m = 10$ equally spaced points between the 85th and the 99th percentile of the distribution of pooled productivities. Table 13 presents values of the t statistics. The test rejects the null hypothesis that the distribution of efficiency of lessees first order stochastically dominates the distribution of efficiency of owners in the top 15% of the pooled efficiency distribution (the bootstrapped p-value is .303). Also the Barrett and Donald' test rejects the null of stochastic dominance (the bootstrapped p-value is 0).

B Pairwise Difference Estimator

First note the parameters β_0 and β_1 are identified from the continuous part of output y. So in what follows let me just use the continuous part of y. Equation (5) says

$$y_{il} = \log q_{il} + \log z_{il} + \epsilon_l$$

Substituting the definitions $q_{il} = \exp(\beta_0 + \beta_1 Age_{il})$ and $z_{il} = \exp(\epsilon_{il})$, we obtain

$$y_{il} = \beta_0 + \beta_1 Age_{il} + \epsilon_{il} + \epsilon_l$$

Pick a real number n. For every aircraft il choose another aircraft jl of the same model l and whose difference $Age_{il} - Age_{jl}$ is as close as possible to $-n$. Now $Age_{il} - Age_{jl} = -n_{ij}$ and note that

$$\begin{aligned} y_{il} - y_{jl} &= \beta_0 + \beta_1 Age_{il} + \epsilon_{il} + \epsilon_l \\ &\quad - (\beta_0 + \beta_1 Age_{jl} + \epsilon_{jl} + \epsilon_l) \end{aligned}$$

Thus

$$\frac{y_{il} - y_{jl}}{Age_{il} - Age_{jl}} = \beta_1 + \frac{\epsilon_{il} - \epsilon_{jl}}{Age_{il} - Age_{jl}}$$

Taking the average over all observations we have that

$$E\left(\frac{y_{il} - y_{jl}}{Age_{il} - Age_{jl}}\right) = \beta_1$$

as differences in carriers' productivities become negligible on aggregate. Moreover note that for n large, $\frac{\epsilon_{il}-\epsilon_{jl}}{Age_{il}-Age_{jl}} \approx \frac{\epsilon_{il}-\epsilon_{jl}}{-n_{ij}}$ becomes very small if ϵ_{il} is bounded (and aircraft cannot fly more than 24 hours a day, so in this application ϵ_{il} is bounded). Thus we have an estimate of β_1 without using instruments.

I have tried for several values of n and in all cases the results are remarkably close to the one reported in Table 6. For example, I obtain $\beta_1 = -.0158$ when $n = 1$ and $\beta_1 = -.0168$ when $n = 5$. Standard errors suggest that a higher n is a more efficient choice (I get bootstrapped standard errors of .0128 for $n = 1$ and bootstrapped standard errors of .0022 for $n = 5$).[57]

Clearly, the above procedure works not only for a fixed n, but also if we choose the average $\bar{y}_l$, or the median $y_{ml} = \beta_0 + \beta_1 Age_{ml} + \epsilon_l$. In this last case, we have

$$y_{il} - y_{ml} = \beta_1 \left(Age_{il} - Age_{ml}\right) + \epsilon_{il}$$

Now, a median regression of $y_{il} - y_{ml}$ on $(Age_{il} - Age_{ml})$ yields an unbiased estimate of β_1. Performing such a regression, we obtain $\beta_1 = -.0169$ (bootstrapped standard errors equal to .00136).

Once β_1 is estimated, all other parameters are easily recovered through either a linear regression or a probit regression. The estimates are very similar to the one reported in Table 6.

C Omitted Proofs

C.1 Proof of Proposition 1

I first show that all carriers are indifferent between leasing and owning aircraft. Let $V_i^O(z)$ $i = 1, 2$, be the value of a carrier of efficiency z that owns and operates a q_i aircraft, $V_i^L(z)$ $i = 1, 2$, the value of a carrier of efficiency z that follows the policy of leasing and operating a q_i aircraft, and $V_3(z)$ the value of a firm that does not operate any aircraft (operates an aircraft $q_3 = 0$). $V_1^O(z)$ is equal to

$$\begin{aligned} V_1^O(z) &= zq_1 + \beta\gamma\left(V_1^O(z) - p_1 + p_2\right) + \\ &\quad \beta\alpha \int_{\underline{z}}^{\overline{z}} \max\left\{V_1^O(z), V_1^L(z) + p_1, V_2^O(z) + p_1 - p_2, V_2^L + p_1, V_3(z) + p_1\right\} dF(z) + \\ &\quad \beta(1 - \alpha - \gamma) V_1^O(z) \end{aligned}$$

where β is the discount factor common to all firms. The first term is the current revenue of the carrier. Then with probability γ the aircraft depreciates and the carrier replaces the depreciated q_2 aircraft with a q_1 aircraft. With probability α the firm gets a new draw of z, so the firm takes expectation over its optimal future actions, conditioning on the aircraft it owns.

The expression for $V_1^L(z)$ is similar. $V_1^L(z)$ is equal to

$$\begin{aligned} V_1^L(z) &= zq_1 - r_1 + \beta\gamma V_1^L(z) + \\ &\quad \beta\alpha \int_{\underline{z}}^{\overline{z}} \max\left\{V_1^O(z) - p_1, V_1^L(z), V_2^O(z) - p_2, V_2^L, V_3(z)\right\} dF(z) + \\ &\quad \beta(1 - \alpha - \gamma) V_1^L(z). \end{aligned}$$

The main difference between $V_1^L(z)$ and $V_1^O(z)$ contains the per-period rental rate r_1, as this a cost flow.

Similarly, $V_2^O(z)$ is given by

$$\begin{aligned} V_2^O(z) &= zq_2 + \beta\gamma\left(V_2^O(z) - p_2\right) + \beta(1 - \alpha - \gamma) V_2^O(z) + \\ &\quad \beta\alpha \int_{\underline{z}}^{\overline{z}} \max\left\{V_1^O(z) - p_1 + p_2, V_1^L(z) + p_2, V_2^O(z), V_2^L(z) + p_2, V_3(z) + p_2\right\} dF(z) \end{aligned}$$

and $V_2^L(z)$ is equal to

$$\begin{aligned} V_2^L(z) &= zq_2 - r_2 + \beta\gamma V_2^L(z) + \beta(1 - \alpha - \gamma) V_2^L(z) + \\ &\quad \beta\alpha \int_{\underline{z}}^{\overline{z}} \max\left\{V_1^O(z) - p_1, V_1^L(z) - r_1, V_2^O(z) - p_2, V_2^L(z) - r_2, V_3(z)\right\} dF(z). \end{aligned}$$

[57] I have also estimated the standard errors using bootstrap procedure and the results are very similar.

Finally, $V_3(z) = V_3$, independent of z, is given by

$$V_3 = \beta\alpha \int_{\underline{z}}^{\overline{z}} \max\left\{V_1^O(z) - p_1, V_1^L(z), V_2^O(z) - p_2, V_2^L(z), V_3\right\} dF(z) + \beta(1-\alpha) V_3$$

Note that if $r_i = p_i - \beta((1-\gamma)p_i + \gamma p_{i+1})$, then $V_i^O(z) - p_i = V_i^L$. I now show that indeed $r_i = p_i - \beta((1-\gamma)p_i + \gamma p_{i+1})$ is the only possible equilibrium.

Suppose not, and assume for example that $r_i > p_i - \beta((1-\gamma)p_i + \gamma p_{i+1})$.Then $V_i^O(z) - p_i < V_i^L(z)$ and no carrier might want to lease an aircraft. Moreover, competition for owned aircraft drives up the prices for owned aircraft until $r_i = p_i - \beta((1-\gamma)p_i + \gamma p_{i+1})$. The case for $r_i < p_i - \beta((1-\gamma)p_i + \gamma p_{i+1})$ is similar.

I now determine the equilibrium allocation of aircraft. I focus for simplicity on the case in which there are only owned aircraft. Given the previous result that all carriers are indifferent between leasing and owning aircraft, this is without loss of generality.

A carrier chooses the quality that maximizes its profits, i.e. a carrier solves

$$\max_{i=1,2,3} V_i(z) - p_i$$

Let

$$J_i = \int_{\underline{z}}^{\overline{z}} \max\left\{V_i(z), \max_{j\neq i} V_j(z) - p_j + p_i\right\} dF(z)$$

denote the expected value of a firm with aircraft q_i when it receives a new draw of efficiency, and note that $J_i - J_j = p_i - p_j$. We have that

$$\begin{aligned} V_2(z) - p_2 - V_3 &= \frac{zq_2 - \beta\gamma p_2 + \beta\alpha(p_2 - p_3)}{1-\beta(1-\alpha)} - p_2 && (13) \\ V_1(z) - p_1 - (V_2(z) - p_2) &= \frac{z(q_1 - q_2) + \beta\gamma(-p_1 + p_2) + \beta\gamma p_2 + \beta\alpha(p_1 - p_2)}{1-\beta(1-\alpha)} - p_1 + p_2 && (14) \end{aligned}$$

which are increasing and linear in z. Hence in equilibrium carriers with high z operate q_1 aircraft, carriers with intermediate values operate q_2 aircraft and carriers with low value operate no aircraft.

The supply of aircraft q_i aircraft is equal to X_i, then equilibrium requires that

$$\begin{aligned} X_1 &= 1 - F(z_1) \\ X_2 &= F(z_1) - F(z_2) \end{aligned}$$

Equilibrium requires determining the endogenous prices and lease rates too. Prices of the aircraft are determined by the indifference condition of the marginal carrier z_i who is indifferent between operating an aircraft of quality q_i or quality q_{i+1}. Solving equations (13) and (14), the resulting prices are

$$p_2 = \frac{z_2 q_2}{1-\beta(1-\gamma_2)}; \qquad p_1 = p_2\left(\frac{1-\beta(1-\gamma_1-\gamma_2)}{1-\beta(1-\gamma_1)}\right) + \frac{z_1(q_1-q_2)}{1-\beta(1-\gamma_1)}$$

and the rental rates are $r_i = p_i - \beta(\gamma p_{i+1} + (1-\gamma)p_i)$

C.2 Proof of Corollary 2

Corollary 2 is a special case of the Proposition 3. We delay the Proof of this result to the Proof of Proposition 3.

C.3 Equilibrium of Subsection 4.3

Let $V_i^O(z)$ $i=1,2$, be the value of a carrier of efficiency z that owns and operates a q_i aircraft, $V_i^L(z)$ $i=1,2$, the value of a carrier of efficiency z that follows the policy of leasing and operating a q_i aircraft, and $V_3(z)$ the value of a firm that does not operate any aircraft (operates an aircraft $q_3=0$)

Let $V_i(z)$, $i=1,2$, be the value of a firm of efficiency z that operates an owned aircraft q_i and $V_3(z)$ the value of a firm that does not operate any aircraft (operates an aircraft $q_3=0$). $V_1^O(z)$ is equal to

$$\begin{aligned}V_1^O(z) &= zq_1+\beta\alpha\int_{\underline{z}}^{\overline{z}}\max\left\{V_1^O(z),V_1^L(z)+p_1-T,V_2^O(z)-p_2+p_1-T,V_2^L(z)+p_1-T,\right.\\ &\quad \left.V_3(z)+p_1-T\right\}dF(z)+\beta(1-\alpha-\gamma)V_1^O(z)+\\ &\quad \beta\gamma\max\left\{V_1^O(z)-p_1+p_2-T,V_1^L(z)+p_2-T,V_2^O(z),V_2^L(z)+p_2-T,V_3(z)+p_2-T\right\}\end{aligned}$$

$V_1^L(z)$ is equal to

$$\begin{aligned}V_1^L(z) &= zq_1-r_1+\beta\alpha\int_{\underline{z}}^{\overline{z}}\max\left\{V_1^O(z)-p_1,V_1^L(z),V_2^O(z)-p_2,V_2^L(z),V_3(z)\right\}dF(z)\\ &\quad +\beta(1-\alpha-\gamma)V_1^L(z)+\beta\gamma V_1^L(z)\end{aligned}$$

Similarly, $V_2^O(z)$ is given by

$$\begin{aligned}V_2^O(z) &= zq_2+\beta\alpha\int_{\underline{z}}^{\overline{z}}\max\left\{V_1^O(z)-p_1+p_2-T,V_1^L(z)+p_2-T,V_2^O(z),V_2^L(z)+p_2-T,\right.\\ &\quad \left.V_3(z)+p_2-T\right\}dF(z)+\beta(1-\alpha-\gamma)V_2^O(z)+\\ &\quad \beta\gamma\max\left\{V_1^O(z)-p_1,V_1^L(z),V_2^O(z),V_2^L(z),V_3(z)\right\}\end{aligned}$$

and $V_2^L(z)$ is equal to

$$\begin{aligned}V_2^L(z) &= zq_2-r_2+\beta\alpha\int_{\underline{z}}^{\overline{z}}\max\left\{V_1^O(z)-p_1,V_1^L(z),V_2^O(z)-p_2,V_2^L(z),V_3(z)\right\}dF(z)\\ &\quad +\beta(1-\alpha-\gamma)V_2^L(z)+\beta\gamma V_2^L(z)\end{aligned}$$

Consider the problem of a firm choosing a q_2 aircraft. Rearranging the expression for $V_2^L(z)$, we obtain

$$V_2^L(z)=\frac{zq_2-r_2+\beta\alpha J^L}{1-\beta(1-\alpha)}$$

where $J^L=\int_{\underline{z}}^{\overline{z}}\max\left\{V_1^O(z)-p_1,V_1^L(z),V_2^O(z)-p_2,V_2^L(z),V_3(z)\right\}dF(z)$. Rearranging the expression for $V_2^O(z)$, we obtain

$$V_2^O(z)=\frac{zq_2+\beta\alpha J_2^O-\beta\gamma_2 p_2}{1-\beta(1-\alpha)}$$

for $J_2^O=\int_{\underline{z}}^{\overline{z}}\max\left\{V_1^O(z)-p_1+p_2-T,V_1^L(z)+p_2-T,V_2^O(z),V_2^L(z)+p_2-T,\ V_3(z)+p_2-T\right\}dF(z)$.

Leasing is preferred to owning if and only if

$$V_2^L(z)\geq V_2^O(z)-p_2 \tag{15}$$

which is equivalent to

$$\frac{zq_2-r_2+\beta\alpha J^L}{1-\beta(1-\alpha)}\geq\frac{zq_2+\beta\alpha J_2^O-\beta\gamma_2 p_2}{1-\beta(1-\alpha)}-p_2$$

which is independent of z. Hence either all carriers prefer leasing versus selling, or prefer selling versus leasing or are exactly indifferent between the two alternatives. Clearly, in equilibrium all these carriers are indifferent between leasing and owning, i.e. $V_2^L(z) = V_2^O(z) - p_2$. Note that this implies that $V_2^O(z) > V_2^L(z) + p_2 - T$.

The problem for the carriers that choose a q_1 aircraft is more complicated, since these carriers are partitioned and some carriers prefer to replace their owned aircraft when it depreciates, while other carriers prefer to keep a q_2 aircraft. As before, leasing is preferred to owning

$$V_1^L(z) \geq V_1^O(z) - p_1 \tag{16}$$

Consider carriers that would choose to replace the owned aircraft that just depreciated to q_2. Equation (16) corresponds to

$$\frac{zq_1 - r_1 + \beta\alpha J^L}{1-\beta(1-\alpha)} \geq \frac{zq_1 + \beta\alpha J_1^O + \beta\gamma_1(-p_1 + p_2 - T)}{1-\beta(1-\alpha)} - p_1$$

which is again independent of z. Hence either these carriers prefer leasing versus selling, or prefer selling versus leasing or are exactly indifferent between the two alternatives.

Consider now carriers that would choose to keep the owned aircraft that just depreciated from q_1 to q_2. Equation (16) corresponds to

$$\frac{zq_1 - r_1 + \beta\alpha J^L}{1-\beta(1-\alpha)} \geq \frac{zq_1 + \beta\alpha J_1^O + \beta\gamma V_2^O(z)}{1-\beta(1-\alpha-\gamma)} - p_1 \tag{17}$$

where

$$V_2^O(z) = \frac{zq_2 + \beta\alpha J_2^O + \beta\gamma\left(V_1^O(z) - p_1\right)}{1-\beta(1-\alpha-\gamma)} \tag{18}$$

Substituting equation (18) into equation (17), we obtain

$$V_1^O(z) = \frac{(1-\beta(1-\alpha-\gamma))\left(zq_1 + \beta\alpha J_1^O\right)}{(1-\beta(1-\alpha-\gamma))^2 - \beta^2\gamma^2} + \frac{\beta\gamma\left(zq_2 + \beta\alpha J_2^O - \beta\gamma p_1\right)}{(1-\beta(1-\alpha-\gamma))^2 - \beta^2\gamma^2}$$

Hence, equation (16) reads as

$$\frac{zq_1 - r_1 + \beta\alpha J^L}{1-\beta(1-\alpha)} \geq \frac{(1-\beta(1-\alpha-\gamma))\left(zq_1 + \beta\alpha J_1^O\right)}{(1-\beta(1-\alpha-\gamma))^2 - \beta^2\gamma^2} + \frac{\beta\gamma\left(zq_2 + \beta\alpha J_2^O - \beta\gamma p_1\right)}{(1-\beta(1-\alpha-\gamma))^2 - \beta^2\gamma^2} - p_1$$

Grouping the term in z, we can rewrite the above equation as

$$\begin{aligned} & \frac{z(q_1 - q_2)\gamma\beta}{(1-\beta(1-\alpha-\gamma))^2 - \beta^2\gamma^2} \\ \geq \quad & -\frac{-r_1 + \beta\alpha J^L}{1-\beta(1-\alpha)} + \frac{(1-\beta(1-\alpha-\gamma))\beta\alpha J_1^O + \beta\gamma\left(\beta\alpha J_2^O - \beta\gamma p_1\right)}{(1-\beta(1-\alpha-\gamma))^2 - \beta^2\gamma^2} - p_1 \end{aligned}$$

which is increasing in z. Therefore, we have two possibilities. In the first case, there exists a z_1^{rep} such that all carriers with efficiency $z \geq z_1^{rep}$ are indifferent between leasing and owning q_1 aircraft and all carriers $z \in \left[z_1^{in}, z_1^{rep}\right]$ choose to own aircraft. In the second case, there exists a carrier z_1^* such that all carriers $z \geq z_1^*$ lease a q_1 aircraft and carriers $z < z_1^*$ own a q_1 aircraft. Clearly, the first case applies when the mass of q_1 aircraft available for lease is small compared to X, while the second applies when X_1^L is relatively bigger.

Equilibrium thus requires that

1. All firms acquiring old q_2 aircraft are indifferent between leasing and owning
$$V_2^O(z) - p_2 = V_2^L(z) \tag{19}$$
and the marginal firms satisfies
$$V_2^O\left(z_2^{in}\right) - p_2 = V_2^L\left(z_2^{in}\right) = V_3 \tag{20}$$
2. The marginal firms selling old q_2 aircraft satisfy
$$V_2^O\left(z_2^{out}\right) = V_3 + p_2 - T \tag{21}$$
3. The marginal firm acquiring a new q_1 aircraft satisfies
$$V_1^O\left(z_1^{in}\right) - p_1 = V_2^O\left(z_1^{in}\right) - p_2 \tag{22}$$
4. The marginal firms selling new q_1 aircraft satisfy
$$V_1^O\left(z_1^{out}\right) = V_2^O\left(z_1^{out}\right) - p_2 + p_1 - T \tag{23}$$
5. The marginal firms replacing old q_2 aircraft to buy new q_1 aircraft satisfy
$$V_1^O\left(z_1^{rep}\right) - p_1 + p_2 - T = V_2^O\left(z_1^{rep}\right) \tag{24}$$
6. Either there exists a z_1^{rep} such that all carriers with efficiency $z \geq z_1^{rep}$ are indifferent between leasing and owning q_1 aircraft and all carriers $z \in \left[z_1^{in}, z_1^{rep}\right]$ choose to own aircraft, or there exists a carrier $z_1^* < z_1^{rep}$ such that all carriers $z \geq z_1^*$ lease a q_1 aircraft and carriers $z < z_1^*$ own a q_1 aircraft. In either case, $z_1 \in \{z_1^*, z_1^{rep}\}$ satisfies
$$V_1^O(z_1) - p_1 = V_1^L(z_1) \tag{25}$$
and carriers $z < z_1$ own a q_1 aircraft.
7. Demand of new q_1 aircraft equates supply[58]. For q_1 aircraft, equilibrium requires that total demand is equal to total supply:
$$\begin{aligned} X_1 = & \left(X_1 - X^L\right)\left(\alpha\left(1 - F\left(z_1^{out}\right)\right) + \gamma\left(1 - H_1\left(z_1^{rep}\right)\right) + 1 - \alpha - \gamma\right) \\ & + X^L\left(\alpha\left(1 - F\left(z_1^{in}\right)\right) + 1 - \alpha\right) \\ & + \left(X_2 - X^L\right)\left(\alpha\left(1 - F\left(z_1^{rep}\right)\right) + \gamma\left(1 - H_2\left(z_1^{in}\right)\right)\right) + X^L\left(\alpha\left(1 - F\left(z_1^{in}\right)\right)\right) \\ & + \left(1 - X_1 - X_2\right)\alpha\left(1 - F\left(z_1^{in}\right)\right) \end{aligned} \tag{26}$$
where H_i is the endogenous steady state distribution of efficiency z of owners of aircraft q_i. For leased q_1 aircraft equilibrium requires that for $z_1 \in \{z_1^*, z_1^{rep}\}$
$$\begin{aligned} X^L = & X^L\left(\alpha\left(1 - F(z_1)\right) + 1 - \alpha\right) + X^L\alpha\left(1 - F(z_1)\right)c \\ & + \left(X_2 - X^L\right)\alpha\left(1 - F\left(z_1^{rep}\right)\right)c + \left(1 - X_1 - X_2\right)\alpha\left(1 - F(z_1)\right)c \end{aligned} \tag{27}$$
where $c = \frac{X^L}{1-X_1}\frac{F\left(z_1^{rep}\right)}{1-F\left(z_1^{rep}\right)}$

[58] I have implicitly excluded the possibility that a firm that owns a new q_1 aircraft and receives a new draw of productivity high enough, sells the new q_1 aircraft in order to lease a new q_1 aircraft. This is obviously not the case when all firms leasing q_1 aircraft are indifferent between leasing and owning, but could in principle arise if T is very small and X_{L_1} is very close to X_1.

8. Demand of old q_2 aircraft equates supply. This implies that

$$\begin{aligned} X_2 &= \left(X_1 - X^L\right)\left(\alpha\left(F\left(z_1^{out}\right) - F\left(z_2^{in}\right)\right) + \gamma H_1\left(z_1^{rep}\right)\right) \\ &\quad + X^L\left(\alpha\left(F\left(z_1^{in}\right) - F\left(z_2^{in}\right)\right)\right) \\ &\quad + \left(X_2 - X^L\right)\left(\alpha\left(F\left(z_1^{rep}\right) - F\left(z_2^{out}\right)\right) + \gamma\left(H_2\left(z_1^{in}\right) - H_2\left(z_2^{in}\right)\right) + 1 - \alpha - \gamma\right) \\ &\quad + X^L\left(\alpha\left(F\left(z_1^{in}\right) - F\left(z_2^{in}\right)\right) + 1 - \alpha\right) \\ &\quad + \left(1 - X_1 - X_2\right)\alpha\left(F\left(z_1^{in}\right) - F\left(z_2^{in}\right)\right) \end{aligned} \tag{28}$$

since carriers are indifferent between leasing and owning q_2 aircraft.

Equilibrium requires that equations (20), (21), (22), (23), (24), (25), (26), (27) and (28) are satisfied. Having obtained the conditions for equilibrium, we can now prove the Propositions.

C.4 Proof of Proposition 3

Consider two q_1 aircraft, one owned and the other leased. The owned aircraft is traded with probability $\alpha F\left(z_1^{out}\right) + \gamma\left(1 - H_1\left(z_1^*\right)\right)$, where H_i is the endogenous steady state distribution of efficiency z of owners of aircraft q_i defined in Subsection C.3. The leased aircraft is traded with probability $\alpha F\left(z_1^*\right) + \gamma$. The result thus follows since $z_1^* > z_1^{out}$ and $H_1\left(z_1^*\right) \leq 1$.

Consider two q_2 aircraft, one owned and the other leased. The owned aircraft is traded with probability $\alpha\left(\left(1 - F\left(z_1^{rep}\right)\right) + F\left(z_2^{out}\right)\right) + \gamma$ while the leased aircraft is traded with probability $\alpha\left(\left(1 - F\left(z_1^{in}\right)\right) + F\left(z_2^{in}\right)\right) + \gamma$ and the result follows since $z_1^{rep} > z_1^{in}$ and $z_2^{out} < z_2^{in}$.

Hence leased aircraft trade more frequently and have an average holding duration lower than owned aircraft. Note that if $T = 0$, then $z_1^* = z_1^{in} = z_1^{out}$ and $z_2^{out} = z_2^{in}$. Hence Corollary 2 follows too.

C.5 Proof of Proposition 4

Let $h_i^j(z)$ $i = 1, 2$ and $j = O, L$ be the distribution of efficiency of carriers choosing to lease (L) or to own (O) aircraft of quality q_i. We now construct each $h_i^j(z)$. We then aggregate $h_1^j(z)$ and $h_2^j(z)$ to obtain the distribution of efficiency of lessees $(j = L)$ and owners $(j = O)$ and prove the Proposition. There are two cases: 1) $z_1^* = z_1^{rep}$ and 2) $z_1^{in} \leq z_1^* < z_1^{rep}$. I present here the proof when $z_1^* = z_1^{rep}$. The other case $z_1^{in} \leq z_1^* < z_1^{rep}$ is almost identical.

$h_1^L(z)$ is given by

$$h_1^L(z) = \left\{ \frac{f(z)}{1 - F\left(z_1^{rep}\right)} \quad \text{for } z_1^{rep} \leq z \right.$$

$h_1^O(z)$ is given by

$$h_1^O(z) = \begin{cases} \alpha f(z) + (1 - \alpha - \gamma) h_1^O(z) & \text{for } z_1^{out} \leq z < z_1^{in} \\ \alpha f(z) + (1 - \alpha - \gamma) h_1^O(z) + \frac{1 - X}{X_1^O}\alpha f(z) + \gamma h_2^O(z) + \frac{X^L}{X_1^O}\alpha f(z) + \frac{X^L}{X_1^O}\alpha f(z) & \text{for } z_1^{in} \leq z < z_1^{rep} \\ \frac{1 - F\left(z_1^{rep}\right) - X^L}{\left(1 - F\left(z_1^{rep}\right)\right) X_1^O} f(z) & \text{for } z_1^{rep} \leq z \end{cases}$$

$h_2^L(z)$ is given by

$$h_2^L(z) = \begin{cases} \alpha f(z) + (1 - \alpha) h_2^L(z) + \frac{1 - X}{X^L} b\alpha f(z) + \frac{X_1}{X_2^L} b\alpha f(z) & \text{for } z_2^{in} \leq z < z_1^{out} \\ \alpha f(z) + (1 - \alpha) h_2^L(z) + \frac{1 - X}{X^L} b\alpha f(z) + \frac{X_2^L}{X^L} b\alpha f(z) & \text{for } z_1^{out} \leq z < z_1^{in} \end{cases}$$

where $b = \frac{1-\left(F\left(z_1^{in}\right)-F\left(z_2^{in}\right)\right)}{\left(F\left(z_1^{out}\right)\frac{X_1^O}{X^L}+F\left(z_1^{in}\right)\frac{X^L}{X^L}-F\left(z_2^{in}\right)\frac{X_1}{X^L}+\left(F\left(z_1^{in}\right)-F\left(z_2^{in}\right)\right)\frac{1-X}{X^L}\right)} > \frac{X^L}{X_2}$ is such that $\int_{z_2^{in}}^{z_1^{in}} h_2^L(z) = 1$. $h_2^O(z)$ is given by

$$h_2^O(z) = \begin{cases} \alpha f(z) + (1-\alpha-\gamma) h_2^O(z) & \text{for } z_2^{out} \le z < z_2^{in} \\ \alpha f(z) + (1-\alpha-\gamma) h_2^O(z) + \frac{1-X}{X_2^O}(1-b)\alpha f(z) \\ \quad + \frac{X_1}{X_2^O}(1-b)\alpha f(z) + \gamma h_2^O(z) & \text{for } z_2^{in} \le z < z_1^{out} \\ \alpha f(z) + (1-\alpha-\gamma) h_2^O(z) + \frac{1-X}{X_2^O}(1-b)\alpha f(z) + \frac{X_1^O}{X_2^O}\gamma h_1^O(z) \\ \quad + \gamma h_2^O(z) + \frac{X^L}{X_2^O}(1-b)\alpha f(z) & \text{for } z_1^{out} \le z < z_1^{in} \\ \alpha f(z) + (1-\alpha-\gamma) h_2^O(z) + \frac{X_1^O}{X_2^O}\gamma h_1^O(z) & \text{for } z_1^{in} \le z < z_1^{rep} \end{cases}$$

Solving for each $h_i^j(z)$ and combining $h_1^j(z)$ and $h_2^j(z)$, we obtain that the distribution of efficiency of owners $h^O(z)$ is equal to

$$h^O(z) = \begin{cases} \frac{X_2^O}{X_1^O+X_2^O}\frac{\alpha f(z)}{\alpha+\gamma} & \text{for } z_2^{out} \le z < z_2^{in} \\ \frac{X_2^O}{X_1^O+X_2^O}\left(f(z) + \frac{1-X_2}{X_2^O}(1-b) f(z)\right) & \text{for } z_2^{in} \le z < z_1^{out} \\ f(z) + \frac{X_2^O}{X_1^O+X_2^O}\left(\frac{1-X}{X_2^O}(1-b) f(z) + \frac{X^L}{X_2^O}(1-b) f(z)\right) & \text{for } z_1^{out} \le z < z_1^{in} \\ \frac{f(z)}{X_1^O+X_2^O} & \text{for } z_1^{in} \le z < z_1^{rep} \\ \frac{X_1^O}{X_1^O+X_2^O}\frac{1-F\left(z_1^{rep}\right)-X^L}{\left(1-F\left(z_1^{rep}\right)\right)X_1^O} f(z) & \text{for } z_1^{rep} \le z \end{cases}$$

and the distribution of efficiency of lessees $h^L(z)$ is equal to

$$h^L(z) = \begin{cases} \frac{X^L}{X^L+X^L}\left(f(z) + \frac{1-X_2}{X_2^L} b f(z)\right) & \text{for } z_2^{in} \le z < z_1^{out} \\ \frac{X^L}{X^L+X^L}\left(f(z) + \frac{1-X}{X^L} b f(z) + \frac{X^L}{X^L} b f(z)\right) & \text{for } z_1^{out} \le z < z_1^{in} \\ 0 & \text{for } z_1^{in} \le z < z_1^{rep} \\ \frac{X^L}{X^L+X^L}\frac{f(z)}{1-F\left(z_1^{rep}\right)} & \text{for } z_1^{rep} \le z \end{cases}$$

Note that the support of distribution of efficiency of lessees $h^L(z)$ is smaller and in particular, the lower bound is higher than the lower bound of the distribution of owners $h^O(z)$, i.e. $z_2^{out} < z_2^{in}$. Moreover, note that the distribution $h^L(z)$ stochastically dominates $h^O(z)$. Hence the average efficiency of lessees is higher than the average efficiency of owners.

C.6 Proof of Proposition 5

Let $y^j, j \in \{O, L\}$ be the average output of an aircraft j. We want to prove that

$$y^L - y^O > 0$$

and the result follows since Proposition 4 established that $h^L(z)$ stochastically dominates $h^O(z)$.

We also want to prove that

$$y_1^L - y_1^O > y_2^L - y_2^O$$

where $y_i^j = \int_{\underline{z}}^{\overline{z}} sq h_i^j(s)\, ds$. The proof is very long and uninspiring. We provide here a sketch. Let $H_i^j(z) = \int_{\underline{z}}^{z} h_i^j(s)\, ds$ be the cumulative distribution function. Note that $H_1^L(z)$ stochastically dominates $H_1^O(z)$. This implies that we always have $y_1^L - y_1^O > 0$. However, $H_2^L(z)$ does not stochastically dominate $H_2^O(z)$

since for $z_1^{in} \leq z < z_1^{rep}$, $H_2^L(z) = 1 > H_2^O(z)$, i.e. among operators of q_2 aircraft the upper bound of the support of the efficiency distribution of owners is higher than lessees'.

Moreover, using equations (22) and (24), we obtain

$$V_1^O\left(z_1^{in}\right) - V_2^O\left(z_1^{in}\right) = p_1 - p_2 = V_1^O\left(z_1^{rep}\right) - V_2^O\left(z_1^{rep}\right) - T$$

which implies

$$V_1^O\left(z_1^{in}\right) - V_1^O\left(z_1^{rep}\right) = V_2^O\left(z_1^{in}\right) - V_2^O\left(z_1^{rep}\right) - T$$

Substituting for the values, we obtain

$$\frac{\left(z_1^{rep} - z_1^{in}\right)(q_1 - q_2)}{1 - \beta(1 - \alpha - \gamma)} = T$$

We similarly obtain

$$\frac{\left(z_2^{in} - z_2^{out}\right) q_2}{1 - \beta(1 - \alpha - \gamma)} = T$$

Note that for $q_1 - q_2 = q_2$, we obtain that $z_1^{rep} - z_1^{in} = z_2^{in} - z_2^{out}$. Provided that the density $f(z)$ is not too different in the two intervals $\left[z_2^{out}, z_2^{in}\right]$ and $\left[z_1^{in}, z_1^{rep}\right]$, then $y_2^L < y_2^O$ since

$$\frac{\alpha f(z)}{\alpha+\gamma} + \frac{X_1^O}{X_2^O}\frac{\gamma}{\alpha+\gamma}\frac{\alpha f(z) + \frac{1-X}{X_1^O}\alpha f(z) + \frac{\alpha\gamma f(z)}{\alpha+\gamma}\frac{X_2^O}{X_1^O} + \frac{X^L}{X_1^O}\alpha f(z) + \frac{X^L}{X_1^O}\alpha f(z)}{\alpha+\gamma-\frac{\gamma^2}{\alpha+\gamma}} > \frac{\alpha f(z)}{\alpha+\gamma}$$

and $b > \frac{X^L}{X_2}$.

Using the densities h_i^j, we obtain that

$$\begin{aligned}
y_1^L &= \frac{1}{1 - F\left(z_1^{rep}\right)} A \\
y_1^O &= \frac{1 - F\left(z_1^{rep}\right) - X^L}{\left(1 - F\left(z_1^{rep}\right)\right) X_1^O} A + QB + \frac{\alpha}{\alpha+\gamma} C \\
y_2^O &= \frac{\alpha}{\alpha+\gamma} B + \frac{X_1^O}{X_2^O}\frac{\gamma}{\alpha+\gamma} QB + \left(1 + \frac{1 - X_2}{X_2^O}(1-b)\right) D + \frac{\alpha}{\alpha+\gamma} E \\
&\quad + \left(1 + \frac{1-X}{X_2^O}(1-b) + \frac{X_1^O}{X_2^O}\frac{\gamma}{\alpha+\gamma} + \frac{X^L}{X_2^O}(1-b)\right) C \\
y_2^L &= \left(1 + \frac{1-X_2}{X_2^L} b\right) D + \left(1 + \frac{1-X}{X_2^L} b + \frac{X^L}{X^L} b\right) C
\end{aligned}$$

where

$A = \int_{z_1^{rep}}^{\overline{z}} z f(z)\,dz$; $B = \int_{z_1^{in}}^{z_1^{rep}} z f(z)\,dz$; $C = \int_{z_1^{out}}^{z_1^{in}} z f(z)\,dz$; $D = \int_{z_2^{in}}^{z_1^{out}} z f(z)\,dz$;

$E = \int_{z_2^{out}}^{z_2^{in}} z f(z)\,dz$; $F = F\left(z_1^{rep}\right)$; $Q = \frac{\alpha + \frac{1-X}{X_1^O}\alpha + \frac{\alpha\gamma}{\alpha+\gamma}\frac{X_2^O}{X_1^O} + \frac{X^L}{X_1^O}\alpha + \frac{X^L}{X_1^O}\alpha}{\alpha+\gamma-\frac{\gamma^2}{\alpha+\gamma}}$

After a few manipulation, we obtain that $y_1^L - y_1^O > y_2^L - y_2^O$ corresponds to

$$\frac{X_1 - (1-F)}{(1-F) X_1^O} A + \frac{\alpha}{\alpha+\gamma}\frac{(\alpha+\gamma)\left(2X_1^O - 1\right)}{(\alpha+2\gamma) X_1^O} B + \left(\frac{1-X_2}{X_2^O}(1-b) - \frac{1-X_2}{X^L} b\right) D$$
$$\left(\left(\frac{1 - X + X^L}{X_2^O}\right)(1-b) + \frac{\gamma-\alpha}{\alpha+\gamma} - \frac{1-X+X^L}{X^L} b\right) C + \frac{\alpha}{\alpha+\gamma} E > 0$$

Note that the term $\frac{X_1-(1-F)}{(1-F)X_1^O}$ is of higher order than all other terms. Hence it dominates all other terms. The result then follows.

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