

# Thick-Market Effects in Real Asset Markets

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## Abstract

Almost all real assets trade in decentralized markets, where trading frictions could inhibit the efficiency of asset allocations and depress asset prices. In this paper, I investigate how trading frictions vary as asset markets get thicker, and what implications market thickness has for asset allocations and prices. Intuitively, it is easier to sell assets that have a thicker market. As a result, firms find it optimal to hold on longer to assets with a thinner market in case their profitability rises in the future. Thus, firms' average productivity is higher and productivity dispersion is lower when markets for firms' assets are thicker. In turn, asset prices are on average higher and have a lower dispersion of transaction prices in thicker asset markets, since prices depend on firms' profitabilities.

I formalize this intuition in a model of trading in decentralized markets with two-sided search and bilateral bargaining. I then use data on commercial aircraft markets to test the implications of the model. As predicted by the theory, the empirical analysis shows that aircraft with a thicker market have: 1) higher turnover; 2) higher capacity utilization; 3) lower dispersion of utilization levels; 4) higher mean prices; and 5) lower dispersion of transaction prices.

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# 1 Introduction

Many assets trade in decentralized markets. Classic examples are financial assets, such as bonds and derivatives, and real assets, such as real estate and capital equipment. The fundamental characteristics of a decentralized market is that traders must incur costs to search for trading partners and that, once a buyer and a seller meet, they must bargain to determine a price. In this paper I consider how the thickness of the market for an asset affects asset allocations and prices in decentralized markets.<sup>1</sup>

Some decentralized markets are very buoyant. The paragon is the secondary market for U.S. Treasury securities, where the daily volume of trade was about \$125 billion in 1994 (Fleming, 1997). Secondary markets for real assets are less bustling, but still some are rather active. For example, among consumer durables, the number of used cars traded every year in the U.S. is more than twice as large as the number of new purchases (Stolyarov, 2002); among capital equipment, the number of transactions for used commercial aircraft is about three times the number of purchases of new aircraft (Gavazza, 2007).

In most decentralized markets, each asset trades several times during its “lifetime”. Therefore parties’ trading decisions incorporate not only the expected cash flow that the asset generates, but also any cost that traders will incur in selling it at a later date.<sup>2</sup> When the number of potential users of the asset is small, trading in decentralized markets generates substantial monetary and opportunity costs, as the search process to find buyers able to generate the highest cash-flow from the asset may be difficult. For example, most capital equipment is specialized by industry, so that used assets typically have greater value inside the industry than outside (Shleifer and Vishny, 1992). Even within an industry, however, one firm’s assets may not be a perfect match for another firm.

Assets with a thin market imply that firms on each side of the market do not search exhaustively for the best matches (Ramey and Shapiro, 2001). In turn, this affects owners’ decision over whether or not to sell when their idiosyncratic profitability changes over time. Instead, the matching between buyers and sellers becomes easier in a thicker asset market. In this sense, assets with a thicker market are more “liquid.” When assets have a very thick market, they transfer immediately to the highest-profitability firms. Instead, it is optimal for inefficient firms to keep assets with a thin market rather than selling them. The reason is that assets with a thin market are more difficult to sell, and thus they have higher option values: firms choose to hold on to them for longer periods of time in case their profitability rises in the future. Hence, when assets have a thin market the average profitability of firms

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<sup>1</sup>I use the expressions market thickness and size of the market interchangeably in the course of the paper.

<sup>2</sup>House and Ozdenoren (forthcoming) construct a model of durable goods where consumers’ demand is influenced by resale concerns. In equilibrium, resale concerns can be so strong that individuals choose to purchase a good that they like less than other available goods.

is lower, and at the same time the dispersion of their profitability is higher. In summary, asset turnover is lower in thinner markets, and assets with a thin market are less efficiently allocated than assets with a thick market.

The effects of a thin market on asset allocations transmits to asset prices. Market thinness decreases the level of asset prices and increases the dispersion of transaction prices. The reason is that when firms bargain over the price, the transaction price depends on each firm’s ability to generate cash-flow from the asset.<sup>3</sup> Assets with a thick market generate a high level of firms’ profitability and a small dispersion of profitability. Hence, transaction prices are high and the dispersion of transaction prices is low. Conversely, when the asset market is thin, the low equilibrium level and high dispersion of firm profitabilities translate into a low average price and high dispersion of transaction prices. Asset prices reflect how active the market is and how efficiently assets are allocated.

In this paper, I formalize the effects of the size of asset markets on asset allocations and prices in a model of trading in decentralized markets with two-sided search and bilateral bargaining over price. The model delivers a rich number of predictions that I empirically test combining several datasets on markets for one class of real assets, commercial aircraft.

The model adapts Diamond’s (1982) seminal paper to asset markets, in a similar way to a growing literature—starting with Duffie, Gârleanu and Pedersen (2005)—that applies search models to financial markets. In particular, the model shares a number of features with the recent contributions by Vayanos and Wang (forthcoming) and Weill (forthcoming), but with an important difference.<sup>4</sup> The distribution of agents’ ability to generate cash-flow from an asset is continuous rather than discrete. This departure allows the characterization of the equilibrium distribution of buyers’ and sellers’ profitabilities and the equilibrium distribution of transaction prices that can be mapped into their empirical counterparts.

The key economic mechanism in the model is that, under a standard assumption on the meeting rate between buyers and sellers,<sup>5</sup> the trading technology exhibits increasing returns to scale, so that as the mass of assets increases the flow of meetings increases more than proportionally. Increasing returns in search capture the notion that trading costs decrease with trading volume, and that assets with a thicker market are more “liquid” (Lippmann and McCall, 1986).<sup>6</sup> Moreover, increasing returns precisely fit the characteristics of aircraft

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<sup>3</sup>Pulvino (1998) empirically establishes that sellers in worse financial conditions sell assets at a lower price. In Section 4.6, I discuss in more detail the relationship between this paper and Pulvino (1998).

<sup>4</sup>See also Duffie, Gârleanu and Pedersen (forthcoming), Miao (2006), Lagos and Rocheteau (2007), Vayanos and Weill (forthcoming), and Weill (forthcoming).

<sup>5</sup>The precise assumption is that buyers and sellers meet according to a Poisson process with a fixed arrival rate. This is quite standard in the literature. See Duffie, Gârleanu and Pedersen (2005 and forthcoming), Vayanos and Wang (forthcoming), and Weill (forthcoming) for a sample of recent papers adopting this assumption.

<sup>6</sup>The literature on liquidity in financial markets generally uses bid-ask spreads, or market depth, or float as measures of liquidity. In markets for corporate assets, however, bid-ask spreads and market depth cannot

markets as reported by industry experts and market participants. For example, according to Lehman Brothers (1998), “aircraft with a large number in current use across a wide array of users will obviously be easier to resell or re-lease than aircraft with limited production and usage.” Thus, assets trade more frequently in a thicker market.

Through the trading technology just described, the size of the asset market has important implications for allocations and prices. Specifically, the model implies that assets with a thicker market: 1) trade more frequently; 2) have higher average utilizations; 3) have lower dispersion of utilization levels; 4) fetch higher average prices; and 5) have lower dispersion of transaction prices.

In the empirical section I combine four distinct datasets concerning the aircraft market to test the above implications of model. Focusing on well-defined assets such as commercial aircraft allows control over a number of factors (i.e. technology differences, human-capital differences, market definitions, etc.) that might confound across-industries studies, and thus allow for a clean identification of the effect of asset market thickness on input allocations and prices. Moreover, the aircraft market provides an ideal candidate for general investigation of a search model of trading in decentralized markets, and in particular of the effects of market thickness. First, secondary markets for aircraft are the typical example of decentralized markets. Aircraft is the only form of capital equipment that can be redeployed to an operator anywhere in the world within a day, and this characteristic means that there are global markets for aircraft. Second, aircraft are differentiated products, designed to serve different markets and different ranges. Thus, the differential size and number of different airline markets imply that the market for different aircraft types have differential thickness. Third, commercial aircraft are registered goods with all major “life” events (date of first flight, maintenance, scrappage, etc.) recorded, so very detailed data are available. Thus, the richness of the data allows me to precisely measure the size of the asset market with the stock of the aircraft of a given type at every point in time.<sup>7</sup> It also allows me to control for a large number of factors that may plague the identification of the effect of market thickness in the empirical analysis. For example, I control for unobservable differences across models and even unobservable differences between vintages of the same model to identify the effect of market thickness on aircraft prices. In addition, I can also control for unobservable differences between aircraft of the same vintage and model, and unobservable characteristics

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be measured, and the variable that is conceptually closer to the float is probably the total stock of aircraft of a given type, i.e. market thickness. Starting with Demsetz (1968), several papers (Garbade and Silber 1976, Tanner and Kochin 1971 are early examples) have empirically investigated the relationship between bid-ask spreads and the float or the number of shareholders (for stocks), or issue size (for bonds). All these papers consistently find lower bid-ask spreads for stocks with larger float or a larger number of shareholders, and for bonds with a larger issue size.

<sup>7</sup>I also measure market thickness by counting the number of operators using an aircraft type in a given year. The empirical results are very similar across the two measures of market thickness.

of the carriers to identify the effect of market thickness on asset allocations.

The empirical analysis confirms all predictions of the model. Moreover, the analysis reveals that the magnitudes of the effects are rather large. A 10 percent increase in the stock of aircraft of a given type implies: 1) a 4.1 percent increase in the hazard of trading the aircraft; 2) a 1.5 percent increase in the average capacity utilization; 3) a 2.6 percent decrease in the absolute percentage deviation of utilizations from the mean utilization; 4) a 2.7 percent increase in the average price; and 5) a 1.0 percent decrease in the absolute percentage deviation of transaction prices from the mean price.

This paper is one of the first to provide quantitative evidence on the effects of market thickness and asset liquidity in the market for capital.<sup>8</sup> The empirical findings suggest that, even within a well-defined asset class such as aircraft, capital is moderately specialized and market thinness is a large impediment to the efficient reallocation of capital. These conclusions have several potential implications. First, the notion of asset market thinness is similar to the notion of asset specificity, and a very large literature has shown the implications of asset specificity for economic institutions (Williamson, 1975), organization of firms (Hart, 1995), financial structure of firms (Shleifer and Vishny, 1992), and even macroeconomic fluctuations (Caballero and Hammour, 1998). However, quantification of specificity has remained scarce. Second, an important literature has investigated the role of costly capital reversibility on investment behavior (e.g., Dixit and Pindyck, 1994), and this paper provides estimates of these costs arising due to market thinness and illiquidity. Third, the paper complements a series of recent papers that study the process of capital reallocation and quantify frictions in such a process (Ramey and Shapiro (1998, 2001), Maksimovic and Phillips (2001), Schlingemann et al. (2002), and Eisfeldt and Rampini (2006)).

The paper also contributes to the literature on productivity dispersion. Capacity utilization is closely related to firm productivity. An important literature (summarized in Bartelsman and Doms, 2000) has documented large and persistent productivity dispersion within narrowly defined industries, and most of the explanations for this dispersion have focused on technological differences between firms. The empirical patterns documented in this paper are similar to the ones uncovered in Syverson (2004, forthcoming), but the economic mechanism that generates these patterns is rather different. In particular, while Syverson focuses on a demand-side factor (consumers' inability to switch between competing suppliers), I focus on a supply-side argument (frictions in the market for capital).<sup>9,10</sup>

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<sup>8</sup>See also Kim (1998); Asplund (2000); Ramey and Shapiro (2001); Benmelech, Garmaise and Moskowitz (2005), and Balasubramanian and Sivasadan (forthcoming).

<sup>9</sup>In independent work, Balasubramanian and Sivasadan (forthcoming) construct an index of sunkness of capital investments for US manufacturing industries, and empirically establish that the mean of industry productivity is lower and the dispersion of productivity is higher in industries with a higher value of the index of sunkness of capital investments.

<sup>10</sup>By focusing on input markets, this paper shares some ideas with Melitz (2003), although the precise

The paper proceeds as follows. Section 2 presents some institutional details on the markets for commercial aircraft. Section 3 introduces a theoretical framework to study the effect of market thickness on asset allocations and prices. The Section informally discusses the main economic forces behind the bilateral search model that is fully developed in Appendix A. Section 4 presents the data used in this paper, and tests the empirical predictions of the model on the effect of market thickness on asset allocations and prices. Section 5 concludes. Appendices B and C contain some mathematical derivations.

## 2 Commercial Aircraft Markets

The commercial aircraft is a unique type of capital. All airlines in the world use the same types of aircraft, and there are relatively few types. Sometimes governments and air-cargo companies purchase aircraft, but the major players are airlines and lessors. Also, aircraft are the only form of capital equipment that can be delivered to a buyer or an operator anywhere in the world within a day and get there under their own power. Thus, the secondary market for aircraft is a single, worldwide market.

The market for used commercial aircraft might seem relatively active compared to the market for other more specialized equipment. However, the absolute number of transactions remains very small compared to financial markets and to other equipment markets. For example, in the 12 months between May 2002 and April 2003, of the total stock of 12409 commercial aircraft that are used for passenger transportation and are older than two years, only 720 (5.8 percent) traded.<sup>11</sup>

The market is organized around privately negotiated transactions.<sup>12</sup> Most major carriers have staff devoted to the acquisition and disposition of aircraft and sometimes independent brokers are used to match buyers and sellers. Aircraft are seldom sold at auctions. Pulvino (1998) reports that in one of the first auctions organized in 1994 to enhance the liquidity of the market, only nine aircraft sold from the 35 offered for sale. Subsequent auctions ended even without a single sale. Hence, prices are very sensitive to party's individual shocks, and

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economic mechanism is rather different. Similarly, this paper has a few similarities with some search-theoretic analysis of the labor market. See Pissarides (1990) for a summary. See also Petrongolo and Pissarides (2006), Bleakley and Lin (2007) and Gan and Zhang (2006) for recent analysis of scale in labor markets.

<sup>11</sup>The comparison with other capital goods is complicated because of the heterogeneity of capital goods. In a cross-industry study of corporate asset sales, Schillingmann et al. (2002) report an across industry average turnover of assets (measured in dollar values) of 5%. In their sample, more than ten 2-digit industries have an average value of turnover higher than 10%, and in some 2-digit industries the average value of turnover is as high as 23%.

<sup>12</sup>This is one characteristic that both Rauch (1999) and Nunn (2007) use to measure asset-specificity. The idea is that if an asset is sold on an organized exchange, then the market for this asset is thick and hence the asset is less specific to the transaction.

the bargaining power of sellers and buyers is an important determinant of transaction prices. For example, Pulvino (1998) finds that sellers with bad financial status sell aircraft at a 14 percent discount relative to the average market price.

Moreover, aircraft are differentiated products, and product differentiation generates economic rents. Each type of aircraft requires human-capital investments in specific skills for pilots, crew and mechanics that increase the degree of physical differentiation. As a result, carriers tend to minimize the number of types of aircraft they operate. Hence, the number of current operators of an aircraft type captures well the number of potential buyers of an aircraft. Product differentiation also implies that aircraft are imperfect substitutes for one another, as different types are designed to serve different markets and different ranges: for example, a Boeing 747 is suited to serve markets where demand is large *and* distance is large. Thus, the differential size and number of different airline markets imply that different aircraft types have differential popularity, and a carrier could choose to operate an aircraft with a rather thin market if it suits better its route structure. For a given type, the number of annual transactions may be small. For example, only 21 used units of the Boeing 747 traded in the 12-month period ending April 2003. Clearly, the popularity of a given type also varies over time, as aircraft follow the typical life cycle of products. Thus, two main factors affect the thickness of the market for a specific aircraft type over time: the production of new units, and the retirement of old units. For example, the Boeing 727 was the most popular commercial aircraft during the 1970s when production rates were high, but today has a rather thin market as it has been phased out of production and many units have been retired.

Airline industry experts and participants in the aircraft market consider the thickness of the market a fundamental characteristic of an aircraft type. For example, as noted in the introduction, Lehman Brothers considers “aircraft with a large number in current use across a wide array of users [...] easier to resell or re-lease than aircraft with limited production and usage”. Similarly, according to Wachovia Securities (2005): “the following are drivers of marketability of a commercial aircraft type: Number of current operators [...]; Number of Aircraft in production run [...]; In-production status/backlog [...]; Existence of a cargo conversion program [...]; Number of young aircraft on ground [...]”. Further, describing the aircraft leasing market,<sup>13</sup> Wachovia Securities (2005) states: “From a lessor’s perspective, a good leasing asset is one of which, “if I get this aircraft back, I want a lot of people that I can talk to about the plane..”.”<sup>14</sup>

Overall, all these observations seem to indicate that aircraft markets are less active than

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<sup>13</sup>Leasing is very popular in the aircraft market, with about 50% of the current stock of commercial aircraft being leased. Gavazza (2007a) explores the effect of leasing on aircraft trading. Gavazza (2008) explores how the liquidity/redeployability of aircraft affects whether aircraft are leased or not, the equilibrium maturity and pricing of lease contracts.

<sup>14</sup>Wachovia Securities, *Structured Products Research, Commercial ABS*, September 2005.

cursory evidence might suggest that they are, in particular for some types. It is then likely that market thickness affects asset allocations and prices. The next section introduces a theoretical framework that illustrates how the thickness of the asset market affects equilibrium asset allocations and prices. The model delivers a rich set of empirical implications that I test in Section 4.

### 3 Theoretical Framework

In this Section, I describe how we should theoretically expect thick markets to differ from thin markets. In Appendix A, I develop a bilateral search model with multiple assets that formally investigates the effects of a thick asset market on prices and allocations. Here I informally discuss the main economic forces behind the model, leaving all derivations to Appendix A. The model delivers testable implications regarding how the primary factor of interest – thickness of the asset market – affects the (endogenously determined) equilibrium asset allocations and prices.

To fix ideas, consider an industry that is populated by a continuum of firms (carriers). Firms’ production function uses a single input (aircraft) to produce output (flights), and for simplicity let us assume that all aircraft are homogenous. The exact form of product market competition among firms is not particularly relevant for the results. The only thing that matters is that firms have heterogenous productivity. More precisely, firms are differentiated by a productivity parameter that determines the firms’ ability to generate cash-flow from the use of an aircraft. Productivity evolves stochastically over time.

The entire focus of the model is on the input market. Firms can choose whether to acquire an aircraft or not if they do not own one, and whether to keep operating the aircraft or sell it if they own one. If a firm wants to trade (either buy or sell) an aircraft, it enters a decentralized search market in which it contacts with other firms willing to trade. A firm seeking to trade an asset meets other firms from the overall population according to a Poisson process with a fixed arrival rate. Once two firms meet and are willing to trade, they negotiate a price to trade.

In this setting, firms endogenously select based on their productivity: higher profitability firms choose to operate aircraft and lower profitability firms choose to stay out of the market. Hence, there exists a unique *buyers’ cutoff*: a value in the productivity distribution such that a firm that does not currently own an aircraft and whose productivity jumps above the cutoff chooses to acquire one. Similarly, there exists a unique *sellers’ cutoff*: a value in the productivity distribution such that a firm that currently owns an aircraft and whose productivity falls below the cutoff chooses to sell it. When there are frictions, buyers’ cutoff is higher than sellers’ cutoff: frictions create a wedge that ex-post prevents sellers from selling, and ex-ante prevents buyers from buying.

The main point is that the buyers' and sellers' cutoffs change with the thickness of the asset market. The key economic force is that, under the search technology described above, sellers (buyers) meet the buyers (sellers) at a rate proportional to the measure of buyers (sellers). Hence, the trading technology fundamentally exhibits increasing returns to scale: doubling the masses of buyers and sellers more than doubles the flow of meetings. Increasing returns in search nicely capture the idea that trading costs are decreasing with trading volume, and precisely fit the characteristics of aircraft markets as reported by industry experts and market participants. Thus, in a thicker market the contact rate between buyers and sellers is higher, so once on the market assets with a thicker market trade faster. In this sense assets with a thicker markets are more liquid (Lippmann and McCall, 1986). Instead, assets with a thin market are illiquid, and thus have a higher option value for asset owners: firms choose to hold on to assets with thin markets for longer periods of time in case their profitability rises in the future. As a result, sellers' cutoff value is lower in a thinner market: it is optimal for inefficient firms to keep their illiquid assets rather than selling them. Similarly, buyers' cutoff value is higher in a thinner market: only very productive firms choose to incur the trading costs to acquire an aircraft. As the asset market becomes thicker, sellers' cutoff value increases and buyers' cutoff value decreases. Indeed, in the limit as the asset market becomes infinitely thick, buyers and sellers cutoffs converge, and the frictionless Walrasian benchmark obtains.

Sellers' and buyers' cutoffs affect the entire (endogenous) distributions of aircraft owners/operators. In particular, since the lower bound of aircraft operators profitability is higher when the market is thicker, the equilibrium average profitability of aircraft operators is higher and the equilibrium dispersion of profitabilities is lower in thicker aircraft markets.

Moreover, when a buyer and a seller bargain over the price at which they trade the asset, the individual abilities to generate cash-flow from the asset determine the buyer's willingness to pay and the seller's willingness to accept, and thus the transaction price. Hence, the effects of market thickness on the equilibrium distribution of firms' profitabilities transmit to the distribution of transaction prices. As a result, asset with a thicker market have a higher average level of asset prices, and simultaneously a lower dispersion of transaction prices.

In summary, the model makes the following predictions. As the market becomes thicker, assets: 1) have a higher turnover; 2) have a higher average level of utilization;<sup>15</sup> 3) have a lower dispersion of utilization; 4) have a higher average price; 5) have a lower dispersion of

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<sup>15</sup>I am implicitly assuming that profitability and capacity utilization are very closely related, and the data seem to confirm this. For example, at the aggregate level aircraft are parked inactive in the desert more frequently in recessions than in booms. After 9/11, when the profitability of the airline industry was severely hit, a large number of carriers decide to ground aircraft. As a result, capacity utilization decreased. Similarly, at the carrier level, the data reveal that Southwest has higher capacity utilization than other US carriers, and that capacity utilization is substantially lower before a carrier enters into bankruptcy.

transaction prices.

## 4 Empirical Analysis

### 4.1 Sources of Data

The empirical analysis in this paper combines four distinct datasets. The first dataset is an extensive database that tracks the history of each western-built commercial aircraft. I use this database to construct two measures of the thickness of each type of aircraft in each year. I then match the two measures (described in detail below) to the other datasets to investigate the role of market thickness on asset allocations and prices. The second database reports the aircraft utilization for the period 1990–2002, and I use this information to investigate several features of aircraft allocations. The third dataset reports the prices of several aircraft models during the period 1967–2003. These prices are average values, similar to “Blue Book” prices. The fourth dataset reports actual prices for a large number of transactions during the period 1978–1991. I now describe each dataset in more detail.

*Aircraft History*—This database was compiled by a producer of aviation-market information systems and reports the history of each Western-built commercial aircraft up to April 2003. For each aircraft serial number, the dataset contains information on the type (e.g. Boeing 737); the model (e.g. Boeing 737-600); the “birth” of the aircraft (date of the first flight); the sequence of operators with the relevant dates of operation; the operational role with each operator; and, if the aircraft is no longer in use, the date of the “death” of the aircraft (date the aircraft was scrapped).

*Aircraft Utilization*—This database was compiled by the same producer of the aircraft history dataset and reports detailed information on the utilization of each aircraft by its operator. More precisely, the file reports the monthly flying hours of each aircraft from January 1990 to April 2003. Monthly utilization is aggregated at the year level, thus obtaining an annual panel for the 1990–2002 period. I discard observations (a serial-number–year pair) if the aircraft changes operator in the year in which the aircraft is traded in order to be able to impute the annual utilization to a single operator.<sup>16</sup>

*Blue Book Prices*—This dataset was compiled by a consulting company that specializes in aircraft appraisals. It is an unbalanced panel reporting the historic values of prices of different vintages for the most popular models during the period 1967–2003. The prices are based on reported transactions and on the company’s experience in consulting, appraisal and fleet evaluation. The prices assume that the transaction was made on the basis of a single

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<sup>16</sup>The results are almost identical when observations are retained.

unit bought with cash from a non-bankrupt seller. All values are in U.S. dollars and I have deflated them using the GDP Implicit Price Deflator with 2000 as the base year.

*Transaction Prices*—This dataset reports actual transaction prices for almost all aircraft traded by U.S. corporations during the period 1978–1991. Prior to 1992, the Department of Transportation (DOT) required price disclosure for all aircraft purchased or sold by U.S. corporations. The transaction prices used in this paper are based on these DOT filings. For each transaction, the filings report the aircraft serial number, buyer and seller identities, transaction price, date of transaction, and whether the transaction was a straight sale or a sale/leaseback. The dataset also reports some technical information, such as the age of the aircraft, the engine type, and the engine noise stage. In the empirical analysis of this paper, I focus on all used aircraft transactions reported in this dataset. All values are in nominal U.S. dollars, and I have again deflated them to the year 2000.<sup>17</sup>

## 4.2 Data Description and Some Suggestive Evidence

Before turning to a more formal empirical analysis, in this section I briefly describe some features of the data – including how I measure the thickness of the market for each type of aircraft in each year – and present some preliminary descriptive patterns.

**Data description** - From the Aircraft History dataset, I can calculate the size of the market for each aircraft in a given year in two ways. The first one is by counting the total stock outstanding of aircraft of type  $I$  in year  $t$ , and I call this variable  $\text{AIRTYPE}_{It}$ . The second one is by counting the total number of carriers operating at least one aircraft of type  $I$  in year  $t$ , and I call this variable  $\text{OPTYPE}_{It}$ . In the theoretical framework the two variables are identical, and in the data they are very highly correlated (the correlation is at least .91 in the samples on which the regressions are run). Note that the two variables vary both across different aircraft types  $I$  and also across different years  $t$ .<sup>18</sup>

I then match  $\text{AIRTYPE}_{It}$  and  $\text{OPTYPE}_{It}$  to the dataset on aircraft utilization and the two datasets on prices to investigate the effects of market thickness on asset allocations and prices. More precisely, to investigate the effect of market thickness on allocations, I match  $\text{AIRTYPE}_{It}$  and  $\text{OPTYPE}_{It}$  to each aircraft's holding duration to study whether aircraft with a thicker market have higher turnover. Further, I match  $\text{AIRTYPE}_{It}$  and  $\text{OPTYPE}_{It}$  to the annual flying hours  $fh_{jit}$  of aircraft  $j$  of model  $i$  in year  $t$  to study how average utilization

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<sup>17</sup>For further details about these data, see Pulvino (1998).

<sup>18</sup>It is important to note that the measures of market thickness are at the aircraft-type level. As specified above, a type is for example Boeing 737, Boeing 747, MD-80, and so on. Within each type, there might be different models. For example, for the type Boeing 737, we have models B737-200, B737-300, and so on. Within each type, the technical specifications of different models are very similar. Thus, comparisons between types exactly capture differences in market size, which is consistent with industry norms.

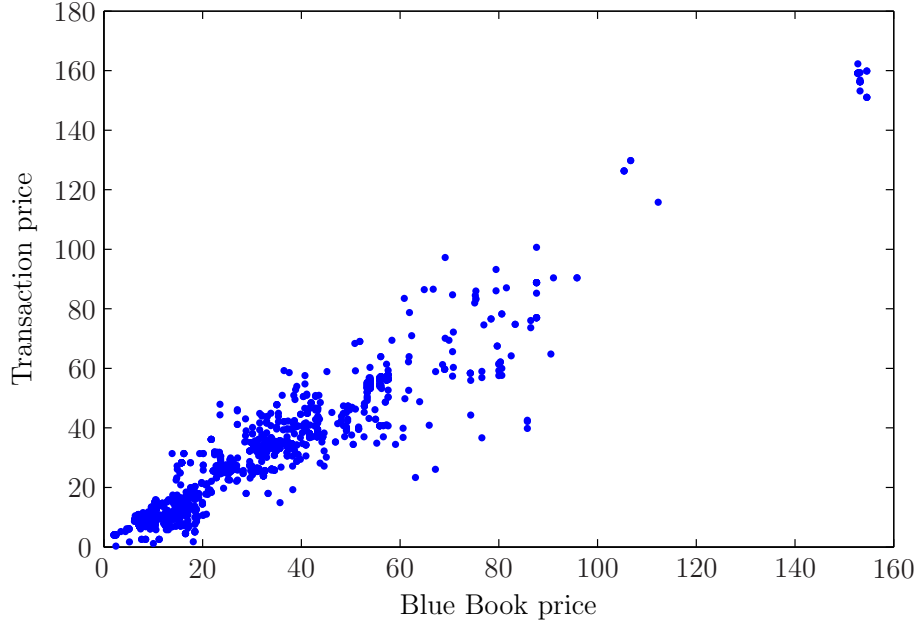


FIG. 1: Transaction price vs. Blue Book price

and the dispersion of utilization levels covary with market thickness. More precisely, to investigate the dispersion of utilization levels I calculate the average flying hours of all age- $a$ -model- $i$ -year- $t$  triples,  $\overline{fh}_{ait}$ . I then compute the absolute value of the percentage deviation of the flying hours  $fh_{jit}$  of aircraft  $j$  of  $AGE_{jit} = a$ -model- $i$ -year- $t$  from the average  $\overline{fh}_{ait}$ , i.e.  $\left| \frac{fh_{jit} - \overline{fh}_{ait}}{\overline{fh}_{ait}} \right|$ .

Similarly, to investigate the effect of market thickness on the average level of asset prices, I match the price  $\bar{p}_{ait}$  of aircraft of age- $a$ -model- $i$ -year- $t$  reported in the Blue Book dataset with the corresponding values of  $AIRTYPE_{It}$  and  $OPTYPE_{It}$ . To investigate the effect of market thickness on the dispersion of transaction prices, I first match each transaction price from the transaction dataset with the average prices of the corresponding age-model-year triple from the Blue Book dataset. Then, I construct the absolute percentage deviation of the transaction price from the Blue Book price  $\left| \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right|$ , where  $p_{jit}$  is the transaction price of aircraft  $j$  of  $AGE_{jit} = a$ -model- $i$ -year- $t$ , and  $\bar{p}_{ait}$  is the Blue Book price just defined. Then I match this measure of price dispersion for model  $i$  to the corresponding values of  $AIRTYPE_{It}$  and  $OPTYPE_{It}$  of type  $I$  ( $i \in I$ ). Figure 1 shows that Blue Book prices and transaction prices are highly correlated (the correlation coefficient is equal to .96), so that the Blue Book prices capture very well the average price of a specific aircraft. Moreover, figure 1 shows that there are some differences between the transaction prices and the Blue Book prices, and in the empirical analysis I investigate whether these differences are systematically correlated with

market thickness.<sup>19</sup>

Table 1 provides summary statistics of the main variables used in the empirical analysis. Panel A considers the turnover of assets by measuring holding durations. The average duration is around seven years, with a standard deviation of 6.5 years. The duration of the first operator of each aircraft tends to be longer than subsequent durations: on average the duration of the first operator is around nine years. Some of the durations are ongoing—that is, they are right-censored—and around 70 percent of durations are completed. Moreover, panel A shows that AIRTYPE and OPTYPE vary substantially, both across types and within type over time. Some aircraft types are very popular, and thus have been produced in large numbers and have many operators; others have been less successful, or are old types that are retired during the sample period and have few operators. The average of AIRTYPE is 1167 and the standard deviation is 1007; the average of OPTYPE is 96 and the standard deviation is 85.

Panel B considers aircraft utilizations. On average aircraft fly around 2,700 hours per year, with a standard deviation of 1,100 hours. Around four percent of all observations in the sample have flying hours equal to zero, that is they are parked inactive in the desert. A fraction of this mass of inactive aircraft is sold to new carriers that acquire capital to enter the industry, and the remaining fraction reenters service with the original owner. Considering only aircraft with positive flying hours, the average utilization is 2,860 hours with a standard deviation of 960 hours. Since the dataset reports utilization data only from 1990, the averages of AIRTYPE and OPTYPE are now higher and, again, they show considerable variation: the averages are 1,435 aircraft and 123 operators, respectively; the standard deviations are 1,101 aircraft and 101 operators, respectively.

Panel C provides summary statistics for the Blue Book dataset. There are 18 different aircraft types in the sample. The average Blue Book price of an aircraft in the sample is 28 million (year 2000) dollars and there is substantial variation in prices (the standard deviation is 24 million dollars). AIRTYPE and OPTYPE show substantial variation, both across types and within type over time. For example, just looking at the Boeing 737, there are as many as 4,173 units and 345 operators in 2003, and as few as 333 units and 38 operators in 1973.

Panel D considers transaction prices. The time period during which transaction prices were reported to the DOT (1978–1991) is considerably shorter than the time period of

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<sup>19</sup>Alternatively, I could investigate the effect of liquidity on average prices using the transaction price  $p_{jit}$  as the dependent variable. However, there are several disadvantages to this procedure: 1) the dataset would no longer be a panel dataset; thus the Arellano and Bond procedure described below cannot be employed. 2) the number of observations would be smaller, and in particular the time-dimension would be much shorter. Similarly, I could investigate the effect of liquidity on the dispersion of transaction prices by calculating the absolute percentage deviation of the transaction price from *average* transaction price of comparable aircraft. The main disadvantage of this procedure is that for many aircraft the average would be calculated from very few observations, often just one.

TABLE 1: Summary statistics

PANEL A: ASSET TURNOVER		
	MEAN	ST. DEV.
HOLDING DURATION	7.02	6.46
TYPES OF AIRCRAFT	26	
AIRCRAFT PER TYPE—AIRTYPE	1167.6	1007.1
OPERATORS PER TYPE—OPTYPE	96.13	85.61
PANEL B: AIRCRAFT UTILIZATION		
FLYING HOURS $fh_{jit}$	2741.13	1097.02
ABSOLUTE PERCENTAGE DEVIATION $\left  \frac{fh_{jit} - \bar{fh}_{ait}}{\bar{fh}_{ait}} \right $	.1883	.2644
PARKED AIRCRAFT	.041	.198
TYPES OF AIRCRAFT	26	
AIRCRAFT PER TYPE—AIRTYPE	1434.58	1100.88
OPERATORS PER TYPE—OPTYPE	122.78	100.84
AGE	11.80	7.89
PANEL C: BLUE BOOK PRICES		
AVERAGE PRICE $\bar{p}_{jit}$	32.32	27.55
TYPES OF AIRCRAFT	18	
AIRCRAFT PER TYPE—AIRTYPE	1019	944
OPERATORS PER TYPE—OPTYPE	86.97	81.09
AGE	9.44	7.50
PANEL D: TRANSACTION PRICES		
TRANSACTION PRICE $p_{jit}$	30.60	24.47
ABSOLUTE PERCENTAGE DEVIATION $\left  \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right $	.171	.193
TYPES OF AIRCRAFT	13	
AIRCRAFT PER TYPE—AIRTYPE	960.6	612.2
OPERATORS PER TYPE—OPTYPE	74.45	46.75
AGE	7.35	6.94

the Blue Book prices (1967–2003). Thus, the number of observations is smaller (1,555), the number of aircraft types is also smaller (13), and overall the variables exhibit smaller variations. Nonetheless, the main variable of interest—the absolute percentage deviation of the transaction price from the corresponding Blue Book price—shows considerable variation (the standard deviation is 19 percent) around its mean of 17 percent. Market thickness—either AIRTYPE or OPTYPE—again shows substantial variation, both across types and within type over time.

The strengths of the data lie in their extensive coverage of many aspects of the aircraft market. This allows a detailed empirical investigation of aircraft allocations and aircraft prices. Moreover, the richness of the aircraft history dataset allows me to measure very precisely the thickness of the market of each aircraft type, with variation both across aircraft types and within type over time. In the empirical analysis, I can thus control for several features of the asset that are often unobserved in other studies that rely solely on cross-sectional data. The time-series variation helps me control for several time-invariant unobserved factors and obtain convincing evidence regarding the effect of asset market thickness on asset allocations and prices.

**Some Suggestive Evidence -** Before turning to a more formal analysis, I would like to present some simple conditional correlations that suggest that market thinness generates substantial frictions. In an ideal setting, we could obtain direct evidence on the importance of frictions by looking at how long an aircraft stays on the market before selling, or how many potential buyers a seller contacts before closing a sale, and see how these quantities are related to the thinness/thickness of the asset market. While this would be a very interesting exercise, unfortunately these quantities are unobserved in the data. However, from the data I can reconstruct one very closely related measure of delay that can illustrate directly the frictions implied by market thinness. In particular, from the Aircraft History Dataset, for each leased aircraft I can reconstruct how many days it stays with its lessor between one lessee and the next one.<sup>20</sup> Clearly, if all aircraft were perfectly liquid assets, we would expect no delay at all between any two consecutive lessees. Moreover, if market thickness had no effects on aircraft allocations, we would expect AIRTYPE and OPTYPE to be uncorrelated with delays.

In Table 2 I report the results of several negative binomial regressions in which the dependent variable is the number of days between two consecutive lessees and the main explanatory variable of interest is the (log of the) thickness of the aircraft market.<sup>21</sup> I also include year fixed-effects and aircraft type fixed-effects in columns (1) and (3), and

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<sup>20</sup>Thus, I can have multiple observations for the same aircraft (a serial number).

<sup>21</sup>I employ a negative binomial specification to more precisely account for the many zeros (about 55 percent of the observations have zero days of delay between two consecutive leases), and the small set of values that the dependent takes on.

TABLE 2: Delays before Leasing Transactions: Negative Binomial Regressions

DAYS BETWEEN TWO LESSEES	(1)	(2)	(3)	(4)
LOG(AIRTYPE)	-.20638 (.02087)		-.25078 (.04050)	
LOG(OPTYPE)		-.13902 (.02411)		-.16737 (.04649)
AGE	.06795 (.00782)	.06410 (.00779)	.04029 (.01310)	.03633 (.01305)
AGE SQUARED	-.00054 (.00024)	-.00041 (.00023)	-.00034 (.00039)	-.00019 (.00039)
LOG-LIKELIHOOD	-30637.14	-30667.57	-7782.05	-7793.91
# OBS	9358	9358	4396	4396

Notes—Standard errors clustered at the aircraft-type-year level in parentheses. The equations estimated in columns (1) and (2) contain aircraft type fixed-effects and year fixed-effects (not reported). The equations estimated in columns (3) and (4) contain aircraft (serial number) fixed-effects and year fixed-effects (not reported).

year fixed-effects and individual aircraft (a serial number) fixed-effects in columns (2) and (4).<sup>22</sup> As the table clearly shows, aircraft with a larger market are redeployed faster to a new lessee, and the results are robust to different ways of measuring market thickness. Moreover, the negative binomial specifications imply that the coefficients of LOG(AIRTYPE) and LOG(OPTYPE) are equal to the elasticities, so that the magnitudes of the conditional correlations are non-trivial. For example, according to the more conservative estimates of columns (1) and (2), a 10% increase in the stock of aircraft AIRTYPE is associated with approximately a 2% decrease in the days between two consecutive lessees, and a 10% increase in the stock of operators OPTYPE is associated with approximately a 1.4% decrease in the

<sup>22</sup>As first observed by Neyman and Scott (1948), estimating fixed effects in a non-linear model could generate the incidental parameter problem if the number of observations per each fixed effect is small. However, when using year and aircraft type fixed effects we have a large number of observations and not too many fixed effects, so the incidental parameter problem is not a concern in the specifications of columns (1) and (3). In the specifications of columns (2) and (4), we have many more fixed effects. Hence, as shown by Hausman, Hall and Griliches (1984), we can use a conditional likelihood approach to consistently estimate the parameters of a negative binomial regression with a large number of fixed effects. However, the use of individual aircraft fixed-effects in the specifications of columns (2) and (4) substantially reduces the number of observations compared to the specifications of columns (1) and (3). The reason is either because there is just one observation per serial number, or because all outcomes within a serial number are identical (and equal to zero.)

days between two consecutive lessees.

While the results reported in Table 2 are consistent with the idea that market thickness generates frictions that affect the allocation of (leased) aircraft, they should also be interpreted with some caution. This is for two reasons. First, the data do not allow us to identify leases that have been renewed by the previous operator. Hence, the inference is based on the selected sample of leased aircraft for which the old lessee decided not to renew the lease. However, a few robustness checks using the cumulative number of days of delay for each leased aircraft throughout its “life” confirm the results of Table 2.<sup>23</sup> These checks suggest that sample selection is not a big concern and corroborate that delays before transactions are shorter for aircraft with a thicker market. Second, in the data the precise date in which the lessor puts the aircraft on the market and starts searching for a new lessee—after the old lessee decides not to renew the lease—is unobserved. However, there does not seem to be any good reason why lessors of aircraft with a thinner market should start searching for a new lessee *later* than lessors of aircraft with a thicker market. Indeed the above evidence suggests that lessors should anticipate longer delays and start searching for a lessee *earlier* when aircraft have a thinner market. Hence, the evidence suggests that market thinness is able to generate frictions that delay transactions. I next turn to a more formal empirical analysis of the causal effects of asset market thickness and on asset allocations and prices.

### 4.3 Empirical Framework and Identification

To test for the effect of market thickness on allocations and prices, I specify the following reduced-form equation:

$$\begin{aligned} y_{jit} &= \beta Z_{jit} + \zeta_i + \eta_t + \epsilon_{jit} \\ &= \beta_0 + \beta_A \text{LOG}(\text{THICKNESS}_{It}) + \beta_X X_{jit} + \zeta_i + \eta_t + \epsilon_{jit} \end{aligned} \quad (1)$$

where the dependent variable  $y_{jit}$  is one of the outcomes of interest (holding duration, utilization, dispersion of utilization, average price, price dispersion) for aircraft  $j$  of model  $i$  within type  $I$  in year  $t$ .  $\text{THICKNESS}_{It}$  is either  $\text{AIRTYPE}$  or  $\text{OPTYPE}$ .  $X_{jit}$  is specific to each individual aircraft, i.e.  $\text{AGE}_{jit}$ .  $\zeta_i$  is an aircraft-model fixed effect,  $\eta_t$  is a year fixed effect and  $\epsilon_{jit}$  is an idiosyncratic unobserved component.

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<sup>23</sup>More precisely, I calculate the cumulative number of days of delay for each leased aircraft throughout its “life”, and investigated how it covaries with the size of the aircraft market. Due to some coding issues, calculating the cumulative number of days of delay is not obvious for aircraft that were owned and later became leased, and vice versa. In any case, using different imputation assumptions, or discarding aircraft that switched from owned to leased or vice versa, I always obtained the same result as the regressions of Table 2: delays are shorter for aircraft with a thicker market. This suggests that sample selection is not a big concern.

The use of the quantity-based measures AIRTYPE and OPTYPE creates a few potential challenges to the identification of the effects of the size of the asset market in equation (1). The reason is that both measures of market thickness are stock variables that includes the flows of new aircraft/operators, and time-varying unobservables that affect the outcome variables might be correlated with these new flows, and thus with AIRTYPE and OPTYPE. For example, an increase in the demand for flights could simultaneously increase aircraft demand, production of new units—and thus AIRTYPE—and entry of new carriers—and thus OPTYPE—on one side, and capacity utilization and/or prices on the other side. Similarly, if aircraft maintenance costs change over time, they could simultaneously affect aircraft demand—and thus AIRTYPE and OPTYPE—and capacity utilization and prices. Moreover, if the unobservables are serially correlated, the unobservables are correlated also with lags and leads of market thickness.

The inclusion of year dummies allows me to control for all aggregate effects and any type of serial correlation of all these effects, and thus to capture aggregate increase in demand and the serial correlation of aggregate demand. However, there might still be within-year variations in demand between models correlated with AIRTYPE and OPTYPE, and persistent. In principle, the direction of the bias caused by variations in demand between models within a given year is ambiguous: deviations from year fixed effects could very well be *negatively* correlated with market thickness. The reason is that the effect of an increase in demand should be bigger for “marginal” aircraft types, that is aircraft that are used by few operators and flown only when demand is very high.

Nonetheless, when I perform the analysis on panel data—capacity utilization, dispersion of capacity utilization, Blue Book price—I deal with these endogeneity concerns using the procedure outlined by Arellano and Bond (1991). Arellano and Bond suggest to estimate a panel-data regression as equation (1) first-differencing the variables to eliminate the persistent component of the unobservable, and then to instrument the first-difference of a potentially endogenous variable  $\Delta z_{it} = z_{it} - z_{it-1}$  with lagged values of the levels  $z_{it-h}$ . More formally, let the outcome equation and the error term be:

$$y_{jit} = \beta Z_{jit} + \zeta_i + \eta_t + \epsilon_{jit}, \quad (2)$$

$$\epsilon_{jit} = \rho \epsilon_{jit-1} + \nu_{jit}. \quad (3)$$

Simply taking first-differences of the variables in equation (2) eliminates the aircraft-model fixed effect  $\zeta_i$ , as well as any fixed term constant within aircraft  $j$ . However, first-differences do not eliminate the persistent component of the error term, as  $\Delta y_{jit} = \beta \Delta Z_{jit} + \Delta \eta_t + \Delta \epsilon_{jit}$ . Subtracting  $\rho y_{jit-1}$  from  $y_{jit}$  eliminates  $\epsilon_{jit} - \rho \epsilon_{jit-1}$ , leaving only the innovation  $\nu_{jit}$  of the unobservable:

$$y_{jit} = \rho y_{jit-1} + \beta Z_{jit} - \beta \rho Z_{jit-1} + (1 - \rho) \zeta_i + \eta_t - \rho \eta_{t-1} + \nu_{jit}. \quad (4)$$

Taking first-differences, the following equation obtains

$$\Delta y_{jit} = \rho \Delta y_{jit-1} + \beta \Delta Z_{jit} - \beta \rho \Delta Z_{jit-1} + \Delta \eta_t - \rho \Delta \eta_{t-1} + \Delta \nu_{jit}. \quad (5)$$

In the differenced form, however, the new errors  $\Delta \nu_{jit}$  are correlated with the differenced lagged dependent variable  $\Delta y_{jit-1}$  by construction, and potentially with the variables  $\Delta Z_{jit}$  and  $\Delta Z_{jit-1}$  as well. Therefore, a vector  $W$  of instruments is required. Arellano and Bond suggest to construct moments  $E(\Delta \nu_{jit} * W)$  and estimate equation (5) via GMM. The vector  $W$  includes  $y_{jit-1-h}$  and  $Z_{ijt-l-h}$   $h \geq 2$  to instrument for  $\Delta y_{jit-1}$  and  $\Delta Z_{jit-l}$ , respectively, as the new error term  $\Delta \nu_{jit}$  is uncorrelated with lags of  $Z_{ijt-l}$  of order higher than two.<sup>24</sup> Moreover, the richness of the data also allows me to use other instruments that should not be correlated with year-to-year short-run variations in demand between different types, such as lagged (with lags of order higher than two) values of the number of models of a given type, the number of years since the aircraft type was first released by its manufacturer, dummies for aircraft manufacturer, and the stock of aircraft of the same type older than five years (for AIRTYPE) or the number of operators of an aircraft of the same type that started to operate the aircraft more than five years ago (for OPTYPE).<sup>25</sup> The idea of instruments such as the number of models of a given type and the number of years since the aircraft type was first released by its manufacturer is that they depend on long-run supply decisions made by the aircraft manufacturer, and thus should not be correlated with year-to-year short-run variations in demand between different models. Using lags of the number of models further reduces concerns of correlation between AIRTYPE or OPTYPE and the innovations in the unobservables. Similarly, at time  $t$  the stock of aircraft older than five years or the number of operators of an aircraft of the same type that started to operate the aircraft more than five years ago are clearly predetermined to the realization of the current period innovation  $\nu_{jit}$ .

As Blundell and Bond (1998) demonstrate, the Arellano and Bond procedure does not work well if the dependent variable—in this case capacity utilization, dispersion of capacity

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<sup>24</sup>First-differencing the data introduces serial correlation in the new errors  $\Delta \nu_{jit}$ . Arellano and Bover (1995) suggest an alternative procedure that does not introduces serial correlation in the new errors. The procedure—called Orthogonal Deviations—consists of constructing the deviation for each observation from the average of future observations in the sample for the same panel-id. However, this approach does not work with autocorrelated errors as in equation (3).

Alternatively, Arellano and Bover (1995) and Blundell and Bond (1998) suggest to add the original equation (1) in levels to the GMM criterion, instrumenting the endogenous variable in levels with first-differences. However, these additional moments are valid under the assumption that first-differences of the endogenous variables are uncorrelated with the persistent component of the unobservable, an assumption that is likely to be violated in the current context.

<sup>25</sup>Aircraft manufacturer dummies would be perfectly collinear with aircraft-model fixed effects if the outcome equation was estimated in levels, but they become good instruments when the aircraft-model fixed effects disappear in the difference equation.

utilization, and Blue Book price—is very persistent. However, this does not appear to be a concern in this case, since the notorious cyclical nature of the airline industry implies that capacity utilization and prices are not very persistent.<sup>26</sup> Similarly, two main shifters of AIRTYPE and OPTYPE (production of new aircraft and retirement of old aircraft) exhibit substantial year-to-year variation.

In the analysis of the effect of market thickness on asset turnover and on the dispersion of transaction prices, either panel-data are not available or Arellano and Bond’s procedure is not appropriate, as it will become clear below. However, the idea of Arellano and Bond’s instrumenting strategy can still be exploited. In particular, I can use the following variables as instruments of the potentially endogenous variable: lagged values of the number of models of a given type, the stock of aircraft older than five years (for AIRTYPE) or the number of operators that started to operate an aircraft more than five years ago (for OPTYPE), the number of years since the aircraft type was first released by its manufacturer, and interactions between them.<sup>27</sup> In these cases in which panel-data are not available, the assumptions required for the instruments to yield consistent estimates are stronger than when panel-data are available and Arellano and Bond’s difference-GMM can be employed. More precisely, as pointed out previously, if the unobservables are very persistent, even distant lags of the endogenous variable remain correlated with the unobservables. For this reason, I exclude the lagged values of AIRTYPE or OPTYPE from the instrument set, only using variables that are clearly predetermined to the realization of the current-period shock as instruments: lagged values of the number of models of a given type, the number of years since the aircraft type was first released by its manufacturer, and the stock of aircraft older than five years or the stock of operators that started to operate the aircraft more than five years ago. This reduces endogeneity concerns to a minimum.

#### 4.4 Results: the Effect of Liquidity on Aircraft Allocations

This subsection investigates the effect of market thickness on allocations. I investigate two related aspects. The first is the effect on asset turnover. The second is the effect on capacity utilization—I analyze the effect of asset market thickness both on the average level of utilization and the dispersion of utilization levels.

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<sup>26</sup>In all regressions, I can reject unit roots.

<sup>27</sup>In practice, the number of years since the aircraft type was first released by its manufacturer is perfectly collinear with aircraft-model fixed effects and year fixed effects, and thus I only used the interactions with the other instruments.

#### 4.4.1 Asset Turnover

The first implication of the model that I test is that assets trade more frequently when their market gets thicker. The theoretical framework highlights that the combination of two factors should affect assets’ trading patterns. First, assets with a thicker market should trade more frequently because they stay “on the market” for a shorter period of time. The economic intuition is that the trading technology exhibits increasing returns to scale, and thus trading costs decrease with the size of the market. Indeed, this is exactly what the analysis of delays between two consecutive lessees indicates. Second, the time it takes to cash in on the asset is a cost for the seller. When assets have a thin market, this cost is higher, and the owner is less likely to put the asset on the market for sale. The reason is that assets with a thin market are less “liquid”, and illiquid assets have higher option values. Thus, owners choose to hold on to assets with a thin market for longer periods of time in case their profitability rises in the future.

As mentioned in the description of the data, the data do not allow me to separately identify these two effects in a precise way for all aircraft (owned and leased). The analysis on delays between two consecutive lessees indicates that the first factor has an effect on the allocation of leased aircraft. In any case, it is plausible to expect that the second factor—higher option value—has a bigger economic relevance. Here I simply analyze the effect of asset market thickness on asset turnover, investigating the holding durations of each aircraft. More precisely, I use a Cox proportional hazard model for the probability of trading an aircraft. Since the specification I use is slightly different from equation (1), I now describe it in some detail. The Cox model assumes that the probability of trading aircraft  $j_{it}$  after  $s$  years from the acquisition given that the aircraft has not been traded before is equal to:

$$h_{jit}(s) = h_{0i}(s) \exp(\beta_A \text{LOG}(\text{THICKNESS}_{It}) + \beta_X X_{jit} + \eta_t). \quad (6)$$

where  $i$  denotes a model within type  $I$ , and  $t$  denotes a year;  $h_{0i}(s)$  is the baseline hazard function, allowed to vary across aircraft models;  $\text{THICKNESS}_{It}$  is either `AIRTYPE` or `OPTYPE`;  $X_{jit}$  is the `AGE` of the aircraft at the beginning of the spell;  $\eta_t$  is a year fixed effect.<sup>28,29</sup> Equation (6) represents a very flexible specification of the conditional probability of trading an aircraft, since the entire shape of the baseline hazard  $h_{0i}(s)$  is allowed to vary across aircraft models.<sup>30</sup> Moreover, this specification does not impose any functional form on the

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<sup>28</sup>To prevent the incidental parameter problem when there were few observations within a fixed effect, I have grouped all years prior to 1960 in a single time-fixed effect (the excluded category), and in the specifications that include carriers fixed effects, all carriers with less than 50 observations in a single carrier-fixed effect (the excluded category).

<sup>29</sup>I have also estimated a version of equation (6) that includes aircraft-vintage fixed effects to control for the year of birth of the aircraft instead of year fixed effects. The results are almost identical to the results in Table 3 and thus are omitted.

<sup>30</sup>I have also estimated a more restrictive specification that allows aircraft-model fixed effects  $\zeta_i$  to shift

model-specific baseline hazard  $h_{0i}(s)$ , so the effect of market thickness is identified purely from variation in AIRTYPE or OPTYPE within a model  $i$ .<sup>31</sup>

As highlighted in the previous section, a potential concern with estimating equation (6) is that the quantity-based measure AIRTYPE or OPTYPE could be correlated with some unobserved components of demand. For example, an unobserved increase in the demand for flights could simultaneously increase production of aircraft and volume of trade, and AIRTYPE or OPTYPE might be correlated with this shock. A few papers in the literature document patterns consistent with this idea in the aggregate economy: Maksimovic and Phillips (2001) report that the number of plants sold is higher in expansion years than in recession years, and Eisfeldt and Rampini (2006) document that the amount of capital reallocation between firms is procyclical. Thus, a positive correlation between AIRTYPE or OPTYPE and asset turnover could be just a confirmation of Maksimovic and Phillips’s and Eisfeldt and Rampini’s findings. Year fixed effects already capture most of the year-to-year variation in demand, but there might still be within year variations in demand between aircraft types that are correlated with the size of the asset market.

To address this potential concern, I use a two-step control function approach as in Blundell and Powell (2003) with instruments for LOG(AIRTYPE) or LOG(OPTYPE).<sup>32</sup> As the previous section describes, I employ instruments that arguably shift the thickness of the asset market variable independently of short-run demand shocks: lagged values of the number of models of a given type, the stock of aircraft older than five years (for AIRTYPE) or the stock of operators that started to operate the aircraft more than five years ago (for OPTYPE), and interactions between these instruments and the number of years since the aircraft type was first released by its manufacturer.<sup>33</sup>

Table 3 presents the results of the second stage. I measure the size of the market with AIRTYPE in columns (1) and (3), and with OPTYPE in columns (2) and (4). The specifica-

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the hazard only proportionally. The precise equation is:

$$h_{jit}(s) = h_0(s) \exp(\beta_A \text{LOG}(\text{THICKNESS}_{It}) + \beta_X X_{jit} + \zeta_i + \eta_t).$$

The results are almost identical to those reported in Table 3, and thus are omitted.

<sup>31</sup>The coefficient of the variable AGE AT THE BEGINNING OF SPELL is identified since each aircraft has multiple operators during its lifetime. If we were considering only the duration of the first operator (i.e. when the aircraft is acquired new), clearly the coefficient of AGE AT THE BEGINNING OF SPELL would not be identified.

<sup>32</sup>The control function approach requires running a first-step regression of the endogenous variable on the instrument plus the other explanatory variables, and computing the residuals. In the second step the hazard is estimated including the residual from the first step as a regressor. These residuals control for the potential endogeneity of liquidity.

<sup>33</sup>In practice, the number of years since the aircraft type was first released by its manufacturer is perfectly collinear with aircraft-type fixed effects and the AGE of the aircraft, and thus used only in interactions.

TABLE 3: Aircraft Turnover: Hazard Model Estimates of Trading

HAZARD	(1)	(2)	(3)	(4)
AGE AT THE BEGINNING OF SPELL	.04058 (.00410)	.03929 (.00406)	−.00148 (.00428)	−.00189 (.00426)
LOG(AIRTYPE)	.41663 (.14361)		.41008 (.15410)	
LOG(OPTYPE)		.69165 (.17384)		.66364 (.18155)
LOG-LIKELIHOOD	−109244.8	−109207.8	−105205.1	−105172.6
# OBS	241649	241649	241649	241649
AIRCRAFT	17398	17398	17398	17398

Notes—Standard errors clustered at the aircraft-type-year level in parentheses. All equations allow the baseline hazard to vary by aircraft-model. The equations estimated in all columns also contain year fixed effects (not reported). The equations estimated in columns (3) and (4) additionally contain carrier fixed effects (not reported).

tion of columns (1) and (2) does not include carrier fixed effects, while the specification of columns (3) and (4) includes them. The results indicate that aircraft with a thicker market have shorter holding durations, and this is robust across the two ways of measuring market thickness. The point estimates mean that an increase of AIRTYPE by 10 percent increases the hazard rate of trading by about 4.1 percent, a considerable magnitude. Similarly, an increase of OPTYPE by 10 percent increases the hazard rate of trading by about 6.9 percent.<sup>34</sup>

Overall, the results reported here provides strong evidence in favor of prediction 1: assets with a thicker market have higher turnover.

<sup>34</sup>One potential issue with the previous analysis is the role of replacement purchases of aircraft. If carriers sell old aircraft when they acquire new ones of the same type, then mechanically we would observe more frequent trading of existing aircraft when more new units of the same type are produced. The quantity-based measure of liquidity AIRTYPE includes new units, and thus the observed correlation between turnover and liquidity could be simply due to replacement purchases. In reality, the evidence reported in Gavazza (2007) shows that aircraft replacement accounts for a minority of aircraft trades, and most trades are instead due to profitability shocks to carriers. Moreover, the observed correlations would still imply that one motive for trade (replacement) is stronger for more popular aircraft, which is perfectly consistent with the idea put forth in this paper that asset liquidity matters for asset allocations and prices. In short, even if all trades were due to replacement, we should still conclude that replacement is more frequent for more popular aircraft, indicating that barriers to trade are lower for more liquid aircraft.

#### 4.4.2 Capacity Utilization

The previous analysis shows that aircraft trade more frequently as their market gets thicker, suggesting that aircraft with a thinner market are more illiquid. This has potential implications for the allocation of the assets. In fact, the model implies that aircraft with a thicker market should be allocated more efficiently. I now investigate more precisely the link between market thickness and allocations, testing prediction 2 that the productivity of aircraft operators should be higher as the aircraft market gets thicker.

One potential issue about testing prediction 2 is that the productivity of carriers is not directly observed in the data. However, theoretical models with endogenous capacity utilization strongly predict that the capital utilization rate is an increasing function of the firm's underlying productivity (e.g., Burnside and Eichenbaum, 1996). Moreover, most of the large empirical literature on productivity cannot precisely distinguish productivity from capacity utilization (see Jorgenson and Griliches, 1967, for an early discussion). Hence, we can learn whether aircraft with a thicker market are more efficiently allocated by investigating the link between aircraft AIRTYPE or OPTYPE and utilization rates. To this end, I estimate equation (1) with  $\log(fh_{jit})$  as a dependent variable, where  $fh_{jit}$  is the total annual flying hours of aircraft  $j$  of model  $i$  in year  $t$ .

The estimation of equation (1) with  $\log(fh_{jit})$  as the dependent variable faces a few econometric challenges. The first challenge is that aircraft are frequently parked inactive in the desert. Technically, parked aircraft imply that the dependent variable is censored at zero. I could generically deal with this complication—estimating a Tobit model via maximum likelihood—but in the data censoring acts in a slightly more subtle way. In particular, all parked aircraft have zero flying hours, but the non-parked aircraft have flying hours that start at around 1,000 hours per year. This gap implies that the effects of the independent variables on the extensive and the intensive margins are likely to be different. Moreover, unobserved heterogeneity in the extensive margin is likely correlated with unobserved heterogeneity in the intensive margin, implying that  $E(\epsilon_{jit} | Q_{jit}, fh_{jit} > 0) \neq 0$  and simple regressions on the sample of aircraft with positive flying hours provide inconsistent estimates of the constant term. However, in practice estimating equation (1) in the first-difference specification—equation (5)—makes the constant term disappear, and all other parameters can then be consistently estimated using only aircraft with positive flying hours. Thus, I estimate two separate equations: one for the extensive margin, and one for the intensive margin.

The Arellano and Bond procedure outlined in section 4.3 relies on the linearity of the estimating equation. Since the procedure allows to deal with many econometric complexities, I use a linear probability model also in the extensive margin equation. Moreover, parking the aircraft in the desert and/or reactivating it once it is parked entails fixed costs of mothballing or de-mothballing the aircraft.<sup>35</sup> These fixed costs generate persistence: once parked, aircraft

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<sup>35</sup>Pulvino (1998) reports that transporting an aircraft to a storage location (usually the desert) costs

TABLE 4: Aircraft Utilization: Arellano and Bond difference-GMM estimates

	(1)	(2)	(3)	(4)
	FLY <sub>t</sub>	FLY <sub>t</sub>	log(fh <sub>jit</sub> )	log(fh <sub>jit</sub> )
AGE	−.00177 (.00061)	−.00870 (.00210)	−.04484 (.00473)	−.03458 (.00458)
LOG(AIRTYPE)	.02081 (.00795)		.15272 (.06130)	
LOG(OPTYPE)		.03258 (.01652)		.13311 (.02318)
FLY <sub>t−1</sub>	.72314 (.06783)	.94186 (.07080)		
# OBS	50212	50212	61209	61209
AIRCRAFT	10132	10132	11321	11321

Notes—Standard errors in parentheses are calculated by applying the finite sample correction proposed by Windmeijer (2005), and are robust to autocorrelation and heteroskedasticity of unknown form. All equations also contain year fixed effects (not reported).

are more likely to be parked in the next period. Thus, I also use the lagged value of the dependent variable as an additional regressor in the extensive-margin equation in levels, which implies that I estimate the equation in first-differences with two lags of the first-differenced binary dependent variable.<sup>36</sup>

Table 4 presents the coefficients of the difference-GMM.<sup>37</sup> Columns (1) and (2) present the results of the extensive-margin equation, and columns (3) and (4) of the intensive margin. According to the estimates in column (1), a 10 percent increase of AIRTYPE is associated with a 0.2 percentage point increase in the probability that the aircraft is flying. The results reported in column (2) using OPTYPE are quite similar. According to the estimates in column (3), conditional on flying a 10 percent increase of AIRTYPE is associated with a 1.5 percent increase in capacity utilization, and again the results obtained using OPTYPE in column (4) are very similar.

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\$10,000 to \$20,000. In addition, fixed mothballing costs include the costs of the material used to cover the aircraft and, in particular, the engines. De-mothballing appears to be substantially more expensive, according to articles in the industry magazine *Aviation Maintenance*.

<sup>36</sup>A large literature, starting with Neyman and Scott (1948), has highlighted the problems of identifying duration dependence from unobserved heterogeneity. However, in the present context, first-differencing the data removes the unobserved heterogeneity, so that duration dependence can be identified without trouble.

<sup>37</sup>The number of observations in the two columns differ because the extensive margin equation contains an additional lag of the dependent variable as a regressor.

Overall, the results support prediction 2 that the productivity of aircraft operators increases as the aircraft market gets thicker. Hence, assets are more efficiently allocated when their market is thicker.

### 4.4.3 Dispersion of Capacity Utilization

As highlighted by the theoretical model, the same economic forces that push aircraft to more productive carriers when the market gets thicker imply that the equilibrium dispersion of carriers' productivities is lower as the asset market gets thicker. Thus, I now turn to the empirical investigation of the dispersion of utilization rates, directly testing prediction 3.

I analyze the link between the size of the aircraft market and dispersion of capacity utilization investigating whether the absolute percentage deviation of flying hours  $\left| \frac{fh_{jit} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right|$  described in subsection 4.2 is lower for aircraft with a thicker market. More precisely, I specify equation (1) with  $\left| \frac{fh_{jit} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right|$  as the dependent variable. I then employ Arellano and Bond's approach to estimate equation (5) with  $\Delta \left| \frac{fh_{jit} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right|$  as the dependent variable via GMM, with instruments for the potentially endogenous variable market thickness.<sup>38</sup>

Table 5 reports the estimated coefficients. Market size is measured with AIRTYPE in columns (1) and (3), and with OPTYPE in columns (2) and (4). The negative coefficients of the market size variables show that as the aircraft market gets thicker, the dispersion of capacity utilization decreases. The coefficients reported in column (1) imply that a 10 percent increase in the stock of aircraft decreases dispersion of utilization by 2.6 percent. The coefficients reported in column (2) imply that a 10 percent increase in the number of operators decreases dispersion by approximately 1 percent.

In columns (3) and (4) I perform the same regressions as in columns (1) and (2), but I only consider observations with positive flying hours. More precisely, I calculate the average  $\overline{fh_{ait}}$  only using observations with  $fh_{jit} > 0$ , and then calculate  $\left| \frac{fh_{jit} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right|_{fh_{jit} > 0}$ . The reason for this choice is that aircraft with zero flying hours mechanically increase the dispersion of utilization levels, and it is instructive to understand whether the dispersion is driven exclusively by parked aircraft. The coefficients reported in column (3) and (4) show that, as expected, the magnitude of the effect of market thickness on dispersion is smaller when only active aircraft are considered. However, the size of the aircraft market still has a sizable effect: a 10 percent increase in AIRTYPE<sub>It</sub> decreases dispersion of utilization by 2.1 percent, and a 10 percent increase in OPTYPE<sub>It</sub> decreases dispersion of utilization by 0.66 percent. These regressions confirm that market thickness affects both the intensive and the extensive

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<sup>38</sup>I also undertook the same procedure calculating the average for each age  $a$ -type  $I$ -year  $t$  tuple, i.e.  $\overline{fh_{ait}}$ , and using  $\left| \frac{fh_{jit} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right|$  as a dependent variable. The results are very similar to those reported in table 5 and thus omitted.

TABLE 5: Dispersion of Capacity Utilization: Arellano and Bond difference-GMM estimates

	(1)	(2)	(3)	(4)
	$\left  \frac{fh_{ijt} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right $	$\left  \frac{fh_{ijt} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right $	$\left  \frac{fh_{ijt} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right _{fh_{ijt} > 0}$	$\left  \frac{fh_{ijt} - \overline{fh_{ait}}}{\overline{fh_{ait}}} \right _{fh_{ijt} > 0}$
AGE	.02427 (.00249)	.02157 (.00257)	.01641 (.00192)	.01615 (.00192)
LOG(AIRTYPE)	-.26440 (.03916)		-.21665 (.03100)	
LOG(OPTYPE)		-.09593 (.01568)		-.06605 (.01138)
# OBS	64282	64282	61209	61209
AIRCRAFT	11596	11596	11321	11321

Notes—Standard errors in parentheses are calculated by applying the finite sample correction proposed by Windmeijer (2005), and are robust to autocorrelation and heteroskedasticity of unknown form. All equations also contain year fixed effects (not reported). The equations estimated in columns (3) and (4) uses only observations with positive flying hours.

margins of utilization.<sup>39,40</sup>

## 4.5 Results: the Effect of Liquidity on Aircraft Prices

Having investigated the effect of market thickness on asset allocations, in this subsection I investigate the effects on prices. I present two sets of results, directly testing predictions 4 and 5 related to the first and second moments of the price distribution.

<sup>39</sup>I have also employed a second empirical strategy that follows directly from the previous analysis of the effect of market thickness on the level of capacity utilization. More precisely, based on the estimates reported in Table 4, I obtain the residuals  $\hat{\epsilon}_{jit}$  of the utilization equation. I then calculate the variance  $\text{VAR}(\hat{\epsilon}_{jit})$  of these residuals, and I regress  $\text{VAR}(\hat{\epsilon}_{jit})$  on AIRTYPE or OPTYPE, aircraft-type fixed effects and year fixed effects. I find that aircraft with a larger market have a lower variance  $\text{VAR}(\hat{\epsilon}_{jit})$ , which is consistent with the results reported in Table 5,

<sup>40</sup>A potential concern with the regressions of Table 5 is that the dependent variable has the average utilization in the denominator, and the regressions reported in Table 5 indicate that average utilization increases as the asset market gets thicker. Hence, to check the robustness of the results, I have run all regressions with  $|fh_{jit} - \overline{fh_{ait}}|$  as the dependent variable. The results are robust to this alternative way of measuring dispersion.

TABLE 6: Aircraft Prices: Arellano and Bond difference-GMM estimates

$\text{LOG}(\bar{p}_{jit})$	(1)	(2)
AGE	-.04492 (.01329)	-.03776 (.01439)
$\text{LOG}(\text{AIRTYPE})$	.27325 (.12201)	
$\text{LOG}(\text{OPTYPE})$		.06529 (.02916)
# OBS	4397	4397
AIRCRAFT (VINTAGE-MODEL)	332	332

Notes—Standard errors in parentheses are calculated by applying the finite sample correction proposed by Windmeijer (2005), and are robust to autocorrelation and heteroskedasticity of unknown form. The equation estimated also contains year fixed-effects (not reported).

#### 4.5.1 Average Prices

To test prediction 4 on the effect of market thickness on aircraft prices, I specify equation (1) with  $\log \bar{p}_{jit}$  as the dependent variable, where  $\bar{p}_{jit}$  is the Blue Book price of an aircraft of vintage  $j$  model  $i$  in year  $t$ .<sup>41</sup> I then estimate the first-difference version (5) with  $\Delta \log \bar{p}_{jit}$  as the dependent variable using GMM, instrumenting for the potentially endogenous variable  $\Delta \text{LOG}(\text{AIRTYPE}_{It})$  and  $\Delta \text{LOG}(\text{OPTYPE}_{It})$ .

Table 6 reports the estimated coefficients. The table shows that aircraft prices increase as their market gets thicker, confirming prediction 4. Moreover, the magnitude of the economic effect is sizable: an increase of AIRTYPE by 10 percent is associated with an increase in the price of the aircraft by 2.7 percent. This magnitude is equivalent to the effect on price of around six months of AGE. Similarly, an increase of OPTYPE by 10 percent is associated with an increase in the price of the aircraft by 0.65 percent.

#### 4.5.2 Price Dispersion

The previous results showed that there exists a clear parallel between the increase in the aircraft price levels and the increase in the level of capacity utilization as the size of the market increases. I now investigate if the same parallel exists for dispersion. In particular, the theoretical model highlights that the dispersion of transaction prices should be the mirror image of the dispersion of utilization levels previously documented. Thus, I now test

<sup>41</sup>Note that the panel variable is thus a model-vintage pair. I have also estimated the price equation using model-age as a panel variable. The results are identical and thus omitted.

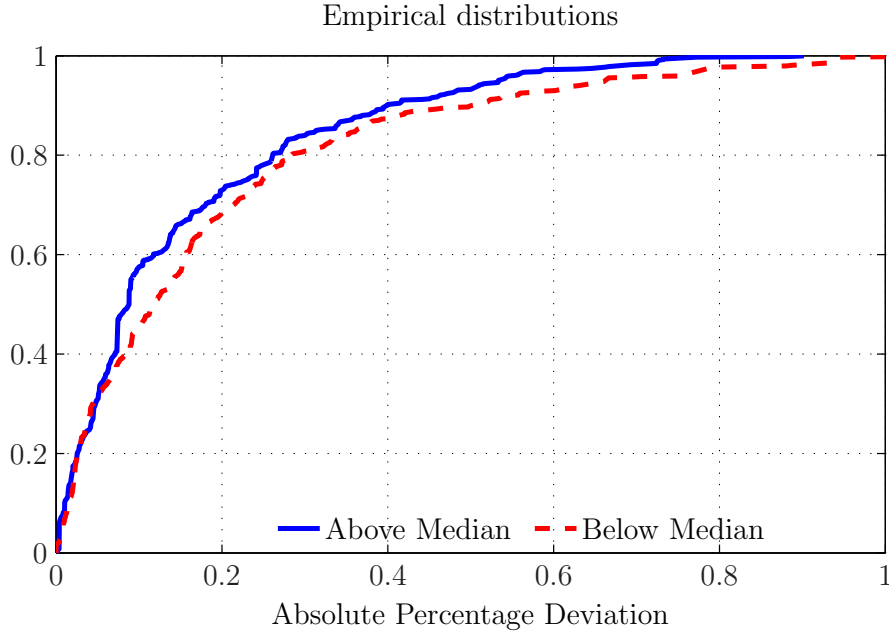


FIG. 2: Empirical distributions of deviations of transaction price from Blue Book price for above- and below-median liquidity.

prediction 5 on the effect of market thickness on the dispersion of transaction prices.

As reported in subsection 4.1, I measure price dispersion using the absolute percentage deviation  $\left| \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right|$  of the transaction price from the Blue Book price, where  $p_{jit}$  is the transaction price of aircraft  $j$  of age  $\text{AGE}_{jit} = a$  model  $i$  in year  $t$ , and  $\bar{p}_{ait}$  is the Blue Book price of aircraft of age  $a$  model  $i$  in year  $t$ . Figure 1 showed that the two price series are highly correlated, so that  $\left| \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right|$  seems a reasonable way to measure the dispersion of transaction prices.

It is instructive to have a sense of the data by simply looking at the empirical distributions of  $\left| \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right|$  corresponding to values of market thickness AIRTYPE above and below the median: figure 2 plots these two empirical distributions.<sup>42</sup> The solid line is the empirical c.d.f. of absolute percentage deviation  $\left| \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right|$  when the corresponding value of AIRTYPE is above the sample median, while the dotted line is the empirical c.d.f. of the same variable when AIRTYPE is below the sample median. The comparison of the two empirical distributions in figure 2 clearly shows that the dispersion of transaction prices is higher for aircraft with a thicker market. The Kolmogorov-Smirnov test clearly rejects equality of two distributions (the  $p$ -value is  $1.7422 \times 10^{-6}$ ).

In order to further investigate the effects of market thickness on the dispersion of transac-

<sup>42</sup>The figure using OPTYPE is very similar.

TABLE 7: Aircraft Price Dispersion: Instrumental Variables

$\frac{p_{jit} - \bar{p}_{jit}}{\bar{p}_{jit}}$	(1)	(2)	(3)	(4)
AGE	.00252 (.00377)	.00265 (.00377)	.00336 (.00609)	.00348 (.00615)
LOG(AIRTYPE)	-.10050 (.04983)		-.12882 (.04908)	
LOG(OPTYPE)		-.13478 (.06107)		-.16105 (.06291)
R <sup>2</sup>	.419	.419	.387	.447
# OBS	1555	1555	1555	1555

Notes—Standard errors clustered at the aircraft-type-year level in parentheses. The equation estimated in columns (1) and (2) also contains aircraft-model, year and noise-stage fixed effects (not reported). The equation estimated in columns (3) and (4) also contain aircraft-model, year, noise-stage and engine-type fixed effects (not reported).

tion prices, I estimate equation (1) using the absolute percentage deviation  $\left| \frac{p_{jit} - \bar{p}_{ait}}{\bar{p}_{ait}} \right|$  as the dependent variable. As the dependent variable is based on transaction prices, no panel-data are available and the Arellano and Bond procedure cannot be used. Thus, I can simply instrument market thickness using the instruments described in section 4.3: lagged values of the number of models of a given type, the stock of aircraft older than five years for AIRTYPE or the number of operators of an aircraft of the same type that started to operate the aircraft more than five years ago for OPTYPE, and interactions between these instruments and the number of years since the aircraft type was first released by its manufacturer. As already highlighted, this IV strategy is a weaker procedure than Arellano and Bond’s difference-GMM; nonetheless, the instruments used are clearly predetermined to the realization of the current-period shock, reducing simultaneity concerns.

Table 7 reports the estimated coefficients. The table clearly shows that the dispersion of transaction prices is lower for aircraft with a thicker market, thus verifying prediction 5. According to the estimates, an increase of AIRTYPE by 10 percent is associated with a decrease in the absolute value of the percentage difference between transaction price and Blue Book price by 1.0-1.3 percent. Similarly, an increase of OPTYPE by 10 percent is associated with a decrease in the absolute value of the percentage difference between transaction price

and Blue Book price by 1.3-1.6 percent.<sup>43,44</sup>

## 4.6 Discussion of Empirical Results

I have investigated the effects of the thickness of the asset market on asset allocations and prices combining several datasets on aircraft markets. The analysis provides strong evidence that assets are more efficiently allocated and command higher prices when the size of their market grows. The results suggest that aircraft become more “liquid” as their market gets thicker, increasing the lower bound of carriers’ equilibrium efficiency levels, resulting in higher utilization rates as well as less dispersion of capacity utilization rates. In turn, the effects of market thickness on utilization transmit to prices, increasing the average level and decreasing the dispersion of transaction prices. Moreover, the richness of the data allowed me to control for a number of unobservable factors that could have made it difficult to cleanly identify the effect of market thickness on prices and allocations. The use of difference-GMM and instruments speak against the possibility that the quantity-based measure AIRTYPE captures the effect of unobserved demand shocks. I now discuss in details the difference between my paper and a few closely related empirical papers, and present evidence against some alternative hypotheses.

**Related papers -** The empirical patterns documented share some similarities with the ones uncovered by a few papers in the literature. Syverson (2004, forthcoming) investigates the determinants of firms’ average productivity and the dispersion of productivity levels. However, the precise economic force behind Syverson’s papers and my paper is rather different. Syverson focuses on a demand-side effect: in his model, consumers can more easily switch between suppliers in a denser market. As a result, suppliers’ average productivity is higher and the dispersion of productivities is lower in denser market. Instead, this paper focuses on a supply-side effect: the thickness of the input market.<sup>45</sup> Hence, Syverson’s papers and my paper offer complementary explanations of similar economic facts, and each explanation is better suited to describe a different industry with different characteristics (spatial differentiation versus decentralized input markets).

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<sup>43</sup>Similarly to the remark in footnote 40, a potential concern with the regressions of Table 5 is that the dependent variable has the average price in the denominator, and the regressions reported in Table 5 indicate that the average price increases as the asset market gets thicker. Hence, to check the robustness of the results, I have run all regressions with  $|p_{jit} - \bar{p}_{ait}|$  as the dependent variable. The results (unreported) are robust to this alternative way of measuring price dispersion.

<sup>44</sup>It may seem puzzling that in some tables the coefficients of AIRTYPE is larger in absolute value than the coefficients of OPTYPE, while in others the opposite is true. As emphasized in Section 4.1, it is important to remember that the data used in the different regressions correspond to different time periods.

<sup>45</sup>See also Balasubramanian and Sivadasan (forthcoming).

Pulvino (1998) investigates the determinants of aircraft transaction prices, and finds that carriers in worse financial conditions sell aircraft at bigger discounts. Two key predictions of the theoretical framework of my paper is that sellers' profitabilities are *endogenously* lower when assets have a thinner market, and that the dispersion of transaction prices is *endogenously* bigger for assets with a thinner market. Clearly, firms' financial conditions and profitabilities are very closely related—economic and financial distress are often two sides of the same coin—, and the dispersion of transaction prices is also very closely related to price discounts. Hence, my paper elucidates Pulvino's results by describing an economic mechanism that *simultaneously* implies that sellers are on average in worse financial condition and that price discounts are bigger when aircraft have a thinner market.

**Alternative Hypotheses** - The literature on durable goods highlights the role of depreciation (quality differentials) in explaining patterns of trade. The literature makes different predictions if parties have symmetric versus asymmetric information on the depreciation (quality) of the asset. Under symmetric information, the literature (Hendel and Lizzeri (1999); Stolyarov (2002)) predicts that lower-quality goods should trade more frequently. In my setting, since assets with a thicker market trade more frequently, we must conclude that these assets are of lower quality. Clearly, this conclusion is inconsistent with the fact that assets with a thicker market have higher capacity utilizations and command higher prices. Thus, theories of quality differentials under symmetric information cannot explain the observed patterns.

Under asymmetric information, higher-quality durable goods trade more frequently (Hendel and Lizzeri, 1999), in contrast with Akerlof's (1970) original analysis. Hence, we must conclude that assets with a thicker market are of higher quality. This explanation might seem able to explain a number of patterns. However, several institutional features of the aircraft market and a closer look at the data show that this explanation is unlikely to account for all observed patterns. First, aircraft maintenance is regulated by the aviation authorities. After a certain number of hours flown, carriers undertake compulsory maintenance. This suggests that quality differences cannot be too high. Moreover, Pulvino (1998) rejects the hypothesis that, conditional on observable characteristics such as age, quality differentials between aircraft explain trade patterns. Furthermore, maintenance records are readily available and all parties can observe the entire history of each aircraft. This suggests that asymmetries of information cannot be too strong. Second, it is important to reiterate that panel data techniques mean that the effect of market thickness on prices is identified from variations in market thickness through the life of a given vintage-type combination, and the effect of market thickness on utilization is identified from variations of market thickness through the life of a given aircraft serial number. Thus, if the patterns were explained by asymmetries of information, then we must conclude that the quality of a given vintage (of a given serial number)

improves over its lifespan in the case of prices (in the case of utilization), which seems very unlikely. In the specific case of prices, moreover, it is not clear why such improvements over the life of the vintage are not capitalized immediately in prices. Third, the observed dispersion of transaction prices is exactly the *opposite* of that predicted by asymmetric-information models. In particular, under information asymmetries we should expect a lower dispersion of transaction prices for assets with more severe information asymmetries, as prices do not depend on unobserved quality differences.

An alternative hypothesis for assets' patterns of trade suggested by the finance literature is that firms sell assets to reduce the degree of firm diversification (e.g., John and Ofek, 1995). This motivation for trade implies that firms tend to sell their marginal assets. However, the evidence is inconsistent with the idea that the majority of assets sold are marginal assets. The reason is that assets that trade more frequently are more popular, so they cannot be marginal assets for all carriers. Moreover, the evidence shows that assets that trade more frequently fetch higher prices. If they were marginal assets, we should expect them to instead fetch lower prices.

In summary, reasonable alternative hypotheses are inconsistent with all empirical patterns documented. I therefore conclude that market thickness has a considerable effect on prices and allocations in the market for capital equipment, as predicted by the theoretical framework.

## 5 Conclusions

In this paper, I have investigated how market thickness affects asset prices and asset allocations in bilateral search markets. I have constructed a model of a bilateral search market to theoretically investigate how trading frictions vary as asset markets get thicker, and what implications market thickness has for asset allocations and prices. The key economic mechanism in the model is that the trading technology fundamentally exhibits increasing returns to scale, so that as the mass of assets increases the flow of meetings increases more than proportionally. As a result, the model implies that assets with a thicker market: 1) trade more frequently; 2) have higher average utilizations; 3) have lower dispersion of utilization levels; 4) fetch higher average prices; and 5) have lower dispersion of transaction prices.

Detailed microdata on assets allow a study of the working of one specific decentralized market, the market for commercial aircraft. The empirical analysis uncovers a number of robust empirical findings, confirming all predictions of the model. A 10 percent increase in the stock of aircraft of a given type implies: 1) a 4.1 percent increase in the hazard of trading the aircraft; 2) a 1.5 percent increase in the average capacity utilization; 3) a 2.6 percent decrease in the absolute percentage deviation of utilizations from the mean utilization; 4) a 2.7 percent increase in the average price; and 5) a 1.0 percent decrease in the absolute

percentage deviation of transaction prices from the mean price.

This paper shows that the thickness of the asset market increases asset liquidity and reduces frictions in input markets, thereby increasing the aggregate efficiency of output markets. Aircraft are among the easiest assets to redeploy across users. Nonetheless, differences between aircraft with a thin market or with a thick market are still non-negligible. This finding has several potential implications. These differences indicate that market thinness acts like a sunk cost of investment, and the literature on irreversible investment finds that sunk costs have a first-order effect on firms' investment decisions. Abel and Eberly (1996) show that even small degrees of irreversibility matter a lot for establishment-level dynamics. However, the aggregate effects of irreversibility are more ambiguous. For example, Veracierto (2002) suggests that investment irreversibilities do not play a significant role for aggregate fluctuations. This paper does not consider aggregate shocks and aggregate fluctuations, but finds that one aggregate effect of the expansion of asset markets is to raise the equilibrium efficiency of the firms that operate these assets. In this sense, market thinness acts here in a similar way to the cost of firing labor acts in the general equilibrium model of Hopenhayn and Rogerson (1993).

This paper further contributes to the literature on productivity and productivity dispersion. Most of the explanations for the large and persistent productivity dispersion observed within industries focus on technological differences between firms. Here I show how productivity dispersion decreases when the asset market gets larger by reducing the option value of holding on to an asset when the productivity of its user declines.

The mechanism identified in this paper potentially applies to the economy as a whole. Investigating whether the market for corporate assets has become larger and more liquid over time, and whether this has affected aggregate productivity, seems an interesting question for future research.

# A Model

In this section I lay out a model of a decentralized market with two-sided search (Mortensen and Wright, 2002) to theoretically investigate the effects of market thickness on asset allocations and prices. The model adapts the framework introduced by Diamond's (1982) seminal paper, as in the recent literature on search in financial markets.

I model frictions of reallocating assets explicitly. In particular, each agent contacts another agent randomly, and this is costly for two reasons: 1) there is an explicit search cost  $c$  that an agent pays in order to actively meet another (random) active agent; 2) there is a time cost in that all agents discount future values by the discount rate  $r > 0$ .

## A.1 Assumptions

Time is continuous and the horizon infinite. There is a total mass  $S'$  of assets and a mass  $A = S' + B' > S'$  of agents, with  $B' > S'$ . All agents are risk neutral and discount the future at the positive rate  $r > 0$ . Agents are differentiated by the parameter  $z$  that determines the ability to generate cash-flow from the use of the asset. The profitability vector  $z$  is distributed in the population according to the cumulative distribution function  $F(z)$  and follows an independent stochastic process: each agent receives a new draw from  $F(z)$  at the instantaneous rate  $\lambda$ .

Each agent can own either zero or one asset, and an agent who wants to trade an asset pays a search cost  $c$ .<sup>46</sup> An agent who wants to trade makes contacts with other traders pairwise independently at Poisson arrival times with intensity  $\gamma > 0$ . Given a contact, because of the random-matching assumption, the probability that a buyer (seller) makes a contact with a seller (buyer) is  $S(B)$ , where  $S$  and  $B$  are the stocks of active sellers and active buyers. In other words, the mass of active sellers  $S$  (active buyers  $B$ ) is the subset of the mass of potential sellers  $S'$  (potential buyers  $B'$ ) that has paid the search cost  $c$ . Thus, conditional on making a contact, all traders are "equally likely" to be contacted. On aggregate, contacts between sellers and buyers occur continually at a total (almost sure) rate of  $\gamma BS$ .

Once an active buyer and an active seller meet, they negotiate a price to trade. I assume that an active buyer and an active seller negotiate a price according to generalized Nash bargaining, where  $\theta \in (0, 1)$  denotes the bargaining power of the buyer.

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<sup>46</sup>Hence, I do not consider quantity decisions, as Duffie, Gârleanu and Pedersen (2005, forthcoming), Miao (2006), Vayanos and Wang (forthcoming), Vayanos and Weill (forthcoming), and Weill (2007, forthcoming). It will be clear that the intuition applies more generally. See Lagos and Rocheteau (2007) for a model that considers quantity decisions.

## A.2 Solution

The potential seller of an aircraft with profitability  $z$  can put it up for sale or keep operating it. In the former case, he pays the search cost  $c$  and meets potential trading partners at rate  $\gamma B$ . In the latter case, he enjoys the flow profit  $z$ . Similarly, a potential buyer  $z$  can pay the search cost  $c$  and meet active sellers at rate  $\gamma S$ , or can wait to search later when his profitability changes. We thus have four categories of agents: active and non-active buyers and sellers. I denote by  $V_B(z)$  the value function of an active buyer, and by  $W_B(z)$  the value function of a non-active buyer. Similarly,  $V_S(z)$  and  $W_S(z)$  are the value functions of an active and non-active seller, respectively.

Intuitively, a potential buyer prefers to be an active buyer when his profitability  $z$  is sufficiently high, and a potential seller prefers to be an active seller when her profitability is sufficiently low. Moreover, an active buyer that has just bought an aircraft does not become immediately (i.e. before  $z$  changes) an active seller, since he would have been better off not buying the aircraft and not paying the search cost. Thus, when an active buyer and active seller meet and trade, they become a non-active seller and a non-active buyer, respectively.

I now derive formally the value functions for active and inactive agents, and the transaction prices at which trade occurs. These value functions allow me to pin down the equilibrium conditions, and to characterize the endogenous distribution of profitabilities of active firms and the endogenous distribution of transaction prices.

The analysis shows that the key element affecting the first two moments of the profitability and transaction price distributions is how potential sellers' and buyers' cutoff values—the values at which potential sellers and buyers are indifferent between being active or inactive—change with the thickness of the market, that is with  $S'$ . In particular, the higher is sellers' cutoff value and the lower is buyers' cutoff value, the higher is the average and the lower is the variance of potential sellers' profitability. A higher average  $z$  then translates into a higher average transaction price, and a lower variance of valuation into a lower variance of transaction prices. In turn, sellers' and buyers' cutoff values are determined by the (endogenous) total number of meetings  $\gamma BS$ .

As spelled out in more detail in Section 3, the key economic force is that the trading technology fundamentally exhibits increasing returns to scale. Hence, sellers' reservation value increases and buyers' reservation value decreases as the asset market gets thicker. In turn, as the mass of assets increases: 1) assets have a higher turnover; 2) the productivity of firms increases; 3) the dispersion of firms' productivity decreases; 4) assets have a higher average price; 5) assets have a lower dispersion of transaction prices.

### A.2.1 Value Functions

Consider an agent with profitability  $b$  and no asset. The agent can choose to pay the search cost  $c$  and search, or can decide to stay inactive.

If the agent decides to be an active buyer, his value function  $V_B(b)$  satisfies

$$\begin{aligned} rV_B(b) = & -c + \gamma S \int \max \{W(b) - p(b, s) - V_B(b), 0\} dG_S(s) \\ & + \lambda \int (\max \{V_B(z), W_B(z)\} - V_B(b)) dF(z) \end{aligned} \quad (7)$$

where  $G_S(s)$  is the endogenous equilibrium distribution of active sellers (which is derived below).

Equation (7) has the usual interpretation of an asset-pricing equation. An active buyer with profitability  $b$  pays the search cost  $c$ . At any date, he chooses which asset to search for and at most one of two possible events might happen to him: 1) at rate  $\gamma S$ , he meets an active seller. If he trades, he becomes an inactive seller, and thus obtains a capital gain equal to  $W(b) - p(b, s) - V_B(b)$ . If he doesn't trade, he has no capital gain. 2) At rate  $\lambda$ , he receives a new profitability draw. After learning his new profitability, he decides whether to remain an active buyer (in which case he has a capital gain/loss equal to  $V_B(z) - V_B(b)$ ), or to become an inactive buyer (in which case he has a capital gain/loss equal to  $W_B(z) - V_B(b)$ ).

Similarly, the value function  $V_S(s)$  of an active seller with profitability  $s$  satisfies the following Bellman equation:

$$\begin{aligned} rV_S(s) = & -c + s + \gamma B \int \max \{p(b, s) + W_B(s) - V_S(s), 0\} dH_B(b) \\ & + \lambda \int (\max \{V_S(z), W_S(z)\} - V_S(s)) dF(z). \end{aligned} \quad (8)$$

where  $H_B(b)$  is the endogenous equilibrium distribution of active buyers (which again is derived below).

The interpretation of equation (8) is now straightforward. An active seller receives an instantaneous payoff flow equal to the difference between her profitability  $s$  and the search cost  $c$ . At rate  $\gamma B$ , she meets an active buyer. If she trades, she obtains a capital gain equal to  $p(b, s) + W_B(s) - V_S(s)$ . If she does not trade, she has no capital gain. At rate  $\lambda$ , she receives a new profitability draw. After learning her new  $z$ , she decides whether to remain an active seller (in which case she has a capital gain/loss equal to  $V_S(z) - V_S(s)$ ) or to become an inactive seller (in which case she has a capital gain/loss equal to  $W_S(z) - V_S(s)$ ).<sup>47</sup>

The value functions  $W_B$  and  $W_S(s)$  of an inactive buyer and of an inactive seller with

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<sup>47</sup>It is easy to see that a meeting between sellers of different assets results in no trade.

profitability  $s$  satisfy:

$$rW_B(b) = \lambda \int (\max \{V_B(z), W_B(z)\} - W_B(b)) dF(z) \quad (9)$$

$$rW_S(s) = s + \lambda \int (\max \{V_S(z), W_S(z)\} - W_S(s)) dF(z). \quad (10)$$

Equations (9) and (10) say that the flow value of an inactive trader is equal to the instantaneous cash-flow (0 for a buyer,  $s$  for a seller) plus the expected capital gain/loss.<sup>48</sup>

When an active buyer  $b$  and an active seller  $s$  meet, if they trade, the negotiated price

$$p(b, s) = \theta (V_S(s) - W_B) + (1 - \theta) (W_S(b) - V_B(b)) \quad (11)$$

is the solution to the following symmetric-information bargaining problem:<sup>49</sup>

$$\begin{aligned} & \max_p [W_S(b) - p - V_B(b)]^\theta [p + W_B - V_S(s)]^{1-\theta} \\ \text{subject to: } & W_S(b) - p \geq V_B(b) \text{ and } p + W_B \geq V_S(s). \end{aligned}$$

Using the equilibrium price (11), the value function of an active buyer  $b$  becomes

$$\begin{aligned} rV_B(b) + c &= \gamma S \theta \int \max \{-V_S(s) + W_B + W_S(b) - V_B(b), 0\} dG_S(s) \\ &+ \lambda \int (\max \{V_B(z), W_B(z)\} - V_B(b)) dF(z). \end{aligned} \quad (12)$$

Similarly, a value function of an active seller  $s$  is:

$$\begin{aligned} rV_S(s) + c &= s + \gamma B (1 - \theta) \int \max \{-V_S(s) + W_B + W_S(b) - V_B(b), 0\} dH_B(b) \\ &+ \lambda \int (\max \{V_S(z), W_S(z)\} - V_S(s)) dF(z). \end{aligned} \quad (13)$$

Since  $V_B(b)$  is increasing in  $b$ , there exists a reservation value  $R_B$  such that only buyers with valuation  $b \geq R_B$  have positive gains from trade.  $R_B$  satisfies

$$V_B(R_B) = \frac{\lambda \int (\max \{V_B(z), W_B\}) dF(z)}{r + \lambda}.$$

Similarly, there exists reservation value  $R_S$  such that only sellers with reservation value  $s \leq R_S$  have positive gains from trade.  $R_S$  satisfies

$$V_S(R_S) = \frac{R_S + \lambda \int \max \{V_S(z), W_S(z)\} dF(z)}{r + \lambda}$$

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<sup>48</sup>Thus, the value of an inactive buyer is independent of his profitability.

<sup>49</sup>The characteristics of aircraft markets described in section 4.6 support the assumption of symmetric information.

When  $r$  is small, it can be shown that  $-V_S(s) + V_B(s) + V_S(b) - V_B(b) \geq 0$  for all possible meetings of active buyers and sellers.<sup>50</sup> Hence, Appendix B shows that we can rewrite the value function of an active buyer as

$$V_B(b) = k(b - R_B) + \frac{\lambda \int \max\{V_B(z), W_B\} dF(z)}{r + \lambda} \quad (14)$$

where  $k = \frac{\gamma S \theta}{(r + \lambda)(r + \lambda + \gamma S \theta)}$ . Similarly, the value function of an active seller is

$$V_S(s) = \frac{s - R_S}{\delta} + \frac{R_S + \lambda \int \max\{V_S(z), W_S(z)\} dF(z)}{r + \lambda} \quad (15)$$

where  $\delta = r + \lambda + \gamma B(1 - \theta)$ . Thus, the transaction price when seller  $s$  and buyer  $b$  meet is equal to

$$\begin{aligned} p(b, s) = & \theta \left( \frac{s - R_S}{\delta} + \frac{R_S}{r + \lambda} \right) + (1 - \theta) \left( \frac{b}{r + \lambda} - k(b - R_B) \right) + \int_{R_S} \frac{\lambda z}{r(r + \lambda)} dF(z) + \\ & \frac{\lambda}{r} \int^{R_S} \left( \frac{z - R_S}{\delta} + \frac{R_S}{r + \lambda} \right) dF(z) - \int_{R_B} \frac{\lambda k(z - R_B)}{r} dF(z). \end{aligned} \quad (16)$$

### A.2.2 Distributions of Buyers and Sellers

I now derive the endogenous equilibrium distribution of potential buyers  $B'$  and potential sellers  $S'$  and the endogenous distribution of active buyers  $B$  and active sellers  $S$ .

Steady state requires that traders' flows for each interval of the distribution functions of potential buyers  $B'$  and potential sellers  $S'$  are equal to traders' flows out. Appendix C shows the exact calculations. Moreover, it is easy to show that for  $c$  sufficiently large,  $R_B > R_S$ . Thus the endogenous distribution of potential sellers  $S'$  satisfies

$$g_{S'}(z) = \begin{cases} \frac{B'}{S'} \frac{\gamma S}{\lambda + \gamma S} f(z) + f(z) & \text{for } R_B \leq z \\ f(z) & \text{for } R_S \leq z < R_B \\ \frac{\lambda}{\lambda + \gamma B} f(z) & \text{for } z < R_S. \end{cases}$$

Similarly, the endogenous distribution of potential buyers satisfies

$$h_{B'}(z) = \begin{cases} \frac{\lambda}{\lambda + \gamma S} f(z) & \text{for } R_B \leq z \\ f(z) & \text{for } R_S \leq z < R_B \\ \frac{S'}{B'} \frac{\gamma B}{\lambda + \gamma B} f(z) + f(z) & \text{for } z < R_S \end{cases}$$

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<sup>50</sup>See Mortensen and Wright (2002).

Hence, the distribution of active sellers is simply

$$g_S(z) = \begin{cases} 0 & \text{for } R_S \leq z \\ \frac{f(z)}{F(R_S)} & \text{for } z < R_S \end{cases} \quad (17)$$

and active buyers is

$$h_B(z) = \begin{cases} \frac{f(z)}{1-F(R_B)} & \text{for } R_B \leq z \\ 0 & \text{for } z < R_B. \end{cases} \quad (18)$$

### A.3 Equilibrium

The equilibrium conditions determine the four endogenous variables  $(R_S, R_B, S, B)$ .

**Definition 1** *A steady-state equilibrium is a set of reservation values  $(R_S, R_B)$ , and a stock of active buyers and sellers  $(B, S)$  satisfying the following conditions:*

1. *The reservation values  $(R_S, R_B)$  satisfy the following indifference conditions.<sup>51</sup>*

$$c = \gamma S \theta \int \left( \frac{R_S - s}{\delta} - \frac{R_S - R_B}{r + \lambda} \right) dG_S(s) \quad (19)$$

$$c = \gamma B (1 - \theta) \int \left( \frac{b - R_S}{r + \lambda} - k(b - R_B) \right) dH_B(b) \quad (20)$$

where  $G_S(s)$  and  $H_B(b)$  are the cumulative distribution functions of active sellers and active buyers, respectively.  $G_S(s)$  and  $H_B(b)$  are derived from the probability density functions  $g_S(s)$  and  $h_B(b)$  defined in (17) and (18);

2. *Active buyers are all potential buyers with profitability above  $R_B$  and active sellers are all potential sellers with profitability below  $R_S$ :*

$$B = (1 - H_{B'}(R_B)) B' = B' (1 - F(R_B)) \frac{\lambda}{\lambda + \gamma S}$$

$$S = G_{S'}(R_S) S' = S' \frac{\lambda}{\lambda + \gamma B} F(R_S)$$

### A.4 A Numerical Illustration

Unfortunately, the equilibrium conditions do not admit an explicit solution of the endogenous variables  $(R_S, R_B, S, B)$  as a function of the exogenous parameters. Thus, in order to understand how the size of the asset market affects the equilibrium distribution of profitabilities

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<sup>51</sup>The conditions are obtained combining equations (12), (14) and (9), and equations (13), (15) and (10), respectively.

and prices, I fix values of the exogenous parameters and the exogenous distribution  $F(z)$ , and then solve the model numerically.<sup>52</sup> More precisely, the numerical solutions illustrate how moments of the distributions of profitabilities and prices change as the mass of assets  $S'$  increases, while holding the ratio of potential sellers (and thus assets)  $S'$  and potential buyers  $B'$  constant.

Figure 3 illustrates several features of the equilibrium. The first plot (first row, first column) simply plots the mass of active buyers  $B$  and active sellers  $S$  as a function of the mass of assets. The plot obviously shows that the masses of active traders increase as the masses of assets and potential traders increase.

The behavior of the endogenous variables  $(R_S, R_{S_2})$  plotted in the second plot (first row, second column) is the key to understand the effects of market thickness on asset allocations and asset prices. The plot shows that sellers' reservation value  $R_S$  increases and buyers' reservation value  $R_B$  decreases as the number of assets increases. This is intuitive: when the asset market is thin, assets are illiquid and the option value of holding on to an illiquid asset is higher. Thus sellers rationally choose to hold on to assets with a thin market for longer periods of time in case their profitability  $z$  rises in the future. Moreover, as market thickness increases, frictions vanish. Hence, the reservation values  $R_S$  and  $R_B$  converge to each other, and their common limit is given by the Walrasian benchmark that solves  $1 - F(R_S) = \frac{S'}{S'+B'}$ .<sup>53</sup>

The plots in the second row document the effects of market thickness on asset allocations. More precisely, the distribution  $g_{S'}(z)$  reflects the efficiency of allocation and in the third plot (second row, first column) I plot how the average profitability  $E(z) = \int z g_{S'}(z) dz$  varies with the mass of assets. The plot clearly shows that the average profitability increases as the asset market becomes thicker. This suggests that on average assets are more efficiently allocated when their market becomes thicker. Thus, if we interpret the profitability parameter  $z$  in the model as the utilization of the asset, the plot shows that the model implies that as the market becomes thicker, aircraft have higher utilization levels. The plot also shows that the average profitability converges to the Walrasian benchmark given by  $\mu + \sigma \frac{\phi\left(\frac{R_S - \mu}{\sigma}\right)}{1 - \Phi\left(\frac{R_S - \mu}{\sigma}\right)}$ , where  $\phi(\cdot)$  and  $\Phi(\cdot)$  denote the standard normal p.d.f and c.d.f., respectively.<sup>54</sup> In the fourth plot (second row, second column) I plot the dispersion of profitabilities  $E\left|\frac{z - E(z)}{E(z)}\right|$ , and the plot shows that the model predicts that the dispersion of profitabilities decreases as asset markets become thicker.

The plots on the third row document the effects of market thickness on asset prices. The fifth plot (third row, first column) of figure 3 documents that the average asset price  $E(p) =$

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<sup>52</sup>The numerical values of the exogenous parameters are:  $\theta = .5$ ;  $c = 50$ ;  $r = .01$ ;  $\gamma = .5$ ;  $\lambda = 4$ ;  $B' = 1.5S'$  and  $F(z)$  is the normal distribution with mean  $\mu$  equal to 100 and standard deviation  $\sigma$  equal to 40.

<sup>53</sup>Given the numerical values assumed, the Walrasian limit of  $R_S = R_B$  is equal to 110.13.

<sup>54</sup>The numerical value of the Walrasian limit is equal to 138.63.

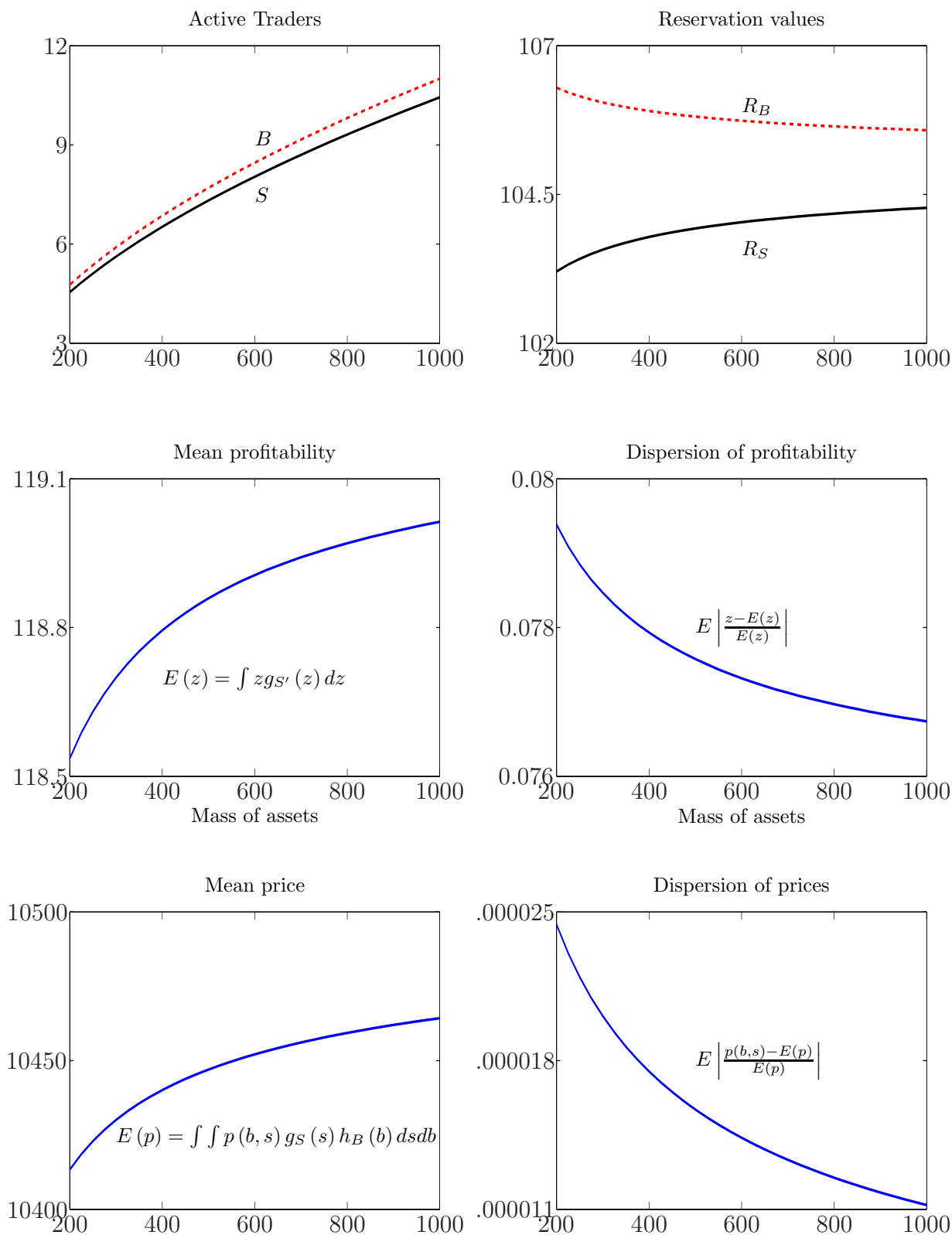


FIG. 3: Numerical solutions

$\int \int p(b, s) g_S(s) h_B(b) ds db$  increases when the asset market becomes thicker. Moreover, the price converges to the Walrasian price  $\frac{R_S}{r}$ . The sixth plot (third row, second column) shows that the dispersion of transaction prices  $E \left| \frac{p(b,s) - E(p)}{E(p)} \right|$  decreases as the size of the asset market increases.<sup>55</sup>

Finally, it is easy to see that assets trade more frequently as the mass of assets increases. This is due to two reasons: 1) sellers' cutoff value is higher, so the probability that assets are put on the market for sale is higher; 2) the meeting rate is higher, so conditional on being on the market assets trade faster.

## B Value Functions and Transaction Prices

To obtain the value functions, first note that  $\frac{\partial V_B(x)}{\partial x}$  satisfies

$$(r + \lambda + \gamma S \theta) \frac{\partial V_B(x)}{\partial x_i} = \frac{\gamma S \theta}{r + \lambda}.$$

Similarly,  $\frac{\partial V_S(x)}{\partial x}$  satisfies

$$\frac{\partial V_S(x)}{\partial x} = \frac{1}{r + \lambda + \gamma B(1 - \theta)}.$$

Thus, both  $V_B(x)$  and  $V_S(x)$  are linear in  $x$ , with slopes given by  $\frac{\partial V_B(x)}{\partial x}$  and  $\frac{\partial V_S(x)}{\partial x}$ , respectively. Moreover, we can use the conditions on the marginal traders  $V_S(R_S)$  and  $V_B(R_B)$  to find the intercepts. Thus we have

$$V_B(b) = k(b - R_B) + \frac{\lambda \int \max \{V_B(z), W_B(z)\} dF(z)}{r + \lambda} \quad (21)$$

$$V_S(s) = \frac{s - R_S}{\delta} + \frac{R_S + \lambda \int \max \{V_S(z), W_S(z)\} dF(z)}{r + \lambda} \quad (22)$$

where  $k = \frac{\gamma S \theta}{(r + \lambda)(r + \lambda + \gamma S \theta)}$  and  $\delta = r + \lambda + \gamma B(1 - \theta)$ .

Moreover, define  $EB$  and  $ES$  as follows:

$$EB = \int \max \{V_B(z), W_B(z)\} dF(z) \quad ; \quad ES = \int \max \{V_S(z), W_S(z)\} dF(z)$$

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<sup>55</sup>I am reporting the quantities  $E \left| \frac{z - E(z)}{E(z)} \right|$  and  $E \left| \frac{p(b,s) - E(p)}{E(p)} \right|$  to measure the dispersion of profitabilities and prices rather than the more common variances because the empirical analysis is based on these quantities  $E \left| \frac{z - E(z)}{E(z)} \right|$  and  $E \left| \frac{p(b,s) - E(p)}{E(p)} \right|$ . The variances of profitabilities and prices display identical qualitative patterns, i.e. they decrease as the number of assets increases.

and note that we can calculate

$$\begin{aligned}
EB &= \int^{R_B} W_B(z) dF(z) + \int_{R_B} V_B(z) dF(z) \\
&= \frac{\lambda EB}{r + \lambda} + \int_{R_B} k(z - R_B) dF(z) = \frac{(r + \lambda) \int_{R_B} k(z - R_B) dF(z)}{r}
\end{aligned}$$

and

$$\begin{aligned}
ES &= \int^{R_S} V_S(z) dF(z) + \int_{R_S} W_S(z) dF(z) \\
&= \int^{R_S} \left( \frac{z - R_S}{\delta} + \frac{R_S + \lambda ES}{r + \lambda} \right) dF(z) + \int_{R_S} \frac{z + \lambda ES}{r + \lambda} dF(z) \\
&= \frac{r + \lambda}{r} \int^{R_S} \left( \frac{z - R_S}{\delta} + \frac{R_S}{r + \lambda} \right) dF(z) + \frac{r + \lambda}{r} \int_{R_S} \frac{z}{r + \lambda} dF(z)
\end{aligned}$$

Thus, when seller  $s$  and buyer  $b$  meet, the transaction price satisfies

$$\begin{aligned}
p(b, s) &= \theta (V_S(s) - W_B(s)) + (1 - \theta) (W_S(b) - V_B(b)) \\
&= \theta \left( \frac{s - R_S}{\delta} + \frac{R_S + \lambda ES}{r + \lambda} - \frac{\lambda EB}{r + \lambda} \right) + (1 - \theta) \left( \frac{b + \lambda ES}{r + \lambda} - k(b - R_B) - \frac{\lambda EB}{r + \lambda} \right) \\
&= \theta \left( \frac{s - R_S}{\delta} + \frac{R_S}{r + \lambda} \right) + (1 - \theta) \left( \frac{b}{r + \lambda} - k(b - R_B) \right) + \left( \frac{\lambda ES}{r + \lambda} - \frac{\lambda EB}{r + \lambda} \right) \\
&= \theta \left( \frac{s - R_S}{\delta} + \frac{R_S}{r + \lambda} \right) + (1 - \theta) \left( \frac{b}{r + \lambda} - k(b - R_B) \right) + \\
&\quad \frac{\lambda}{r} \left( \int^{R_S} \left( \frac{z - R_S}{\delta} + \frac{R_S}{r + \lambda} \right) dF(z) + \int_{R_S} \frac{z}{r + \lambda} dF(z) - \int_{R_B} k(z - R_B) dF(z) \right)
\end{aligned}$$

## C Steady State Distributions of Buyers $B'$ and Sellers $S'$

Let  $g_{S'}(\cdot, t)$  and  $h_{B'}(\cdot, t)$  be the distributions of potential sellers and potential buyers, respectively. Consider a small interval of time of length  $\epsilon$ . Up to terms in  $o(\epsilon)$ , the distributions of potential sellers  $g_{S'}(\cdot, t)$  evolves from time  $t$  to time  $t + \epsilon$  according to:

$$g_{S'}(z, t + \epsilon) = \begin{cases} \gamma S \frac{B'}{S'} \epsilon h_{B'}(z, t) + \lambda \epsilon f(z, t) + (1 - \lambda \epsilon) g_{S'}(z, t) & \text{for } R_B \leq z \\ \lambda \epsilon f(z, t) + (1 - \lambda \epsilon) g_{S'}(z, t) & \text{for } R_S \leq z < R_B \\ \lambda \epsilon f(z, t) + (1 - \lambda \epsilon - \gamma B \epsilon) g_{S'}(z, t) & \text{for } z < R_S \end{cases}$$

Similarly, the distribution of potential buyers  $h_B(\cdot, t)$  evolves over time according to:

$$h_{B'}(z, t + \epsilon) = \begin{cases} \lambda \epsilon f(z, t) + (1 - \lambda \epsilon - \gamma S \epsilon) h_{B'}(z, t) & \text{for } R_B \leq z \\ \lambda \epsilon f(z, t) + (1 - \lambda \epsilon) h_{B'}(z, t) & \text{for } R_S \leq z < R_B \\ \gamma B \frac{S'}{B'} \epsilon g_{S'}(z, t) + \lambda \epsilon f(z, t) + (1 - \lambda \epsilon) h_{B'}(z, t) & \text{for } z < R_S \end{cases}$$

Rearranging and taking the limit for  $\epsilon \rightarrow 0$ , the steady-state distributions (17) and (18) are obtained.

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