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Quantity Discounts and Capital Misallocation in Vertical Relationships*

Ken Onishi†

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Abstract

I study transactions between aircraft manufacturers and airlines as well as airlines' utilization of their fleet. Aircraft production is characterized by economies of scale via learning-by-doing, which creates a trade-off between current profit and future competitive advantage in the aircraft market. The latter consideration makes large buyers more attractive than small buyers and induces quantity discounts. The resulting nonlinear pricing strategy may distort both production and allocation in favor of large buyers. In the data, there is a negative correlation between the size of aircraft orders and the per-unit price, and a positive correlation between the price paid and the utilization rate of the aircraft model. The pattern in the data suggests that the manufacturers' price discrimination leads to misallocation of aircraft. To assess whether there is an inefficient allocation, I construct and estimate a dynamic model of the aircraft market that includes a model of utilization. Using the estimated model, I conduct counterfactual simulations where I find that uniform pricing increases aircraft production by 10% and total welfare by 1.6%.

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1 Introduction

Most economic activities involve vertical relationships where upstream firms supply capital/intermediate goods to downstream firms and downstream firms supply final goods to consumers. In upstream markets, price discrimination is common and affects competition in downstream markets via capital allocation. Though price discrimination in upstream markets may have a large impact in both upstream and downstream markets, whether capital is efficiently produced and allocated in vertical relationships has been an open empirical question.

In this paper, I study the welfare consequence of price discrimination in the aircraft market using detailed data on aircraft transactions and aircraft utilization. The richness in the data allows me to study the connection between the vertical relationship in the aircraft (upstream) market and productivity in the airline (downstream) market. I construct and estimate a model of the industries in which competition and economies of scale in production lead to price discrimination in the aircraft market with higher discounts to larger buyers. The existence of quantity discounts may distort both production and allocation and leave room for improving social welfare from the policy maker's point of view. For a fixed production amount of aircraft, social welfare and productivity improve in the airline market with aircraft reallocation. Also, potential policy interventions, such as forcing manufacturers to post a uniform price, may induce more-intense competition and help restore efficiency in aircraft production.

To motivate the model, I first present a set of descriptive regressions. In the data, I find evidence that manufactures are exercising quantity discounts, in which airlines that buy large quantities pay less for each unit of aircraft. Also, I find evidence that airlines paying more for each unit utilize the aircraft more. These observations suggest the existence of aircraft misallocation. The production of air transportation has two important inputs: the number of aircraft and utilization of the aircraft. Profit maximizing airlines equate the marginal revenue, or the marginal productivity, to the marginal price of the input. As a result, airlines facing a higher marginal price of aircraft buys less aircraft and, instead, increases the utilization rate. The first observation suggests that there exists dispersion of the marginal price of aircraft. The second observation suggests that airlines take the relative factor price into account when deciding the amount of inputs, i.e., airlines facing a higher marginal price of aircraft use the existing fleet more intensively rather than buying more aircraft, which creates a positive correlation between the price of aircraft ant the utilization rate. From the social planner's point of view, however, the input decision needs to be made to minimize the social cost of production. If the dispersion of the aircraft price is a result of strategic incentive of manufacturers, the dispersion may create distortion in production of air transportation through the input choice of airlines. This distortion is similar to those studies in Restuccia and Rogerson (2008) and Hsieh and Klenow (2009). They consider a production function with capital and labor as inputs and identify exogenous dispersion of capital price as the source of capital misallocation. In this paper, I further study why there exists such dispersion in capital (aircraft) price rather than treating it exogenous, and quantify the welfare consequence of such dispersion.

One possible explanation for the capital price dispersion is the existence of economies of scale on the supply side. As pointed out in the existing literature, aircraft production is characterized by a learning-by-doing effect. The learning-by-doing effect creates a trade-off between the current profit and future intensity of competition. By lowering the current price aggressively, aircraft manufactures can attract more orders, which translates into a lower marginal cost in the future. To lower future competition intensity, buyers with larger orders are more attractive than buyers with small orders. Serving a large buyer reduces the manufacturer's own future marginal cost through the learning-by-doing effect and, at the same time, takes away the opponent's opportunity to reduce the future marginal cost. This effect creates the incentive to strategically serve large buyers by offering a quantity discount. If the quantity discount is a consequence of supply-side factors, the allocation of aircraft may create inefficiency because a large buyer receives a more favorable price than a small buyer for the marginal unit, even though the small buyer is willing to pay more for the marginal unit than the large buyer.

In this paper, I first construct a simple model to show that the existence of economies of scale together with competition among manufacturers may induce quantity discounts. I find that, in the model, forcing uniform pricing increases both production and total welfare. By forcing uniform pricing, manufacturers do not compete by making a favorable offer to the large buyer but simply by producing more. Intuitively, policy makers can force manufacturers to compete with equal intensity for all buyers, which may result in higher overall competition intensity and help increase total welfare. Indeed, if the good is an aircraft, the model can explain the pattern in the data. The strategic incentive of manufacturers induces quantity discount and dispersion of aircraft price. Through airlines' profit maximizing choice of inputs, the dispersion further creates dispersion of marginal capital productivity and utilization rate, which further translates into capital misallocation and inefficiency.

In the estimation, I build a dynamic model with economies of scale in production and multidimensional heterogeneity—heterogeneity in profitability and ease of investment—in airlines, where manufacturers propose price menu as a function of product quantity and airline characteristics. Manufacturers use the price menu to price discriminate among airlines and screen the ease of investment within airlines, which may create inefficiency. The nature of the airline industry makes the use of the standard Markov Perfect Equilibrium concept difficult. There are many airlines in the market and, therefore, the dimension of the state space becomes too large to deal with. To overcome this problem, I extend the Oblivious Equilibrium concept proposed by Weintraub et al. (2008). I assume that aircraft manufacturers and airlines are partially oblivious of some states, which makes the whole model tractable.

The object of interest in the estimation is the parameter on the airlines' utilization model and the aircraft production model. The parameter on the utilization model and the heterogeneity in profitability among airlines are identified from the variation in the utilization rate. As Gavazza (2011) and other papers on capital productivity note, productivity and the capital utilization rate are closely tied. In the model, there is a one-to-one correspondence between marginal productivity and the utilization rate, which allows for the identification of airlines' profitability from the data. The supply-side parameter is identified from the pricing optimality and variation across time. By estimating the dynamic model of supply and demand, the static marginal cost of production is identified. Then, by relating the static marginal cost to cumulative production, the marginal cost, as a function of cumulative production, can be identified. In the estimation, I propose a simple procedure to estimate models with oblivious equilibrium concepts.

Using the estimated parameters, I quantify the welfare loss caused by misallocation and evaluate the effectiveness of potential policy interventions. I find that forcing manufacturers to post a single uniform price increases aircraft production by 11% and total welfare by 1.6%, which suggests that the intuition from the theoretical example still holds in the structrual model of the industry. I also compare the result under "Grand Menu Pricing" regulation, where manufacturers are forced to post a price menu that only depends on the quantity but not on airline characteristics. "Grand Menu Pricing" allows manufacturers to price discriminate airlines by nonlinear pricing, which may incrase aircraft production by screening airlines in the dimension of ease of investment. In fact, I find that "Grand Menu Pricing" regulation increases aircraft production by 10% and total welfare by 3.3%.

2 Literature

This paper is related to several strands of the literature. First, this study is related to the literature on input misallocation. Input reallocation has been understood as an important drive force of aggregate TFP growth. Restuccia and Rogerson (2008) and Hsieh and Klenow (2009) estimate that about 30% to 60% higher aggregate TFP growth can be achieved by input reallocation. As is pointed out in the literature, one source of misallocation is input price dispersion.[1] In this paper, I study the implication of input price dispersion resulted from price discrimination in vertical relationships.

Another important literature that the paper contributes to is the literature on non-linear pricing and vertical relationships. The screening aspect of the non-linear pricing has been extensively studied. The literature started in a monopoly setting with a focus on information asymmetry. Miravete (2002) and Miravete (2003) empirically examine the effect of uncertainty and information asymmetry on the firm's pricing strategy. The literature has further grown to introduce competition. Stole (1995) shows that second degree price discrimination is sustainable even in a multi-firm setting. There are number of papers including Rochet and Stole (2002) and Armstrong and Vickers (2010) that further explore the role of non-linear pricing under oligopoly. In contrast to the intense

[1]Foster et al. (2008) points out that not only input but also output price dispersion is an important factor to understand the productivity growth and reallocation.

study of theoretical implication, little is known empirically. Busse and Rysman (2005) documents the relationship between competition and the curvature of the price-quantity menu. Another important aspect of non-linear pricing arise in vertical relationships between upstream and downstream firms. The primary interest is to identify if the firms use non-linear pricing to avoid double marginalization. Villas-Boas (2002) establishes an estimation and inference method from market level data. However, the actual transaction data is still ideally needed to understand the precise structure of the market. Mortimer (2008) investigates the welfare implication of revenue sharing between upstream and downstream firms using the actual contracts in the video rental industry. In particular, this paper is closely related to the literature on the size-related buyers' purchasing power. There is a growing literature on the buyer-size effect on price discounts. A number of theoretical papers including Chipty and Snyder (1999), Snyder (1996) and Gans and King (2002) shows the upstream competition may lead to quantity discounts. Ellison and Snyder (2010) empirically shows that buyer-size effect on price discounts appears only under upstream competition and there is no quantity discounts if the upstream firm is a monopolist. Sorensen (2003) studies the transaction price between hospitals and insurers, and identifies the buyer size as a source of the price discount. The findings in this paper are consistent with the literature. Furthermore, I identify a new mechanism that induces quantity discounts and potential inefficiency.

The third strand of the literature to which this paper is related is the literature on the learning-by-doing. The empirical study of the learning-by-doing starts in engineering as early as Wright (1936) in the aircraft production industry. The learning-by-doing effect attracted intense research interest in economics, too. Spence (1981) analyzes the theoretical aspects of the relationship between the learning curve and competition. Fudenberg and Tirole (1983) analyzes the market performance and strategic incentives in a model with a learning-by-doing effect. Cabral and Riordan (1994) analyzes the strategic incentive coming from the learning-by-doing effect in a differentiated good market where two firms compete by setting price, and shows the possibility of predatory pricing. In addition to the theoretical literature, there is a growing body of work on the estimation of the learning effects. Thornton and Thompson (2001) estimates the effect of the learning-by-doing in the wartime shipbuilding industry and Ohashi (2005) evaluates the efficiency gain from the government subsidy in the Japanese steel industry. Paired with the learning-by-doing, organizational forgetting also attracted economists' attention. Benkard (2000), Levitt et al. (2012) and Thompson (2007), among other papers, find empirical evidence that there exists a learning-and-forgetting, and Benkard (2004) estimates a model for commercial aircrafts with dynamic aspects of the learning-and-forgetting. Besanko et al. (2010) conducts detailed analysis of the industry dynamics with a learning-and-forgetting effect and concludes the existence of the learning-and-forgetting increase the incentive to price more aggressively than the industries without learning-and-forgetting. The theoretical and empirical literature on the learning-by-doing effect has emphasis on the production without any strategic role on the demand side, and the price is simply taken as uniform to all buyers. On the other hand, in the context of the aircraft market, the price dispersion is quite high and non-linear pricing seems to play an important role to explain the market structure.

This paper is also related to the empirical literature on dynamic models. Dating back to Ericson and Pakes (1995), dynamic models has been developed by series of authors including Bajari et al. (2007), Pakes et al. (2007), etc.. I estimate the value function as a nonparametric function of the sate. The idea of estimating the value function as a nonparametric function is presented in Kalouptsidi (2010). In contrast to Kalouptsidi (2010), where the value function is estimated from price data of used ship, I estimate the value function by relying on the within period variation of players' investment decision.

3 Data

3.1 Basic Data Summary

The analysis presented in this paper is based on several different data sources: aircraft transaction data that occurred from 1978 to 1991, airlines' aircraft utilization data, data on characteristics of market participants and industry data book on production schedule, order history and delivery history. [2]

The first data set is constructed based on the Department of Transportation and Federal Aviation

[2] Throughout this paper the transaction price is converted to the real price at 1991.

Administration filings assembled by Avmark Inc.. DOT and FAA track histories of all commercial aircraft operating in the United States. During the sample period, they collected data on the aircraft transaction price, the aircraft serial number, and the buyer-seller identity. Table 1 summarizes the basic information contained in the data. In the data period, the main aircraft manufacturers are Boeing and McDonnell Douglas. Airbus increased its presence later and increased the competition intensity, which urged Boeing and McDonnell Douglas to merge in 1997. During the data period, more than 5,000 aircraft were traded. About half of the transaction were made in the primary market where aircraft manufacturers trade with airlines, and the rest were made in the secondary market where airlines trade used aircraft each other. Though both primary and secondary markets seem equally active, there are a huge difference in the participants.[3] The main buyers in the secondary market are foreign airlines and cargo companies such as UPS and FedEx, who buy used/old aircraft from domestic airlines. In the data period, the role of aircraft leasing was not as important as now. The fraction of leased aircraft in the airlines' fleet is more than 40% in 2013, but it is less than 2% in 1980.[4]

Table 1: Transaction Data Summary

Data Period	1978 – 1991
Total Transaction	5122
Primary	2457
Secondary	2665
# of Manufacturers	7
Share of Boeing	63.44 %
Share of McDonnell Douglas	23.42 %

The second data set is constructed from Air carrier aircraft utilization and propulsion reliability report published by FAA. This reports fleets and total utilization hours of each model for each airlines operating in the United States from 1979 to present. The utilization hours data are the

[3]The two largest sellers in the secondary market are Eastern Air Lines and United Airlines, and the two largest buyers in the secondary market are FedEx and UPS.

[4]For example, see the article in Economist at http://www.economist.com/node/21543195.

total utilization hours of each airline–aircraft model pair, but not the utilization hours of each individual aircraft. To match the data period as close to the transaction data as possible, I use the utilization data from 1979 to 1991. I constructed the remaining data set by combining a several different data source: Air Carrier Financial Reports, Jet Airliner Production List and data published on Boeing's website. After all combined, the data set contains basic financial characteristics of market participants and production schedules of each aircraft models. Table 2 summarize the basic information of the airline industries. The data period corresponds to just after the deregulation in airline industries which created aggressive investment/disinvestment behavior of airlines. Also, compared to 2010s, there are a lot more airlines in both major and regional business. In terms of the market share, most of the market is served by the major airlines despite of the large number of regional airlines. [5]

Table 2: Airline Data Summary

Data Period	1979 – 1991
# of Airlines	37
Major Airlines	15
Regional Airlines	22
Asset Size of Airlines (in $ million)	1,666
(Standard Deviation)	(2,195)
Flight Revenue (in $ million)	1,777
(Standard Deviation)	(2,313)
Share of Major Airlines	91.31 %

From the data, I construct several new variables. The transaction data collected by DOT and FAA track all the transaction, where the unit of observation is each transaction of individual aircraft. To capture the effect of quantity in the transaction price, I aggregate the data in "airline–model" level and "bargaining" level. First, I aggregate total transaction for each airline and aircraft model pair. This airline–model paired quantity captures the total number of the same aircraft that each airline purchased during the whole sample period. Here the unit of observation

[5] Here the major/regional airlines are defined as in the classification in Air Carrier Financial Reports.

is the airline-model level. Also, by merging the transaction price data and order/delivery history data, I construct total number of aircraft ordered and total price paid at each aircraft order. This airline–model–bargain specific quantity and payment captures the size of each order. Here the unit of observation is the airline–model–order level. Finally, I construct annual utilization rate from the total utilization data and fleet data. I first construct the average utilization hours for each airline and aircraft model. In the data, I see both each airlines' total flying hours and the number of fleet for each model, which allows me to calculate the airline–model specific average utilization hours as the former divided by latter. Then, I take the mean value of the average utilization hours across years and airlines and calculate the overall average utilization hours of each model. I define the airline–model specific utilization rate as the ratio between the airline–model specific average utilization hours and the overall average utilization hours of the same model. Here the unit of observation is airline–model–year level.

Table 3 shows the basic statistics of the price and quantity data. The first row shows the price dispersion in the data. The variable is defined as the transaction price over the mean price of the same aircraft model. In the data, there are 2,457 transactions between manufacturers and airlines in total. The mean value is one by construction but the median value is less than 1, which suggests the existence of quantity discounts. The next two rows show the quantity dispersion. The variable in the second row is the airline–model level total transactions defined above and captures the purchase amount of the same aircraft model for each airline. The dispersion is quite large, where some airlines just purchase one or two of the same aircraft but some airlines purchase more than 30. The third row shows the quantity dispersion denominated by the total production. The variable is constructed as the ratio of the variable in the second row divided by the total production in the same period, and captures the share of a airline in the same model. The dispersion still remains large. Some airlines have shares of less than 1% in a given model, but some airlines have shares of more than 30%. The data show that the airlines' purchase behavior is quite heterogeneous in both the price they pay and the quantities they buy.

Figure 1 and 2 shows examples of the price dispersion and the relationship between unit price and airline ratio. Both figures are calculated from the data on transaction price of Boeing 737,

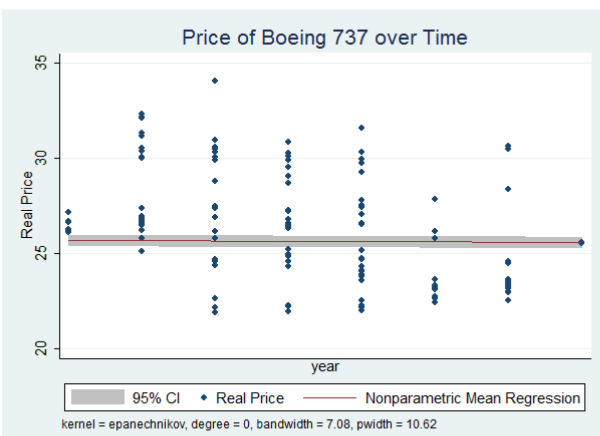
Table 3: Price and Quantity Dispersion

	10%	25%	50%	75%	90%	mean	std	N
transaction price / model average price	.842	.897	.966	1.059	1.198	1	.192	2457
airline - model paired quantity	1	2	3	10	26	9.90	18.18	248
airline ratio	.006	.016	.041	.133	.285	.104	.149	248

The unit of observation is each transaction for the first row and each airline-model pair for the second and third rows. "airline ratio" is defined as airline–model paired quantities divided by the total production during my sample period, and meant to capture the fraction of total production each airline accounts for.

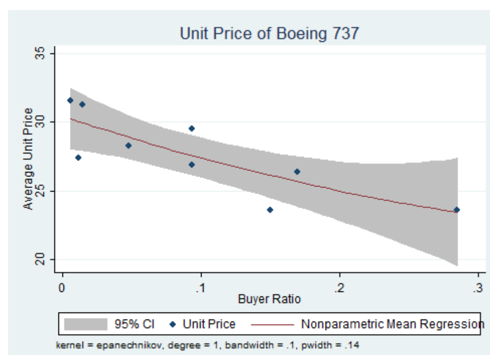
which is the best selling aircraft in the data period. Figure 1 shows the nonparametric mean regression result of the transaction price on the transaction year. The mean price is fairly stable over the year, but there exists notable dispersion within year. Similarly, figure 2 shows the relationship between airline ratio and the average unit price. There still exists dispersion in price, but figure 1 suggests that some part of the dispersion is explained by the dispersion in quantity.

Figure 1: Price Dispersion



This graph plots the transaction price of Boeing 737-300 over time. Each dot represents one transaction.

Figure 2: Unit Price and Airline Ratio



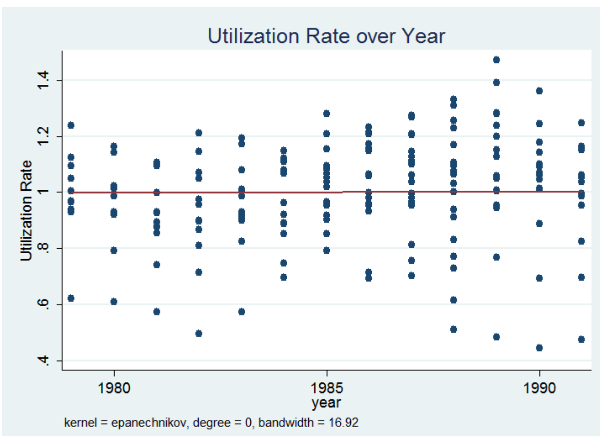
This graph plots the average unit price of Boeing 737-300 as a function of airline ratio. Each dot represents one airline.

Figure 3 and 4 shows the utilization rate across airlines over time. Here the utilization rate is defined as each airlines average utilization hours per aircraft divided by industry wide utilization hours per aircraft.[6] Within each year, there exists dispersion in utilization rate across airlines,

[6]Here the utilization rate is defined differently from the one defined above. The average utilization hours are the simply the total utilization hours of each airlines by pooling all aircraft model. I employ the new variable since

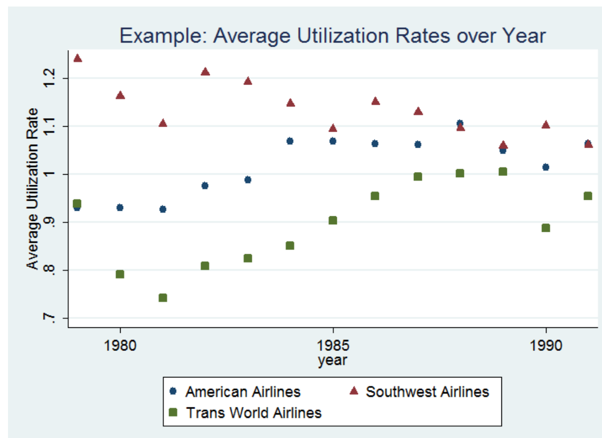
but there exist no clear trend over time. In figure 4, I pick up three airlines (American Airlines, Trans World Airlines and Southwest Airlines) to decompose the pattern in utilization rate into each airline level. For each airline, there still exists dispersion in the utilization rate over time, but figure 4 also suggests that main part of the dispersion in figure 3 comes from heterogeneity in airlines. There are some airlines, including Southwest Airlines, that consistently utilize aircraft more than the industry average, and some airlines that utilize aircraft consistently less. This heterogeneity translates into high cross-sectional dispersion as indicated in figure 3.

Figure 3: Utilization Rate of All Airlines



This graph plots the utilization rate of each airlines. Each dot represents one airline.

Figure 4: Example: Utilization Rate



This graph plots a example of the utilization rate. Each circle represents the utilization rate of American Airlines, each triangular represents that of Southwest Airlines, and each square represents that of Trans World Airlines.

3.2 Descriptive Regression

In this subsection, I present evidence that suggests that (1) aircraft manufacturers price discriminate airlines and use non-linear pricing strategies; (2) the manufacturers' price discrimination creates inefficiency in aircraft allocation and transportation production. For this purpose, I look at the relationship between the unit price of aircraft and order quantities in the order data and the relationship between the average unit price airline pays and the average annual utilization rate

figure 3 and 4 is meant to graphically show the pattern in the utilization rate across airlines. The airline–model specific utilization rate is used in the regressions presented in the subsequent sections.

of the aircraft in the utilization data.

First, I present a negative correlation between the unit price and the order quantities to assess if (1) aircraft manufacturers price discriminate airlines and use non-linear pricing strategies. In order to analyze the correlation of these two variables, I use the data on transaction quantities and the payment at each order, and regress the unit price of aircraft on the quantity measure and other control variables. The regressions take the following form. For each unit price or price discounts at each aircraft order,

$$y_{ijt} = \alpha q_{ijt} + x'_{ijt}\beta + \epsilon_{ijt},$$

where y_{ijt} is either p_{ijt}, which is the unit price of the model j payed by airline i at time t, or d_{ijt}, which is the discount ratio of transaction defined as $\frac{\text{mean price of model } j - p_{ijt}}{\text{mean price of model } j}$. q_{ijt} is meant to capture the effect of quantities on the price and discount. I use "airline ratio" and "order ratio" for this regression. The first variable is the same as in the third row of table 3 and the second variable is defined as $\frac{\text{model } j'\text{stotal quantity airline } i \text{ bargained at time} t}{\text{model } j's \text{ total quantity produced}}$. I use the order fractions of total production rather than absolute value of order quantities to normalize the effect of the quantity discount. The total quantity produced vary from 34 to more than hundreds depending on the model and the same amount of purchase among different models may have different meaning depending on the production size.[7] x_{ijt} includes variables such as observable characteristics of market participants, time fixed effect, model fixed effect, airline-manufacturer pair fixed effect.

Table 4 shows the regression result of the unit price and the discount ratio. The coefficients on both the airline ratio and order ratio suggest there exist quantity discounts. Introducing the seller×buyer pair dummy increase the number of regressor remarkably, which causes the loss of significance of the coefficient on airline ratio. But the sign itself stays the same. Asset, domestic revenue and international revenue are characteristics of buyers. The company size of buyers measured by their asset size does not have any significant effect on the price they pay. The coefficients on the other variables suggest the nature of the market. First, the coefficient on "cumulative ratio", which is defined as $\frac{\text{model } j'\text{stotal quantity produced up to time } t}{\text{model } j's \text{ total quantity produced}}$, has a significant effect to reduce the price of the aircraft. This result suggests that there is a learning-by-doing effect where cumulative produc-

[7]Instead of using denominated quantity, I also run the same regression on the actual quantity. The results are qualitatively the same.

tion experience decreases the marginal cost of production. Also, the "rival availability", dummy variable that takes the value of 1 if there exists a similar aircraft sold by different manufacturers, has a significant effect to reduce the price, which suggests manufacturers face competition.

In the next set of regressions, I show the positive correlation between the price paid and the utilization rate to assess if (2) the manufacturers' price discrimination creates inefficiency in aircraft allocation and transportation production. I regress the average annual utilization rate of each model on the price paid and other control variables. The regressions take the following form. For each annual utilization rate of each aircraft model,

$$u_{ijt} = \eta p_{ijt} + y'_{ijt}\delta + e_{ijt}$$

where u_{ijt} is either the average utilization hours, which is defined as the airline i's average hours of operation of model j at time t, or the average utilization rate, which is the average utilization hours of airline i over the average utilization hours of all airlines within the same model. p_{ijt} is meant to capture the effect of the price paid. I use two variables for p_{ijt}; the mean price airline i paid to model j over the overall mean price paid to model j, and discount ratio of airline as defined above. y_{ijt} includes the same control variables as x_{ijt} does in the previous set of regressions.

Table 5 shows the regression results. The results show a positive and significant correlation between the price paid and the utilization rate, which suggests the manufacturers pricing strategy in the upstream market further affects how airlines behave in the airline (downstream) market.

3.3 Interpretation of the Descriptive Results

The data suggest that (I) there is dispersion in price within the same period; (II) the dispersion is caused by manufacturers' non-linear pricing strategies; (III) the resulting non-linear pricing further distorts aircraft allocation and air transportation production. Table 3 and figure 3 provide direct evidence of price dispersion in the aircraft market and table 4 and figure 4 provide evidence that aircraft manufacturers price discriminate airlines and use non-linear pricing strategies.[8] Regarding

[8] To be precise, to argue that the manufacturers use non-linear pricing strategies, I need to provide the counterfactual price as a function of the quantity rather than showing a negative correlation between the price and quantities. Since I only observe the transaction price and quantity that actually happened rather than the com-

Table 4: Regression of Unit Price and Discount Ratio

	unit price	unit price	discount ratio	discount ratio
airline ratio	-43.60***	-25.31*	1.04***	0.60*
	(11.15)	(14.45)	(0.24)	(0.31)
order ratio	-2.56***	-2.38***	0.08***	0.10***
	(0.88)	(0.89)	(0.02)	(0.02)
asset	4.84E-07	4.89E-07	-6.87E-09	-1.03E-08
	(5.03E-07)	(5.04E-07)	(1.10E-08)	(1.13E-08)
domestic revenue	1.46E-08	-5.28E-07	4.29E-09	3.28E-09
	(7.58E-07)	(7.74E-07)	(1.66E-08)	(1.68E-08)
intel revenue	-2.10E-06**	-3.21E-06***	6.95E-08***	9.17E-08***
	(9.19E-07)	(9.63E-07)	(2.02E-08)	(2.08E-08)
cumulative ratio	-11.72**	-6.20	0.42***	0.33***
	(5.38)	(5.28)	(0.12)	(0.11)
rival availability	-3.87***	-3.45***	0.14***	0.11***
	(1.30)	(1.30)	(0.03)	(0.03)
model dummy	x	x	x	x
seller dummy	x	x	x	x
airline dummy	x	x	x	x
airline x seller dummy	-	x	-	x
time dummy	x	x	x	x
other controls	x	x	x	x
Observation	388	388	388	388
Adjusted-R2	0.9628	0.9674	0.5674	0.6324

This table reports the estimated coefficients of the OLS regression of the unit price and the discount ratio. The dependent variable is the unit price at the order in the first two columns and the discount ratio for the last two columns. The unit of observation is a aircraft order which consists of the order quantity and total payment. The unit price is defined as the total payment divided by the order quantity. The discount ratio is defined as the mean price of the same model aircraft minus the unit price divided by the mean price.
"asset" represents the asset size of the airline, "domestic revenue" represents the airlines' flight revenue in the domestic routs, "intel revenue" represents the airlines' flight revenue in the international routs, "cumulative ratio" represents the cumulative production fraction at the time the order was made and "rival availability" represents a dummy variable that takes 1 if there was any other similar aircraft model available.
For each variable, the first row shows the estimates and the second shows the standard deviation. *** represents 1% significance, ** represents 5% significance and * represents 10% significance. Only subset of variables are reported in the table. The coefficients on both the airline ratio and order ratio suggest there exist quantity discounts.

Table 5: Regression of Average Utilization

	Utilization Hours	Utilization Rate	Utilization Hours	Utilization Rate
buyer price			57.34**	0.20**
/ mean price			(26.22)	(0.10)
discount ratio	-71.03**	-.28**		
	(28.79)	(.11)		
fleet	0.39***	0.17E-2***	0.40***	0.17E-2***
	(0.08)	(0.03E-2)	(0.09)	(0.03E-2)
asset	-3.02E-06**	-1.21E-08**	-3.15E-06**	-1.27E-08**
	(1.47E-06)	(5.68E-09)	(1.47E-06)	(5.67E-09)
model fixed effect	x	x	x	x
airline fixed effect	x	x	x	x
other controls	x	x	x	x
Observation	989	989	989	989
Adjusted-R2	0.5999	0.4834	0.5993	0.4819

This table reports the estimated coefficients of the OLS regression of the average utilization hours and the average utilization rate. The dependent variable is the average utilization hours in the first and the third columns and the average discount ratio for the second and fourth columns. The unit of observation is an annual utilization hours of each aircraft model in each airline's fleet. The average utilization hours are defined as the total utilization hours of each aircraft model divided by the number of the same model aircraft in each airline's fleet. The average utilization rate is defined as the average utilization hours divided by the industry average utilization hours of the same aircraft model.

"fleet" represents the number of aircraft that was in the airline's fleet and "asset" represents the asset size of the airline.

For each variable, the first row shows the estimates and the second shows the standard deviation. *** represents 1% significance, ** represents 5% significance and * represents 10% significance. Only subset of variables are reported in the table.

(Ⅲ), the positive correlation between the price and the utilization rate is a natural observation given the price dispersion. Consider a air transportation production function with complementarity between aircraft and utilization, such as $y = f(K, U) = K^{\alpha}U^{\beta}$ where K denotes the number of aircraft and U denotes the utilization rate. Profit maximizing airlines equate the marginal revenue from aircraft to the price of aircraft, and equate the marginal revenue from utilization to the cost of utilization. With complementarity between aircraft and utilization, the relative cost of aircraft and utilization affects the input choice of airlines. Airlines facing a higher price of aircraft decreases the input amount of aircraft and, instead, increases the input amount of utilization. For example, in the case of the Cobb–Douglas production function, $\frac{U}{K} = \frac{r}{w}\frac{\beta}{\alpha}$ where r denotes the aircraft price and w denotes the cost of utilization. Such profit maximizing behavior of airlines creates a positive correlation between the price of aircraft and utilization rate. However, from social welfare point of view, the input choice should be made to minimize the social cost of production. If the aircraft price dispersion is a result of manufacturers' strategic behavior, the input choice does not necessary minimizing social cost. Table 5 provides evidence that the aircraft price dispersion affects the production behavior of airlines. According to the argument above, such effect may creates inefficiency by distorting airlines' input choice. The natural next questions are how much the inefficiency is and what kind of policy intervention can help us restore efficiency. To answer those questions, I start building a dynamic model of the aircraft and airline industries from the next section.

4 Model

Before moving to the full model that I estimate structurally, I describe a simple theoretical example to motivate the counterfactual simulation I conduct in the later section of this paper. In this example, I show that uniform pricing has a pro-competitive effect with economies of scale in

plete menu of the price-quantity relationship, the correlation can be always rationalized by a linear pricing strategy with transaction specific slopes. However, it is a known fact that order quantities are an important factor to get discounts when manufacturers and airlines negotiate over the price. The following articles in Bloomberg and the Economist are the examples that support that the manufacturers price discriminate airlines and use a non-linear pricing strategy. http://www.bloomberg.com/news/2013-02-28/air-lease-expands-with-3-2-billion-order-for-boeing-777s.html, http://www.economist.com/blogs/gulliver/2013/06/easyjet .

production.

4.1 Motivating Example

This subsection describe a simple motivating example to argue how the learning-by-doing effect leads to quantity discounts and how uniform pricing help us restore efficiency. Those readers who are interested in empirical analysis can proceed directly to the next subsection. **Seller**

Suppose there are two firms, $S1$ and $S2$, selling a homogeneous intermediate good in two periods and the two sellers have the same production function. The marginal cost of production is constant within each period, but exhibits dynamic economies of scale via a learning-by-doing effect. Let the marginal cost of production be

$$MC^t(q_i^t) = c - kq_i^{t-1},$$

where q_i^{t-1} is the cumulative production amount of firm i up to period $t-1$, and k captures the degree of learning-by-doing. Assuming there is no discounting.

Buyer

At each period, short-lived buyers arrive at the market. Buyers are heterogeneous in their demand of the good. Let $D_j^t(p) = D_j^t - p$ denote the demand function of buyer $j \in \{1,2\}$ in period t. I assume that $D_1^t > D_2^t$.

Game Structure

The timing of the pricing and purchase decision is the following.

Period 1

1. Two buyers arrive the market.
2. Two seller simultaneously offer a (possibly different) liner price to each buyer.
3. Each buyer decides how much to buy the good given the offered price.

Period 2 The same structure repeats.

To simplify the analysis and to avoid complication coming from a tie, assume downstream firms choose to buy from $S1$ if the same price is offered.

Proposition 1: There is an equilibrium with quantity discounts in the first period where the seller offers a lower price to the buyer with the higher demand.

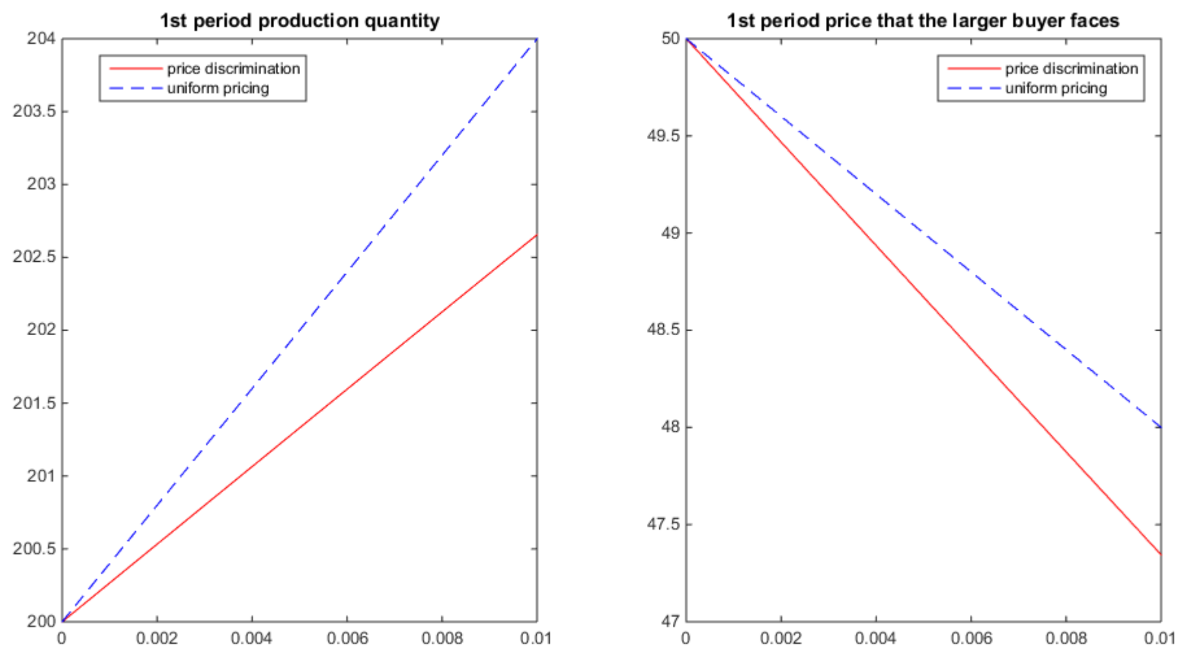
Proof: In Appendix. ■

The intuition behind the proposition is simple. Even though the sellers have the same production function, the learning-by-doing effect creates market power in the second period due to the difference in the production in the first period. If one of the seller produces more in the first period, the seller has lower marginal cost than its rival and, therefore, it can earn positive profit in the second period. Such effect is foreseen and the sellers compete to produce more in the first period. To produce more in the first period, the sellers need to attract the buyer with the higher demand and compete to offer a low price. As a result, the positive profit in the second period is competed away to offer the lowest possible price for the buyer with the higher demand. On the other hand, the competition for the buyer with the lower demand is looser since attracting only the buyer with lower demand is not enough to produce more than the rival seller.

Effect of Uniform Pricing

Now suppose we force the seller to set the uniform price for all buyers. Now, the second period profit is not competed away in the competition for the buyer with the higher demand. Instead, now the sellers need to set the lowest uniform price to produce more in the first period. As a result, the second period profit is not competed away to get the buyer with the higher demand. Rather, it is competed away to offer the lowest price, which increases the total quantity produced in the first period. Note that, given the environment, the production quantity in the first period is sufficient statistics for welfare comparison. Figure 5 shows the first period production quantity on the left and the first period price that the large buyer faces on the right as a function of k, the degree of the learning-by-doing effect. Uniform pricing achieves higher production quantity than price discrimination in total. However, the price the large buyer faces is lower under price discrimination. When there is no learning-by-doing effect, the model is the same as the usual Bertrand competition model. As the effect become larger, the strategic incentive of price discrimination increases and the difference in outcome becomes larger.

Figure 5: Price Dispersion vs Uniform Pricing



This graph plots the production quantity in the first period and the first period price that the large buyer faces under price discrimination scheme and uniform pricing scheme. The horizontal axes represent different value of k, the magnitude of the learning-by-doing effect. The vertical axes represent the quantity and price, respectively. The red solid lines show the value under price discrimination and the blue dashed line show the value under uniform pricing scheme.

The parameter value is fixed at $D_1^t = 200$, $D_2^t = 100$ and $c = 50$.

The pro-competitiveness of uniform pricing has an intuitive explanation. With price discrimination, the buyer with the higher demand can force the sellers to treat him better since they can foresee that attracting her is necessary to have lower marginal cost in the second period. On the other hand, the sellers also have an incentive to exploit as much from the buyer with the lower demand and the buyers in the second period. As a result, the competition for the buyer with higher demand become intense but the competition for the other buyer becomes loose. Uniform pricing eliminates such effect and force the seller to compete with equal intensity for both buyers, which creates the pro-competitive effect.

4.2 Timing and Game Structure of the Full Model

The previous example is illustrating effectiveness of uniform pricing. However, it does not tell us if we can apply the same reasoning in a vertical structure and/or in the actual situation in the aircraft and airline industries. Let me now introduce the full model of the industries to further analyze the consequence of price discrimination in the aircraft and airline industries.

Time, indexed by t, is discrete and infinite. At every t, each manufacture, indexed by j, announce the price schedule of its products, indexed by $m \in M_j$, as a function of quantity and airline characteristics. At each period, airlines, indexed by i, utilize their current fleet, and at the end of the period they choose their fleet for the next period given the price schedule of the aircraft. The timeline of the model at each period is the following:

1. Airlines draw observable idiosyncratic shocks on cost of aircraft utilization
2. Airlines simultaneously decide how much to utilize their fleet and compete with their utilization hours
3. Each manufacture announces its price schedules as a function of quantity and airline characteristics
4. Airlines draw idiosyncratic shock on the cost of investment for each model and decide their next period fleet

4.3 Period Payoff from Utilization

At the beginning of the period, each airline draws idiosyncratic shocks, $\epsilon_{it} = (\epsilon_{it}^1, \cdots, \epsilon_{it}^M)$, on utilization cost of each model. The airline i's cost of utilizing a model m aircraft for u hours is

$$c^m(u, \epsilon_{it}^m) = c_0^m + u\left(c_1^m + c_2^m u + \epsilon_{it}^m\right),$$

where $c_1^m + c_2^m u + \epsilon_{it}^m$ captures the marginal cost of utilization.

If airline i has f_{it}^m units of aircraft and if the average utilization hours of model m is u, then the total cost of operation and total utilization hours are

$$f_{it}^m \times c^m(u, \epsilon_{it}^m) \text{ and } f_{it}^m \times u,$$

respectively. Also, at every t, airline i faces a residual demand function given the utilization decision of all other airlines. Airline i faces the following inverse demand curve

$$P_i^t(Q_i, Q_{-i}) = d_t + \gamma_i - \delta_1 Q_i - \delta_2 \sum_{j \neq i} Q_j,$$

where Q_l is airline l's total utilization hours, d_t is the time specific profitability of unit utilization hour at period t and γ_i is the airline specific profitability of utilization.

The utilization decision of each airline is static and airlines compete by the utilization hours given their fleet. Additional to the aircraft each airline owns, airlines can operates aircraft leased form financial companies. Let r_t^m denote the rental cost of an aircraft at period t and l_{it}^m denote the number of aircraft that airline i rents at period t. Here I assume the leasing market and the used aircraft market is competitive and the rental price is determined exogenously. Then the best response function of airline i given Q_{-i} can be defined as

$$\begin{aligned} BR_i^t(Q_{-it}) = \underset{Q_{it}, L_{it}}{\arg\max} \Bigg\{ & \Big(d_t + \gamma_i - \delta_1 Q_{it} - \delta_2 \sum_{j \neq i} Q_{jt} \Big) Q_{it} \\ & - \sum_{m=1}^{M} \big(f_{it}^m + l_{it}^m \big) c^m(u_{it}^m, \epsilon_{it}^m) \\ & - \sum_{m=1}^{M} l_{it}^m r_t^m \Bigg\} \\ & \text{s.t. } Q_{it} = \sum_{m=1}^{M} \big(f_{it}^m + l_{it}^m \big) u_{it}^m \ , \end{aligned}$$

where $L_{it} = (l_{it}^1, \cdots, l_{it}^M)$ denotes a vector that counts i's number of the rental choice of aircrafts. Also, let $F_{it} = (f_{it}^1, \cdots, f_{it}^M)$ denote the vector that represents airline i's fleet in the subsequent section in this paper.

Since airlines simultaneously decide their utilization hours, Nash equilibrium is characterized as the fixed point of the best response function. The profit each airline derive at each period in equilibrium is

$$\pi_t(Q^*_{it}, Q^*_{-it}, \gamma_i) = \left(d_t + \gamma_i - \delta_1 Q^*_{it} - \delta_2 \sum_{j \neq i} Q^*_{jt} \right) Q^*_{it} \\ - \sum_{m=1}^{M} \left(f^m_{it} + l^{m*}_{it} \right) c^m(u^{m*}_{it}, \epsilon^m_{it}) - \sum_{m=1}^{M} l^{m*}_{it} r^m_t \\ \text{s.t. } Q^*_{it} = \sum_{m=1}^{M} \left(f^m_{it} + l^m_{it} \right) u^{m*}_{it} \ ,$$

where $(Q^*_{it}, L^*_{it}) = BR^t_i(Q^*_{-it})$.

4.4 Investment Decision

Let $\pi^t_i(F_t)$ be the expected profit of airline i at period t in the equilibrium of the game described above as a function of airlines' fleet $F_t = (F_{1t}, \cdots, F_{It})$. Suppose airline i is expecting the sequence of airlines' fleet $\{F_{-it}\}^\infty_{t=s}$ and the sequence of aircraft pricing menu $\{p_t(q, \gamma) = \big(p^1_t(q^1, \gamma), \cdots, p^M_t(q^t, \gamma)\big)\}^\infty_{t=s}$. Airline i maximizes the expected discounted sum of the future profit defined as follows:

$$V_s(F_{is}, \gamma_i, \{F_{-it}\}^\infty_{t=s}, \{p_t(q,\gamma)\}^\infty_{t=s}) = \max_{\{F_{it}\}^\infty_{t=s}} E\left[\textstyle\sum^\infty_{t=s+1} \beta^{(t-s)} \left(\pi^t_i(F_t) - p_{t-1}\big(q_{it}, \gamma_i\big) + \eta'_{it}\big(q_{it}\big)\right)\right] \\ \text{subject to } F_{it+1} = \delta^f_{it} F_{it} + q_{it}, \tag{1}$$

where $\eta_{it} = (\eta^1_{it}, \cdots, \eta^M_{it})$ is a model specific idiosyncratic shock on the cost of investment and δ^f_{it} is the depreciation rate of aircraft.[9] By the recursive structure, airline i's investment strategy can be characterized as a maximization problem of the following object. At each period, airline i's

[9]Here I assume the depreciation of aircraft is exogenous to all model variables.

strategy given $p_s(\cdot)$ is,

$$\sigma(F_{is}, \gamma_i, \eta_{is}, \{F_{-it}\}_{t=s}^{\infty}, \{p_t(q,\gamma)\}_{t=s}^{\infty})$$
$$= \max_{F_{is+1}} \left\{ -p_s\big(q_{is}, F_{is}, \gamma_i\big) + \eta_{is}'\big(q_{is}\big) + \beta V_{is+1}(F_{is+1}, \gamma_i, \{F_{-it}\}_{t=s}^{\infty}, \{p_t(q,\gamma)\}_{t=s}^{\infty}) \right\}.$$

4.5 Aircraft Production and Pricing

In this subsection, I describe the model of aircraft production and manufacturers' pricing strategy. First, I define the production environment of the aircrafts. At period t, manufacture j has a static constant marginal cost of producing one unit of model m aircraft, MC_{jt}^m. The marginal cost depends on the manufacturer's current experience, E_t^m, and defined as

$$MC_{jt}^m = mc_{jt}^m(E_t^m), \text{ where } \frac{dmc_{jt}^m(E)}{dE} < 0.$$

The experience evolves according to the following process. Let the production amount of aircraft model m at period t denote by q_t^m, then

$$E_{t+1}^m = \delta E_t^m + q_t^m.$$

Note that the production experience exhibits "learning-and-forgetting", which is a common phenomenon in capital production.[10] Under the production environment, the period profit of the manufacture j can be described as follows. Let $p_{jt}^m(\cdot)$ denotes the price-quantity schedule of aircraft model m and let q_{it}^m denotes airline i's demand of aircraft model m at period t. Then the manufacture j's period profit at t, $\pi_{jt}^{p_t}(E_{jt}, q_t)$, is described as

$$\pi_{jt}^{p_t}(E_t, q_t) = \sum_{m \in M_j} \left(\sum_{i \in I} p_{jt}^m(q_{it}^m, \gamma_i) - q_t^m mc_{jt}^m(E_t^m) \right),$$

where $q_t^m = \sum_{i \in I} q_{it}^m$.

[10] Benkard (2000) provide empirical evidence of "learning-and-forgetting" in aircraft production. There are also a number of papers, including Levitt et al. (2012) and Thompson (2007), that provide evidence of the phenomenon in different industries.

Suppose manufacturer j is expecting the airlines' investment strategy, σ, the sequence of airlines' fleet, $\{F_t\}_{t=s}^{\infty}$, and the sequence of aircraft pricing menu of its rival manufacturer, $\{p_{-jt}(q,\gamma)\}$. Manufacturer j maximizes the expected discounted sum of the future profit defined as follows. Now, let $p_{jt}(q,\gamma,E_t,F_t)$ denote the price menu manufacture j propose given the state of manufacturers and airlines. The value function of manufacturer j is defined as

$$V_{js}(E_s,\sigma,\{F_t\}_{t=s}^{\infty},\{p_{-jt}(q,\gamma)\}) = \max_{\{p_{jt}(\cdot)\}} E\left[\sum_{t=s}^{\infty}\beta^{(t-s)}\pi_{jt}^{p_t}(E_t,q_t) \mid \{p_t(\cdot)\}\right], \tag{2}$$

where q_t and the evolution of state E_t are induced from the investment strategy of airlines and its rival's pricing strategy. By the recursive structure, manufacturer j's pricing strategy can be characterized as a maximization problem of the following object. At each period, manufacturer j's strategy is,

$$\begin{aligned} p_{js} &= \sigma_j^p(E_s,F_s,\sigma,\{p_{-jt}(q,\gamma)\}) \\ &= \max_p \left\{E\left[\pi_{js}^{p_s}(E_s,q_s) + \beta V_{js}(\delta E_s + q_s,\sigma,\{F_t\}_{t=s}^{\infty},\{p_{-jt}(q,\gamma)\}) \mid p\right]\right\}. \end{aligned}$$

4.6 Solution Concept

To close the model, I use Oblivious Equilibrium as the solution concept in this paper. Oblivious Equilibrium(OE) is a solution concept proposed by Weintraub et al. (2008), in which each firm is assumed to make decisions based only on its own state and knowledge of the long-run average industry state, but not on the current information about competitors' states. OE is convenient in industries with many firms, and Weintraub et al. (2008) provides reasons to use OE as a close approximation to Markov Perfect Equilibrium (MPE).

In this paper, I make the following two assumptions.

Assumption 1. *Airlines play Oblivious strategy. When airline i makes its investment decision, it bases its decision only on its own fleet, current proposed pricing menu and the long-run average industry state. In particular, when airline i takes expectation of expression (1), it takes expectation given the sequence of airlines' fleet* $\{F_{-it} = F_{-i}^*\}_{t=s}^{\infty}$ *and the sequence of aircraft pricing menu*

$\{p_t(\cdot) = p^*(\cdot)\}_{t=s}^{\infty}$, *where* F_{-i}^* *and* $p^*(\cdot)$ *is the long-run average fleet of airlines and the pricing menu of manufacturers.*

Assumption 2. *Manufacturers play Oblivious strategy, where they are oblivious of airlines' actual fleet. When manufacturer* j *decides the pricing menu of its product, it bases its decision only on its own state, other manufacturers' states and the long-run average industry state of airlines. In particular, when manufacturer* j *takes expectation of expression (2), it takes expectation given the sequence of airlines' fleet* $\{F_t = F^*\}_{t=s}^{\infty}$.

The most related paper to these assumptions is Benkard et al. (2013), where the authors develop an application of OE to to concentrated industries. In the paper, the authors define an extended notion of oblivious equilibrium, Partially Oblivious Equilibrium (POE), in which the state of a subset of players enter into the players' strategies. Since players ignore the actual state of all other players in OE, POE is a generalization of OE in the sense that the players take the actual state of some of the players into account. Since there are more than thirty airlines in the data, the dimension of the state variables is too large to solve the model using Markov Perfect Equilibrium. Adopting OE (POE) makes the model tractable and feasible to estimate. Also, since there are a large number of airlines, assuming players are oblivious of the actual state of airlines may work as a good approximation of MPE.

5 Estimation and Identification

In the estimation, I take three steps to estimate the whole model. First, I estimate the parameters on the utilization model and the airline specific profitability. The utilization model is a completely static model and it can be estimated from the static optimality of the observed utilization decision separately from all the remaining model. Using the estimates, I next estimate the value function of the airlines where I heavily take advantage of the oblivious assumptions. By substituting the estimated airline specific profitability and putting distributional assumptions on the cost of investment, I estimate the value function nonparametrically. Finally, I estimate the parameters on the production model. With the estimated value function of airlines, I can estimate the outcome of the transaction between manufacturers and airlines for any arbitrary pricing menus. The optimality of the observed pricing menus induces a set of inequalities, which identifies the parameter. In this section, I describe the estimation and identification step by step.

To simplify the notation, $\{F_i^*\}$ and $\{p^*(q,\gamma)\}$ are not explicitly written when I write down the value function.

5.1 Utilization Model

I specify the inverse demand curve as follows. Since major airlines and regional airlines shows different patterns in the utilization, I allow the parameter to take different values between these two types of airlines.

The inverse demand function takes the following form if airline i is a major airline

$$P_i^t(Q_i, Q_{-i}) = d_t + \gamma_i - \delta_{\text{major}} Q_i - \sum_{j \neq i, j \in \text{major}} \delta_{\text{major}}^{\text{major}} Q_j - \sum_{j \neq i, j \in \text{regional}} \delta_{\text{major}}^{\text{regional}} Q_j,$$

and if airline i is a regional airline

$$P_i^t(Q_i, Q_{-i}) = d_t + \gamma_i - \delta_{\text{regional}} Q_i - \sum_{j \neq i, j \in \text{major}} \delta_{\text{regional}}^{\text{major}} Q_j - \sum_{j \neq i, j \in \text{regional}} \delta_{\text{regional}}^{\text{regional}} Q_j,$$

where γ captures the airline specific profitability of utilization and d_t captures the time specific demand sifter. Also, I specify the cost of utilization as

$$c^m(u, \epsilon_{it}^m) = c_0 + u\left(c_1^m + \kappa c_1^m u + \epsilon_{it}^m\right).$$

where κ captures the increasing marginal cost of utilization and ϵ_{it}^m is independent across time, model and airlines.

Assumption 3 (Distributional of the Shock on the Utilization Cost). *ϵs are distributed identically and independently as $N(0, \sigma_\epsilon^2)$.*

Assumption 4 (Distribution of the Demand State). *d_ts are distributed identically and independently as $N(d, \sigma_d^2)$.*

The parameter to be estimated is $d = (d_1, \cdots, d_T)$, $\gamma = (\gamma_1, \cdots, \gamma_I)$, δ, c_0, $c_1 = (c_1^1, \cdots, c_1^M)$, κ and σ_ϵ^2. The data contains annual utilization hours, c_{it}^m and the leasing decision of airlines, l_{it}^m. One important missing information is the rental cost aircraft, which I estimate using the data on the transaction price of used aircraft.

Assumption 5 (Leasing Market)**.** *The aircraft leasing market and secondary market are competitive and the rental price of aircraft is distributed as $N(r, \sigma_r^2)$ at each year.*

This assumption allows me to estimate the rental cost of aircraft. In the data, I observe the transaction price of aircraft, which is informative about the cost of holding an aircraft for one year. Suppose a leasing company buy an aircraft at year t and sell it at $t+1$, the difference in the aircraft price at t and $t+1$ is the rental cost of the aircraft under the assumption of competitiveness. In the subsequent analysis, I substitute the estimated rental price in the estimation of the utilization model parameter.[11] The parameter is identified from the variation in the utilization rate and the variation in rental choice. For a fixed fleet, airlines equate the marginal cost and the marginal revenue of utilization. The variation in the utilization rate identifies the relative value of the parameter of utilization cost and profitability. For example, the relative value of d_t and γ_is are identified from the relative level of utilization rate across airlines and time. Conditional on the fleet, the variation in utilization rate across airlines identifies the relative level of γ_i, and the variation in overall utilization level across year identifies that of d_t. The rental choice identifies the absolute level of the parameter.

[11] In the estimation of the rental price, I first estimate the used aircraft price nonparametrically for each model, m, and year, t. I specify the estimation equation as

$$p_{lt}^m = p_t^m(age_{lt}) + \varepsilon_{lt}^m,$$

where l is a index for transactions, p_{lt}^m is the observed transaction price of model m aircraft that is age_{lt} year old and ε_{lt}^m is meant to capture measurement error. Gavazza (2011) notes that the actual transaction price is explained well by the list price, which is calculated by the age of the model. The rental price is estimated by

$$r_t^m = \widehat{p_t^m}(\widehat{age_{lt}}) - \beta \widehat{p_{t+1}^m}(\widehat{age_{lt}} + 1),$$

where $\widehat{age_{lt}}$ is the average age of the model m used aircraft traded at time t and β is the discount factor. Here I set the discount factor to be 0.95.

The optimal utilization hours of airline i satisfies

$$\frac{\partial P_i^t(Q_{it}, Q_{-it}) - C_i(Q_{it})}{\partial u_{it}^m} = 0$$
$$\Leftrightarrow P_i^t(Q_t) - \delta_i u_{it}^m - (c_1^m + 2\kappa c_1^m u + \epsilon_{it}^m) = 0 \quad \forall m.$$

This equality conditions translate into a set of moment equality, which is

$$\mathbf{E}\left[\big(d_t - \gamma_i - \delta_1 Q_{it} - \delta_2 \sum_{-i} Q_{-it}\big) - \delta_1 u_{it}^m - \big(c_1^m + 2\kappa c_1^m u_{it}^m\big)\right] = 0 \quad \forall m,\ i,\ t.$$

The absolute value of the parameter and c_0 is identified from the optimality of the rental choice. The cost increasing (benefit of decreasing) the observed rental choice can not be larger than the decrease (increase) in the per unit utilization cost, which identifies the fixed cost, c_0, and the absolute value of the parameter. The rental decision of airline i satisfies the optimality condition as follows.

$$\begin{aligned}
&\max_{Q_{it}, L_{it}} \left(d_{it} - \delta_i Q_{it} - \sum_{j \neq i} \delta_j Q_{jt}\right) Q_{it} \\
&\quad - \sum_{m=1}^{M} \big(f_{it}^m + l_{it}^m\big) c^m(u_{it}^m, \epsilon_{it}^m) - \sum_{m=1}^{M} l_{it}^m r_t^m \\
&\quad \geq \max_{Q_{it}, L_{it} \neq L_{it}^*} \left(d_{it} - \delta_i Q_{it} - \sum_{j \neq i} \delta_j Q_{jt}\right) Q_{it} \\
&\qquad - \sum_{m=1}^{M} \big(f_{it}^m + l_{it}^m\big) c^m(u_{it}^m, \epsilon_{it}^m) - \sum_{m=1}^{M} l_{it}^m r_t^m
\end{aligned}$$

This inequality conditions translate into a set of moment inequality conditions for the parameters. I estimate the parameter by minimizing the objective function which has both the above equality and inequality conditions.

5.2 Investment Decision

First, I specify the distribution of the shocks on investment cost.

Assumption 6 (Distributional Assumption on the Error)**.** *ηs are distributed identically and independently as $N(0, \sigma_\eta^2)$.*

At each period, airline i maximizes the value function given the proposed price menus and the period shock on investment cost. In the maximization problem, $\{p_s\big(q_{is}, \gamma_i\big)\}$ can be backed out from the data. Therefor the only dynamic part to be estimated is the value function. With the distributional assumption on η, the optimality of the airlines' fleet choice induces the likelihood of the data.

I take two steps in the estimation of the value function. In the first step, I estimate the manufacturers' pricing menus nonparametrically. In the second step, I substitute the estimated pricing menus in the likelihood function and estimate the value function nonparametrically by sieve MLE. From the optimality of the airline i's investment decision,

$$q_{is} = \sigma(F_{is}, \gamma_i) = \arg\max_q \left\{-p_s\big(q, \gamma_i\big) + \eta'_{is}\big(q\big) + V_{is+1}(q + \delta_f F_{is}, \gamma_i)\right\}.$$

If the price menu is observed, the condition above translates into conditions on the range of η_{is}. From the optimality condition, changing q_{is} to $q_{is}+1$ or $q_{is}-1$ gives,

$$\begin{aligned}
&-\big(p_s\big(q_{is}, \gamma_i\big) - p_s\big(q_{is}+1, \gamma_i\big)\big) + (V_{is+1}(q_{is} + \delta_f F_{is}, \gamma_i) - V_{is+1}(q_{is} + 1 + \delta_f F_{is}, \gamma_i)) \geq \eta_{is} \\
&-\big(p_s\big(q_{is}, \gamma_i\big) - p_s\big(q_{is}-1, \gamma_i\big)\big) + (V_{is+1}(q_{is} + \delta_f F_{is}, \gamma_i) - V_{is+1}(q_{is} - 1 + \delta_f F_{is}, \gamma_i)) \geq -\eta_{is}.
\end{aligned}$$

Therefore, the probability of observing q_{is} in the data is equal to

$$\begin{aligned}
Pr\Big(&-\big(p_s\big(q_{is}, \gamma_i\big) - p_s\big(q_{is}+1, \gamma_i\big)\big) + (V_{is+1}(q_{is} + \delta_f F_{is}, \gamma_i) - V_{is+1}(q_{is} + 1 + \delta_f F_{is}, \gamma_i)) \\
&\geq \eta_{is} \geq \big(p_s\big(q_{is}, \gamma_i\big) - p_s\big(q_{is}-1, \gamma_i\big)\big) - (V_{is+1}(q_{is} + \delta_f F_{is}, \gamma_i) - V_{is+1}(q_{is} - 1 + \delta_f F_{is}, \gamma_i))\Big).
\end{aligned} \tag{3}$$

By approximating the value function by a sieve function, I can estimate the parameter on the sieve function by MLE. However, this approach is not feasible because the price menu is not observed and, therefore, a two step approach is needed.

In the data, I observe $(p_{it}^m, q_{it}^m, \widehat{\gamma}_i)$ for each aircraft order, which allows me to estimate the price menu nonparametrically. In the first step, I estimate the pricing menu using the following specification. For each t,

$$p_{it}^m = p_t^m\big(q_{it}^m, \gamma_i\big) + e_{mit},$$

where e_{mit} is independent with q_{it}^m and γ_i.[12] Here e_{mit} is meant to capture measurement error in the data. By approximating p_t^m by a sieve function and substituting $\widehat{\gamma}_i$ for γ_i, the price menu can be estimated by a standard nonparametric regression method. Also, I estimate the depreciation rate of aircraft, δ_f, from the owned fleet data directly by estimating the following equation by OLS:

$$f_{i,t+1}^m - q_{it}^m = \delta_f f_{it}^m + e_{mit}^{\delta_f},$$

where $e_{mit}^{\delta_f}$ is assumed to mean zero and independent with all model variable.

In the second step, I substitute $\widehat{p_{it}^m}$, $\widehat{\gamma}_i$ and $\widehat{\delta_f}$ for p_{it}^m, γ_i and δ_f in the expression (3), which induces the likelihood of the data as

$$\begin{aligned} Pr\Big(&- \big(\widehat{p_s}\big(q_{is}, \widehat{\gamma}_i\big) - \widehat{p_s}\big(q_{is}+1, \widehat{\gamma}_i\big)\big) + (V_{is+1}(q_{is} + \delta_f F_{is}, \widehat{\gamma}_i) - V_{is+1}(q_{is} + 1 + \delta_f F_{is}, \widehat{\gamma}_i)) \\ &\geq \eta_{is} \geq \big(\widehat{p_s}\big(q_{is}, \widehat{\gamma}_i\big) - \widehat{p_s}\big(q_{is}-1, \widehat{\gamma}_i\big)\big) - (V_{is+1}(q_{is} + \delta_f F_{is}, \widehat{\gamma}_i) - V_{is+1}(q_{is} - 1 + \delta_f F_{is}, \widehat{\gamma}_i))\Big). \end{aligned} \tag{4}$$

As long as $\widehat{p_s}$ and $\widehat{\gamma}_i$ are consistent for p_{it}^m and γ_i, the probability in expression (3) and (4) are asymptotically equivalent. Therefore, sieve MLE in which I maximize the likelihood in expression (4) gives a consistent estimator for the airline's value function. [13]

[12]Under the model, the price menu is a function of the state and it should be estimated as a function of the state rather than than an independent function for each t. However, the state of manufacturers is not observed since the depreciation rate of the experience, δ, is unknown and it is infeasible to estimate it as a function of the state. One alternative estimation strategy is to jointly estimate the production side parameter, but it is computationally demanding. In order to estimate the airlines' value function, a consistent estimator of the price menu for each t is sufficient.

[13]In the estimation, I approximate the objective by a polynomial function of its argument.

5.3 Aircraft Production

In this subsection, I describe the estimation of the aircraft production parameter. First, I specify the production technology as follows.

$$MC_{jt}^{m} = mc^{m} + \zeta \left((E_t^m)^{-\rho} \right), E_{t+1}^m = \delta E_t^m + q_t^m,$$

where ζ, ρ and δ is the parameter to be estimated.

The estimation relies on simulations similar to Bajari et al. (2007). Let $V_j(E_t, \sigma^p)$ denote the expected discounted sum of the future profit of manufacturer j when manufacturers play strategy σ^p. The optimality of the observed pricing menu gives the following inequality conditions.

$$V_j(E_t, \sigma^{p*}) \geq V_j(E_t, \sigma_j^p, \sigma_{-j}^{p*}) \qquad \forall \sigma_j^p,\ j \quad . \tag{5}$$

Given the estimated value function of airlines, I can simulate the transaction outcome for arbitrary pricing menus. Therefore, I can simulate both left and right hand side of the inequality, which construct a set of inequality conditions. I assume that the production parameter is identified by the inequality conditions and the parameter can be estimated similar to the method proposed by Bajari et al. (2007). A notable difference from Bajari et al. (2007) comes from the fact that the exact state is not observed in my model. Even though I see the complete history of the aircraft production history, the exact state is a function of the depreciation rate of the experience, δ, and the production history. When I simulate $V_j(E_t, \sigma^{p*}; \theta^m)$ for a fixed parameter value θ^m, I first calculate $E_t(\delta)$. Given the value of $E_t(\delta)$, I next estimate the observed price menu as a nonparametric function of $E_t(\delta)$, quantity and $\widehat{\gamma_i}$. After I estimate the value function of airlines and observed pricing strategy, I can simulate the sequence of market outcome for arbitrary length, which gives the value of $V_j(E_t, \sigma^{p*}; \theta^m)$ by taking the average of many different sequence of market outcome. Similarly, by creating an alternative pricing strategy, I can simulate the value of $V_j(E_t, \sigma_j^p, \sigma_{-j}^{p*})$. I estimate the parameter using the inequality (5). To be precise, the estimator, $\widehat{\theta}$, is

$$\widehat{\theta} = \arg\min \sum_j \sum_{alt} \left(\min \left\{ V_j(E_t, \sigma^{p*}) - V_j(E_t, \sigma_j^{p,alt}, \sigma_{-j}^{p*}), 0 \right\} \right)^2 .$$

6 Result and Counterfactual

In this section, I present the estimation and counterfactual result. Table 6 shows the main estimates of the parameter. κ captures the increasing part of the marginal cost of utilization. Since the marginal cost of utilization is increasing, the dispersion in the utilization rate implies the welfare loss. For any fixed amount of total utilization hours, the total utilization cost is minimized when the utilization rate is equalized among airlines. In the aircraft production, ζ captures the production cost that goes to 0 as the manufacturers' experience goes to infinity. The learning-by-doing accounts for up to about 30% of the total cost of production. Compared to the existing literature, the estimates are in a reasonable range. Benkard (2000) reports the forgetting rate to be about 61% and the effect of the cost reduction to be about 40%. [14]

Table 6: Estimated Parameters

Utilization Model		Production Model	
Parameter	Estimates	Parameter	Estimates
δ_m	1.6250e-004	$\overline{MC}_{\text{boeing}}$	18.1790
	[1.6250e-004,1.6250e-004]		[11.8071, 24.5026]
δ_r	0.1372	$\overline{MC}_{\text{McD}}$	20.6391
	[0.1372,0.1372]		[14.0366, 25.5326]
c_0	0.1218	ζ	7.5892
	[0.1218,0.1218]		[6.3708, 10.6718]
$\overline{c_1}$	0.0894	ρ	0.2692
	[0.0790,0.0923]		[0.2691, 0.2692]
κ	0.5376	δ	0.7296
	[0.5376,0.5376]		[0.7182, 0.7368]

The confidence intervals are calculated by Bootstrap. The estimates for c_1s are reported as the mean value of all aircraft models. $\overline{MC}_{\text{boeing}}$ and $\overline{MC}_{\text{McD}}$ are the mean value of the constant production cost of aircraft produced by Boeing and McDonell Douglas, respectively.

[14] Levitt et al. (2012) and Thompson (2007) report much higher depriciation rate. They report the estimates for δ (compounded for annual rate) to be about 20% to 50%.

In the counterfactual analysis, I compare the equilibrium market outcome and welfare under two alternative market designs: the manufacturers post a single uniform price to all airlines for each of their products (Uniform Pricing); the manufacturers post one price-quantity menu to all airlines for each of their products (Grand Menu Pricing).[15] The first counterfactual analysis is motivated by the theory side. The theoretical example presented in the previous section suggests that regulating manufacturers' pricing by uniform pricing policy increases total welfare. The natural next question is that if this prediction is still true in the industry and, in case if it is true, how much welfare gain can be made by potential policy interventions. The second contractual analysis is motivated from from antitrust point of view. Under the current situation, different airlines faces different marginal price even after controlling for the quantity, which may distort fair competition in the airline market. The manufacturers' pricing favor particular airlines, the favored airlines can take competitive advantage in the airline market through capital allocation and other airlines may harm from that. Robinson-Patman Act (Secondary-Line) forbids seller to price discriminate buyers if the price discrimination creates harm in competition among buyers. The advantage and disadvantage of the act has been extensively studied[16] and this counterfactual analysis provides an additional view on this topic by assessing the market outcome and welfare under a situation where all downstream firms have access to the same price menu.

Table 7 shows the counterfactual equilibrium outcome compared to the current situation. The first half of the table shows the counterfactual outcome under the uniform pricing regulation. By forcing uniform pricing, the average price of aircraft decreases and the production amount increases for both Boeing and McDonnell Douglas. The increase in aircraft production results in more total utilization hours and lower utilization rates. Since the marginal cost of utilization is increasing and the average aircraft price has decreased, airlines buy more aircraft and decrease the utilization rate, which ends up in lower the utilization rate. Similar patterns are reported in the second half of the table 7. The second half reports the equilibrium outcome under the grand menu pricing regulation. Under the grand menu pricing, manufacturers can still sort airlines by proposing non-linear pricing menu, but manufacturers need to offer the same menu to all airlines. Since

[15]The computation of the counterfactual equilibrium is described in the appendix.

[16]Though it is an important regulation to maintain fair competition, the Robinson-Patman act has been rarely effective recently. See Luchs et al. (2010) for a detailed summary.

Table 7: Counterfactual Outcome

	Boeing	McDonnell Douglas	Total	Airlines
		Uniform Pricing		
Average Price Change	−9.46%	−5.59%	−8.45%	–
Average production Change	12.34%	6.02%	10.59%	–
Utilization Rate	–	–	–	−9.32%
Total Utilization Hours	–	–	–	0.28%
		Grand Menu Pricing		
Average Price Change	−6.54%	−12.56%	−8.28%	–
Average production Change	8.32%	14.71%	10.01%	–
Utilization Rate	–	–	–	−7.44%
Total Utilization Hours	–	–	–	1.89%

the menu can be non-linear, the pricing can creates dispersion in the marginal price. However, allowing a non-linear pricing has, at least, two advantages over uniform pricing. Under uniform pricing regulation, both upstream firms and downstream firms suffer from double-marginalization, which may be mitigated by allowing non-linear pricing. Also, non-linear pricing helps upstream firms to screen downstream firms in the dimension of unobserved demand size. It is theoretically known that, under the existence of asymmetric information in buyers' demand, allowing sellers to design non-linear pricing to screen the buyers helps to increase production. These two positive effect on aircraft production offset the inefficiency coming from dispersion in marginal price. The important take away from table 7 is that both counterfactual results suggest that the main source of inefficiency is manufacturers' price discriminatin across airlines and shutting down the channel of such price discrimination can help to restore efficiency.

Table 8 shows the counterfactual welfare change under uniform pricing and grand menu pricing. In both cases, manufacturers faces higher competition intensity and decreases their price on average. However, the manufacturers' profit is almost unchanged. Higher competition intensity leads to lower revenue per unit sales but, at the same time, it increases total production and leads to lower unit costs via the learning-by-doing effect. In terms of welfare, higher competition intensity leads the price closer to the long-run marginal cost of production, which helps to restore efficiency.

Table 8: Counterfactual Welfare

	Boeing	McDonnell Douglas	Airlines	Total
	Uniform Pricing			
Welfare Change (in %)	0.14%	-0.89%	10.61%	2.51%
Welfare Change (in $ 1M)	20	-9	489	500
	Grand Menu Pricing			
Welfare Change (in %)	0.14%	-0.10%	10.88%	2.60%
Welfare Change (in $ 1M)	19	-2	501	518

As in the previous table, the counterfactual results are similar in both uniform pricing and grand menu pricing cases, which again suggests ensuring a fair competition environment is important to help the market mechanism to work well.

7 Conclusion

In this paper, I present evidence that suggests capital misallocation in aircraft and airline industries. I present a simple theoretical example to show that the learning-by-doing effect in production and competition among upstream firms lead to aircraft price discrimination. The existence of economies of scale in production creates a incentive to treat large buyers better, which distorts both production and allocation of aircraft in favor of large buyers. I further construct and estimate a dynamic structural model of the industries. The model captures economies of scale in aircraft production via a learning-by-doing effect and both second and third degree price discrimination in aircraft market. Using the estimated parameter, I simulate the equilibrium outcome under alternative pricing regulations. The result suggests that manufacturers' ability to price discriminate airlines results in lower production of aircraft and lower total welfare. Forcing manufacturers to treat all airlines equally does not only ensures fair competition in the airline industry but also increases efficiency in both aircraft and airline industries.

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Appendix

Proof of the Proposition 1

For the sake of simplifying the analysis, let me assume that the parameters, c, k and D_i^t, are in a range that the marginal revenue from the demand curve D_i^t is smaller than $c - k(D_1^1 + D_2^1)$ when the price is c.[17]

Second Period

Suppose the first period production of each seller is q_1^1 and q_2^1 where $q_1^1 \geq q_2^1$. Since $S1$ has a lower marginal cost, it undercuts the price of $S2$ for both buyers to maximize the second period profit. The lowest price $S2$ can offer is $MC_2(q_2^1)$ and, therefore, the second period profit that $S2$ can earn (as a function of q_1^1 and q_2^1) is

$$\pi_1^2(q_1^1, q_2^1) = \left(D_1^2(MC_2(q_2^1)) + D_1^2(MC_2(q_2^1))\right)(MC_2(q_1^1) - MC_2(q_2^1)) = (D_1^2 + D_2^2 - 2c + 2kq_2^1)k(q_1^1 - q_2^1).$$

First Period

The following pricing is an equilibrium price in the first period. $S1$ and $S2$ propose the same linear price $p_1^1 = c$ to buyer 1 and the same linear price $p_2^1 < p_1^1$ to buyer 2 where p_2^1 satisfy $\pi_1^2(D_1^1(p_1^1) + D_2^1(p_2^1), 0) = (p_2^1 - c)D_2^1(p_2^1)$. At this price, both firms earn profit of zero in total. $S1$ incurs negative profit in the first period and get the loss back by earning positive profit in the second period. $S2$ does not make any sales and earns zero in both periods.

This is an equilibrium because no seller has an incentive to change the pricing. $S2$ has no incentive to change the price in the first period. In the equilibrium, $S2$ does not make any sales and increasing any of the price doesn't increase his profit. If he decrease any of the price in the first period, he incurs more loss than the profit he can get in the second period. Similarly, $S1$ has no incentive to increase or decrease any of the price.

[17] This assumption allows us to simplify the second period analysis. If this assumption is not true, the profit maximizing price of the dominant firm may be strictly lower than the other firm. In such case, we need to derive the second period equilibrium price. On the other hand, under the assumption, we can directly conclude that the dominant firm just undercut the other firm.

Computation of the Counterfactual Equilibrium

In the counterfactual analysis, I again use the same POE concept to find the counterfactual equilibrium. The computation of counterfactual equilibrium has an outer loop and an inner loop. In the inner loop,

1. For a given pricing policy of manufacturers and a given industry long-run average flying hours, compute the airline's value function and derive the airline's investment policy and air transportation production behavior,
2. Compute the industry long-run average flying hours given the derived investment policy and production behavior, and
3. Repeat the steps above until the industry long-run average flying hours converges.

In the outer loop,

1. Given the airline's value function found in the inner loop, find the equilibrium pricing strategy of manufacturers,
2. Use the pricing strategy found in step 1 and run the inner loop to get the airline's value function, and
3. Repeat the steps above until the pricing strategy converges.