

Quantity Discounts and Capital Misallocation in Vertical Relationships*

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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. There is a negative correlation between the size of aircraft orders and the per-unit price. There is also a positive correlation between the price paid and the utilization rate of the aircraft model, which suggests that the manufacturers' price discrimination leads to the misallocation of aircraft. To assess whether there is an inefficient allocation, I model the market and show that price discrimination by upstream firms may lead to an inefficient outcome compared with uniform pricing. Then, I construct and estimate a dynamic model of the aircraft market that includes a model of utilization. Finally, I conduct counterfactual simulations using the estimated parameters. 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 less for each unit utilize the aircraft less. The positive correlation between the price paid and the utilization rate suggests misallocation. The utilization rate indicates the marginal profitability or operational efficiency of the airline. From the social planner's point of view, more aircraft should be allocated to airlines with higher marginal profitability or higher marginal operational efficiency. On the other hand, the data suggest that aircraft are not allocated according to marginal profitability. Rather, the data suggest that airlines with lower marginal profitability face a lower aircraft unit price and, therefore, have easier access to the marginal aircraft, which causes inefficiency with misallocation.

One possible explanation for the source of inefficiency 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 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 and misallocation. The intuition of the result is simple. To reduce future competition intensity, manufacturers compete for the large buyer, which distorts both production and allocation. 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 capital, the model can explain the pattern in the data. Suppose the capital is used in final-good production where the production function is characterized by the amount of capital and the utilization rate. Also, suppose there is a cost associated with utilization. To maximize profit, final-good producers determine the amount of capital and utilization rate using the relative marginal factor price of capital and utilization. Therefore, final-good producers facing a lower price of capital substitute capital for utilization, and those facing a higher price do the opposite, which creates a positive correlation between the capital price and utilization rate.

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 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 and often indistinguishable. In the model, there is a one-to-one correspondence between profitability 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 counterfactual analysis, 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 structural 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 increase 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. 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 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

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

(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, List, and Syverson (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, Dorazelski, Kryukov, and Satterthwaite (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, Benkard, and Levin (2007), Pakes, Ostrovsky, and Berry (2007), etc.. I estimate the value function as a nonparametric function of the state. The idea of estimating the value function as a nonparametric function is presented in Kalouptside (2010). In contrast to Kalouptside (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 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

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

³The 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.

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 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

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

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

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 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.

Table 3: Price and Quantity Dispersion

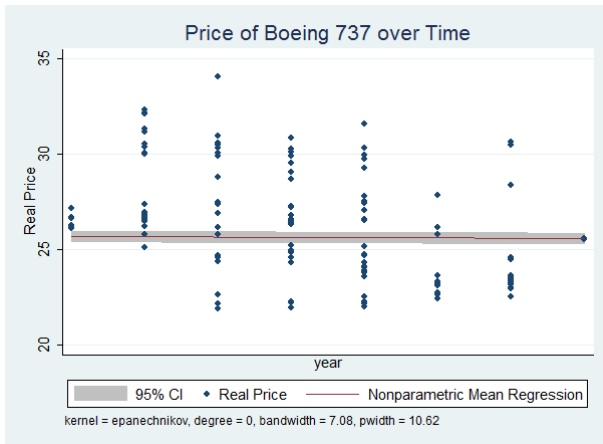
	10%	25%	50%	75%	90%	mean	std	N
transaction price / model average price	.842	.897	.966	1.059	1.198	1	.192	2457
airline - model paired quantity	1	2	3	10	26	9.90	18.18	248
airline ratio	.006	.016	.041	.133	.285	.104	.149	248

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.

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, 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

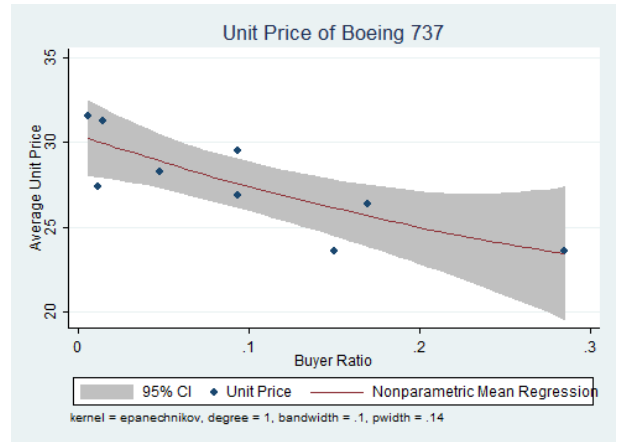
suggests that some part of the dispersion is explained by the dispersion in quantity.

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

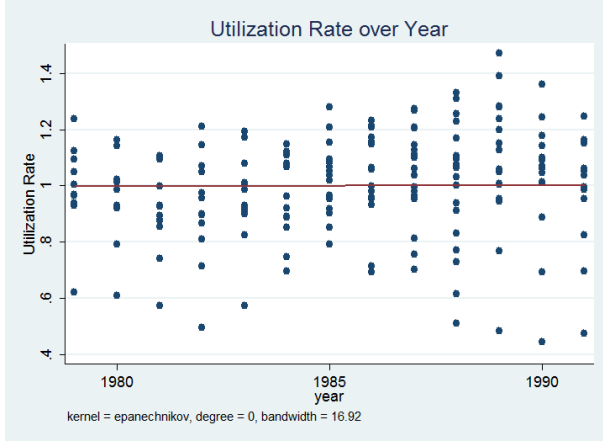


This graph plots the average unit price of Boeing 737-300 as a function of airline ratio. Each dot represents one airline.

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, 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.

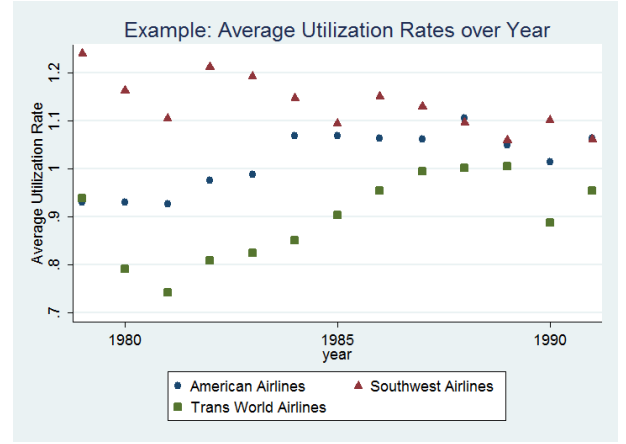
⁶Here the utilization rate is defined differently from the one defined above. The average utilization hours are the simply the total utilization hours of each airlines by pooling all aircraft model. I employ the new variable since figure 3 and 4 is meant to graphically show the pattern in the utilization rate across airlines. The airline-model specific utilization rate is used in the regressions presented in the subsequent sections.

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 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 paid 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 employed “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 $\frac{\text{model } j' \text{ total quantity airline } i \text{ bargained at time } t}{\text{model } j' \text{ s total quantity produced}}$. I employ the order fractions of total production rather than 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, etc..

Table 4 shows the regression result of the unit price and the discount ratio. 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. Introducing seller×buyer dummy increase the number of regressors 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. Company size of buyers measured by their asset size does not have any significant effect on the price they pay.

The regression result on a few other variable may suggest the nature of the market. First, the coefficient on “cumulative ratio”, which is defined as $\frac{\text{model } j' \text{ total quantity produced up to time } t}{\text{model } j' \text{ s total quantity produced}}$, has a significant effect to reduce the price of the aircraft. This result may suggest that there is a learning-by-doing effect where cumulative production experience decreases the marginal cost of production. Also, the “rival availability”⁸ has a significant effect to reduce the price, which suggests manufacturers face competition and the competition translates into the price reduction.

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. In order to analyze the correlation, I regress the average

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

Table 4: Regression of Unit Price and Discount Ratio

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

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 employ 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 positive and significant correlation between the price paid and the utilization rate, which suggest a positive correlation between the price paid and airlines' willingness-to-pay. If all airlines faces the same marginal cost of operating aircraft, then airlines having a higher marginal profitability will operate the aircraft more intensively. And as a result, airlines' marginal willingness-to-pay to the aircraft and the average utilization rate will have positive monotonic relationship. Thus, the results in table 5 suggest that airlines with higher marginal willingness-to-pay are facing higher marginal price, which also suggest misallocation of aircraft.

3.3 Interpretation of the Descriptive Results

The data suggest that (I) there is dispersion in price within the same period; (II) manufacturers price discriminate airlines and use non-linear pricing strategies; (III) the manufacturers price discrimination creates inefficiency in aircraft allocation and 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. 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

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** (28.79)	-.28** (.11)		
fleet	0.39*** (0.08)	0.17E-2*** (0.03E-2)	0.40*** (0.09)	0.17E-2*** (0.03E-2)
asset	-3.02E-06** (1.47e-06)	-1.21e-08** (5.68e-09)	-3.15E-06** (1.47E-06)	-1.27E-08** (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.

price and quantity that actually happened rather than the complete 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.⁹

Table 5 provide evidence that (III) the manufacturers price discrimination creates inefficiency in aircraft allocation and transportation production. Ideally, to provide direct evidence of misallocation, I need to present that there is dispersion in marginal productivity of aircraft across airlines. However, marginal productivity of aircraft is difficult to measure. Instead, I use the utilization rate as the indicator for marginal productivity, which is a standard proxy in the capital utilization literature. For example, there is one-to-one correspondence between airlines' productivity and the utilization rate in Gavazza (2011).¹⁰ An important assumption behind is that the marginal cost of utilization is increasing. When airlines decide the utilization rate, they equate marginal cost of utilization to the marginal productivity. If the marginal cost of utilization is increasing, a high utilization rate implies a high marginal cost and, therefore, high marginal productivity. If we believe that the utilization rate is a good indicator for the marginal productivity, table 5 suggests that the manufacturers' price discrimination creates inefficiency in aircraft allocation and distorts production of transportation. From social planner's point of view, more aircraft should be allocated to airlines with high marginal productivity. However, the data suggest that airlines with low utilization rate, therefore low marginal productivity, face lower price and have easier access to the marginal aircraft, which creates misallocation of aircraft. The aircraft misallocation creates welfare loss in airline market by creating inefficiency in production of transportation.

⁹The 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> .

¹⁰In Gavazza (2011), airlines derive per aircraft profit of $\pi(u, \theta) = \theta u - 0.5u^2$, where u is the utilization rate and θ is the productivity of the aircraft. Here, the optimal utilization rate $u^* = \theta$.

4 Model

The results in the previous section raise the following questions: Why is the misallocation sustained in the equilibrium? How much is the welfare loss coming from the misallocation? To answer the questions, I take a structural approach in the subsequent sections of the paper.

To start the analysis, I describe the model of the aircraft transactions and utilization in this section.

4.1 Theoretical Example

Before moving to the full model that I estimate structurally, I describe a simple theoretical example to derive intuition for why there is allocative inefficiency and how we can restore the welfare loss by potential policy interventions. To start with, I present a model of upstream firms and downstream firms without any utilization part.

Upstream

Suppose two ex-ante identical firms, $U1$ and $U2$, sell a homogeneous intermediate good in two periods. 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

$$MC_t(q_{it}) = c^u - kq_{it-1},$$

where q_{it-1} is the cumulative production amount of firm i up to period $t - 1$, and k captures the degree of learning-by-doing.

Downstream

At each period, short-lived downstream firms arrive at the market. Downstream firms are heterogeneous in their demand of the intermediate good. Downstream firm derives utility from consuming the good and has a utility function $u(\theta, q) = \theta q - \frac{1}{2}q^2$, where θ captures the heterogeneity of downstream firms. The utility function induces a demand curve $D(p, \theta) = \theta - p$. Also assume that the downstream firms live only one period.

Game Structure

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

Period 1

1. Downstream firms arrive the market.
2. Upstream firms observe each downstream firm's θ and simultaneously offer a (possibly different) price to each downstream firm.
3. Each downstream firm decides how much to buy the good given the offered price and receives utility from consumption minus the price she pays.

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 $U1$ if the same price is offered.

Proposition 1: There is an equilibrium with quantity discount in the first period.

Proof: In Appendix. ■

The intuition behind the proposition is simple. The learning-by-doing effect creates ex-post market power in the second period. If one upstream firm produce more in the first period, the firm has lower marginal cost than its rival and earns profit by undercutting its rival's marginal cost. Given this ex-post market power, upstream firms compete in the first period to produce more. Suppose that there are two downstream firms in the first period and also suppose the downstream firms are heterogeneous in their demand for the intermediate good, the downstream firm with larger demand is more attractive since serving the larger downstream firm increases production more and determines which upstream firm will have the market power in the second period. Therefore, competition between upstream firms lead to competition for the larger downstream firm, which results in a quantity discount. Under the equilibrium with quantity discounts, the smaller downstream pays more than the long-run marginal cost and the upstream firm earns long-run profit. However, the long-run profit is extracted by the larger downstream firm as a result of competition between upstream firms and she receive lower price than the smaller downstream firm. The dispersion in the marginal price creates allocative inefficiency. Also, if the downstream firms in the example use the good to produce final goods, then this example can also explain the

positive correlation between the price paid and utilization rate.¹¹

Also it is notable that forcing uniform pricing increases total production and total welfare in the example. The intuition behind the result is the following. If price discrimination is possible, upstream firms compete by making offers to large buyers as favorable as they can, which distort both production and allocation. By forcing to offer a single price to every consumer, upstream firms compete by setting the price as low as they can, which increases production and the producer surplus made in the second period. As a result, the total welfare increases.

The observed pattern in the data is consistent with the theoretical example, which evokes a need for structural estimation as a natural next step of this paper. The example suggests that there is inefficiency in both allocation and production, which can be partly restored by potential policy interventions. To quantify the welfare loss and the effectiveness of the potential policy interventions, I construct and estimate a dynamic model of the aircraft transactions and the airlines' fleet utilization in the subsequent sections.

4.2 Timing and Game Structure

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

¹¹In the example, upstream firms can only post a linear price. Even if the upstream firms can post a fully non-linear pricing menu, the same intuition holds as long as if there are externalities among buyers. See Appendix for a detailed example.

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, $\epsilon_{it} = (\epsilon_{it}^1, \dots, \epsilon_{it}^M)$, on utilization cost of each model. The airline i 's cost of utilizing a model m aircraft for u hours is

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

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_i is airline i '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 operate aircraft leased from 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

$$BR_i^t(Q_{-it}) = \arg \max_{Q_{it}, L_{it}} \left\{ \left(d_t + \gamma_i - \delta_1 Q_{it} - \delta_2 \sum_{j \neq i} Q_{jt} \right) Q_{it} - \sum_{m=1}^M (f_{it}^m + l_{it}^m) c^m(u_{it}^m, \epsilon_{it}^m) - \sum_{m=1}^M l_{it}^m r_t^m \right\}$$

$$\text{s.t. } Q_{it} = \sum_{m=1}^M (f_{it}^m + l_{it}^m) u_{it}^m,$$

where $L_{it} = (l_{it}^1, \dots, l_{it}^M)$ denotes a vector that counts i 's number of the rental choice of aircrafts. Also, let $F_{it} = (f_{it}^1, \dots, f_{it}^M)$ 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

$$\pi_t(Q_{it}^*, Q_{-it}^*, \gamma_i) = \left(d_t + \gamma_i - \delta_1 Q_{it}^* - \delta_2 \sum_{j \neq i} Q_{jt}^* \right) Q_{it}^* - \sum_{m=1}^M (f_{it}^m + l_{it}^{m*}) c^m(u_{it}^{m*}, \epsilon_{it}^m) - \sum_{m=1}^M l_{it}^{m*} r_t^m$$

$$\text{s.t. } Q_{it}^* = \sum_{m=1}^M (f_{it}^m + l_{it}^m) u_{it}^{m*},$$

where $(Q_{it}^*, L_{it}^*) = BR_i^t(Q_{-it}^*)$.

4.4 Investment Decision

Let $\pi_i^t(F_t)$ be the expected profit of airline i at period t in the equilibrium of the game described above as a function of airlines' fleet $F_t = (F_{1t}, \dots, F_{It})$. Suppose airline i is expecting the sequence of airlines' fleet $\{F_{-it}\}_{t=s}^{\infty}$ and the sequence of aircraft pricing menu $\{p_t(q, \gamma) = (p_t^1(q^1, \gamma), \dots, p_t^M(q^t, \gamma))\}_{t=s}^{\infty}$. Airline i maximizes the expected discounted sum of the future profit

defined as follows:

$$V_s(F_{is}, \gamma_i, \{F_{-it}\}_{t=s}^\infty, \{p_t(q, \gamma)\}_{t=s}^\infty) = \max_{\{F_{it}\}_{t=s}^\infty} E \left[\sum_{t=s+1}^\infty \beta^{(t-s)} (\pi_i^t(F_t) - p_{t-1}(q_{it}, \gamma_i) + \eta'_{it}(q_{it})) \right]$$

subject to $F_{it+1} = \delta_{it}^f F_{it} + q_{it},$

(1)

where $\eta_{it} = (\eta_{it}^1, \dots, \eta_{it}^M)$ is a model specific idiosyncratic shock on the cost of investment and δ_{it}^f is the depreciation rate of aircraft. 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 strategy given $p_s(\cdot)$ is,

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

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.¹² 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 , $\pi_{jt}^{pt}(E_{jt}, q_t)$, is described as

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

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

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

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

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,

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

¹²Benkard (2000) provide empirical evidence of “learning-and-forgetting” in aircraft production. There are also a number of papers, including Levitt, List, and Syverson (2012) and Thompson (2007), that provide evidence of the phenomenon in different industries.

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, Benkard, and Roy (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, Benkard, and Roy (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, Jeziorski, and Weintraub (2013), where the authors develop an application of OE 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

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

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). ϵ_s are distributed identically and independently as $N(0, \sigma_\epsilon^2)$.

Assumption 4 (Distribution of the Demand State). d_{it} s are distributed identically and independently as $N(d, \sigma_d^2)$.

The parameter to be estimated is $d = (d_1, \dots, d_T)$, $\gamma = (\gamma_1, \dots, \gamma_I)$, δ , c_0 , $c_1 = (c_1^1, \dots, c_1^M)$, 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.¹³ 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_i s 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.

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

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

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

¹³In 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

$$p_{it}^m = p_t^m(\text{age}_{it}) + \varepsilon_{it}^m,$$

where l is a index for transactions, p_{it}^m is the observed transaction price of model m aircraft that is age_{it} year old and ε_{it}^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

$$r_t^m = \widehat{p}_t^m(\widehat{\text{age}}_{it}) - \beta \widehat{p}_{t+1}^m(\widehat{\text{age}}_{it} + 1),$$

where $\widehat{\text{age}}_{it}$ 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.

as follows.

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

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). *η_s 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, $\{p_s(q_{is}, \gamma_i)\}$ can be backed out from the data. Therefore 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,

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

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,

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

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

$$\begin{aligned} & Pr\left(- (p_s(q_{is}, \gamma_i) - p_s(q_{is} + 1, \gamma_i)) + (V_{is+1}(q_{is} + F_{is}, \gamma_i) - V_{is+1}(q_{is} + 1 + F_{is}, \gamma_i)) \right. \\ & \left. \geq \eta_{is} \geq (p_s(q_{is}, \gamma_i) - p_s(q_{is} - 1, \gamma_i)) - (V_{is+1}(q_{is} + F_{is}, \gamma_i) - V_{is+1}(q_{is} - 1 + F_{is}, \gamma_i))\right). \quad (3) \end{aligned}$$

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 $(p_{it}^m, q_{it}^m, \hat{\gamma}_i)$ 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 ,

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

where e_{mit} is independent with q_{it}^m and γ_i .¹⁴ Here e_{mit} is meant to capture measurement error in the data. By approximating p_t^m by a sieve function and substituting $\hat{\gamma}_i$ for γ_i , the price menu can be estimated by a standard nonparametric regression method.

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

¹⁴Under 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.

likelihood of the data as

$$\begin{aligned} & Pr\left(-\left(\widehat{p}_s(q_{is}, \widehat{\gamma}_i) - \widehat{p}_s(q_{is} + 1, \widehat{\gamma}_i)\right) + (V_{is+1}(q_{is} + F_{is}, \widehat{\gamma}_i) - V_{is+1}(q_{is} + 1 + F_{is}, \widehat{\gamma}_i))\right. \\ & \quad \left. \geq \eta_{is} \geq \left(\widehat{p}_s(q_{is}, \widehat{\gamma}_i) - \widehat{p}_s(q_{is} - 1, \widehat{\gamma}_i)\right) - (V_{is+1}(q_{is} + F_{is}, \widehat{\gamma}_i) - V_{is+1}(q_{is} - 1 + F_{is}, \widehat{\gamma}_i))\right). \end{aligned} \quad (4)$$

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. ¹⁵

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, Benkard, and Levin (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.

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

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, Benkard, and Levin (2007). A notable difference from Bajari, Benkard, and Levin (2007) comes from the fact that the exact state is not observed in my model. Even though I see the

¹⁵In the estimation, I approximate the objective by a polynomial function of its argument.

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 $\hat{\gamma}_i$. 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, $\hat{\theta}$, is

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

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%.¹⁶

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). The first counterfactual analysis is

¹⁶Levitt, List, and Syverson (2012) and Thompson (2007) report much higher depreciation rate. They report the estimates for δ (compounded for annual rate) to be about 20% to 50%.

Table 6: Estimated Parameters

Utilization Model		Production Model	
Parameter	Estimates	Parameter	Estimates
δ_m	1.6250e-004 [1.6250e-004,1.6250e-004]	$\overline{MC}_{\text{boeing}}$	18.1790 [11.8071, 24.5026]
δ_r	0.1372 [0.1372,0.1372]	$\overline{MC}_{\text{McD}}$	20.6391 [14.0366, 25.5326]
c_0	0.1218 [0.1218,0.1218]	ζ	7.5892 [6.3708, 10.6718]
\overline{c}_1	0.0894 [0.0790,0.0923]	ρ	0.2692 [0.2691, 0.2692]
κ	0.5376 [0.5376,0.5376]	δ	0.7296 [0.7182, 0.7368]

The confidence intervals are calculated by Bootstrap. The estimates for c_1 s 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.

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 studied¹⁷ 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

¹⁷Though it is an important regulation to maintain fair competition, the Robinson-Patman act has been rarely effective recently. See Luchs, Geylani, Dukes, and Srinivasan (2010) for a detailed summary.

Table 7: Counterfactual Outcome

	Uniform Pricing			
	Boeing	McDonnell Douglas	Total	Airlines
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%

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 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 discrimination across airlines and shutting down the channel of such price discrimination can help to restore efficiency.

Table 8: Counterfactual Welfare

	Uniform Pricing				
	Boeing	McDonnell Douglas	Airlines	Consumer	Total
Welfare Change (in %)	0.14%	-0.89%	10.61%	0.38%	1.62%
Welfare Change (in \$ 1M)	20	-9	489	58	557
	Grand Menu Pricing				
Welfare Change (in %)	0.14%	-0.10%	10.88%	4.18%	3.33%
Welfare Change (in \$ 1M)	19	-2	501	626	1144

Table 8 shows the counterfactual welfare change under uniform pricing and grand menu pricing. In both cases, manufacturers face higher competition intensity and decrease 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. 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 an 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

Suppose two downstream firms $U1$ with $\theta = \theta_1$ and $U2$ with $\theta = \theta_1$ visit the market at period 1 and $U3$ with $\theta = \theta_3$ visits the market at period 2. I show that there exist an equilibrium with quantity discounts by backward induction.

Let Q_1 and Q_2 be the first period production amount of $U1$ and $U2$, respectively. Suppose $Q_1 > Q_2$. Then, at the second period, $U1$ has lower marginal cost than $U2$ and $U1$ earns profit by undercutting the marginal cost of $U2$. The profit $U1$ earns can be described as

$$\pi^2(Q_1, Q_2) = \max_{p_1^2 < c^u - kQ_2} \{(\theta_3 - p_1^2) (p_1^2 - (c^u - kQ_1))\}.$$

Given the expression, there is an equilibrium with the following quantity discounts in the first period.

In the first period, both upstream firm propose $p = c^u$ to $D2$ and $p = p^*$ to $D1$ where p^* solves $(c - p^*)(\theta_1 - p^*) = \pi^2(\theta_1 - p^* + \theta_2 - c^u, 0)$. In the second period, given Q_1 and Q_2 , the production amount of $U1$ and $U2$ respectively, the dominant firm U_i propose $p = p^{}$ and the other firm U_j propose $p = c$ to $D3$ where**

$$p^{**} = \arg \max_{p_i^2 < c^u - kQ_j} \{(\theta_3 - p_i^2) (p_i^2 - (c^u - kQ_i))\}.$$

This strategy clearly consists equilibrium, since both $U1$ and $U2$ only gets zero or negative profit from any deviation. ¹⁸

¹⁸In this example, there are multiple equilibrium. The multiplicity comes from the fact that all upstream firms propose the price menus simultaneously. This equilibrium is the only equilibrium under some equilibrium refinement. For example, consider a following alternative model with dynamic structure within period. At each period, downstream firms first go to $U1$ to receive the price offer. If they disagree on the price, they can go to $U2$ to receive the offer from $U2$, but the profit will be discounted by some discount factor $\delta < 1$. In this game, there is a unique equilibrium, and by taking the limit where $\delta \rightarrow 1$, the equilibrium described above is the only supported equilibrium.

Comparison with Uniform Pricing

Now consider a policy intervention which force the upstream firms to post a uniform price to all downstream firms in the previous example. Then, the following consists an equilibrium.

In the first period, both upstream firm propose $p = p_u^*$ to all downstream firms where p_u^* solves $(c - p_u^*)(\theta_1 + \theta_2 - p_u^*) = \pi^2(\theta_1 + \theta_2 - p_u^*, 0)$. In the second period, given Q_1 and Q_2 , the production amount of $U1$ and $U2$ respectively, the dominant firm U_i propose $p = p_u^{}$ and the other firm U_j propose $p = c$ to $D3$ where**

$$p_u^{**} = \arg \max_{p_i^2 < c^u - kQ_j} \{(\theta_3 - p_i^2)(p_i^2 - (c^u - kQ_i))\}.$$

Note that $p^* > p_u^*$ and $p^{**} > p_u^{**}$. It shows that with uniform pricing regulation, the production increases in both the first and second period and increases total welfare.

Examples of Positive Relationship Between Price and Utilization Rate

Suppose two ex-ante identical upstream firms sell homogeneous intermediate good in two periods. The marginal cost of production is constant within period, but exhibits dynamic economy of scale by the learning-by-doing effect. In the example, assume the marginal cost of production is

$$MC_i(q_{t-1}) = c - kq_{t-1},$$

where q_{t-1} is the cumulative production amount up to period $t - 1$, and k captures the degree of learning-by-doing.

Also, suppose at each period two downstream firms arrive. Each downstream firm operates in a monopoly market and faces a final good demand curve of $D(p, \theta) = \theta - p$, where θ captures the heterogeneity of each downstream firm's profitability. To produce the final good, downstream firms utilize the intermediated good. Let q be the amount of intermediate good and u be the utilization

rate. Suppose the production function and cost function are given as follow:

$$\begin{aligned} \text{out put} &= qu \\ \text{cost} &= q(u + au^2), \end{aligned}$$

where a captures the increasingly marginal cost of utilization. Each downstream firm first purchases the intermediate good and then decides how much to utilize it.

Now consider a Bertrand game where upstream firms choose price in the intermediate good market and downstream firms choose the price and utilization rate. Suppose downstream firms with $\theta = \theta_1$ and $\theta = \theta_2 > \theta_1$ arrive at period 1 and both downstream firms are with $\theta = \theta_3$ at period 2 .

To abstract away the screening aspect, suppose upstream firms can offer different price for each downstream firms.¹⁹ There is a subgame perfect equilibrium where the downstream firm with $\theta = \theta_2$ receives more favorable offer. The intuition behind the result is the same as the previous example.

Given the game structure, first solve for the downstream firm given θ and amount of intermediate good q . The profit that the downstream firm gets can be expressed as a function of the utilization rate,

$$\pi(u, q, \theta) = (\theta - uq)uq - q(u + au^2).$$

The optimal utilization rate will be

$$u^* = \frac{(\theta - 1)}{2(q + a)},$$

and the optimal monopoly profit is

$$\pi^*(q, \theta) = \frac{(\theta - 1)^2 q}{4(q + a)}.$$

This monopoly profit induces a demand function in the intermediate goods market. The demand

¹⁹Also, to avoid complication coming from ties, assume if the offered prices are the same, all downstream firms prefer buying the good from firm 1.

function of type θ downstream firm is simply the derivative of π^* and

$$D(q, \theta) = \frac{\partial}{\partial q} \pi^*(q, \theta) = \frac{(\theta - 1)^2 a}{4(q + a)^2}.$$

Now, I can solve for the subgame perfect equilibrium.

First, note that in period 2, if one of the upstream firm has advantage in the production cost, he charges all the downstream firms a price equals to the marginal cost of the other upstream firm.

Let the profit of firm i in the period 2 given the period 1 production denote by $\pi_{2i}^u(q_i^1, q_j^1)$.

Now consider the period 1 incentive. In equilibrium, firm 2 offer $p^1 = c$ to $\theta = \theta_1$, but price, p^2 , strictly less than c to $\theta = \theta_2$. Here the reason for the pricing to be an equilibrium is the same as in the previous example.

Next, consider the relationship between the offered price and the utilization rate. Downstream firms equate the offered price and the marginal profit, which gives

$$p = D(q, \theta).$$

By solving for u^* ,

$$u^* = \sqrt{\frac{p}{a}}.$$

This equation implies that there is a one-to-one correspondence and a positive relationship between the price offered and utilization rate. The intuition is simple. When downstream firms make their production decision, they take two factor prices into account; the price of capital and the cost of utilization. If a downstream firm is offered a lower price of capital, the relative price of capital become lower and, therefore, buys more capital and decreases the utilization rate.

Full Example with Arbitrary Contracting with Externalities among Downstream Firms.

Upstream Firm

Suppose two ex-ante identical upstream firms, U1 and U2, sell a homogeneous intermediate good in two periods. The marginal cost of production is constant within each period, but exhibits dynamic economies of scale via learning-by-doing effect. Let the marginal cost of production be

$$MC_t(q_{it}) = c^u - kq_{it},$$

where q_t is the cumulative production amount up to period t , and k captures the degree of learning-by-doing.

Downstream Firm

At each period, downstream firms arrive at the market. They use the intermediate good to produce a homogeneous final good. Any intermediate input produces the same amount of the final goods without any additional cost.

Each downstream firms faces an demand curve $P(q, \theta_i) = \theta_i - \sum_j q_j$ and compete with each other by choosing quantities (Cournot competition).

Timing

1. Upstream firms observe downstream firms c 's and simultaneously propose a price-quantity menu to each downstream firm
2. Downstream firms decide from which upstream firm to buy and how much of it
3. Downstream firms simultaneously decide about how much to produce of the final good

To avoid complications, if the downstream firms are indifferent, they prefer buying from U1.

Example

Suppose

period 1 2 downstream firms D1 with θ_1 and D2 with θ_2 arrive. ($\theta_1 > \theta_2$)

period 2 2 downstream firms D3 with θ_1 and D4 with θ_2 arrive. ($\theta_1 > \theta_2$)

What Social Planner would do.

Given a total production amount of the intermediate good, the social planner allocates the intermediate good to maximize total welfare. Since the total welfare can be described as

$$(\theta_1 - (q_1 + q_2))q_1 + (\theta_2 - (q_1 + q_2))q_2,$$

in the allocation that maximize the total welfare, one downstream firm with the highest θ use all of the intermediate good. This result characterizes the social planner's solution in the intermediate good allocation. In the intermediate production, since there exists a learning-by-doing effect, the production cost of intermediate good is minimized when one upstream firm does all the production for any amount of total production, which characterize the social planner's problem in the intermediate good production. Therefore, at each period, one upstream firm produces all the intermediate good and one downstream firm with the highest θ produces all the final goods up to the point where $P(Q_t, \theta) = \theta - Q_t =$ Long-run marginal cost of the intermediate good.

Equilibrium with Arbitrary Pricing Menu

By backward induction.

2nd Period

Let Q_1 and Q_2 be the production quantity of $U1$ and $U2$ in the 1st period. Let $Q_1 > Q_2$.

The following consists an equilibrium.

1. $U2$ propose a simple linear pricing menu $p(q) = q \times (c^u - kQ_2)$ to both downstream firms.
2. $U1$ propose (1) a simple linear pricing menu $p(q) = q \times (c^u - kQ_2)$ to $D4$ and (2) two part tariff

$p(q) = F_2(Q_1, Q_2) + q \times (c^u - kQ_1)$ to $D3$, where

$$F_2(Q_1, Q_2) = \frac{1}{4} \{k^2(Q_1^2 - Q_2^2) + 2k(Q_1 - Q_2)(\theta_1 - c^u)\}.$$

In the equilibrium, the dominant upstream firm produces all the intermediate good. Since the dominant upstream firm has lower marginal cost, it can always undercut the rival's price. In the downstream market, $D3$ act as if its marginal cost is $c^u - kQ_2$ and $D4$ act as if its marginal cost is $c^u - kQ_1$. Since $U1$ makes the menu to maximize industry profit and tries to extract it all by two part tariff, $U1$ under-supply to $D4$. And $U1$ sets the marginal price equals to the true marginal cost to $D3$ so that $D3$ maximize the profit in the downstream market. However, the amount of the profit that $U1$ can extract is constrained by the fact that both downstream firms can deviate from $U1$'s menu and by the intermediate good from $U2$. The maximum amount of profit that $U1$ can extract is defined by $F_2(Q_1, Q_2)$.

1st Period

Given the analysis above, I next explain the equilibrium in the first period. First, let me describe the equilibrium.

The following consists an equilibrium.

1. $U1$ propose (1) simple linear pricing menu $p(q) = qc^u$ to $D2$ and (2) non-linear pricing $p(q) = qc^u - F_2(q_1^* + q, 0)$ to $D2$, where q_1^* is the equilibrium quantity $D1$ chooses.
2. $U2$ propose the same price-quantity menu as $U1$.

The equilibrium pricing maximizes the industry profit subject to the fact that one of the upstream firms can always supply the intermediate good to downstream firms at the cost of c^u . Since downstream firms favor $U1$, in equilibrium, one upstream firm ($U1$) produces all the intermediate good and designs the menu to maximize the joint surplus of $U1$ and the downstream firms.