Interactions in the Markets for Narrow and Wide-body Commercial Aircraft

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Abstract

The competitive structure of the market for wide-body commercial passenger aircraft has been extensively explored by the literature because the market features several interesting analytic properties such as learning-by-doing, differentiated products, and active trade policy. This paper extends understanding of both the narrow and wide-body commercial, passenger aircraft markets by investigating the competition between firms that produce only in the narrow-body market, such as the Commercial Aircraft Corporation of China (COMAC), and firms that produce in both the narrow and wide-body markets, such as Boeing. A simple, multimarket oligopoly model in the vein of Bulow et al. (1985) is developed and three different cases are analyzed. Price and delivery data is used to assess the validity of the model and provide some interpretation. Finally, the results of the first part are used to discuss the factors that would affect the entry of COMAC into the wide-body market.

Section 1. Introduction

The production of a commercial passenger aircraft is a complex, risky, and long process, and only a handful of firms are usually found in the market at any point in time. Historically, having a successful national aircraft producer has been a source of pride for countries—it is seen as an indicator of their technological expertise. This motivation has led to trade tensions, notably between the United States (US) and Europe, regarding subsidies to aircraft producers. Thus, in order to make thoughtful critiques of trade policy, a number of scholarly studies of the industry, in particular of the large, wide-body segment, have been undertaken in order to determine the socially optimal number of firms in the market. The industry, however, also has many other properties that are of interest to researchers, such as significant learning-by-doing in production, firms operating in multiple market segments, and product differentiation; because there are generally few firms in operation at a given time, it is computationally feasible to use this industry to test economic theories of these phenomena.

Recently, significant advances have been made by Benkard (2004) and Irwin and Pavcnik (2004) in modeling the aircraft production industry. Benkard posits a fully specified, empirical, dynamic, oligopoly model using production data on the Lockheed L-1011, which was conceived and produced unsuccessfully in the late 1960s and 1970s. From this model, a good approximation of the market emerges which is used to analyze learning, welfare, entry dynamics, and other key aspects of the industry. Irwin and Pavcnik specifically analyze the 1992 trade agreement between the US and European Union (EU) and the possible effects of the entry of the Airbus A380, which is intended to challenge the long held dominance of the Boeing 747 in the high capacity, long range market. Both of these papers and the rest of the scholarly literature, however, tend to focus on the two-aisle planes produced almost exclusively by Boeing and Airbus (the only other major producers of these large planes were McDonnell-Douglas and Lockheed, but McDonnell-Douglas merged with Boeing in 1997 and Lockheed exited the market in the early 1980s).

Wide-body planes are not the entire story, though. Narrow-body planes that typically seat 90-175 passengers are important for shorter, regional routes within hub-and-spoke air networks, and both Boeing and Airbus have been active producers of these smaller planes. The Boeing 737 is the best-selling commercial aircraft in the history of the industry with over 7,400 planes delivered as of the end of 2012. There are also firms which produce and compete successfully in the narrow-body market but not the wide-body market. These include Bombardier of Canada, Embraer of Brazil, and the Commercial Aircraft Corporation of China (COMAC). Bombardier and Embraer both emerged as serious competitors in the late 1990s and have become successful players in the narrow-body market today; COMAC is yet to make its first delivery, but its support from the Chinese government, which seems determined to back national champions, suggests it is a company to take seriously.

The narrow-body market has been treated as an outside good in previous research on the wide-body market, but there is evidence that suggests there may be cost linkages between developing small and large plane programs. Markish (2002) provides a valuation analysis for commercial aircraft programs for the entire lifecycle from concept to disposal. A detailed cost model for the development phase of production is produced in which he suggests that since aircraft models often share similar characteristics once the development on one plane has been done, the early development costs on a new one may be significantly lower. This may occur because much of the work can be taken from the earlier program and modified rather than generated from scratch. If these cost linkages between aircraft programs are important even for planes across different passenger and range segments, then once a firm has entered either the wide or narrow-body market it might be easier to enter the other market than attempting to enter without a prior presence in the other. Thus, the firms which are currently only in the narrow-body market might be better candidates for future entrants into the wide-body market than other firms considering entry into the wide-body market only. And, given the Chinese government’s enthusiasm and willingness to commit significant investment in national firms, COMAC is a case of a narrow-body producer that may eventually enter the wide-body market.

Therefore, the purpose of this paper is twofold. The first is to extend understanding of the commercial, passenger aircraft market by investigating the competition between firms that produce only in the narrow-body market, such as COMAC, and firms that produce in both the narrow and wide-body markets, such as Boeing. A simple, multimarket oligopoly model in the vein of Bulow et al. (1985) is developed and three different cases are analyzed based on evidence of the industry. Then price and delivery data is used to assess the validity of the model and provide some interpretation. Finally, the results of the first part are used to discuss the factors that would affect the entry of COMAC into the wide-body market.

This paper is organized as follows: Section 2 discusses the market in greater depth based on both industry sources and scholarly research; Section 3 reviews the background of the theoretical model and then develops and analyzes it for three cases; Section 4 presents models for aircraft demand and sources of data; Section 5 discusses the estimation procedure and reports the results; and Section 6 concludes.

Section 2. Industry Background and Analysis

2.1 World Demand Forecast

Boeing and Airbus both put out twenty year market forecasts in 2011 for aircraft demand which provide some insight into the qualitative nature of the market demand and how the two major producers expect demand to evolve over the coming two decades. There are some differences in how Boeing and Airbus categorize planes which lead to discrepancies in the data. Boeing classifies planes as single-aisle or two-aisle and then subcategorizes by the number of seats. So within the narrow-body segment, there are regional jets, planes with 90-175 seats, and planes with over 175 seats. Within two-aisle planes there are small, medium, and large which categorize planes by the number of seats. Airbus also breaks the fleet up into single-aisle and twin-aisle planes but they reserve a category for very large aircrafts. In this paper the Boeing categories are used: narrow-body planes refers to single-aisle planes with 90-175 seats and planes with over 175 seats; wide-body planes are planes categorized as two-aisles by Boeing.

At the close of 2011, Boeing estimates that there were 12,610 active narrow-body planes in the world passenger aircraft fleet, which accounts for 63% of the world fleet. This number is forecasted to grow to 27,430 planes by 2031, making up 69% of the world total. The wide-body market is also expected to grow from 4,500 planes in 2011 to 10,140 planes by 2031, going from 23% of the world fleet to 25%. Boeing predicts that demand will move away from small regional jets and into narrow and wide-body planes as total demand increases. Airbus takes a contrasting view and measures narrow-body planes as 78% of the world fleet in 2011 and projects that share will decrease to 74% by 2031. In the wide-body market, which excludes very large aircraft such as the A380 and 747, Airbus expects the share of the fleet to decrease from 21% to 20%.

Within the narrow and wide-body market segments, Boeing lists thirty-eight planes as actively in production or already launched. In the narrow-body market these are the Boeing 737-

600, 737-700, 737-800, 737-900ER, and 737 MAX 9; Airbus A318, A319, A320, A319neo, A320neo, A321, and A321neo; COMAC ARJ-900 and C919; Bombardier CRJ-1000, CS100, and CS300; Embraer 190 and 195; UAC MS 21-200 , 21-300, and 21-400; and Tupolev TU-204 and TU-214. In the wide-body market the actively produced planes are the Boeing 767, 787, 777, and 747-8; Airbus A330-200, A350-800, A330-300, A340, A350-900, A350-1000, and A380; and Ilyushin IL-96. This paper focuses entirely on planes produced by Boeing, Airbus, Bombardier, Embraer, and COMAC because data is readily available for their planes.

2.2 The Chinese Aircraft Market

One of the purposes of this paper is to investigate what the characteristics of the narrow and wide-body commercial aircraft markets suggest for the prospects of commercial success for COMAC in both markets over the coming years. The Chinese government has demonstrated willingness to invest capital in high technology sectors and to use its influence in the domestic markets to try and affect outcomes. Currently, the major Chinese airlines need to have all plane purchases approved by the government, and this has led Chinese firms to have fleets that are very diversified by supplier. According to the RAND report *Ready for Takeoff: China's Advancing Aerospace Industry*, in 2007 the Chinese fleet was made up of 55% Boeing planes and 43% Airbus planes with the remaining 2% mostly made up of older McDonnell-Douglas planes produced prior to that firm's merger with Boeing. Given the power the Chinese government has over aircraft purchases and because the Chinese passenger air market is expected to grow phenomenally over the next twenty years, understanding the specifics of Chinese demand will be helpful in investigating COMAC.

The demand for passenger air travel in China has grown significantly since China began to implement market reforms in 1978. The true beginning of development in passenger air travel was in 1980 when the Civil Aviation Administration of China (CAAC) became independent of the military. In the three decades since, passenger volumes have grown rapidly, airlines have consolidated their operations, and air travel networks have solidified into a hub and spoke system. The projections for continued growth in Chinese GDP and personal income will have implications for the demand of wide-bodied aircraft.

Since 1980, three major airlines have dominated the market: Air China, China Southern, and China Eastern. These three airlines are based out of Beijing, Guangzhou, and Shanghai, respectively, which are all large air transportation hubs. There was a major consolidation in 2002 in which many smaller airlines were subsumed by the majors, and the industry was reorganized around the three majors with each one having a trunk line at its service core.

According to Boeing forecasts, domestic revenue passenger-kilometers (RPK), a measure of passenger traffic flows, in China is expected to grow from 380.11 billion in 2011 to 1,140.40 billion in 2031 which represents a 281% total increase and a 6.9% annual increase. This is compared to the more mature North American market which is expected to grow from 952.94 billion in 2011 to 1,451.61 billion in 2031, which works out to a 2.2% annual increase. Boeing also projects the need for 1,450 wide-bodied aircraft to supply the China market in 2031, which represents a 303% increase over the same time period. Airbus projections are in line with Boeing's on wide-body aircraft. In China, Boeing projects that wide-body aircraft will increase from 18.8% of the total fleet to 24.2% from 2011 through 2031.

Generally, wide-body planes are used on trunk routes where there are consistently high passenger volumes. Three routes had flows greater than two million passengers a year in 2005: Beijing – Shanghai, Beijing – Guangzhou, and Shanghai – Shenzhen. According to the RAND report, 50% of domestic Chinese air travel is within the Beijing-Shanghai-Guangzhou triangle, and these routes are operated by the three majors. This ties the continued growth and stability of the majors directly to the development of demand for wide-body planes on Chinese air routes. Extremely high volume lines such as these are where the airlines are able to realize cost benefits from flying fewer, larger airplanes rather than several, smaller ones. Continued increased flows on these lines and the growth of flows on other lines would be key drivers of new, wide-body orders.

Currently, COMAC is only in the market for narrow-body planes with the ARJ21 and C919 models. The ARJ21 is a 90 seat plane that was developed by COMAC in partnership with the Canadian firm Bombardier. Even though final assembly takes place in China, the technically challenging work of the subsystems and wings is being done outside the country. According to the *Airline Monitor,* by the end of 2011 there were 250 orders for the ARJ21, and most of these are from small, domestic Chinese airlines, but COMAC expects to produce up to 850 of these planes within the next two decades. The RAND report caveats the order numbers, though, pointing out that some of the reported orders are only letters of intent or even weaker commitments.

The C919 is in many ways the more interesting and serious domestic aircraft project being pursued by COMAC. It is being produced to seat between 130 and 170 passengers putting it in direct competition with the Boeing 737 and Airbus A320, which have been in the market in some model type since 1963 and 1984, respectively. Production of the C919 is expected by 2014 with the first deliveries by 2020. The *Airline Monitor* reports that by the end of 2011 there were 175 orders for the C919. It is believed that COMAC hopes to eventually produce 150 C919s per year principally to meet domestic demand but also to sell on the international markets.

Despite the rosy view of the demand for Chinese passenger air service over the next twenty years, it is far from clear on a descriptive basis whether COMAC will be able to succeed in the narrow-body market or expand into the wide-body market. Even though the major airlines in China are heavily influenced by the state in aircraft purchases, there is tension about the extent of their commitment to COMAC and the C919 project. According to the RAND study, Air China, China Southern, and China Eastern had only fifteen orders for the C919 between them in 2011. And, they have expressed concerns about tying themselves to an expensive and possibly risky venture.

2.3 Airplane Program Costs and Project Valuations

In the aerospace engineering literature, some helpful work has been done estimating cost functions for the development of airplane programs in part from the motivation that airplane manufacturers themselves may not even have a complete grasp on what their true costs are. Markish (2002) provides a sufficient summary of most of the literature which is of interest because of the insights it provides into what drives costs on specific models at a very detailed level.

Markish observes that the cost of an airplane can be broken down roughly into two parts: development and manufacturing. Development includes design work, fabrication of the required tools, testing, and certification. His process is to break down an aircraft into parts such as wings, fuselage, systems etc., from there the costs of engineering, manufacturing engineering, tool design, tool fabrication, and support are estimated for each part. An important observation is that there may be significant commonality effects within the development process. If a single firm produces multiple planes then some of the parts or processes needed to produce one type of plane can be reused in making another without having to incur the costs of development again. Hence, a firm that only produces narrow-body planes but is considering whether it should produce wide bodies may face lower development costs for the wide-body planes if they are able to use a non-trivial amount of the work and tools from their narrow-body projects. Or, for a firm that already produces both plane types, innovations or changes in the cost structure of one plane could have spillovers into the other market. However, the cost savings from commonality are extremely hard to quantify and are therefore difficult to estimate, so the author uses a rough approximation to capture this effect in the cost model.

The manufacturing cost estimation is approached in a similar fashion. An aircraft is broken up into parts and then costs for manufacturing each part are broken out by labor, material, and other costs, which include quality assurance and recurring costs in engineering and tooling. It is in this process where significant learning-by-doing enters into the model through the labor parameter. As is discussed more in the next section, the learning process captures the effect that over time and repeated application, workers become more efficient at producing planes, thus reducing marginal costs as the total quantity of planes produced increases. The learning process is the cost parameter that the economics literature analyzing the commercial, passenger aircraft industry tends to focus on because theoretical learning-by-doing models have a long history and are well understood; and their effects on the market often yield interesting and sometimes unexpected results. These cost models, though, suggest that in addition to learning, there are other spillover processes at work in the production of commercial aircraft that can have significant effects which might affect the true level of fixed costs for an aircraft being produced by a firm which is already an incumbent either in the market in which the plane is entering or in a related market.

2.4 Literature Review

The market for commercial, passenger aircraft has been studied in depth by economists for well over thirty years now. The limited number of competitors, huge development costs, presence of strong learning effects, and national prestige of having a national aircraft manufacturer are just a few of the reasons the industry appeals to the researcher. This research has led to a consensus about many aspects of the market, especially for wide-bodied planes, which, as categorized by Boeing, can carry from 180 to over 400 passengers. Today, Boeing and Airbus are the only firms producing in the market for wide-bodied airplanes.

An early paper on the market for wide-bodied aircraft was written by Baldwin and Krugman (1988) and focuses on welfare and international trade policy issues raised by the particular competition of this market. The issues of interest are estimating the size of the subsidy made to Airbus by Europe and the welfare effects on consumers in the US, Europe and the rest of the world due to Airbus' presence in the market. Demand by airlines is modeled as a choice between the Boeing 767 the Airbus A300, and airlines compare the marginal benefits of the planes based on the number of planes of the same type that are already in their fleet. A constant elasticity of demand is assumed. On the supply side, a Cournot model with learning is used, and it is assumed that firms act only as monopolists on the residual demands. In the base case, they allow for Airbus to be subsidized sufficiently for it to be in the market, and a value for the demand elasticity is chosen. The simulation shows that once Airbus enters the market, prices trend downwards only slowly. This is taken as a *prima facie* confirmation of the approach because it is widely known that prices in the commercial aircraft industry remain constant over time. In terms of the subsidy, the model suggests that it has a predominantly redistributive effect in moving surplus from Boeing to both Airbus and consumers. However, the authors acknowledge the limits of their results and neither claim to make any statements about how entry in the industry operates, nor the strategies Boeing and Airbus might employ as new planes enter the market.

This paper was followed by Klepper (1990) who analyzed the industry by hypothesizing that competition is waged in capacities. The firms choose capacity levels and play a Cournot price game in the short run, and in the long run the choice of capacity determines the competition. With demand for future orders uncertain, producers need to commit to capacities ahead of time based on unreliable demand estimates. Klepper claims that, in extreme cases where realized demand is less than expected, planes may be produced without a buyer. However, the assumption that capacity is the strategic variable used by aircraft manufacturers seems to be implausible as extensive and persistent backlogs in production are observed in this industry. Proceeding, the effects of a firm entering this market are analyzed and projected out over a twenty year period. Identical cost-functions are used for two firms in the market, which are representative of Boeing and Airbus. These firms produce products in three market segments: short range, narrow-body; short/medium, range wide-body; and long range wide-body. The demand function is assumed to be linear and forecasted demand estimates are used in the simulation. The results show Boeing dominating the narrow-body market and roughly splitting the remaining two with Airbus. The model as calibrated suggests a very long time horizon for firms to realize a profit upon entering; the proposed entrant is just making a profit at the end of the simulation. The welfare of consumers of having one versus two competitors is also investigated and it is suggested that a Boeing and Airbus duopoly reduces overall welfare compared to a Boeing monopoly. The claim is that the strong effects of economies of scale and scope in this industry drive profits, so even though two firms produce more consumer surplus, the reduction in total profits by moving from one firm to two beats out the increase in consumer surplus.

A major contribution was made by Benkard (2004) who uses a fully specified dynamic, empirical model to investigate the properties of the wide-bodied aircraft industry. He incorporates institutional forgetting into the learning aspects of the model, which takes into account that firms periodically lay off workers and then rehire. Thus, the workers need to be retrained on how the production process works, which can take years and hampers productivity in the meantime. The model estimates a 36% learning parameter which means that when production experience is doubled the labor requirements fall by 36%. The requirement for a detailed set of cost data is an important limitation in all analyses of this industry because the changing nature of the cost structure over time plays such an important role in making an airplane. This paper gets around this by using an extremely detailed data set for the Lockheed L-1011, which had exited the market after unsuccessfully trying to compete against the McDonnell-Douglas DC-10 and Boeing 747. The complicated, detailed model that emerges gives a reasonably complete picture of the industry. The simulation suggests pricing strategies and policies that match closely the observed prices that Lockheed negotiated for the L-1011. The fact that the below marginal cost pricing is persistent through the life of the L-1011 in the simulation is taken as good evidence for the validity of the model since this behavior departs so drastically from what is expected of profit maximizing firms. The discrepancies that do exist may be due to the extremely high substitutability between the L-1011 and DC-10, which may not be taken fully into account by the model. It also suggests a time horizon of 10-15 years for firms to reach profitability, if they ever do. The model also allows for firms to produce three types of wide-bodied planes: Small, Medium, and Large, which are chosen based on the number of seats on the plane.

Demand estimates are made using data from 1975 through 1994, and the model of demand using the number of seats, number of engines, price, and other characteristics as parameters. The results suggest that new wide-body planes substitute more readily with each other than with either used jet planes or narrow-body planes. This result is coupled with high cross-price elasticity estimates.

The model further suggests several important aspects about the industry concentration and dynamics. Concentrations are initially very high and there are many firms in the market, but over time concentrations drop off dramatically. Of the three plane types considered, large planes are the least likely to enter the market. These predictions agree with previous beliefs about the nature of the industry. A twenty year, representative simulation brings to light some of the dynamics. Over the course of the simulation five firms variously enter and exit with one of them staying in for only a short while, exiting just as it reaches the bottom of its learning curve. The other four remain in until the end of the simulation, only three ever earn profits on their planes, and those profits are not, in each case, sufficient to provide a positive return on the total investment. This simulation matches reasonably well with industry data observed from the 1970s through the 1990s. Lockheed stayed in only for a little while and never did well with the L-1011, and Boeing and Airbus dominated with McDonnell-Douglas muddling along.

This thorough model and analysis of the industry is a major step toward understanding how the commercial aircraft industry works in practice. However, several assumptions had to be made to make the problem computationally feasible. In particular, the model ignores joint profit maximizations across product ranges by the same firm, which effectively treats the firms as producers of a single product, as if the firms decide which one of the possible models to produce based on a random draw. However, we see Boeing and Airbus actively producing many models in all the major plane size categories. So there seems to be evidence that a firm’s involvement in multiple markets is important to its strategy in them. Similarly, because airlines have a decision to fly one plane or two – or many – over a route, the demands for different planes may be interrelated.

Working concurrently to Benkard (2004) a paper by Irwin and Pavcnik (2004) estimates a differentiated product demand system for the wide-bodied market in order to evaluate the price effects of both the 1992 trade agreement on subsidies between the US and Europe and the entry on the A380 super-jumbo, which made its first delivery in 2007. Unlike Benkard (2004) the authors did not have access to detailed cost data, so the demand model is estimated using publically available data on prices, sales, and airplane characteristics. They also allow for market segmentation and product differentiation, an aspect of the market that was not deeply investigated by Benkard (2004) because of the computational burden that would be required in the fully specified model. Particularly, the commercial airplane market is segmented into narrow bodies, medium range wide bodies, and long range wide bodies. Firms looking to purchase a wide-body plane have a choice of purchasing a new wide-body or an outside good, which is a narrow-body or a used wide-body. The estimation results suggest that planes within the same market segment are better substitutes than planes in other market segments. So the introduction of a new product or strategy has more effect on shares within the same market than within the other markets.

The authors do not assume a specific type of competitive structure and only rely on firms maximizing the present discounted value of profits. In equilibrium, the firms equate the marginal revenue product of each plane to the dynamic marginal costs, which are equal to the current marginal cost plus discounted value of cost savings accumulated by the learning process. They test the model under several structures using a multi-product Bertrand scenario as the base case. The results show average markup margins decreasing over time, suggesting competition has increased in the wide-body market over the time period in question. They also find that firms that sell planes in both wide-body market segments can sustain higher price markups than firms that operate in only one segment. Markups are at their lowest point when new products enter the market, which supports previous results in the literature that planes are initially sold at massive discounts because firms can access lower costs later on as they work down the learning curve.

Using the results of their model, the authors find that the 1992 treaty did result in an increase in the prices of Boeing and Airbus planes. They estimate that the price increases which are observed in the data of 3.7 – 7.5% represent an increase in the marginal costs of both firms of about 5 – 10%. The simulation of entry by the A380 into the market for long range wide-body planes leads to Airbus picking up 17.4% of the long range market. The entry also causes long range planes to lose share to medium range planes by 1.6%. Further, even though Airbus is predicted to pick up considerable share of the long range market, the A380 substantially undercuts demand for other Airbus planes in the medium range market.

The issues that Boeing and Airbus face as multi-product firms are highlighted in this paper and seem to be important issues in their overall strategies. The authors ignore the interactions of the medium and long range wide-body market with the narrow-body market because the trade issues in which they are interested do not apply to the narrow-body segment, and because there are more planes and firms in the narrow-body segment, making analysis more difficult. However, if demands for these three types of planes are significantly interrelated then the narrow-body market could be important in determining outcomes in the wide-body market. For example airlines, especially major firms that serve many routes, may make purchase decisions based on a desire to diversify their fleets to serve their multiple markets. And, it is thought that some airlines may purchase fleets which favor one producer over another in order to take advantage of cost savings in repair services.

Section 3. Theoretical Model

3.1 Model Background

While the market for wide-bodied aircraft alone, even with product differentiation within this market, is now on its way to being well-understood, it is still an open question as to what the effects are of firms being in the market for both wide-bodied and narrow-bodied planes. As of 2011 Boeing and Airbus were actively producing planes in the narrow-body market which made up 63% of the world fleet share and was expected to grow to 69% by 2031, according to Boeing predictions. When considering the purchase of an airplane, airlines can choose to either buy a single, large plane to fly fewer routes or buy multiple small planes which will run more frequently. This decision suggests that wide and narrow-body planes have strong interrelated demands. So, in order to better understand the commercial aircraft industry as a whole and how the wide-bodied market in particular operates, it is necessary to extend the analysis to explicitly study the wide and narrow-body markets together.

The model presented below to analyze the narrow and wide-body commercial aircraft industries is a multimarket oligopoly model of the type presented in Bulow et al. (1985). The authors’ analysis departs from the observation that if a firm operates in two markets a change in one market can affect the outcomes of the other market by changing competitors’ strategic choices by changing the firm’s own marginal costs. They consider a scenario in which there are two firms: A and B and two markets: 1 and 2. Firm A is a monopoly in market 1, and Firms A and B compete simultaneously in market 2 using a strategic variable, such as price or quantity or advertising. Then, a positive shock *Z* in market A is added, and the effects are considered. They then compute the total derivatives of profit functions with respect to *Z* and conclude that the effect on total profits can be determined by the consideration of two relationships: whether there are joint economies or diseconomies and if the goods in market 2 are strategic substitutes. Joint economies and diseconomies arise from whether Firm A increases or decreases its marginal profits by producing in both markets. Strategic substitutes and complements describe the optimal strategy of Firm B if A pursues a more aggressive strategy, i.e. lowering prices or increasing quantities. They define strategic substitutes as goods for which it is optimal for B, in the sense that doing so increases its marginal profits, to respond aggressively to A; a price cut by A would be met with a price cut by B. Strategic complements are goods for which B does not respond aggressively to A; if A lowers prices, B will respond by increasing prices.

This framework is then extended to consider a host of cases. Sequential markets are analyzed because of their importance in learning-by-doing cases where the price chosen in the first period affects the cost function in the second. This type of problem is similar to earlier ones considered in the literature which suggest that firms may overinvest in capacity in the first period in order to lower marginal costs later on. This type of strategy can also be used to deter potential entrants by forcing them to invest in high fixed costs upfront. The authors suggest that the case of overinvestment is actually a special case of the more general problem and that underinvestment may also be a rational strategy. Specifically, if the goods are strategic complements and the competition is in prices, then a firm may underinvest in capacity to maximize profits. They provide an example where in a situation with price competition and linear demand entry can be deterred by an overinvestment strategy, but underinvestment will be used to avoid a price war if entry is inevitable.

The base case is also considered where the strategic variables are prices instead of quantities, which implies that products are differentiated. It is shown that the strategic relationship of the goods if marginal costs are constant depends entirely on the elasticity of the firm’s own output. If marginal costs are not constant, then the picture gets more complicated. For constant elasticity, increasing marginal costs implies strategic complements, and decreasing marginal costs implies strategic substitutes. If demand is linear and marginal costs are increasing, then the goods are always strategic complements. These are just a few examples, but it is clear that the possibilities rely on several key parameters: elasticity, marginal costs, and demand.

One important case noted briefly in this paper is when demands in the markets are interrelated. In that scenario, instead of joint economies and diseconomies, the way the two goods produced by a single firm in multiple markets interact with each other is important. In this type of case, firms must consider whether demand in market 1 is complementary to demand in market 2 or not. If the demands are complementary then selling in market 1 will help the firm's prospects of selling in market 2. This is a key issue that will come into play in the markets for narrow and wide-body planes. Airbus initially entered the market for wide-body planes with the A300, but now it produces seven models in the narrow-body market such as the A318, A319, A320, A321, and variations on those lines. Similarly, Boeing is active in both markets with the 737 and its variations in the narrow-body market and many different models in the wide-body market such as the 747, 767, and 777.

3.2 Model Presentation and Analysis

Using the multimarket oligopoly framework of Bulow et al. (1985) which is presented above, a stylized model will be developed to investigate how the narrow and wide-body markets are interrelated. In this model there are two markets: the market for narrow-body planes and the market for wide-body planes. Following the classifications used by Boeing in its *Current Market Outlook 2012-2031*, narrow-body planes include single-aisle planes that seat 90-175 and more passengers and wide-body planes include two-aisle planes that seat 180-400 plus passengers. This is a generalization of the previous literature which tends to focus only on the wide-body market and segments it into either two or three classes of planes based on their seating capacity and range. Since the focus of this paper is to investigate linkages between the narrow and wide-body markets, product differentiation within the wide-body market is not considered. Further, it is assumed that narrow and wide-body planes are substitutes for each other. This assumption deserves a little attention, though. When considering an aircraft for a route, the airline faces a choice of flying more passengers on fewer trips with a larger plane or few passengers on less frequent trips using a smaller plane. If there is sufficient traffic flow, then typically the former choice is more cost effective from an operating standpoint. However, for airlines that have routes which are both long and short or have different volumes along them, then it may be that the airline will purchase narrow and wide-body planes as complements. In the literature only the substitution scenario seems to be relevant, though, so that is the assumption made here.

There are three cases considered using the theoretical model. The first follows directly from Bulow et al. (1985) and is the case described above with two firms, the markets for narrow-body and wide-body planes and interrelated demands. In case two, demands are made to be linear. Case three incorporates learning-by-doing in which as firms produce more planes they reduce their marginal costs. Typically this situation is modeled in multiple period models, but to simplify the analysis, here learning takes place all in a single period. To justify this, one may consider the period to be the lifespan of the product; after producing the first plane the next one requires less labor input because workers have learned about the production process. This continues throughout the production process so the marginal cost of the last plane produced will be less than that of the first one.

In these two markets, there are two representative firms. The first firm sells in both the narrow and wide-body markets, and the other sells only in the narrow-body market. The existing literature has not come to a consensus as to whether price or quantity competition is more appropriate for the commercial aircraft industry, but here competition is in prices and products are differentiated. Price was chosen because of the significant amount of negotiation that goes into individual plane contracts, which takes into account not only the price of the plane itself but also a number of "green stamps" which include repair guarantees and other allowances. This is presented as a single period model so the firms maximize their profits with respect to the prices of the planes they produce. The following equations describe the situation:

$$\text{(1)} \qquad \max_{p_1^B, p_2^B} \Pi^B = p_1^B * q_1^B(p_1^B, p_2^B, p_2^C) + p_2^B * q_2^B(p_1^B, p_2^B, p_2^C) - C^B\left(q_1^B(\bullet), q_2^B(\bullet)\right)$$

$$\text{(2)} \qquad \max_{p_2^C} \Pi^C = p_2^C * q_2^C(p_1^B, p_2^B, p_2^C) - C^C\left(q_2^C(\bullet)\right)$$

Here, Π^i, i = B, C, is the profit to Firm i, and Firm B operates in both the narrow and wide-body markets and Firm C operates only in the narrow-body market. Quantities are given by q_m^i, i = B, C and m = 1, 2, where B and C are as before and m is the market in which the good is sold with Market 1 representing the wide-body market and Market 2 the narrow-body.

There are three first-order conditions which are as follows:

$$\text{(3)} \qquad \frac{\partial \Pi^B}{\partial p_1^B} = q_1^B + p_1^B \frac{\partial q_1^B}{\partial p_1^B} + p_2^B \frac{\partial q_1^B}{\partial p_1^B} - MC_1^B \frac{\partial q_1^B}{\partial p_1^B} - MC_2^B \frac{\partial q_2^B}{\partial p_1^B} = 0$$

$$\frac{\partial \Pi^B}{\partial p_2^B} = q_2^B + p_2^B \frac{\partial q_2^B}{\partial p_2^B} + p_1^B \frac{\partial q_1^B}{\partial p_2^B} - MC_1^B \frac{\partial q_1^B}{\partial p_2^B} - MC_2^B \frac{\partial q_2^B}{\partial p_2^B} = 0 \tag{4}$$

$$\frac{\partial \Pi^C}{\partial p_2^C} = q_2^C + p_2^C \frac{\partial q_2^C}{\partial p_2^C} - MC_2^C \frac{\partial q_2^C}{\partial p_2^C} = 0 \tag{5}$$

In (4), (5) and (6) $MC_m^i = \frac{\partial C_m^i}{\partial q_m^i}$ is the marginal cost to Firm *i* of producing a plane in the *m*-th market. Now, to determine the effect a shock in wide-body plane market has on the strategy of the firm which is only in narrow plane market, it must be determined if there are joint economies or diseconomies and if the two plane types are strategic substitutes or complements.

The joint economies or diseconomies are determined by analyzing the sign of $\frac{\partial^2 \Pi^B}{\partial p_1^B \partial p_2^B}$. So, equation (3) is differentiated with respect to p_1^B:

$$\frac{\partial^2 \Pi^B}{\partial p_1^B \partial p_2^B} = \frac{\partial q_1^B}{\partial p_2^B} + p_1^B \frac{\partial^2 q_1^B}{\partial p_1^B \partial p_2^B} + \frac{\partial q_2^B}{\partial p_1^B} + p_2^B \frac{\partial^2 q_2^B}{\partial p_1^B \partial p_2^B} - \frac{\partial^2 C^B}{\partial (q_1^B)^2} \frac{\partial q_1^B}{\partial p_1^B} \frac{\partial q_1^B}{\partial p_2^B} - \frac{\partial^2 C^B}{\partial (q_2^B)^2} \frac{\partial q_2^B}{\partial p_1^B} \frac{\partial q_2^B}{\partial p_2^B}$$

$$= p_1^B \frac{\partial}{\partial p_2^B} \frac{\partial q_1^B}{\partial p_1^B} + p_2^B \frac{\partial}{\partial p_2^B} \frac{\partial q_2^B}{\partial p_1^B} + \frac{\partial q_1^B}{\partial p_2^B}\left(1 - \frac{\partial^2 C^B}{\partial (q_1^B)^2} \frac{\partial q_1^B}{\partial p_1^B}\right) + \frac{\partial q_2^B}{\partial p_1^B}\left(1 - \frac{\partial^2 C^B}{\partial (q_2^B)^2} \frac{\partial q_2^B}{\partial p_2^B}\right) \tag{6}$$

The sign of (6) comes down to four terms. The first is $\frac{\partial}{\partial p_2^B} \frac{\partial q_1^B}{\partial p_1^B}$, the rate at which the slope of the demand curve for wide-body planes changes when the price of narrow bodies increases. The next term is $\frac{\partial}{\partial p_2^B} \frac{\partial q_2^B}{\partial p_1^B}$ which measures the rate at which wide-body planes are substituted for narrow bodies as the price of narrow bodies changes. And, the final two terms measure whether the marginal costs with respect to both products are increasing, decreasing or constant. In both cases if marginal costs are increasing, then $\frac{\partial q_m^B}{\partial p_n^B}\left(1 - \frac{\partial^2 C^B}{\partial (q_m^B)^2} \frac{\partial q_m^B}{\partial p_m^B}\right) > 0$. And, even if marginal costs are decreasing if $\frac{1}{\frac{\partial q_m^B}{\partial p_m^B}} \leq \frac{\partial^2 C^B}{\partial (q_m^B)^2} < 0$, in other words, even with decreasing marginal costs, as long as they decrease faster than the inverse of the slope of demand for that product, the net effect will be positive. Generally, though, there may be joint economies or diseconomies in this general case.

Turning to the strategic properties of the goods, we analyze the sign of $\frac{\partial^2 \Pi^C}{\partial p_2^C \partial p_2^B}$. Equation (5) is differentiated with respect to p_2^B:

$$\frac{\partial^2 \Pi^C}{\partial p_2^C \partial p_2^B} = \frac{\partial q_2^C}{\partial p_2^B} + p_2^C \frac{\partial^2 q_2^C}{\partial p_2^C \partial p_2^B} - \frac{\partial^2 C^C}{\partial (q_2^C)^2} \frac{\partial q_2^C}{\partial p_2^C} \frac{\partial q_2^C}{\partial p_2^B}$$

(7) $$= p_2^B \frac{\partial}{\partial p_2^B}\frac{\partial q_2^C}{\partial p_2^C} + \frac{\partial q_2^C}{\partial p_2^B}\left(1 - \frac{\partial^2 C^C}{\partial \left(q_2^C\right)^2}\frac{\partial q_2^C}{\partial p_2^C}\right)$$

Similarly, the sign of (7) comes down to the properties of the marginal cost function and how the slope of the demand function for narrow-body planes produced by Firm C changes when Firm B changes the price of its narrow-body planes. Also, even if marginal costs are decreasing, the sign of the entire second term will be positive as long as $\frac{1}{\frac{\partial q_m^B}{\partial p_m^B}} \leq \frac{\partial^2 C^B}{\partial \left(q_m^B\right)^2} < 0$.

Now, we will consider the case where all of the demand functions are linear. A typical demand function looks like

(8) $$q_m^i = a - bp_m^i + cp_n^i + dp_n^j$$

Here *m* and *n* index the narrow and wide-body markets, *i* and *j* index the two firms and *a, b, c* and *d* are constants. The signs on the constants come from the assumption that products are substitutes. Now, equations (6) and (7) are revisited. Equation (6) reduces to

(9) $$\frac{\partial^2 \Pi^B}{\partial p_1^B \partial p_2^B} = \frac{\partial q_1^B}{\partial p_2^B}\left(1 - \frac{\partial^2 C^B}{\partial \left(q_1^B\right)^2}\frac{\partial q_1^B}{\partial p_1^B}\right) + \frac{\partial q_2^B}{\partial p_1^B}\left(1 - \frac{\partial^2 C^B}{\partial \left(q_2^B\right)^2}\frac{\partial q_2^B}{\partial p_2^B}\right)$$

So the sign of (9) is completely determined by whether the marginal costs to Firm B of producing narrow and wide-body planes are increasing, decreasing or constant. As discussed above the only case in which the sign actually turns negative on either term in (9) is if marginal costs are decreasing and $\frac{\partial^2 C^B}{\partial \left(q_m^B\right)^2} < \frac{1}{\frac{\partial q_m^B}{\partial p_m^B}}$. The sign on equation (9) may also be negative if one of the marginal costs is increasing but the other is decreasing at a faster rate. For example, if narrow-body planes' marginal costs decrease rapidly because the planes are smaller and learning the production process does not take as long as on large planes, then the sign of (9) would be negative, implying the presence of joint diseconomies. A similar story holds in equation (7) when there are linear demands:

(10) $$\frac{\partial^2 \Pi^C}{\partial p_2^C \partial p_2^B} = \frac{\partial q_2^C}{\partial p_2^B}\left(1 - \frac{\partial^2 C^C}{\partial \left(q_2^C\right)^2}\frac{\partial q_2^C}{\partial p_2^C}\right)$$

The sign on (10) will be determined entirely by whether marginal costs are increasing, decreasing or constant. But, the only time the sign (10) is negative is if $\frac{\partial^2 C^C}{\partial \left(q_m^C\right)^2} < \frac{1}{\frac{\partial q_2^C}{\partial p_2^C}}$. If this is the case, then narrow-body planes produced by different firms are strategic substitutes. So, a price cut (an aggressive move) by Firm B would be met with price increase by Firm C.

Finally, the model is extended to allow for a simplistic learning-by-doing effect in which as more planes are produced the marginal cost of producing the next one decreases. In this case a new cost function is defined as follows

$$(11) \qquad C^i = C^i\left(q_1^i(\bullet), q_2^i(\bullet), E^i\left(q_1^i(\bullet), q_2^i(\bullet)\right)\right)$$

Here, the function $E^i\left(q_1^i(\bullet), q_2^i(\bullet)\right)$ is an experience function and has the following properties: (A) $\frac{\partial E}{\partial q_1^i} < 0$ and (B) $\frac{\partial^2 E}{\partial\left(q_1^i\right)^2} < 0$. Condition (A) shows that as the firm accumulates experience it is able to reduce its costs by producing the product more efficiently, and condition (B) limits the accumulation of experience. Both conditions (A) and (B) are present in the narrow and wide-body commercial aircraft industry.

The addition of the experience function changes the first order conditions so that equations (3), (4) and (5) are now

$$(12) \qquad \frac{\partial \Pi^B}{\partial p_1^B} = q_1^B + p_1^B \frac{\partial q_1^B}{\partial p_1^B} + p_2^B \frac{\partial q_1^B}{\partial p_1^B} - \frac{\partial C^B}{\partial q_1^B}\frac{\partial q_1^B}{\partial p_1^B} - \frac{\partial C^B}{\partial q_2^B}\frac{\partial q_2^B}{\partial p_1^B} - \frac{\partial C^B}{\partial E^B}\left(\frac{\partial E^B}{\partial q_1^B}\frac{\partial q_1^B}{\partial p_1^B} + \frac{\partial E^B}{\partial q_2^B}\frac{\partial q_2^B}{\partial p_1^B}\right) = 0$$

$$(13) \qquad \frac{\partial \Pi^B}{\partial p_2^B} = q_2^B + p_2^B \frac{\partial q_2^B}{\partial p_2^B} + p_1^B \frac{\partial q_1^B}{\partial p_2^B} - \frac{\partial C^B}{\partial q_1^B}\frac{\partial q_1^B}{\partial p_2^B} - \frac{\partial C^B}{\partial q_2^B}\frac{\partial q_2^B}{\partial p_2^B} - \frac{\partial C^B}{\partial E^B}\left(\frac{\partial E^B}{\partial q_1^B}\frac{\partial q_1^B}{\partial p_2^B} + \frac{\partial E^B}{\partial q_2^B}\frac{\partial q_2^B}{\partial p_2^B}\right) = 0$$

$$(14) \qquad \frac{\partial \Pi^C}{\partial p_2^C} = q_2^C + p_2^C \frac{\partial q_2^C}{\partial p_2^C} - \frac{\partial C^C}{\partial q_2^C}\frac{\partial q_2^C}{\partial p_2^C} - \frac{\partial C^C}{\partial E^C}\frac{\partial E^C}{\partial q_2^C}\frac{\partial q_2^C}{\partial p_2^C} = 0$$

As before now, the joint economies or diseconomies as well as the strategic relationships are considered. These conditions become

$$(15) \qquad \frac{\partial^2 \Pi^B}{\partial p_1^B \partial p_2^B} = p_1^B \frac{\partial}{\partial p_2^B}\frac{\partial q_1^B}{\partial p_1^B} + p_2^B \frac{\partial}{\partial p_2^B}\frac{\partial q_2^B}{\partial p_1^B} + \frac{\partial q_1^B}{\partial p_2^B}\left(1 - \frac{\partial^2 C^B}{\partial\left(q_1^B\right)^2}\frac{\partial q_1^B}{\partial p_1^B} - \frac{\partial^2 C^B}{\partial\left(E^B\right)^2}\frac{\partial^2 E^B}{\partial\left(q_1^B\right)^2}\frac{\partial q_1^B}{\partial p_1^B}\right) + \frac{\partial q_2^B}{\partial p_1^B}\left(1 - \frac{\partial^2 C^B}{\partial\left(q_2^B\right)^2}\frac{\partial q_2^B}{\partial p_2^B} - \frac{\partial^2 C^B}{\partial\left(E^B\right)^2}\frac{\partial^2 E^B}{\partial\left(q_2^B\right)^2}\frac{\partial q_2^B}{\partial p_2^B}\right)$$

$$(16) \qquad \frac{\partial^2 \Pi^C}{\partial p_2^C \partial p_2^B} = p_2^B \frac{\partial}{\partial p_2^B}\frac{\partial q_2^C}{\partial p_2^C} + \frac{\partial q_2^C}{\partial p_2^B}\left(1 - \frac{\partial^2 C^C}{\partial\left(q_2^C\right)^2}\frac{\partial q_2^C}{\partial p_2^C} - \frac{\partial^2 C^C}{\partial\left(E^C\right)^2}\frac{\partial^2 E^C}{\partial\left(q_2^C\right)^2}\frac{\partial q_2^C}{\partial p_2^C}\right)$$

In the joint economies and diseconomies equation (15), the analysis is the same in the general case with the added complication of the rate at which costs increase or decrease as experience is accumulated. So, the sign on the fourth and fifth terms of (15) will depend on the comparison of the rate at which marginal costs change with new output with the rate at which marginal costs decrease with the added experience of that output. The same is true in determining the strategic properties of the goods in (16). The total change in marginal costs to Firm C from a change in the price charge by Firm B in Market 2 depends on whether the experience accumulated by producing additional output diminishes costs faster than the rate at which the new output increases them.

Section 4. Data Presentation and Analysis

4.1 Models of Demand

In order to estimate own and cross-price elasticities for narrow and wide-body planes and to see how the demands are related for planes in different segments produced by the same firm, several sets of models of demand were constructed. It is known from the literature that prices are relatively uncorrelated over time and that differentiation by seats and range, and gross domestic product (GDP) are important drivers of demand. Three sets of models were constructed to specify demand for narrow and wide-body planes produced by Boeing and Airbus given different sets of parameters.

The first set of models sets deliveries in a given year as a function of the unit price, the average price weighted by deliveries of planes produced by other firms in the same market segment, the average price weighted by deliveries of all planes in the other market segment, a dummy variable indicating the model type, and GDP of four regions: the US, EU, Latin America, and Asia. The dummy variables are included to capture the idiosyncrasies of the individual models. For example, planes are often differentiated by seat count and maximum range, but planes are also produced to the specifications of the buyer, and this individual purchase data is not available. So the dummy variable captures the unique properties of the individual models that are of interest to airlines. Regional GDP captures the effect that changes in income have on the demand for air travel, and thus, airplanes. In addition to current year GDP, two model variations are considered that use GDP lagged by one and two years. Since planes delivered in a given year represent orders placed several years before, lagged GDP may be a better indicator of deliveries as it represents the information available to airlines at the approximate time of order. Finally, for the narrow-body market only, two other variations are made that replace the weighted average price of all wide-body planes with the weighted average price of wide-body planes produced by the same firm and the weighted average price of wide-body planes produced by other firms. Table 4.1 lists the six demand models for narrow-body planes produced by Airbus:

Table 4.1: Demand models for Airbus narrow-body planes at time *t*

ln_deliver$_t$	**Model 1**	**Model 2**	**Model 3**	**Model 4**	**Model 5**	**Model 6**
ln_unitprice$_t$	x	x	x	x	x	x
ln_narrowWAP_noAir$_t$	x	x	x	x	x	x
ln_wideWAP$_t$	x					
ln_wideWAP_noBoe$_t$		x		x		x
ln_wideWAP_noAir$_t$		x		x		
a318$_t$	x	x	x	x	x	x
a319$_t$	x	x	x	x	x	x
a320$_t$	x	x	x	x	x	x
gdp_eu$_t$	x	x				
gdp_us$_t$	x	x				
gdp_latam$_t$	x	x				
gdp_asia$_t$	x	x				
gdp_eu$_{t-1}$			x	x		
gdp_us$_{t-1}$			x	x		
gdp_latam$_t$			x	x		
gdp_asia$_{t-1}$			x	x		
gdp_eu$_{t-2}$					x	x
gdp_us$_{t-2}$					x	x
gdp_latam$_{t-2}$					x	x
gdp_asia$_{t-2}$					x	x

The second set of models replaces the dummy variables for model type with terms that interact the dummy variables with the unit price. These variables are included to capture the ways the unique properties of individual models directly affect the price of the planes. The models for this set of cases are identical to those in Table 4.1, except that the variables *a318*, *a319,* and *a320* are replaced with *ln_unitpricea318, ln_unitpricea319* and *ln_unitpricea320*. The third set of models includes both the dummy and interaction terms.

In all the model variations outlined above, delivery and price data are all assumed to vary as natural logarithms. This functional form is assumed to make calculating the own and cross price elasticities more straightforward.

From the discussion in Section 3, all of the price variables are expected to be endogenous. Using the case of Airbus and the variables in Table 4.1, it is expected that a change in the unit price of a narrow-body plane produced by Airbus will increase deliveries of those planes, decrease deliveries of the other narrow-body planes in the market, and decrease deliveries of wide-body planes as airlines find it more cost effective to run larger planes less frequently over air routes. This implies that the sign on *ln_narrowWAP_noAir* 4.1 should be positive, and it will depend on *ln_unitprice* and *ln_wideWAP*. Likewise, *ln_wideWAP* is expected to be positive because as wide-body planes get more expensive, firms will move toward buying narrow-body planes and run them more frequently over the same routes as the wide bodies. In the cases where two variables, which distinguish between planes produced by Airbus and Boeing, are used, the signs are less clear. For *ln_wideWAP_noAir*, as wide-body planes produced by Boeing get more expensive, airlines can either switch to wide-body Airbus planes or narrow-body planes produced by any firm in the market (Boeing, Airbus, Embraer etc.) so the sign could be positive or negative. The same is true for *ln_wideWAP_noBoe*, but if airlines prefer to have fleets that favor a single producer to take advantage of repair cost synergies, as Section 2suggests they may, then the sign will be positive: as wide-body planes produced by Airbus get cheaper, airlines will also buy more narrow-body planes made by Airbus.

4.2 Model Estimation Procedure

From the preceding discussion, it is clear that *ln_unitprice, ln_narrowWAP_noAir, ln_wideWAP, ln_wideWAP_noAir* and *ln_wideWAP_noBoe* are all expected to be endogenous in the model. Thus, the model estimation is done using an instrumental variable two-stage least squares procedure. Following suggestions in Irwin and Pavcnik (2004) and Benkard (2004), the number of years the plane has been in production, which is calculated from the year of the first delivery of the model; the price of aluminum in the current year, the year prior, and two years prior; and the hourly manufacturing wage of the country in which the producer is headquartered for the current year, and two years prior are all used as instrumental variables.

All of the IVs above are chosen because they are expected to be correlated with the price variables, through their relationship to the manufacturer's cost, but not with deliveries. The number of years a plane has been in production works because of the strong learning effects in the production process; firms have more price flexibility the longer a plane has been in production because their marginal costs decrease as more units are produced. However, airlines should be indifferent to planes of the same model type that differ only in the year of production. Aluminum and the manufacturing wage are the primary cost drivers in the production process, which is discussed by Markish (2002), so they will be key drivers of the cost structure in a given year.

In the estimation of the models for each firm and market, three versions of each model were estimated using the IVs for only the current year, the current year and a one year lag, and the current year and a two year lag. For the models that include interaction terms, all of the IVs were also interacted with dummy variables and included in the estimation in order to account for the model specific effects the IVs have on the interaction terms. Finally, due to the order condition which requires the number of instrumented variables to equal the number of instruments, the cases corresponding to Model 2, Model 4, and Model 6 in Table 4.1 for Boeing and Airbus could not be estimated.

In total, 156 regressions were run to estimate the models above for the demand for narrow-body Airbus planes, narrow-body Boeing planes, wide-body Airbus planes, and wide-body Boeing planes. There were 67 observations used to calculate the estimates for narrow, Airbus demand; 61 for narrow, Boeing; 76 for wide, Airbus; and 108 for wide, Boeing. The observations were taken from time series data for the years 1974-2011 for the wide-body demand systems and from 1988-2011 for narrow-body demands.

Additionally, several alternative models were tested for the narrow, Airbus market. In one, regional GDP was replaced by regional revenue passenger miles (RPM), a measure of airline passenger traffic which is calculated by multiplying the number of fare paying passengers by the miles traveled in a given year. It is widely assumed that RPM is a function of GDP, and the estimation results do not indicate differences from the same models estimated using GDP. Also, the dummy and interaction terms were substituted for data on number of seats, maximum range, and operating cost. Additionally, time trend variables were included in order to test for the significance of a price changes over time. Models including just a linear time variable and some including a linear and quadratic variable were tested. These substitutions and additions to the core set of models yielded results which were very similar to those where the model dummies were used. Several of these models are reported in the Appendix for reference.

Section 4.3 About the Data Sources

Data on deliveries, unit prices, years in production, seats, passengers, range, and RPM are taken from the *Airline Monitor*, an industry publication. The unit prices are calculated by estimating aggregate sales for a model type in a given year and dividing by the number of deliveries. Some models were missing data on seats, passengers and range, and these missing data points were filled using information available on the websites of Boeing and Airbus. The world aluminum price index was downloaded from online datasets provided by the IMF and is indexed with 2005 equal to 100. Data on hourly compensation costs in manufacturing for Europe, the US, Canada, and Brazil were downloaded from the US Bureau of Labor Statistics and are reported on a dollar basis with the year 2000 equal to 100. The data for Europe were calculated as a weighted average following the method used in Irwin and Pavcnik (2004) in which data for France, Germany, and Great Britain are given weights of 0.4, 0.4 and 0.2, respectively. These weights were chosen to represent each country’s rough ownership share in Airbus. Real GDP data was downloaded from a dataset provided by the US Department of Agriculture and was compiled from data published by the World Bank and IMF.

Section 5. Results

From the 156 estimations, a picture of the demand for narrow and wide-body planes produced by Airbus and Boeing emerges. Out of the estimate models, several are presented below for each segment for Airbus and Boeing; the selections were made based on significance of the results and consistency with the other estimations, the existing literature and what is known about the industry. Both instrumental variable two-stage least squares estimations and OLS results are reported in the tables that follow. Additional model results are reported in the appendix. In all cases, robust standard errors are reported in parentheses below the coefficient estimates because it is likely that the data exhibit serial correlation and heteroskedasticity.

5.1 The narrow-body market

Tables 5.1 and 5.2 list results for the demand for narrow-body planes produced by Airbus and Boeing. Regional GDP is lagged by two years and the estimations which include the weighted average price for all wide-body planes and those that break the wide-body market up by producer are included. For Airbus, *ln_unitprice* is highly significant and implies an own price elasticity of between 6 and 9. The case of Boeing is more ambiguous because the results are not very significant, but all four cases presented suggest a similar picture to each other and to the demand for Airbus's narrow planes.

For both firms, the cross price elasticities do not show up as statistically significant at a high level, except for the price of non-Airbus-produced narrow-body planes in one estimation. However, all exhibit the correct sign which suggests that narrow-body planes produced by different firms are reasonable substitutes for each other. The cross-price elasticities for the entire wide-body market – although not statistically significant – do show up with the opposite sign than expected, suggesting that as wide-body planes get more expensive, airlines actually purchase fewer narrow-body planes, rather than switching toward using them more often and more frequently. But looking at the results, which split up the wide-body market into planes produced by Airbus and by Boeing, may provide an answer. In both cases the coefficients on prices for the firms' own wide-body planes are negative, which suggests that as wide-body planes produced by Airbus, for example, go down, airlines are more likely to buy narrow-body planes also made by Airbus. This suggests that an airline's preference for a particular supplier may be more important than the price in the entire other market. These effects may come from the presence of the previously discussed "green stamps" included in purchase contracts which provide guaranteed service agreements and other provisions.

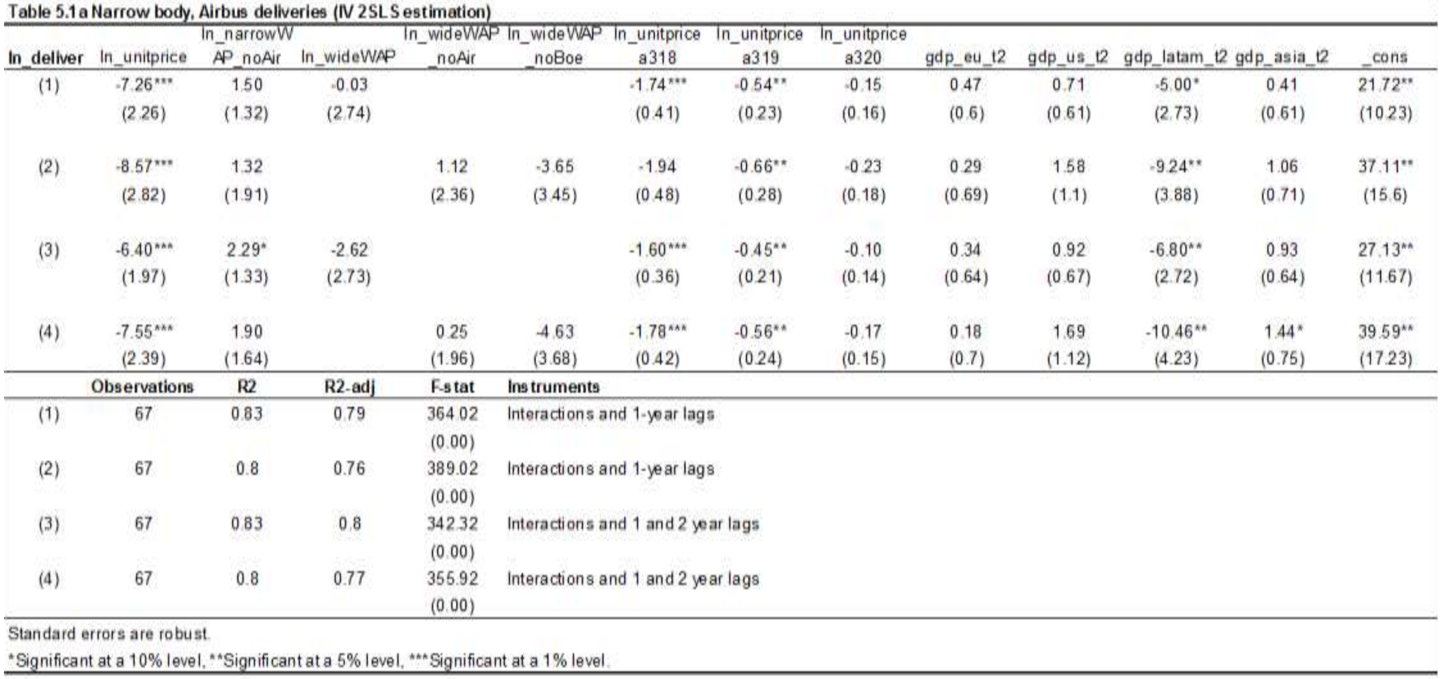

Table 5.1a Narrow body, Airbus deliveries (IV 2SLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP_noAir	ln_wideWAP	ln_wideWAP_noAir	ln_wideWAP_noBoe	ln_unitprice a318	ln_unitprice a319	ln_unitprice a320	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	-7.26***	1.50	-0.03			-1.74***	-0.54**	-0.15	0.47	0.71	-5.00*	0.41	21.72**
	(2.26)	(1.32)	(2.74)			(0.41)	(0.23)	(0.16)	(0.6)	(0.61)	(2.73)	(0.61)	(10.23)
(2)	-8.57***	1.32		1.12	-3.65	-1.94	-0.66**	-0.23	0.29	1.58	-9.24**	1.06	37.11**
	(2.82)	(1.91)		(2.36)	(3.45)	(0.48)	(0.28)	(0.18)	(0.69)	(1.1)	(3.88)	(0.71)	(15.6)
(3)	-6.40***	2.29*	-2.62			-1.60***	-0.45**	-0.10	0.34	0.92	-6.80**	0.93	27.13**
	(1.97)	(1.33)	(2.73)			(0.36)	(0.21)	(0.14)	(0.64)	(0.67)	(2.72)	(0.64)	(11.67)
(4)	-7.55***	1.90		0.25	-4.63	-1.78***	-0.56**	-0.17	0.18	1.69	-10.46**	1.44*	39.59**
	(2.39)	(1.64)		(1.96)	(3.68)	(0.42)	(0.24)	(0.15)	(0.7)	(1.12)	(4.23)	(0.75)	(17.23)

	Observations	R2	R2-adj	F-stat	Instruments
(1)	67	0.83	0.79	364.02	Interactions and 1-year lags
				(0.00)	
(2)	67	0.8	0.76	389.02	Interactions and 1-year lags
				(0.00)	
(3)	67	0.83	0.8	342.32	Interactions and 1 and 2 year lags
				(0.00)	
(4)	67	0.8	0.77	355.92	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

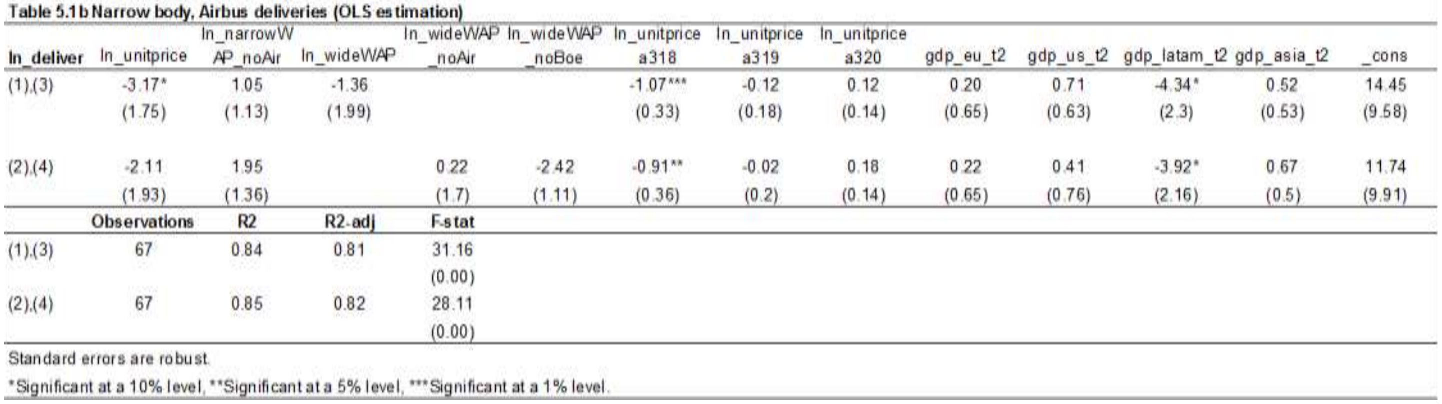

Table 5.1b Narrow body, Airbus deliveries (OLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP_noAir	ln_wideWAP	ln_wideWAP_noAir	ln_wideWAP_noBoe	ln_unitprice a318	ln_unitprice a319	ln_unitprice a320	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1),(3)	-3.17*	1.05	-1.36			-1.07***	-0.12	0.12	0.20	0.71	-4.34*	0.52	14.45
	(1.75)	(1.13)	(1.99)			(0.33)	(0.18)	(0.14)	(0.65)	(0.63)	(2.3)	(0.53)	(9.58)
(2),(4)	-2.11	1.95		0.22	-2.42	-0.91**	-0.02	0.18	0.22	0.41	-3.92*	0.67	11.74
	(1.93)	(1.36)		(1.7)	(1.11)	(0.36)	(0.2)	(0.14)	(0.65)	(0.76)	(2.16)	(0.5)	(9.91)

	Observations	R2	R2-adj	F-stat
(1),(3)	67	0.84	0.81	31.16
				(0.00)
(2),(4)	67	0.85	0.82	28.11
				(0.00)

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

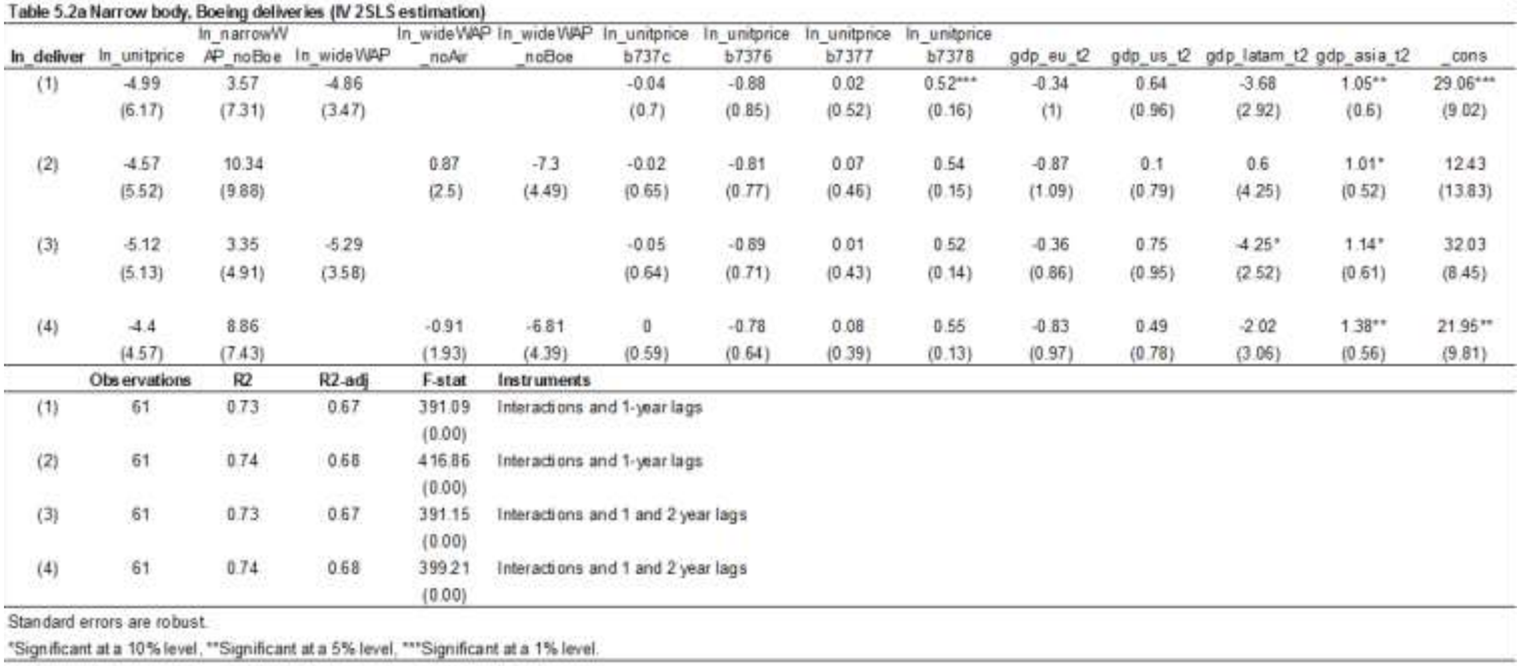

Table 5.2a Narrow body, Boeing deliveries (IV 2SLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP_noBoe	ln_wideWAP	ln_wideWAP_noAir	ln_wideWAP_noBoe	ln_unitprice b737c	ln_unitprice b7376	ln_unitprice b7377	ln_unitprice b7378	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	-4.99	3.57	-4.86			-0.04	-0.88	0.02	0.52***	-0.34	0.64	-3.68	1.05**	29.06***
	(6.17)	(7.31)	(3.47)			(0.7)	(0.85)	(0.52)	(0.16)	(1)	(0.96)	(2.92)	(0.6)	(9.02)
(2)	-4.57	10.34		0.87	-7.3	-0.02	-0.81	0.07	0.54	-0.87	0.1	0.6	1.01*	12.43
	(5.52)	(9.88)		(2.5)	(4.49)	(0.65)	(0.77)	(0.46)	(0.15)	(1.09)	(0.79)	(4.25)	(0.52)	(13.83)
(3)	-5.12	3.35	-5.29			-0.05	-0.89	0.01	0.52	-0.36	0.75	-4.25*	1.14*	32.03
	(5.13)	(4.91)	(3.58)			(0.64)	(0.71)	(0.43)	(0.14)	(0.86)	(0.95)	(2.52)	(0.61)	(8.45)
(4)	-4.4	8.86		-0.91	-6.81	0	-0.78	0.08	0.55	-0.83	0.49	-2.02	1.38**	21.95**
	(4.57)	(7.43)		(1.93)	(4.39)	(0.59)	(0.64)	(0.39)	(0.13)	(0.97)	(0.78)	(3.06)	(0.56)	(9.81)

	Observations	R2	R2-adj	F-stat	Instruments
(1)	61	0.73	0.67	391.09	Interactions and 1-year lags
				(0.00)	
(2)	61	0.74	0.68	416.86	Interactions and 1-year lags
				(0.00)	
(3)	61	0.73	0.67	391.15	Interactions and 1 and 2 year lags
				(0.00)	
(4)	61	0.74	0.68	399.21	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

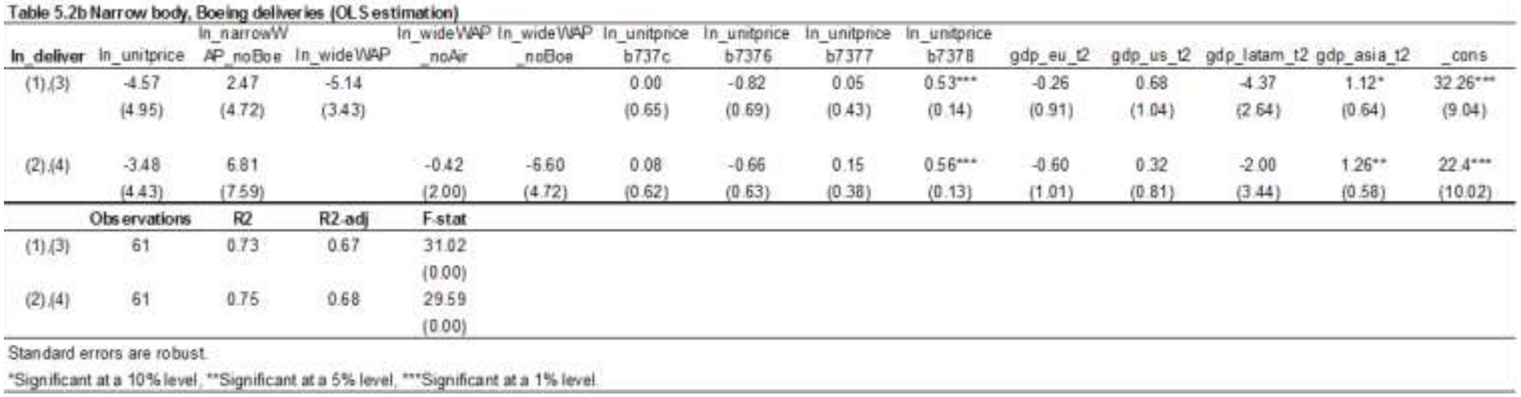

Table 5.2b Narrow body, Boeing deliveries (OLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP_noBoe	ln_wideWAP	ln_wideWAP_noAir	ln_wideWAP_noBoe	ln_unitprice b737c	ln_unitprice b7376	ln_unitprice b7377	ln_unitprice b7378	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1),(3)	-4.57	2.47	-5.14			0.00	-0.82	0.05	0.53***	-0.26	0.68	-4.37	1.12*	32.26***
	(4.95)	(4.72)	(3.43)			(0.65)	(0.69)	(0.43)	(0.14)	(0.91)	(1.04)	(2.64)	(0.64)	(9.04)
(2),(4)	-3.48	6.81		-0.42	-6.60	0.08	-0.66	0.15	0.56***	-0.60	0.32	-2.00	1.26**	22.4***
	(4.43)	(7.59)		(2.00)	(4.72)	(0.62)	(0.63)	(0.38)	(0.13)	(1.01)	(0.81)	(3.44)	(0.58)	(10.02)

	Observations	R2	R2-adj	F-stat
(1),(3)	61	0.73	0.67	31.02
				(0.00)
(2),(4)	61	0.75	0.68	29.59
				(0.00)

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

5.2 The wide-body market

The estimation results for the wide-body market tell a story that is familiar from the existing literature. Own price elasticities for Boeing are significant at the 1% level and suggest a range of 7-8, which agrees with the estimates in Irwin and Pavcnik (2004) of 4 – 10. The own price elasticities for Airbus are significant at the 10% level in one of the two models presented and, taken with the results in some of the other estimations, imply a range of 2 – 8.

Cross-price elasticities exhibit the expected sign in both markets and agree with the results in the narrow market that suggest that wide and narrow-body planes are imperfect substitutes. The values for the cross-price elasticities differ considerably for Boeing and Airbus, which deserves some attention. For Boeing, the results suggest that a 7 to 8% drop (increase) in the price of narrow-body planes will reduce (increase) demand for Boeing, wide bodies by one percent, while for Airbus only a 1 to 2% change is needed in the price of narrow bodies to induce a 1% change in demand for Airbus, wide bodies. Though the results are only statistically significant in the Boeing estimations, there may yet be a good reason for these differences. Until 2007 when Airbus began deliveries of the A380, Boeing was the only producer of a very high capacity, long range plane: the 747. It has been suggested that the 747, and now the A380, essentially occupies its own market for super-jumbo planes because it differs so dramatically in its characteristics from other wide-body planes in seats and maximum range. So, the presence of the 747 may require a more significant change in the prices of narrow-body planes before airlines would consider switching toward or away from such a large, unique plane. And since the A380 has only been in the market for a few years, the effects of having this huge plane may not yet be seen in the Airbus estimations.

Lagged, regional GDP in the US, Latin America, and Asia also shows up as highly significant in all but one of the reported estimations for the wide-body markets. The Airbus estimations suggest that a two year lag is appropriate, while the Boeing results are more significant when a one year lag is used. In the estimations for both Boeing and Airbus, the signs of the coefficients on regional GDP suggest that as incomes increase in Europe and Latin America, demand for wide bodies goes up; this agrees with the intuition that as people get richer they fly more. However, the coefficients have negative signs in both the US and Asia, which would suggest that people fly on big planes less as GDP goes up. Perhaps as incomes increase in the US and Asia, people begin to favor flying on smaller, private planes on regional routes rather than flying major trunk routes to reach their destinations. In this sense, wide-body planes act as an inferior good and narrow-body planes and regional jets as luxury goods. So as people get richer they prefer to fly on smaller, more personalized planes. Further evidence for this interpretation comes from the regional GDP data in the narrow-body market where we see the reverse sign pattern on the coefficients in the US and Asia. So as GDP goes up in both of those regions, demand for narrow-body planes increases. The results in the narrow market, however, are not as statistically significant as in the wide market estimations.

Table 5.3a Wide body, Airbus deliveries (IV 2SLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP	ln_wideWAP_noAir	ln_unitprice a300310	ln_unitprice a330	ln_unitprice a340	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	-4.57*	2.41	3.93	-0.53	-0.16	-0.13	0.74	-1.45**	6.72***	-0.96***	-3.84
	(2.44)	(1.66)	(2.61)	(0.36)	(0.28)	(0.19)	(0.99)	(0.65)	(2.4)	(0.29)	(4.52)
(2)	-2.84	1.53	1.76	-0.26	0.02	-0.01	0.67	-1.07	6.00***	-0.95***	-0.95
	(1.74)	(1.34)	(1.74)	(0.27)	(0.21)	(0.16)	(0.99)	(0.67)	(2.00)	(0.26)	(3.68)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	76	0.18	0.05	55.28	Interactions and 1-year lags
				(0.00)	
(2)	76	0.25	0.13	53.37	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table 5.3b Wide body, Airbus deliveries (OLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP	ln_wideWAP_noAir	ln_unitprice a300310	ln_unitprice a330	ln_unitprice a340	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1),(2)	-1.39	1.09	1.46*	-0.07	0.15	0.08	-0.03	-0.6	6.06***	-0.88***	-1.93
	(1.04)	(0.88)	(0.87)	(0.15)	(0.13)	(0.12)	(1.20)	(0.88)	(2.06)	(0.25)	(2.81)

	Observations	**R2**	**R2-adj**	**F-stat**
(1),(2)	76	0.29	0.18	6.29
				(0.00)

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table 5.4a Wide body, Boeing deliveries (IV 2SLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP	ln_wideWAP_noBoe	b747	b757	b767	gdp_eu_t1	gdp_us_t1	gdp_latam_t1	gdp_asia_t1	_cons
(1)	-7.71***	7.5**	2.04	0.42	-7.61	-4.46	1.68	-2.36***	6.51***	-1.15***	2.38
	(2.20)	(3.38)	(3.96)	(0.56)	(1.95)	(1.04)	(1.07)	(0.79)	(2.54)	(0.45)	(5.22)
(2)	-7.20***	8.55***	0.42	0.31	-7.19	-4.24	1.31	-2.15***	6.96***	-1.06**	4.29
	(2.14)	(3.27)	(3.53)	(0.52)	(1.92)	(1.04)	(0.97)	(0.71)	(2.57)	(0.41)	(4.56)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	108	-	-	46.75	1-year lags
				(0.00)	
(2)	108	-	-	46.00	1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table 5.4b Wide body, Boeing deliveries (OLS estimation)

ln_deliver	ln_unitprice	ln_narrowWAP	ln_wideWAP_noBoe	b747	b757	b767	gdp_eu_t1	gdp_us_t1	gdp_latam_t1	gdp_asia_t1	_cons
(1),(2)	-0.09	3.35***	-2.32**	-0.91***	-1.00	-0.93	0.29	-0.74**	0.68	0.14	4.67***
	(1.09)	(0.95)	(1.08)	(0.23)	(1.09)	(0.6)	(0.41)	(0.38)	(1.08)	(0.24)	(1.69)

	Observations	**R2**	**R2-adj**	**F-stat**
(1),(2)	108	0.40	0.34	8.28
				(0.00)

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Section 6. Conclusion

Returning to the multimarket oligopoly model presented in section 3, it was shown that in the general case of differentiated products with price competition, the presence of joint economies or diseconomies and strategic complements or substitutes relies on cross price effects and the cost functions. The properties of aircraft companies' cost functions were not empirically tested here because they have received significant, previous attention. However, some of the questions regarding the properties of demand can be answered.

It was shown above that the question of joint economies or diseconomies relies on the sign of four terms, two of which are involved in the demand for narrow and wide-body planes produced by Firm B. The term $\frac{\partial}{\partial p_2^B}\frac{\partial q_2^B}{\partial p_1^B}$ measures how the rate of substitution for wide-body planes and narrow-body planes produced by the same firm changes as the price of narrow-body planes increases or decreases. This term cannot be directly analyzed using the demand equations specified in section 4, but some conclusions can still be inferred from the results. There is good evidence that as the price of wide-body planes made by one firm goes down airlines will also purchase more narrow-body planes from the same firm. However, the goods are still imperfect substitutes so if narrow-body planes decrease in price as well, airlines will gradually shift into running more narrow bodies. So it is expected that the sign of $\frac{\partial}{\partial p_2^B}\frac{\partial q_2^B}{\partial p_1^B}$ will be negative, because the rate at which airlines buy more narrow-body planes from Firm B, in response to a price decrease (increase) of wide bodies produced by the firm, will increase (decrease) but at a decreasing rate. The next term is $\frac{\partial}{\partial p_2^B}\frac{\partial q_1^B}{\partial p_1^B}$, which captures how demand for Firm B's wide-body planes changes as a result of a change in the price of narrow-body planes made by Firm B. This term is likely negative as well because, as discussed, as the price of Firm B narrow-body planes decreases, airlines will buy more wide bodies as well, so this will dampen the effects of the first order price effect.

Turning to the cost terms in the joint economies and diseconomies analysis, $\frac{\partial q_m^B}{\partial p_n^B}\left(1 - \frac{\partial^2 C^B}{\partial (q_m^B)^2}\frac{\partial q_m^B}{\partial p_m^B}\right)$, it is reasonable to suggest that first order substitution effects measured by $\frac{\partial q_m^B}{\partial p_n^B}$ will swamp the second order effects just discussed because of the high levels of cross price elasticities reported in section 4 and the literature. And, with the assumption of decreasing marginal costs, the remaining question is whether $\frac{1}{\frac{\partial q_m^B}{\partial p_m^B}} \leq \frac{\partial^2 C^B}{\partial \left(q_m^B\right)^2} < 0$. This result will likely change over time because learning will not continue at the same rate for the entire production run of an aircraft program. So early on, when learning is high this term may be significantly negative leading to joint diseconomies. But over time, as learning rates decline, the term will become less negative, and joint economies will emerge. In fact, this seems to be the most likely case because firms initially enter either the narrow or wide-body market at first and gradually move into the other. Airbus started out in the wide-body market with the A300, taking its first order in 1971, and it was not until 1984 that it took the first order for the narrow-body A320.

Moving to the strategic properties of the competition, on the demand side the analysis hinges on the sign of $\frac{\partial}{\partial p_2^B}\frac{\partial q_2^C}{\partial p_2^C}$, which is the rate at which demand for Firm C’s narrow-body planes changes due to fluctuations in the price of Firm B’s narrow-body planes. The sign here is likely to be positive because it is seen in section 4 that narrow-body planes produced by different firms are good substitutes. So firms will demand fewer narrow-body planes made by Firm C at an increasing rate as Firm B’s prices also decrease. The analysis on the cost term is the same as the discussion on joint economies and diseconomies. Thus it is expected that over time, the net effect will be positive, suggesting that narrow-body planes produced by different firms are strategic complements. This is what was expected based on the anecdotal information about the industry on the risk and threat of price wars between similar models made by different firms.

Turning to the question of COMAC and its prospects, the demand analysis brings out some intriguing results. From the models for demand for Airbus and Boeing narrow-body planes, there is evidence that airlines will tend to purchase narrow and wide-body planes made by the same firm. Thus, firms that establish themselves in the narrow market will be at an advantage should they expand production into the wide-body market because many of the airlines already purchasing the narrow-body planes will purchase the new wide bodies from the same firm. The importance of special, “green stamp” provisions in the purchase contracts, which specify repair arrangements and other cost-reducing features, cannot be overlooked.

However, for the same reasons it may be difficult for COMAC to even begin a credible line of narrow-body planes. Since airlines like to purchase wide and narrow-body planes from the same firm, there may not be very good incentive for them to go out and buy a plane from a new, untested producer such as COMAC. This reluctance is observed within the Chinese airline industry already, where the three major carriers – Air China, China Eastern, and China Southern – have expressed their reluctance to commit to orders of the narrow-body C919 that they believe is a highly risky project. Their fleets are made up almost entirely of Boeing and Airbus planes (55% and 45%, respectively) so it may not be cost effective for them to commit to purchases of any type of narrow-body aircraft that may increase the average operating cost of the narrow portion of their fleet by losing the ability to take advantage of repair and service options on larger proportions of their fleet.

A further concern about the future of COMAC is its limited commitments from non-Chinese airlines. In the narrow-body demand estimations for Boeing and Airbus, regional GDPs were of limited significance, but in the wide-body market, they were significant elements in the estimation of market deliveries. This suggests that if COMAC does not successfully diversify to extra-Chinese markets, prospects for the domestic market growth notwithstanding, it may have difficulty becoming a world player in the commercial aircraft industry. Narrow-body planes are ubiquitous along world airline routes because these planes are the workhorses of many airlines; so it is conceivable that COMAC might be able to thrive off of the Chinese market if the Chinese government successfully convinces (or forces) the domestic airlines to replace retiring narrow-body planes with ARJ-21s and C919s. But, if they want to develop a wide-body program to complement the narrow-body one, then getting foreign airlines to purchase their aircraft will be crucial.

Therefore, the markets for narrow and wide-body commercial aircraft have important effects on each other that may have implications for how both markets will develop over the next several decades. Further research is needed to quantify the conclusions on the long term joint economies and strategic complements properties of the competition in order to better understand the dynamics and effects of these properties. The role that entry in one market has on the other is a key issue that deserves more rigorous attention than could be afforded it here. And, the degree to which the joint development of narrow and wide-body aircraft models simultaneously by a firm affects the cost structure should be investigated to see how much firms may be able to reduce their initial investment cost through research and development.

Appendix: Alternative Demand Models

Table A.1a Narrow Body, Airbus deliveries

ln_deliver	ln_unitprice	ln_narrowWAP_noAir	ln_wideWAP	ln_unitprice a318	ln_unitprice a319	ln_unitprice a320	a318	a319	a320	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	-6.82	2.48*	-2.11				-5.70*	-1.73	-0.45	0.41	0.79	-6.41***	0.85	25.89***
	(5.45)	(1.37)	(3.99)				(3.07)	(1.96)	(1.35)	(0.79)	(0.59)	(2.32)	(0.66)	(8.23)
(2)	-7.35**	1.84	-0.09				-6.00***	-1.92*	-0.56	0.51	0.61	-4.91**	0.43	21.25**
	(3.1)	(1.18)	(2.62)				(1.75)	(1.13)	(0.78)	(0.67)	(0.59)	(2.35)	(0.55)	(9.34)
(3)	-9.56***	2.46*	-0.11	19.61*	1.15	1.76	-74.6**	-6.81	-7.61	0.83	0.37	-4.8**	0.35	26.73***
	(2.94)	(1.34)	(2.35)	(10.54)	(2.42)	(2.12)	(36.91)	(9.36)	(8)	(0.57)	(0.51)	(2.25)	(0.5)	(10.25)
(4)	-9.80***	2.86**	-0.86	20.45*	"3.73**	2.14	-77.58**	-16.17**	-9.06	0.75	0.39	-5.28**	0.55	30.04***
	(2.47)	(1.34)	(2.08)	(11.52)	(1.63)	(1.77)	(40.1)	(6.37)	(6.64)	(0.61)	(0.56)	(2.26)	(0.53)	(9.55)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	67	0.83	0.80	375.29	1-year lags
				(0.00)	
(2)	67	0.83	0.80	371.73	1 and 2 year lags
				(0.00)	
(3)	67	0.84	0.81	454.55	Interactions and 1-year lags
				(0.00)	
(4)	67	0.85	0.82	459.06	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table A.1b Narrow body, Airbus deliveries (with time trends)

ln_deliver	ln_unitprice	ln_narrowWAP_noAir	ln_wideWAP	ln_unitprice a318	ln_unitprice a319	ln_unitprice a320	t	t2	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	-5.59**	3.30*	2.80	-1.46***	-0.37	-0.03	-0.41		-0.03	1.06*	-3.79	1.07	-4.5
	(2.54)	(1.81)	(3.22)	(0.46)	(0.26)	(0.18)	(0.32)		(0.65)	(0.57)	(2.73)	(0.82)	(21.49)
(2)	-5.13**	4.00*	-0.27	-1.39***	-0.33	-0.01	-0.35		-0.06	1.18**	-5.84**	1.50*	5.06
	(2.47)	(2.09)	(2.67)	(0.45)	(0.26)	(0.17)	(0.36)		(0.62)	(0.53)	(2.4)	(0.82)	(23.87)
(3)	-5.71**	3.20	0.54	-1.48***	-0.38	-0.05	-0.28	-0.0004	0.05	1.06*	-5.08*	1.16	6.46
	(2.56)	-2.9	(3.57)	(0.46)	(0.26)	(0.18)	(0.45)	(0.0033)	(0.69)	(0.58)	(2.67)	(0.98)	(27.84)
(4)	-5.19**	3.73	-0.46	-1.40***	-0.33	-0.02	-0.31	-0.0005	-0.03	1.17**	-5.79**	1.45*	6.94
	(2.31)	(2.46)	(2.60)	(0.42)	(0.24)	(0.17)	(0.34)	(0.0030)	(0.62)	(0.52)	(2.57)	(0.85)	(21.93)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	67	0.83	0.80	391.11	Interactions and 1-year lags
				(0.00)	
(2)	67	0.84	0.80	388.23	Interactions and 1 and 2 year lags
				(0.00)	
(3)	67	0.84	0.80	411.48	Interactions and 1-year lags
				(0.00)	
(4)	67	0.84	0.80	362.27	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table A.1c Narrow body, Airbus deliveries (with seats, range, operating costs)

ln_deliver	ln_unitprice	ln_narrowWAP_noAir	ln_wideWAP	ln_unitprice seats	ln_unitpricerange	ln_unitprice opcost	seats	range	opcost	gdp_eu	gdp_us	gdp_latam	gdp_asia	_cons
(1)	-14.97***	-0.89	-2.55	0.02***	0.001	0.0001***				0.87	0.40	-3.15	0.18	34.39**
	(5.85)	(1.52)	(4.33)	(0.01)	(0.0003)	(0.00002)				(0.63)	(0.93)	(3.07)	(0.56)	(18.52)
(2)	-16.11	3.53	11.19				0.16	0.01	0.00	2.48	-2.18	-2.60	-0.19	-52.03
	(19.01)	(3.12)	(8.96)				(0.15)	(0.005)	(0.0004)	(1.56)	(1.91)	(11.41)	(1.64)	(37.37)

	Observations	**R2**	**F-stat**	**Instruments**
(1)	55	0.62	185.31	Interactions and 1-year lags
			(0.00)	
(2)	55	0.71	239.65	No interactions nor lags
			(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table A.1d Narrow body, Airbus deliveries (with RPM)

ln_deliver	ln_unitprice	ln_narrowWAP_noAir	ln_wideWAP	ln_unitprice a318	ln_unitprice a319	ln_unitprice a320	a318	a319	a320	rpm_us	rpm_eu	rpm_latam	rpm_asia	_cons
(1)	-4.47	2.74**	2.40	17.71	0.50	0.47	-65.24	-2.69	-1.57	1.33	-0.22	-2.15	-18.82	0.32
	(3.56)	(1.14)	(3.36)	(11.74)	(2.72)	(2.39)	(41.37)	(10.56)	(9.03)	(2.39)	(3.45)	(5.99)	(24.12)	(8.80)

	Observations	**R2**	**F-stat**	**Instruments**
(1)	63	0.83	423.72	Interactions and 1-year lags
			(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table A.2 Narrow body, Boeing deliveries

ln_deliver	ln_unitprice	ln_narrowWAP_noBoe	ln_wideWAP	ln_unitprice b737c	ln_unitprice b7376	ln_unitprice b7377	ln_unitprice b7378	b737c	b7376	b7377	b7378	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	-24.41	25.87	0.03					-6.38	-12.00	-5.44	0.16	-2.77	1.49	5.76	-0.13	7.56
	(24.47)	(29.31)	(10.92)					(7.9)	(11.39)	(6.95)	(2.32)	(3.27)	(1.46)	(15.67)	(2.40)	(43.27)
(2)	-0.78	-1.90	-8.99					1.18	-0.98	1.26	2.36***	0.06	1.03	-9.00	1.94	48.54**
	(8.55)	(7.48)	(8.49)					(3.28)	(4.12)	(2.49)	(0.9)	(1.13)	(1.2)	(6.94)	(1.51)	(21.71)
(3)	-8.29**	3.47	-0.62	-3.76	-1.32	16.85	6.24	11.35	0.00	-60.93*	-21.84	-0.42	0.04	-1.46	0.83	26.15
	(3.82)	(34.58)	(48.62)	(18.79)	(531.29)	(189.95)	(195.6)	(710.88)	(1588.32)	(33.51)	(50.42)	(5.24)	(9.18)	(18.97)	(0.99)	(16.23)
(4)	-8.35	1.48	-2.03	-1.17	0.29	20.66***	7.70	2.17	-5.49	-74.54***	-27.36	-0.19	0.02	-3.06	1.12**	39.09
	-7.4	(3.29)	(3.31)	-6.7	(8.61)	(7.28)	(7.39)	(25.46)	(32.27)	(27.84)	(28.52)	(0.76)	(0.81)	(2.07)	(0.48)	(24.77)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	61	0.45	0.33	119.99	1-year lags
				(0.00)	
(2)	61	0.71	0.65	480.18	1 and 2 year lags
				(0.00)	
(3)	61	0.80	0.73	495.90	Interactions and 1-year lags
				(0.00)	
(4)	61	0.80	0.74	576.50	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table A.3 Wide body, Airbus deliveries

ln_deliver	ln_unitprice	ln_narrowWAP	ln_wideWAP	ln_unitprice a300310	ln_unitprice a330	ln_unitprice a340	a300310	a330	a340	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	11.44	-6.51	-7.75				8.92	7.18	4.95	-0.24	1.27	0.34	-0.60	-3.25
	(7.87)	(4.55)	(6.84)				(5.58)	(3.91)	(2.76)	(1.4)	(1.71)	(4.26)	(0.62)	(9.97)
(2)	4.07	-2.36	-1.86				3.64	3.45	2.33*	-0.16	0.16	3.57	-0.74	-3.74
	(3.2)0	(2.25)	(2.13)				(2.38)	(1.67)	(1.31)	(1.21)	(1.08)	(2.26)	(0.32)	(5.2)
(3)	-0.60	6.29	3.82	-6.25	12.93	0.01	27.18	-60.24	0.00	0.25	-1.45	6.73	-1.09	-29.95**
	(3.59)	(153.96)	(256.11)	(67.72)	(90.77)	(179.46)	(739.9)	(783.97)	(1577.43)	(8.76)	(54.19)	(126.37)	(9.58)	(13.41)
(4)	13.24***	4.30	1.66	-16.75	1.87	-12.32	85.52	0.00	65.96	0.25	-0.98	5.29	-1.05**	-87.61***
	-1.9	(20.49)	(9.78)	(10.39)	(182.45)	(149.6)	(751.81)	(1032.94)	(208.19)	(2.46)	(3.33)	(17.16)	(0.49)	(13.4)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	76	-	-	16.98	1-year lags
				(0.00)	
(2)	76	0.13	-0.01	32.15	1 and 2 year lags
				(0.00)	
(3)	76	0.51	0.40	94.94	Interactions and 1-year lags
				(0.00)	
(4)	76	0.60	0.52	2622.30	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

Table A.4 Wide body, Boeing deliveries

ln_deliver	ln_unitprice	ln_narrowWAP	ln_wideWAP	ln_unitprice b747	ln_unitprice b757	ln_unitprice b767	b747	b757	b767	gdp_eu_t2	gdp_us_t2	gdp_latam_t2	gdp_asia_t2	_cons
(1)	1.46	5.85***	-7.31***	-0.25***	0.09	-0.05				-0.08	-0.75*	1.17	0.71**	10.27
	(1.35)	(1.77)	(2.43)	(0.06)	(0.32)	(0.15)				-0.5	-0.4	(1.64)	(0.31)	(3.14)
(2)	1.27	5.36***	-6.52***	-0.24***	0.05	-0.07				-0.03	-0.74*	0.94	0.67**	9.49***
	-1.2	(1.82)	(2.17)	(0.06)	(0.29)	(0.14)				(0.46)	-0.4	(1.78)	(0.28)	-2.9
(3)	4.08***	5.73***	-3.61	-6.49***	-5.54***	-5.85***	31.21***	25.00***	26.94***	0.27	-0.95***	2.72*	-0.01	-19.63*
	(1.55)	(1.76)	(3.07)	(1.61)	(1.71)	(1.56)	(8.05)	(7.69)	(7.42)	(0.37)	(0.36)	(1.46)	(0.28)	(10.19)
(4)	3.76**	6.22***	-3.11	-6.88***	-6.02***	-6.24***	33.23***	26.61***	28.54***	0.35	-1.09***	3.31**	-0.12	-22.15**
	(1.59)	-1.8	(2.87)	(1.73)	-1.8	(1.64)	(8.64)	(8.07)	-7.8	(0.39)	-0.4	(1.68)	(0.32)	(10.69)

	Observations	**R2**	**R2-adj**	**F-stat**	**Instruments**
(1)	108	0.32	0.25	94.66	Interactions and 1-year lags
				(0.00)	
(2)	108	0.36	0.29	86.78	Interactions and 1 and 2 year lags
				(0.00)	
(3)	108	0.38	0.29	152.19	Interactions and 1-year lags
				(0.00)	
(4)	108	0.38	0.29	141.18	Interactions and 1 and 2 year lags
				(0.00)	

Standard errors are robust.

*Significant at a 10% level, **Significant at a 5% level, ***Significant at a 1% level.

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References

Airbus, *Global Market Forecast 2012-2031*, 2012. As of March 11, 2013: http://www.airbus.com/company/market/forecast/?eID=dam_frontend_push&docID=27599.

Andersen, Peder. "China's Growing Market for Large Civil Aircraft." (2008).

Baldwin, Richard, and Paul Krugman. "Industrial policy and international competition in wide-bodied jet aircraft." In *Trade policy issues and empirical analysis*, pp. 45-78. University of Chicago Press, 1988.

Benkard, C. Lanier. "A dynamic analysis of the market for wide-bodied commercial aircraft." *The Review of Economic Studies* 71, no. 3 (2004): 581-611.

Boeing, *Current Market Outlook 2012-2031*, 2012. As of March 11, 2013: http://www.boeing.com/assets/pdf/commercial/cmo/pdf/Boeing_Current_Market_Outlook_2012.pdf.

Bulow, Jeremy I., John Geanakoplos, and Paul D. Klemperer. "Multimarket Oligopoly." *Cowles Foundation Discussion Papers* 674 (1983).

______. "Multimarket oligopoly: Strategic substitutes and complements." *The Journal of Political Economy* 93, no. 3 (1985): 488-511.

Cabral, L., and T. Kretschmer. "Competition in the Wide-Body Aircraft Market." *pages. stern. nyu. edu/~ lcabral/teaching/widebody. pdf* (2001).

Cliff, Roger, Chad JR Ohlandt, and David Yang. *Ready for Takeoff: China's Advancing Aerospace Industry*. Rand Corporation, 2011.

De Vany, Arthur, and Gail Frey. "Backlogs and the value of excess capacity in the steel industry." *The American Economic Review* 72, no. 3 (1982): 441-451.

Dixit, Avinash. "A Model of Duopoly Suggesting a Theory of Entry Barriers." *The Bell Journal of Economics* (1979): 20-32.

______. "The role of investment in entry-deterrence." *The Economic Journal* 90, no. 357 (1980): 95-106.

Ferreri, Domenico. *Marketing and Management in the High-Technology Sector: Strategies and Tactics in the Commercial Airplane Industry*. Westport, Conn.: Praeger, 2003.

Fusillo, Mike. "Excess capacity and entry deterrence: the case of ocean liner shipping markets." *Maritime Economics & Logistics* 5, no. 2 (2003): 100-115.

Goldstein, Andrea. "EMBRAER: From national champion to global player." *Financial Times* (1995).

Hilke, John C. "Excess capacity and entry: some empirical evidence." *The Journal of Industrial Economics* 33, no. 2 (1984): 233-240.

Irwin, Douglas A., and Nina Pavcnik. "Airbus versus Boeing revisited: international competition in the aircraft market." *Journal of International Economics* 64, no. 2 (2004): 223-245.

Jin, Fengjun, Fahui Wang, and Yu Liu. "Geographic Patterns of Air Passenger Transport in China 1980–1998: Imprints of Economic Growth, Regional Inequality, and Network Development." *The Professional Geographer* 56, no. 4 (2004): 471-487.

Kadiyali, Vrinda. "Entry, its deterrence, and its accommodation: A study of the US photographic film industry." *The Rand Journal of Economics* (1996): 452-478.

Kalouptsidi, Myrto. *Time to build and fluctuations in bulk shipping*. Working Paper, Princeton University, Department of Economics, 2011.

Kirman, William I., and Robert T. Masson. "Capacity signals and entry deterrence." *International Journal of Industrial Organization* 4, no. 1 (1986): 25-42.

Klepper, Gernot. "Entry into the market for large transport aircraft." *European Economic Review* 34, no. 4 (1990): 775-798.

Markish, Jacob. "Valuation techniques for commercial aircraft program design." PhD diss., Massachusetts Institute of Technology, 2002.

Mathis, Stephen, and Janet Koscianski. "Excess capacity as a barrier to entry in the US titanium industry." *International Journal of Industrial Organization* 15, no. 2 (1997): 263-281.

Schmalensee, Richard. "Entry deterrence in the ready-to-eat breakfast cereal industry." *The Bell Journal of Economics* (1978): 305-327.

Spulber, Daniel F. "Capacity, output, and sequential entry." *The American Economic Review* 71, no. 3 (1981): 503-514.

Tirole, Jean. *The theory of industrial organization*. MIT press, 1988.

United States International Trade Commission. *Competitive assessment of the US large civil aircraft aerostructures industry: investigation*. No. 332-414. US International Trade Commission, 2001.

Wang, JiaoE, and FengJun Jin. "China's air passenger transport: An analysis of recent trends." *Eurasian Geography and Economics* 48, no. 4 (2007): 469-480.

Wilson, Robert. "Strategic models of entry deterrence." *Handbook of game theory with economic applications* 1 (1992): 305-329.

Wooldridge, Jeffrey M. *Introductory Econometrics: A Modern Approach*. 3rd ed. Mason, OH: Thomson/South-Western, 2006.

Zhang, Yahua, and David K. Round. "China's airline deregulation since 1997 and the driving forces behind the 2002 airline consolidations." *Journal of air transport management* 14, no. 3 (2008): 130-142.