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ABSTRACT

This paper examines international competition in the commercial aircraft industry. We estimate a discrete choice, differentiated products demand system for wide-body aircraft and examine the Airbus-Boeing rivalry under various assumptions on firm conduct. We then use this structure to evaluate two trade disputes between the United States and European Union. Our results suggest that the aircraft prices increased by about 3 percent after the 1992 U.S. – E.U. agreement on trade in civil aircraft that limits subsidies. This price hike is consistent with a 7.5 percent increase in firms' marginal costs after the subsidy cuts. We also simulate the impact of the future entry of the Airbus A-380 super-jumbo aircraft on the demand for other wide-bodied aircraft, notably the Boeing 747. We find that the A-380 could reduce the market share of the 747 by up to 14 percent in the long range wide-body market segment (depending upon the discounts offered on the A-380), but would reduce the market for Airbus's existing wide-bodies by an even greater margin.

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1. Introduction

One of the recurring trade disputes between the United States and Europe concerns the rivalry between Airbus and Boeing in the market for wide-body aircraft. Airbus first began production of aircraft in the early 1970s with substantial financial assistance from European governments. As Airbus succeeded in making inroads into many of Boeing's markets, Boeing alleged that Airbus benefited from unfair subsidies and has pressured U.S. trade authorities to counteract Europe's financial support. As a result, the United States and European Community signed an agreement on trade in civil aircraft in 1992 that limited government subsides for aircraft production. This agreement, however, has come under new strain as Airbus introduces the A-380 super jumbo aircraft designed to compete directly against the Boeing 747.

Competition in the wide-bodied aircraft industry has attracted attention not just because of the controversy surrounding the Airbus subsidies, but because of the industry's unusual market structure, in which economies of scale are enormous relative to market demand. The aircraft sector provides a textbook example of an industry in which trade policy could affect the strategic interaction between a domestic and an international rival and shift profits in favor of the domestic firm, as proposed in Brander and Spencer's (1985) canonical model of strategic trade policy. Previous studies of the commercial aircraft market, notably Baldwin and Krugman (1987), Klepper (1990, 1994), and Neven and Seabright (1995), used calibrated simulations to analyze the competitive interaction of Airbus and Boeing. These simulations focused on Airbus's impact on the costs and profits of its competitors and on consumer surplus as a way of evaluating the welfare effects of Airbus's market presence.

This paper takes an empirical approach to examining international competition and trade disputes in the wide-body aircraft market. We employ Berry's (1994) method of estimating

demand in an oligopoly market with differentiated products using data on commercial aircraft prices, sales, and characteristics from 1969 to 1998.[1] This approach provides us with estimates of price and cross-price elasticities of demand, which allow us to assess how closely related in demand various aircraft are. The demand system, combined with an assumption on firms' (static) market conduct, also yields estimates of price-cost markups, allowing us to determine whether competitive pressures have increased in this segment of the market as a result of Airbus's entry and Lockheed and McDonnell-Douglas's exit.

We then focus on two aspects of the international rivalry between Airbus and Boeing. First, we examine whether the 1992 U.S-E.U. agreement on trade in civil aircraft limiting aircraft subsidies had a significant impact on pricing in the aircraft market. We determine that the agreement appears to have raised the prices of both Airbus and Boeing aircraft by about 3 percent in the narrow- and wide-body market. Our structural model and estimates of the wide-body market suggest that these price increases are consistent with a 7.5 percent rise in the marginal cost of production after the subsidy cuts. Second, we use our demand estimates to estimate the impact of the introduction of the A-380 on the prices and market shares of other wide-body aircraft, notably the Boeing 747. We find that the A-380 can be expected to have a significant negative effect on the prices and sales of the 747 within the wide-body market, but an even greater adverse effect on demand for Airbus's existing wide-body aircraft (the A-330 and A-340). This result highlights the fact that as Airbus and Boeing expand their product line over time, profit maximization by multi-product firms becomes more complicated as demand for a firm's existing models is sensitive to the price and characteristics of its new models.

[1] Our approach of estimating demand is in the spirit of Berry, Levinsohn, and Pakes (1999) and Goldberg (1995) who examine the impact of trade restraints in the automobile industry.

One recent study that combines elements of demand estimation and industry simulation is Benkard (2003). He estimates demand parameter for wide-body aircraft and uses them with estimates of a cost function that accounts for learning by doing to compute numerically the dynamic equilibrium in the aircraft market and simulate the evolution of the industry. He also simulates the welfare implications of an antitrust policy that places an upper bound on the market share that any one firm can achieve and finds that this harms consumers. Although our approach to estimating market demand is similar (we allow for additional market segmentation in the market for medium- and long- range wide-body aircraft, an important differentiation according to our empirical results), our paper ultimately addresses a different set of issues.

Section 2 of this paper discusses the institutional detail of the aircraft industry, estimates discrete choice demand system, and calculates the markups implied by various assumptions on firm conduct. Section 3 estimates the effect of the 1992 U.S.-E.U. aircraft trade agreement on aircraft pricing, and simulates the effects of the A-380 entry on the market share and prices of existing wide-body aircraft. Section 4 concludes.

2. Structural Estimates of Aircraft Demand and Markups

The market for aircraft is typically divided into two product categories: narrow-body and wide-body aircraft. Narrow-body aircraft are single aisle, short-range aircraft (up to 6,000 km) that typically carry between 100 to 200 passengers. The leading aircraft in this category are the Boeing 737, the Boeing 757, and the Airbus A-320. Wide-body aircraft are double aisle, medium to long-range aircraft (up to 14,000 km) that can carry between 200 to 450 passengers. The leading aircraft in this category are the Boeing 747, the Boeing 777, and the Airbus A-300. Narrow- and wide-body aircraft are imperfect substitutes for one another because the planes are designed to serve different markets, and competition is much more intense within each category

than between them. Figure 1 plots the typical number of seats and the range of various aircraft and clearly indicates how localized the competition is within the narrow-body and wide-body segment.

We focus mainly on the wide-body segment of the aircraft industry in part because most of the international trade disputes have centered on competition in this product range. The increase in international travel since the 1970s has made this a rapidly growing segment of aircraft demand. The wide-body market has also been very profitable: the Boeing 747, for example, is said to account for as much as a third of Boeing's entire profits in certain years. As a result, Airbus, for example, entered the aircraft market in this segment with the A-300 in 1974, and only later began competing in the narrow-body market with the launch of the A-320 in 1988. There are fewer product lines in wide-body segment of the market, and the number of aircraft sold is much smaller than in narrow-body segment. The cumulative output of the best selling wide-body Boeing 747 has only reached about 1,185 units in 1998 (it was introduced in 1969), and the best selling Airbus aircraft A300 sold only 481 units between 1974 and 1998. As a result, competition tends to be more intense in wide body market because, since from the firm's perspective, each additional sale generates valuable revenue. In contrast, narrow-body planes often sell well above 1,000 units over their lifespan, with Boeing 737 selling over 3,200 units until 1998.

2.1 Demand for Wide-Body Aircraft

The structure of our aircraft demand system is based on the discrete choice random utility framework outlined in Berry (1994). This framework enables us to estimate the demand for a differentiated product using product-level data on sales, prices, and other product attributes, without observing the purchases made by individual consumers. In this framework, consumers

(airlines) have a choice of purchasing either one of several wide-body aircraft or an outside good. Because aircraft are durable goods, we follow Benkard (2003) and incorporate used planes in the demand estimation. In particular, the outside good consists of new narrow-body aircraft and used wide-body planes. Utility from the outside good is normalized at zero. The total potential market therefore consists of all new aircraft and used wide-body aircraft.

We model each wide-body aircraft as a bundle of characteristics that airlines value. These characteristics include price, range, passenger seating, and takeoff weight. Our framework also allows the airlines to value aircraft characteristics that are not directly observed. Airline i's utility of purchasing product j (u_{ij}) can be expressed as a linear function of aircraft j's characteristics and tastes idiosyncratic to airline i:

$$u_{ij} = x_j\beta - \alpha p_j + \xi_j + \tau_{ij}$$

where x_j is a vector of product j's attributes, and p_j is aircraft price. ξ_j represents aircraft j's characteristics that the airlines value, and τ_{ij} captures airline i's specific taste for aircraft j, both of which are not observed by the econometrician. The mean utility level that product j yields to airlines is denoted by δ_j, so that $\delta_j \equiv x_j\beta - \alpha p_j + \xi_j$. Note that in this framework all variation in the valuation of aircraft across airlines stems from the unobserved additive taste term τ_{ij}.

We allow consumer-specific tastes to be correlated across products with similar characteristics by using a nested logit demand model. We group wide-body planes into two distinct market segments g: medium-range and long-range wide-body aircrafts.[2] Consumers also have an option of not purchasing a wide-body plane and purchasing the outside good. We can then rewrite the consumer taste parameter τ_{ij} as $\tau_{ij} \equiv v_{ig}(\sigma) + (1-\sigma)\varepsilon_{ij}$. Term ε_{ij} captures

[2] The medium-range wide-bodies include the Boeing 767 and the Airbus A-300 and A-310. The long-range wide-bodies include the Boeing 747 and 777, the Airbus A-330 and A-340, and the MD-11.

consumer tastes that are identically and independently distributed across products and consumers according to the extreme value distribution. Term v_{ig} captures the common taste that airline i has for all aircraft in market segment g.[3] The common taste depends on the distribution parameter σ $(0 \le \sigma < 1)$, which indicates the degree of substitutability between products within a market segment. When σ is zero, consumer tastes are independent across all aircraft and there is no market segmentation. The higher the σ, the more correlated the consumer tastes are for products within the same market segment and the competition among products is stronger within than across market segments.[4]

Given the set of available aircraft, airlines are assumed to select the aircraft that gives them the highest utility.[5] Consumer i will choose aircraft j if:

$u_{ij} \ge u_{ik}$.

Given the distributional assumptions on consumer tastes and functional form for utility, we can aggregate over individual consumer purchases to obtain predicted aggregate market share s_j of aircraft j:

$$(1) \qquad s_j(\delta,\sigma) = \frac{e^{\delta_j/(1-\sigma)}}{D_g} \frac{D_g^{1-\sigma}}{(\sum_g D_g^{1-\sigma})}$$
$$where\ D_g \equiv \sum_{j \in g} e^{\delta_j/(1-\sigma)}$$

[3] Since ε_{ij} is an extreme value random variable, τ_{ij} is an extreme value random variable (Berry (1994)).
[4] In his wide-body aircraft demand estimates, Benkard (2003) also allows for market segmentation between the outside good and wide-body market, but does not distinguish between the medium- and long-range segments of the wide-body market. Our estimates of σ indicate the importance of allowing for the additional market segmentation. In addition, he estimates the model using data from 1975 to 1994 whereas our data span 1969 to 1998. The additional years of data are important because the A-330, A-340, and Boeing 777 only enter the market in 1993 and 1995.
[5] Note that this framework allows an airline to purchase only one aircraft at a time. Airlines often bundle their orders and concurrently purchase several aircraft. Since we do not observe individual purchases, we cannot address this issue. Hendel (1999) explicitly models and estimates the demand for computers allowing for multiple purchases.

The first term in this expression is aircraft j's market share in its market segment, while the second term is the market share of a market segment g in the overall aircraft market. Since the outside good yields zero utility by assumption, δ_0 is 0 and D_0 is 1. We can invert the predicted market share for product j to obtain an analytic expression for mean utility level δ_j as a function of demand parameters and distributional parameter σ:

$$\ln S_j - \sigma \ln S_{j|g} - \ln S_o = \delta_j(S,\sigma) \equiv x_j\beta + \alpha p_j + \xi_j$$

Rearranging the above equation yields our estimating equation for demand:

$$(2) \quad \ln S_j - \ln S_o = x_j\beta + \alpha p_j + \sigma \ln S_{j|g} + \xi_j$$

where S_j is the observed market share of product j, S_0 is the observed market share of the outside good, and $S_{j|g}$ is the observed market share of product j within its market segment g.

2.2 Estimation Results

We estimate demand equation (2) using annual product level data on aircraft prices, sales, and characteristics from 1969 to 1998. The data cover worldwide sales by Airbus, Boeing, McDonnell Douglas, and Lockheed Martin in the wide-body market segment.[6] Table 1 presents the descriptive statistics of the data; further information on sources and data construction are described in the Data Appendix.[7] Note that in this study, market share is measured in terms of number of planes sold (rather than revenue share).

There are three issues in estimating (2). First, although the econometrician does not observe aircraft quality ξ_j, the aircraft producers likely set the price of product j to reflect the

[6] Our sample includes all wide-body planes: Boeing 747, Boeing 767, Boeing 777, DC-10, MD-11, L-1011, A-300, A-310, A-330, A-340.

[7] Relying on product-level information about the market (since we do not have information on individual airline purchases) obviously limits our empirical strategy. For example, we cannot explicitly address that airlines purchase the same type of aircraft at different prices and that aircraft (for example 747) purchased by different airlines differ in their characteristics such as seat configuration. Instead, we use typical characteristics such as typical seat arrangement for a given airline reported in industry journals. See data description for details.

product quality. The aircraft prices are therefore likely correlated with unobserved quality. Second, the within-group market share $S_{j|g}$ are also likely correlated with ξ_j. We therefore instrument for the two variables with two types of instruments: cost-shifters (hourly manufacturing wages in the E.U. and the U.S. and the price of aluminum), and the characteristics of the rival aircraft x_{-j} averaged over the entire wide-body market and averaged over products within each market segment. Cost shifters affect product prices, but are uncorrelated with product j's unobserved quality. Similarly, rival products' characteristics influence the market share and prices of rival aircraft, and through strategic interaction, also affect the pricing decisions and market shares of the product j in question. However, they are not econometrically correlated with product j's unobserved quality ξ_j. The key identifying assumption is that product attributes x_j are not correlated with ξ_j. The demand equation is linear in all parameters and the error term, so it can be estimated by two-stage least squares.[8] Third, errors are likely heteroskedastic and serially correlated.[9] We thus report standard errors that are robust to arbitrary forms of heteroskedasticity and serial correlation.

Table 2 presents the estimation results. Column 1 reports the OLS estimates of the demand parameters and column 2 reports two-stage least squares estimates (IV). Accounting for the endogeneity of price and within market segment market share affects the estimated parameters. For example, the OLS estimate of the price coefficient in column 1 is -.0265, while the magnitude of coefficient on price increases (in absolute value) in the IV regression (-.0488). These estimates are in line with our expectation of upward bias in the OLS coefficient. The

[8] Note that estimating the demand equation separately from the pricing equation (i.e. the supply side) does not affect the consistency of the estimates.

[9] One potential source of heteroskedasticity is the sampling error in the dependent variable due to low number of planes of particular type sold in each year. For example, the average number of planes of particular type sold is 26 (the 25th percentile is 14 and the 75th percentile is 37). Our standard errors are robust to arbitrary forms of heteroskedasticity, so they also account for this potential source of heteroskedasticity.

coefficients on other product attributes seem sensible. Focusing on the IV estimates in column 2, the additional take-off weight, additional seating and range are positively related to aircraft market share. Note that the coefficients on these characteristics are not estimated very precisely, which is not surprising given the low number of products and the fact that aircraft manufacturers do not change typical characteristics for a given aircraft model very frequently.

The estimated value of σ is 0.45, which suggests that planes within the medium- and long-range market segment are better substitutes for each other than planes across the market segments. This has important implications for competition among various aircraft. If a new product is introduced into a long-range wide-body market (for example, Airbus A-380), it will erode the market share of the products such as Boeing 747 and Airbus 340 more than the market share of Boeing 767, which competes mostly with medium-range planes.

Similarly, if, for example, the Boeing 747 increases its price, this increases the market share of its rivals in the long-range wide-body market segment by more than the market share of its competitors in the medium-rage market segment. To address the substitutability of products more formally, we use the estimates for the coefficient on prices α and substitutability parameter σ from column 2 to calculate the own and cross-price elasticities of demand derived from market share equation (1):

$$\eta_{j,j} = \frac{\partial s_j}{\partial p_j}\frac{p_j}{s_j} = -\alpha p_j s_j + \alpha p_j \left(\frac{1}{(1-\sigma)} - \frac{\sigma}{(1-\sigma)} s_{j|g}\right)$$

$$\eta_{j,k} = \frac{\partial s_j}{\partial p_k}\frac{p_k}{s_j} = -\alpha p_k s_k \quad if \;\; j \neq k \quad k \notin g, j \in g$$

$$\eta_{j,k} = \frac{\partial s_j}{\partial p_k}\frac{p_k}{s_j} = -\alpha p_k s_k \left(\frac{\sigma}{(1-\sigma)}\frac{s_{k|g}}{s_k} + 1\right) \quad if \;\; j \neq k \quad j,k \in g$$

where η_{jj} is product j's own-price elasticity of demand, η_{jk} is the cross-price elasticity between product j and k, and differs depending upon whether the products belong to the same market segment.

Table 3 presents the weighted means of the elasticities over time in columns 1-3. The average demand elasticity increases in absolute value over time, averaging about -2.9 in the early 1970s to -7.8 in the late 1990s. These estimates suggest that a 1 percent increase in the price lowers a plane's market share by 2.9% (7.8%) during the early 1970s (late 1990s). Thus, the aircraft market appears to have become much more competitive over time, despite the exit of many firms, due to the increase in number of different aircraft produced by each firm and the growing stock of used aircraft that is potentially on the market. Within a year, the own-price elasticities also differ across products, for example, ranging from -4.3 for Boeing 767 to -11.2 for Boeing 747 in 1998.

In addition, the estimates of the cross-price elasticities reported in column 2 (for products in the same market segment) and 3 (for product in different market segments) suggest that products within each market segment are closer substitutes for each other than products across the segments. For example, the average cross-price elasticity during the late 1990s suggests that a 1 percent increase in the price of a product leads on average to 1.4 percent increase in the market share of the products in the same segment and only .05 percent increase in the market share of the product in a different market segment.[10] Note that all these elasticity estimates are in line with the estimates of substitutability of foreign and domestic goods used in the trade

[10] The cross-price elasticities actually decline in general over time. This is not surprising, since the number of products in the market has increased. Thus, the effect of a price increase of a product on the market share of *each* of its competitors diminishes.

literature trying to explain the home market bias in consumption surveyed by Obstfeld and Rogoff (2001).

2.3 Aircraft Markup Estimates

We can obtain consistent estimates of product demand without assuming the mode of competition among the firms. However, in order to calculate firm markups we need to assume a specific form of firm conduct. Suppose that firm f maximizes the present discounted value of its profits given by:

$$(3) \qquad \pi_{ft} = E_t\left[\sum_{t=s}^{\infty}\beta^t\left(\sum_{j\in F_{ft}} p_{jt}q_{jt}(p) - c_{jt}q_{jt}(p)\right)\right]$$

where E_t is the expectation operator conditional on information at time t, β is the discount factor, q_{jt} is quantity of product j at time t and $q_{it} = s_{it}M_t$, c_{jt} is the marginal cost of product j at time t, and all other notation follows from previous notation. This objective function accounts for two characteristics of the aircraft industry—learning by doing in production and multi-product firms. First, the existence of learning by doing implies that firm's choices today affect the costs of production in the future through accumulated experience. Firms likely consider these intertemporal linkages in their profit maximizing decision. In particular, these dynamic considerations might make it profitable for a firm to price below marginal cost during the initial stages of production in order to quickly accumulate the experience and reduce the future cost of production. Second, Airbus, McDonnell Douglas, and Boeing are multi-product firms that are selling several products during most time periods. Thus, when Boeing considers lowering a price of one of its products, this will not only reduce the market share of Airbus's products, but might also undercut the sales of Boeing's other products. Boeing might then lower its prices by less than in a situation when it only sells one product.

There is mixed evidence on whether aircraft producers compete in prices or quantities. Anecdotal evidence on the widespread use of price discounts and favorable financing options suggests that aircraft companies compete in prices. As an example, a Harvard Business School case study reports significant underbidding between Boeing and Airbus, and cites the former Airbus Chairman Alan Boyd admitting to "pricing for market share...we had to do it in order to get our feet in the door." Yet price competition might be a questionable assumption during the periods when firms face capacity constraints. Tyson (1992) reports that the industry sources claim that capacity constraints were not binding during the 1980s. Although this informal evidence tends to support price competition, we compute markups based on both Bertrand and Cournot modes of competition for purposes of comparison. [11]

Assuming that firms compete in prices, first-order conditions for profit maximizing firm f with respect to product j at time t yield:

$$\sum_{k \in F_{ft}} (p_{kt} - c_{kt}) \frac{ds_{kt}}{dp_{jt}} + s_{jt} + E_t \left[\sum_{n=t+1}^{\infty} \beta^n q_{jn} \frac{\partial c_{jn}}{\partial q_{jt}} \frac{ds_{jt}}{dp_{jt}} \right] = 0$$

To derive a pricing equation for each product j at time t, we use vector notation. Let p_t denote a Jx1 price vector at time t, c_t a Jx1 vector of marginal costs, and s_t a Jx1 vector of market shares of all products offered at time t (time subscript is omitted in the notation). Let Ω_t be a JxJ matrix whose element in row j and column k equals $-\frac{\partial s_k}{\partial p_j}$ if aircraft j and k are produced by the same firm and 0 otherwise. Let f_t be a Jx1 vector whose element in row j (f_{jt}) equals

[11] We focus on derivation of Bertrand equilibrium in the text. Appendix 1 derives the equilibrium pricing equation for Cournot competition.

$E_t\left[\sum_{n=t+1}^{\infty}\beta^n q_{jn}\frac{\partial c_{jn}}{\partial q_{jt}}\right]$. We can then rewrite the first order profit maximizing conditions in vector form as:

(4) $p_t - \Omega_t^{-1} s_t = c_t + f_t \equiv c_t^*$

Equation (4) indicates that in equilibrium, the firms equate marginal revenue of product j to the product j's "dynamic marginal cost" c_{jt}*, i.e. the sum of current marginal cost c_{jt} and the expected discounted value of reduction in future cost attributed to current output, f_{jt}. This setting encompasses the possibility that profit maximizing firms price below the current marginal cost in order to gain experience that lowers the future cost of production.

If firms were static profit maximizers or there was no learning by doing in production, the expected discounted value of reduction in future cost attributed to current output, f_{jt} would be zero. Equation (4) would then equate marginal revenue to current marginal cost, and dynamic marginal cost would equal to current marginal cost (ie. c=c*). Thus, equation 4, combined with our demand parameter estimates and the data on prices and market shares, would enable us to calculate the markup margin over price ($(p_{jt} - c_{jt})/p_{jt}$) for each product j at time t. However, in the presence of learning by doing, calculation of markup margins also requires an estimate of learning rate in order to differentiate between dynamic and current marginal cost.

We would ideally obtain an estimate of learning rate by estimating a traditional learning model where current marginal cost is a function of cumulative output E_{jt}:

(5) $c_{jt} = A_j E_{jt}^{\theta} \quad with\ E_{jt} = \sum_{s=1}^{t-1} q_{jt}\ and\ E_{j1} \equiv 1$

where A_j is a firm specific cost parameter and parameter θ measures the learning rate.[12] The estimation of (5) ideally requires information on unit cost of production and cumulative output. Unfortunately, we do not have access to detailed cost data to obtain estimates of θ (as, for example, in Benkard (2000 and 2003)). As a result, we would need to base our estimate on a product's dynamic marginal costs implied by the equilibrium condition (4). High learning rate would imply that dynamic marginal cost should decrease through time. However, the implied costs do not drastically decline during the first few years after the entry.[13] This might be at first surprising given high estimates of learning rate for aircraft in Benkard (2000) and semiconductors by Irwin and Klenow (1994). However, the cost curves in the numerical simulations of Benkard's (2003) dynamic oligopoly model of aircraft industry (that do not rely on price data) are basically flat 2 to 3 years following the introduction of a plane (see figure 6 in his paper). [14] We think that the lack of steep decline in cost in the first few years following the entry in our data is due to the fact that our cost estimates (unlike estimates by Benkard (2000, 2003)) rely heavily on price of aircraft. Aircraft prices, however, are not declining drastically through time (as, for example, in semiconductor industry).

Rather than relying on our data to obtain an estimate of learning parameter, we instead compute current marginal cost (and thus markup margins) for several potential values of the learning parameter the following way. First, using data on quantity produced, we compute the

[12] The learning rate is calculated as $1-2^{\theta}$. For example, a 20% learning rate (associated with θ of -.33) implies that a doubling of output reduces unit cost of production by 20 percent.

[13] In fact, regressions of the logarithm of dynamic marginal costs on various combinations of input prices, log of cumulative output, time trend, and product fixed effects in general yield a coefficient on cumulative output that is not statistically different from zero.

[14] Using detailed data on labor inputs for L-1011, Benkard (2003) suggests that learning effects seem to matter initially in the production process, but are not a key factor later on: for most years, learning effects are small in relation to the production run. He shows that learning is effectively exhausted once L-1011 production reaches about 80 aircraft. Most Boeing aircraft sell at least this many products within two or three years after introduction (the Boeing 777 took 4 years to reach that level), while most Airbus aircraft reach this figure within the first 4 to 5 years after the initial launch.

ratio between dynamic marginal costs and current marginal cost, implied by cost function (5), $d_{jt} \equiv c^{*S}_{jt} / c^{S}_{jt}$. In our calculations of the expected discounted value of reduction in future cost attributed to current output, f_{jt}, we assume that firms have perfect foresight and that firms consider cost reductions for 10 periods into the future.[15] Because our data ends in 1998, we obviously do not observe full 10 years of future production for products starting in 1989. When future data is not available, we make use of quantity reported for the last year of our data (1998) and compute output at t+1 as .7 times output at time t (where t=1998) and continue to do so until the 10-year time horizon is reached for each product-year observation with unavailable future data.[16] Given that most aircraft have already had significant experience accumulated in 1998 and have thus already taken advantage of significant learning economies, the simulations are not very sensitive to the assumption on unobserved future output. We set the discount rate β of .95.

When learning rate is high, dynamic marginal cost will be much lower than the current marginal cost in the initial stages of production. However, as firms accumulate sufficient experience, the expected future cost declines associated with current output will become smaller. Thus the dynamic marginal cost will be similar to the current marginal costs. Hence, the ratio d_{jt} should increase through the life of an aircraft toward 1 as firms take advantage of learning economies of scale and future reductions in marginal cost due to higher current output become less important.[17]

[15] Given that most cost reductions occur in the first two to four years after the entry, it is unlikely that longer time horizons would yield very different conclusions.

[16] A regression of current output on lagged output yields a coefficient of .7. We have also experimented with simply assuming that all future (unobserved) periods produce output that is the same as in the last period observed (i.e. 1998). That exercise did not yield very different conclusions as the presented analysis (likely because by 1998 most planes have already substantially reduced cost of production and thus additional future cost reductions from current production do not play a large role).

[17] In fact, at 20% learning rate, our data suggest that the output weighted average of the ratio (over all aircraft) is .47 in the first year of production, .72 in the second year, .8 in the 4th year, and .9 in the 10th year of production.

Second, we take our estimates of dynamic marginal costs implied by (4) as given. We then compute a measure of current marginal cost as $c_{jt} = \frac{c^*_{jt}}{d_{jt}}$ and use it to compute markup margins $(p_{jt} - c_{jt})/p_{jt}$. We perform this exercise for several values of learning parameter θ ranging from 0 to -.4, which correspond to learning rate of 0 to 25 percent.[18]

Table 4 presents weighted averages of various markup margins through time. Different panels of the table correspond to calculations based on different values of learning parameter. The three columns report markup margins based on assumption of multiproduct Bertrand, single product Bertrand, and multiproduct Cournot competition. Several interesting findings emerge. Let us first focus on the markup margins when learning rate is zero, which correspond to markup margins obtained in static profit maximization. First, multi-product Bertrand estimates suggest that the average markup margins decline from .36 in the early 1970s to .15 in the late 1990s. This indicates that the competition in the aircraft market has increased over time despite the presence of only a few firms.

Second, the multi-product firm markups are higher than single-product firm markups and the difference becomes much more pronounced over time. While no firm offered more than one wide-body aircraft in the 1970s, Airbus and Boeing introduced new products starting in the 1980s. When firms have several closely related products on the market, they become less aggressive in terms of price competition because reducing the price on one product reduces demand for its other products. (Nina – is that intuition correct?) As a result, the markups accounting for multi-product firms are on average 12 percent higher than the single-firm markups in the 1990s. Finally, the markup estimates are not very sensitive to whether firms

[18] This procedure would yield markup margins reported in table 4 when learning rate is zero (i.e. θ=0).

compete in prices or quantities. Cournot markup margins and display similar patterns as the Bertrand markup margins.

Given the importance of dynamics in early stages of production, let us now consider markup margins when we account for learning by doing. Markup margins based on the learning parameter -.3, which approximately corresponds to a 20 percent learning rate might be potentially of most interest. Estimates of traditional learning rate by Benkard suggest the learning parameter of -.29 over the lifespan of L-1011 (i.e. 18 percent learning rate).[19] This corresponds to the learning rate of 20 percent suggested by industry sources.[20]

Several interesting patterns emerge. (Nina – these are not shown on the table, right?) First, accounting for dynamics yields negative markups, especially during the first few years following the entry and in scenarios with higher learning rate. For example, our markup margins range from -1.1 to .37 at 20 percent learning rate. Overall, markups are lowest during the 1974 to 1978 period, 1984 to 1988 period, and 1994 to 1998 period. This pattern is consistent with the fact that those periods follow market entry and thus intensified competition. For example, A-300 entered in 1974, following the entry of DC10 in 1971 and L-1011 n 1972. A-310 and Boeing 767 entered in 1982 and 1983, respectively. Anecdotal evidence suggests increased competition for the market share in both of these entry episodes.[21] Moreover, even when we account for dynamics we continue to find that multiproduct markups exceed single product markup margins and that the difference between the two increases through time. Similarly, the markup estimates are not very sensitive to the assumption on the mode of competition (Bertrand vs. Cournot).

[19]Benkard also estimates cost functions where he explicitly accounts for forgetting. We do not separately identify learning and forgetting. Thus the learning rate could be viewed as a net learning rate.
[20]This information is based on personal correspondence with the chief economist of Boeing, Bill Swan.
[21] Moreover, A330 and A340 entered in 1993 and Boeing 777 entered in 1995.

We next compare these markup margins to estimates by Benkard (2003). Benkard (2003) simulates a dynamic model of the aircraft industry assuming that firms compete in quantities. It is difficult to make direct comparisons between his results and ours because he simplifies the industry's structure and product varieties to reduce the computational burden of dynamic simulations. His model does an excellent job matching the observed markups of L-1011 (or the type of plane that matches l-1011 in his simulations), whose actual markup margin over price is essentially zero or negative throughout its lifespan. Our estimates for L-1011 based on 20 percent learning rate yield markup margins between -.19 to .2. His simulations also suggest that other plane types have negative markups during the first 2-3 years. However, calculations based on the graphs of his simulated prices and costs suggest that most aircraft other than L-1011 in the industry simulation actually have positive markups during most of their lifespan (except for the first 2-3 years). In particular, in most periods after the initial 2-3 years, other aircraft have markup margins around 14 to 17 percent with occasional periods when markup margins drop to 3 to 5%. We also find a similar pattern.

In sum, our structural estimates capture several important features of the aircraft industry that we incorporate in our study of the trade disputes in the next section. In particular, our demand estimates suggest significant segmentation within the wide-body aircraft market, which is consistent with the anecdotal evidence on the near monopoly power enjoyed until early 1990s by the Boeing 747 in the long-range market. Markup estimates that incorporate dynamics often yield negative markup margins, especially during the planes entrance into the market. The markup estimates suggest that competition in the wide-body aircraft market is increasing over time, especially during periods of new entry. While the levels of static markup estimates following the first introduction of a product should be taken with caution, ignoring the dynamics

might not be as problematic in the later periods of airplane's life. We also find that the estimates of markups are relatively insensitive to the assumption of different modes of competition among the firms (Bertrand vs. Cournot). However, since Airbus and Boeing expand their products over time, the markup estimates become increasingly sensitive to accounting for multi-product firm profit maximization. Some of these industry characteristics have not been noted in the previous studies of the industry.

3. Aspects of Airbus Competition

The results from the previous section lend some new insight into the structure of demand and competition in the wide-body aircraft market. The structural estimates, however, can be used to explore additional issues that are commonly raised in considering this market. In particular, we examine the impact of two important events: (1) the 1992 agreement between the United States and European Community regarding subsidies and competition in the aircraft production, and (2) the entry of the A-380, Airbus's new wide body that aims to compete directly with the Boeing 747.

3.1 Impact of the 1992 Agreement

Following the trade tensions between the United States and the European Union surrounding the subsidized entry of the A-300 in the early 1970s, the rivalry between Boeing and Airbus intensified considerably after Airbus introduced the narrow-body A-320 in the mid-1980s. After Air India cancelled an order for Boeing 757s when Airbus offered steep discounts on the A-320, the U.S. government intervened on Boeing's behalf. The United States threatened using the countervailing duty laws or opening a Section 301 case against Airbus unless an agreement on subsidies was reached. In 1992, the United States and European Community reached a bilateral agreement on trade in civil aircraft (see Tyson 1992 and Pavcnik 2002). The

agreement establishes limits on the direct and indirect (military) subsidies used to finance the development of new aircraft. The maximum allowed direct subsidy is 33 percent of development costs. In addition to development subsidies, governments also provide assistance to domestic producers through measures that might affect variable cost of production. As a result, the agreement has several provisions that affect the *variable* production cost of aircraft and might thus affect pricing in the aircraft market. For example, the agreement prohibits production subsidies and restricts the government's ability to help the domestic aircraft producer offer financing to airlines. The agreement also requires detailed reporting on subsidies, interest rates, and repayment conditions, and establishes procedures to monitor the agreement. Finally, the agreements repayment provision requires that Airbus make repayments on a per-plane basis rather than delay repayment until the end of the loan. This provision reduces the risk that Airbus can significantly cut price to capture certain sales, but it does not guarantee this result.

The unanswered question is whether the 1992 bilateral agreement had any impact on pricing in the aircraft market. In particular, one would a priori expect the agreement to increase prices because the agreements provision on financing, production subsidies, and repayments of the loan implicitly increase the marginal cost of an aircraft. Although we can never truly identify the effect of the 1992 U.S.-E.U. agreement on aircraft prices, our data enable use to compare the aircraft prices before and after the agreement. We thus regress aircraft prices (in logs) on a dummy variable set at unity from 1992 and other potential determinants of price. We control for other time-varying factors that could affect the pricing of aircraft through the inclusion of GDP growth, price of petroleum, market segment Herfindahl index, and a time trend. Product fixed

effects control for the differences in characteristics across aircraft that affect pricing.[22] Since the estimated coefficients are not statistically different from each other when we estimate the separate narrow-body and wide-body market segment separately, we pool the data from both market segments to gain efficiency. We restrict our analysis to data from 1985 onwards so that we have equal number of time periods before and after the treaty.

Table 4a contains the results. The coefficients on the treaty indicator in columns 1-4 suggest that prices of aircraft have on average increased after the 1992 U.S. – E.U. trade agreement. The estimates range from 9.4 to 3.7 percent as we add controls for other time-varying factors that could independently affect prices such as market concentration captured by Herfindahl index (column 1), GDP growth and price of petroleum (column 2), a time trend (column 3), and all of the above controls (column 4).[23] In columns 6-9, we allow the treaty to have a differential impact on Airbus's pricing by interacting the treaty indicator with the Airbus indicator. Our results suggest that the agreement did not have a differential impact on the pricing of Airbus. The coefficient on the interaction of treaty and Airbus is always insignificant. Moreover, the coefficients on the treaty indicator are similar to the magnitudes obtained in columns 1-4.

One potential problem with our analysis is that the positive coefficient on the treaty indicator could simply reflect extremely high prices in one unusual year following 1992 rather than consistently higher prices from 1992 onwards (or extremely low prices in one unusual year before 1992). To check for this possibility we consider general trends in prices during the years

[22] The characteristics of most planes do not vary during this period. Thus, aircraft fixed effect accounts for them. In unreported regressions, we have also experimented with inclusion of plane characteristics in random effects regressions. They yield similar findings.

[23] Some planes exit the market before 1992 and some planes enter the market after 1992. Their effect on the competition is captured through the Herfindahl index. Also, since we rely on the product fixed effects, the coefficient on the treaty indicator is identified by the price variation for the products that were in the market before and after the agreement.

surrounding the 1992 agreement by regressing aircraft prices (in logs) on year indicators (1991 is the omitted indicator) and product fixed effects. The coefficients on year indicators are depicted in figure 2. The coefficients on year indicators for 1992 onwards are all positive and significantly higher than zero. As a result, it is unlikely that one particular year is driving our findings.[24]

Overall, our evidence suggests that the 1992 U.S.-E.U. agreement limiting aircraft subsidies appears to have raised prices of Boeing and Airbus aircraft. This behavior is consistent with a Cournot or a Bertrand duopoly model in which subsidies are eliminated. Given that no publicly available data exist on the magnitude of the subsidy reductions, it is difficult to judge whether these price increases are big or small. However, the structural model and estimates for the wide-body aircraft from section 2 enable us to check how big of subsidy reductions these price increases potentially imply. In particular, we use the estimates of demand parameters, marginal costs c implied by Bertrand pricing equilibrium, predicted market share equation (1), and equilibrium pricing equation (4) to simulate equilibrium prices under various increases in firms' marginal costs (i.e. various reductions in subsidies). We consider firms' marginal cost increases ranging from 5 to 20 percent. In these simulations we assume that dynamic marginal cost equal to the current marginal costs. Because all but one of the planes sold in 1992 have been on the market for at least 10 years, they have likely already taken advantage of learning and the future cost reductions from current output are likely small.[25] In fact, the weighted average of the ratio of dynamic to current marginal cost based on the calculations reported in section 2.3 is .89 when learning rate is approximately 30%. This confirms that firms have already

[24]Columns 5 and 10 of table 4a repeat regressions in columns 4 and 9 without the 1985 data (1985 has unusually low prices). We continue to find a positive coefficient on the treaty indicator.
[25] MD-11 is an exception since it entered in 1990.

accumulated significant experience and that abstracting from future cost reductions associated with current output might not be that problematic.

Table 4b reports the average prices of wide-body aircraft under each of the scenarios and the average percent increase in prices (relative to the baseline of no change in marginal cost). The table suggests that the observed average 3.7 to 7.5 percent price increases correspond to about 5 to 10 percent increase in the marginal costs of firms.

3.2 Impact of A-380 Entry

The most recent trade controversy has centered on government funding for Airbus's super-jumbo aircraft, the A-380, whose first deliveries are expected in the year 2006. As Figure 1 indicates, the A-380 will be the world's largest passenger aircraft, designed to carry between 550 to 650 people, have a range of over 14,200 km (8,000 miles), and have a takeoff payload of 540,000 kg. The governments of France, Germany, and the United Kingdom are expected to cover about one-third of the estimated $12 billion in development costs. The United States has warned the European governments that the Airbus financing may violate the 1992 agreement and subsidy rules established in the World Trade Organization in 1994. The EU has countered by asking that indirect subsidies to Boeing from military and NASA contracts be examined.[26]

Press reports indicate that the list price of the A-380 is $235 million, but also suggest that discounts on the order of at least 10 percent are being negotiated with potential buyers. Some reports even indicate that 35 percent discounts have been offered, but the industry observers believe such large discounts will not last for long. Airbus has indicated that 250 aircraft must be sold for it to break even and cover the enormous development costs. Airbus has only decided to go ahead with the production once the advanced orders hit the 50-plane mark, and about 60 planes have been ordered (as of early 2001). The A-380 is designed to compete directly against

[26] See Pavcnik (2002) for the details about the dispute.

the Boeing 747 at the high end of the wide-body market. Airbus claims that due to the operating-cost effectiveness of the A-380 (relative to Boeing 747), the airlines flying the A-380 need to fill only 33 additional passenger seats to break even (relative to Boeing 747 break-even passenger requirement). Boeing denies that there is a profitable market for such "super jumbos" and is planning on producing modified versions of the 747 to compete against the A-380.

Given the heated trade debate and controversy surrounding the A-380 entry, we simulate the impact of the entry on the prices and market share of *existing* aircraft using our structural parameter estimates and product characteristics from section 2. We proceed as follows. First, an estimate of A-380 mean utility level requires values for A-380 observed attributes and unobserved quality. We take the announced prices and characteristics of the A-380 as given.[27] Moreover we assume that its unobserved quality equals the unobserved quality of A-340 in 1998. We use the A-340 unobserved quality (rather than the unobserved quality of the 747), because Airbus planes potentially share similar unobserved characteristics. Note that A-340 unobserved quality does not fluctuate much over time and it follows a similar time path as the unobserved quality of 747 (albeit unobserved quality of 747 is about 1.7 times higher).[28] Thus, focusing on the 1998 values is not likely to be problematic. Nevertheless, errors in determining the unobserved quality of A-380 could potentially affect our simulation. As a result, we perform several robustness checks where we set the quality of A-380 to be 10, 20, and 50 percent higher than the quality of A-340, as well as equal to the quality of 747.

Using the estimates of the demand parameters and the information on the A-380 attributes we next predict the A-380 mean utility level δ. One potential problem with this

[27] The A-380 list price is adjusted to 1995 dollars so that they are comparable with the rest of our data.
[28] The unobserved quality of A-340 also follows a similar trend to the unobserved quality of A-330 with the exception of the initial two years. A-330 quality is low in the initial year, it then increases, and they relatively levels off.

analysis is that because of the unprecedented size of A-380, the demand estimates might not apply to A-380. We perform two checks for whether our demand system is potentially misspecified. First, we estimate a version of the demand equation in which we include the square and cubic value of the predicted dependent variable. The two nonlinear variables are insignificant and the F-test of joint insignificance yields a p-value of .15. Second, we graph the demand residuals against various included aircraft characteristics. Visual inspection of the graphs does not show significant nonlinear trends in the residuals. Thus, out of sample predictions are likely not very problematic. We then incorporate the A-380 mean utility level δ in the predicted market share expression (1) for each of the existing products and the outside good. Finally, using this "augmented" predicted market share equations (1) and the pricing equation (4), we simulate the new equilibrium prices and market shares for each of the existing products.

A-380 likely has an incentive to initially offer large price discounts (and potentially price below marginal cost) to secure a large market share and to take advantage of economies of scale. We thus explicitly consider how price discounts on A-380 affect the A-380 current market share and simulate the annual post entry market when the A-380 is sold at the list price, at a 10 percent discount, at a 20 percent discount, and at a 30 percent discount. Moreover, by comparing the ratio of dynamic to current marginal cost we can actually check whether the existing planes have already substantially exhausted gains from learning by 1998. If this ratio is close to one, firms do not anticipate significant future cost reductions associated with current output. The weighted averaged of the ratio in 1998 is .92 (when we assume 20% learning rate; the ratio is above .96 for five out of eight aircraft) which suggests that abstracting from the dynamic aspects for *existing* planes is likely not very problematic. By 1998, all the existing planes have been on the market

for at least four years and have thus already captured most of the benefits of learning by doing. As a result, we focus on static equilibrium for *existing* planes (i.e. we equate the current marginal cost to dynamic marginal cost).

Table 6 presents these results. The top part of the table reports overall market share and the changes in overall market share under different scenarios relative to the no entry case. The middle part of the table reports the aircraft market share within a market segment (and respective changes in market share relative to the no entry case). The bottom part of the table reports prices (and respective changes in prices relative to the no entry case). Given that the press releases suggest significant initial price discounts on the A-380, we focus on the results when the A-380 is sold at a 20 percent discount. The no entry case always serves as the comparison group.

Several interesting findings emerge. First, the A-380 gains about 1 percent of the overall annual market (which translates into 38 aircraft), and 17.4 percent of the long-range market segment. Boeing 747, for example, controls 1.2 percent of the overall market prior to the A-380 entry (28.5 percent of the long-range market segment). Second, the simulation results reflect the importance of market segmentation within the wide-body market. As a result of A-380 entry, the overall market share of a long-range wide body aircraft (for example Boeing 747) declines by 2.5 percent (.0002 decline in market share), while the overall market share of a medium-range plane (for example Boeing 767) declines only by .9 percent (.0001 decline in market share). This translates into the total annual loss of 7 sales by the existing long-range varieties and the total annual loss of .3 sales by the existing medium-range wide body varieties. Third, the market share loss is substantial for Airbus's own products, especially in the long-range market segment since their prices do not fall as much following the A-380 entry. The A-380 substantially undercuts the demand for the A-330 and A-340, which illustrates the risk that multi-product

firms face in introducing new models. For example, the A-380 lowers the combined market share within wide-body market segment of the A-330 and A-340 by more than it lowers the within wide-body market share of the 747. Moreover, the declines in prices of wide-body Boeing aircraft range from 0.9 to 1.3 percent, while the declines in prices of existing Airbus wide-body aircraft are about .3 percent. Nevertheless, the overall market share of Airbus still increases. Overall, given that the industry sources indicate that the Boeing 747 accounts for a substantial portion of Boeing's profits, the subsidized A-380 entry into the market might have a significant negative impact on the U.S. producer and lead to future conflicts in U.S.-E.U. trade relations.

Finally, the comparison of the results across various pricing options for the A-380 reveals the importance of price discounts in securing a higher market share for the A-380. While Airbus is only able to sell 1 A-380 per year at the list price (corresponding to .02 percent market share), the annual sales of the A-380 increase to 6 planes at a 10 percent discount (.1 percent market share), 38 sales at 20 percent discount (1 percent market share), and 177 sales at 30 percent discount (4 percent market share). Our results thus seem to be consistent with the reports that cumulative orders for the A-380 are now around 60 planes and that some of these aircraft have been sold at significant discounts.

As mentioned earlier, we have performed several robustness checks using different values for unobserved A-380 quality. Appendix table 1 and 2 consider the effect of A-380 entry under 10 and 20 percent price discounts assuming that the quality of A-380 is 10, 20 and 50 percent higher than the quality of A-340 and equal to the quality of 747 (about 76 percent higher than the quality of A-340). Let us focus on Appendix table 1. Unsurprisingly, as the A-380 quality increases, A-380 secures a bigger market share. While, Airbus sells 6 planes when the

quality of A-380 equals the quality A-340 at 10 percent discounts, a 10, 20 and 50 percent higher quality yields 7, 8, and 11 sales, respectively. Moreover, Airbus would sell 15 A-380 if the quality of A-380 matched the quality of 747. Despite higher sales of A-380, we continue to find that A-380 not only negatively impacts 747 but also A-330 and A-340 and all the other characteristics of simulated results reported in table 6.

Before we conclude, the question obviously arises whether Airbus can sell enough A-380s at relatively high prices to recoup its development and production costs. Let us consider the predictions of simulations, where Airbus sells the A-380 at a 20 percent discount off its $230 million list price reported in table 6. Without additional growth in demand, this yields 38 annual sales, amounting to 760 planes sold and $140 billion in revenues over the next 20 years (ignoring discounting). These figures suggest that the A-380 will likely cover its development costs (estimated to be $12 billion), and that Airbus might be able to repay government loans. However, the estimates fall short of Airbus's forecast that the airlines will demand 1,500 superjumbos over the next 20 years, yielding around $345 billion in revenues. In fact, the simulated number of total sales is closer to Boeing's predictions that market will only demand around 700 superjumbos overall. According to Boeing, these sales are insufficient for the project to eventually become profitable. Of course, the above analysis abstracts from other potential reasons for bringing A-380 to the market. For example, although many airline fleets include both Boeing and Airbus airplanes, there might be some synergies in owning all Airbus planes. If that is the case, the introduction of a long range plane such as A-380 might thus induce additional airlines to switch away from Boeing to Airbus planes.

4. Conclusions

This paper has taken an empirical look at international competition and trade disputes in the wide-body aircraft market. Given that the aircraft industry continues to be the source of trade friction between the United States and the European Union, our main goal was to evaluate two key trade issues. We find evidence that is consistent with the 1992 U.S. – E.U. agreement to limit subsidies resulting in higher aircraft prices. Although we cannot say anything about the magnitude of the government development subsidies that have helped aircraft producers to launch their products, our evaluation of the 1992 agreement suggests the observed price increases after the agreement are consistent with increases in firms' marginal costs by about 5 percent. We also predict that the introduction of the Airbus A-380 will substitute most strongly for existing Airbus aircraft rather than the Boeing 747, although the negative impact on demand for the 747 is not negligible. The extent of this substitution depends critically on the price discounts that Airbus offers on the A-380.

To reach these conclusions, the paper estimated the demand for wide-body aircraft and firm markups under various assumptions on the mode of competition. This exercise yields several insights into the wide-body aircraft market. First, we find evidence of significant market segmentation between the medium-range and long-range wide body planes, which is important in evaluating the impact of the new Airbus A-380 entry. This market segmentation is also consistent with the market dominance of the Boeing 747 during the past 20 years. Second, our estimates of demand elasticities and markups suggest increased market competition especially during times of new entry despite the small number of firms. Third, the markup estimates implied by the Bertrand and Cournot competition are relatively similar. This might be explained by the growing presence of multi-product firms in the industry. As producers expand the range of products, their incentive to aggressively underbid their rivals is diminished, since price cuts

might also hurt their own sales of other products. Thus, the distinction between Bertrand and Cournot competition becomes less clear.

This industry feature might have some implications for the literature on the strategic trade policy. Theory models such as Bradner and Spencer (1985) and Eaton and Grossman (1986) have shown that the optimal trade policy to shift profits across countries is sensitive to whether the firms compete in prices or quantities.[29] These models have focused on single-product firms. Our results suggest that the existence of multi-product firms makes the Bertrand behavior less aggressive and this distinction less clear. Moreover, the presence of multi-product firms makes it more challenging for the aircraft companies to successfully introduce new aircraft without hurting their existing product line. This is demonstrated in our simulations of the A-380 entry into the market. We predict that the entry will lower the combined market share of Airbus's existing long-range wide-bodies by more than the market share of Boeing 747.

Nevertheless, many questions remain unanswered. Most importantly, without more detailed information on production cost, we also cannot address the issues of strategic trade policy that are more dynamic in nature such as the role of government subsidies to promote the aircraft market entry. Benkard (2003) provides a first step in this direction.

[29] Maggi (1996) presents a model in which firms' mode of competition is determined endogenously by the importance of capacity constraints and studies the implications of strategic trade policy in that context.

Data Appendix

We take our data on annual aircraft deliveries and average sales price from 1969 to 1998 from the industry publication The Airline Monitor (May 1999 issue). Aircraft characteristics, such as passengers, range, take-off weight, typical number of seats were taken from various issues of Jane's World Aircraft. Summary statistics on data are provided in Table 1 for wide-body and narrow-body aircraft. Data on A-380 characteristics was obtained from the Airbus Industrie web site (http://www.airbus.com/pdfs/A380/BRIEF2000.pdf).

Data on producer price indices, exchange rates, price of petroleum, GDP growth, and the price of aluminum are taken from IMF's International Financial Statistics Yearbook. Data on the U.S. hourly manufacturing wages and the U.S. producer price index is from the Bureau of Labor Statistics (online data). Data on hourly manufacturing wages for France, Germany (the states comprising former West Germany), and Great Britain are from the Yearbook of Labor Statistics published by the International Labor Organization. We computed a weighted average of hourly manufacturing wages in France (weight is .4), Germany (weight is .4), and Great Britain (weight is .2) using weights that mimic the individual country's ownership shares in the Airbus Consortium. Similar procedure was used to compute the producer price index for Airbus. All values are expressed in 1995 U.S. dollars.

Appendix 1—Cournot Equilibrium

When the firms compete in quantities, the first order conditions for profit maximizing firm f with respect to product j at time t yield:

$$\sum_{k \in F_{jt}} \frac{dp_{kt}}{ds_{jt}} * s_{kt} + (p_{jt} - c_{jt}) + E_t\left[\sum_{n=t+1}^{\infty} \beta^n q_{jn} \frac{\partial c_{jn}}{\partial q_{jt}}\right] = 0$$

To derive a pricing equation for each product j at time t, we use vector notation. Let p_t denote a Jx1 price vector, c_t a Jx1 vector of marginal costs, and s a Jx1 vector of market shares of all products offered at time t (time subscript is omitted in the notation). Let Ω_t^c be a JxJ matrix whose element in row k and column j equals $-\frac{\partial p_j}{\partial s_k}$ if aircraft j and k are produced by the same firm and 0 otherwise. Let f_t be a Jx1 vector whose element in row j (f_{jt}) equals $E_t\left[\sum_{n=t+1}^{\infty} \beta^n q_{jn} \frac{\partial c_{jn}}{\partial q_{jt}}\right]$. We can then rewrite the first order profit maximizing conditions in vector form as:

$$p_t - \Omega_t^c s_t = c_t + f_t \equiv c_t^*$$

We still need to find the expression for $\frac{\partial p_j}{\partial s_k}$. As discussed in section 2.1, Berry (1994) shows that one can invert the predicted market share function for product j (1) to obtain an analytic expression for the mean utility level of product j δ_j as a function of product market share and distributional parameter σ:

$$\delta_j(S, \sigma) = \ln S_j - \sigma \ln S_{j|g} - \ln S_o .$$

Moreover, remember that the mean utility level of product j is defined as $\delta_j \equiv x_j \beta - \alpha p_j + \xi_j$. Thus:

$$\frac{\partial p_j}{\partial s_j} = \frac{\partial p_j}{\partial \delta_j}\frac{\partial \delta_j}{\partial s_j} = \frac{1}{\alpha}\left(\frac{1}{s_j} - \frac{\sigma}{s_j} + \frac{\sigma}{s_g} + \frac{1}{s_o}\right)$$

where s_g is the market share of the market segment g in the overall market and s_o is the market share of the outside good.

Similarly,

$$\frac{\partial p_j}{\partial s_k} = \frac{\partial p_j}{\partial \delta_j}\frac{\partial \delta_j}{\partial \delta_k}\frac{\partial \delta_k}{\partial s_k} = \frac{1}{\alpha}\frac{\partial \delta_j}{\partial \delta_k}\left(\frac{1}{s_k} - \frac{\sigma}{s_k} + \frac{\sigma}{s_g} + \frac{1}{s_o}\right).$$

We still need to obtain $\frac{\partial \delta_j}{\partial \delta_k}$ in the above expression. By implicit function theorem:

$\frac{\partial \delta_j}{\partial \delta_k} = -\frac{\frac{\partial s_j}{\partial \delta_k}}{\frac{\partial s_j}{\partial \delta_j}}$. Differentiating (1) with respect to mean utility of product j and k thus yields:

$$\frac{\partial \delta_j}{\partial \delta_k} = \begin{cases} \dfrac{s_k\left(\frac{\sigma}{(1-\sigma)}s_g^{-1} + 1\right)}{\frac{1}{(1-\sigma)} - s_j\left(\frac{\sigma}{(1-\sigma)}s_g^{-1} + 1\right)} & if \quad j,k \in g \\ \dfrac{s_k}{\frac{1}{(1-\sigma)} - s_j\left(\frac{\sigma}{(1-\sigma)}s_g^{-1} + 1\right)} & if \quad j \in g, k \notin g. \end{cases}$$

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Figure 1—Range and Typical Number of Seats for Wide Body and Narrow Body Aircraft