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Airbus versus Boeing revisited: international competition in the aircraft market

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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 aircraft prices increased by about 3.7% after the 1992 US–EU agreement on trade in civil aircraft that limits subsidies. This price hike is consistent with a 5% 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 14.8 percentage points 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.

Keywords: Trade policy; Aircraft industry

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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

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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 US 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 (1988); Klepper (1990, 1994); 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 assumptions on firms' market conduct and learning parameter in production, 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.[2]

We then focus on two aspects of the international rivalry between Airbus and Boeing. First, we examine whether the 1992 US–EU agreement on trade in civil aircraft limiting aircraft subsidies had a significant impact on pricing in the aircraft market. We find that the agreement appears to have raised the prices of both Airbus

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

[2] 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.

and Boeing aircraft by about 3.7% 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 about 5% 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.

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 6000 km) that typically carry between 100 and 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 and 450 passengers. The leading aircraft in this category are the Boeing 747, the Boeing 777, and the Airbus A-300. Within the wide-body market, planes also differ significantly in terms of their characteristics depending on whether they are aimed at serving the medium-range (i.e. Boeing 767, the Airbus A-300 and A-310, DC-10, and L-1011) or long-range market (i.e. Boeing 747 and 777, the Airbus A-330 and A-340, and the MD-11). As a result, we can view narrow-body, medium-range wide-body, and long-range wide-body aircraft as imperfect substitutes for one another because the planes are designed to serve different markets. Fig. 1 plots the typical number of seats and the range of various aircraft and indicates how localized the competition is within the narrow-body, medium-range wide-body, and long-range wide-body segment.

We focus mainly on the wide-body segment of the 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 1185 units in 1998 (it was introduced in 1969), and the best selling Airbus aircraft A-300 sold only 481 units between 1974 and 1998. As a result, competition tends to be more intense in the wide-body market, since from the

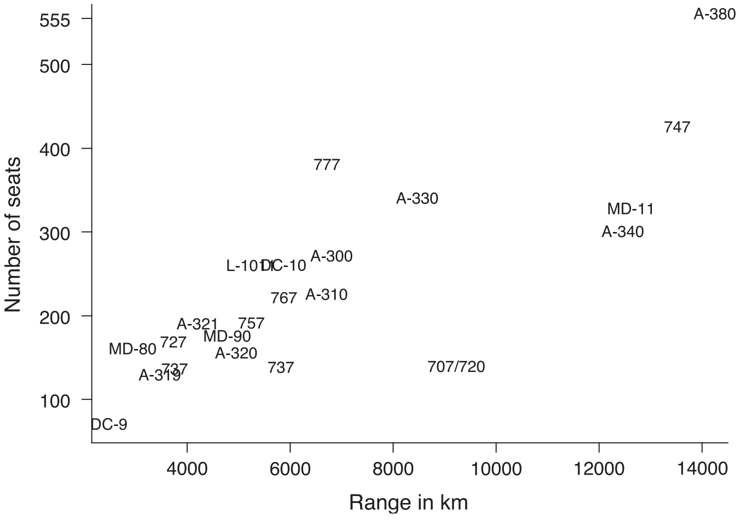

Fig. 1. Range and typical number of seats for wide- and narrow-body aircraft.

firm's perspective, each additional sale generates valuable revenue. In contrast, narrow-body planes often sell well above 1000 units over their lifespan, with Boeing 737 selling over 3200 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, so that $u_{ij}=x_j\beta-\alpha p_j+\xi_j+\tau_{ij}$, 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. 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 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. The common taste depends on the distribution parameter σ $(0 \leq \sigma < 1)$, which indicates the degree of substitutability between products within a market segment. When σ is 0, 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.[3]

Given the set of available aircraft, airlines are assumed to select the aircraft that gives them the highest utility.[4] Consumer i will choose aircraft j if $u_{ij} \geq u_{ik}$. 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:

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

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 and distribution parameter σ: $\ln S_j - \sigma \ln S_{j|g} - \ln S_0 = \delta_j(S, \sigma) \equiv x_j\beta + \alpha p_j + \xi_j$. Rearranging the above equation yields our estimating equation for demand:

$$\ln S_j - \ln S_0 = x_j\beta + \alpha p_j + \sigma \ln S_{j|g} + \xi_j \tag{2}$$

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.

[3] Benkard (2003) 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 1969–1998. The additional years of data are important because the A-330, A-340, and Boeing 777 only enter the market in 1993 and 1995.

[4] While this framework allows an airline to purchase only one aircraft at a time, airlines often 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.

Table 1
Descriptive statistics

Variable	Number of plane-years	Mean	S.D.
Wide-body aircraft			
Price (million 1995 $)	148	80	26
Quantity sold	148	26	18
Market share	148	0.203	0.160
Take off weight (ton)	148	225	77
Typical number of seats	148	293	67
Range (thousand km)	148	8.04	2.68
Narrow-body aircraft			
Price (million 1995 $)	141	29	10
Quantity sold	141	58	46
Market share	141	0.213	0.149
Take off weight (ton)	141	74	27
Typical number of seats	141	143	37
Range (thousand km)	141	4.46	2.18

Data from 1969 to 1998. Market share refers to product's market share in the narrow- or wide-body market.

2.2. Estimation results

We estimate demand Eq. (2) using annual product level data on wide-body aircraft prices, sales, and characteristics from 1969 to 1998. The data cover worldwide sales by Airbus, Boeing, McDonnell Douglas, and Lockheed Martin. Table 1 presents the descriptive statistics of the data; further information on sources and data construction are described in Section 5. 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 Eq. (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 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 instrument for the two variables with two types of instruments: cost-shifters (hourly manufacturing wages in the EU and the US 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.[5]

[5] Estimating the demand equation separately from the pricing equation (i.e. the supply side) does not affect the consistency of the estimates.

Table 2
Estimates of demand equation

	OLS (1)	IV (2)
Price	– 0.0265*** [0.0049]	– 0.0488*** [0.0139]
Take off weight	0.0026 [0.0025]	0.0012 [0.0024]
Number of seats	0.0032 [0.0026]	0.0107 [0.0064]
Range	0.02 [0.051]	0.112 [0.082]
GDP growth	– 0.029 [0.018]	– 0.012 [0.021]
Petroleum price	– 0.007 [0.006]	– 0.01 [0.008]
σ	0.976*** [0.080]	0.448* [0.248]
Adjusted R^2	0.82	0.63

Robust S.E.s adjusted for clustering by plane are reported in parenthesis. ***, **, and * indicate significance at a 1%, 5%, and 10% level, respectively. Number of observations is 148.

Finally, errors are likely heteroskedastic and serially correlated.[6] We thus report standard errors (S.E.) 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 -0.0265, while the magnitude of coefficient on price increases (in absolute value) in the IV regression (-0.0488). These estimates are in line with our expectation of upward bias in the OLS coefficient. The 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. 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.

This substitutability of products is quantified in Table 3 that presents the weighted means of the own and cross price elasticities of demand.[7] The average demand elasticity

[6] 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.

[7] The elasticity formulas are available in an unpublished appendix available on the authors' web sites.

Table 3
Price elasticities

Period	Price elasticities		
	Own price (1)	Cross price same segment (2)	Cross price across segments (3)
1969–1973	−2.901	2.570	0.502
1974–1978	−3.750	1.604	0.098
1979–1983	−4.079	1.858	0.101
1984–1988	−4.822	1.789	0.047
1989–1993	−6.410	2.007	0.071
1994–1998	−7.813	1.436	0.047

The reported elasticities are output-weighted period averages.

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% 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 price sensitive over time, despite the exit of some firms, potentially 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% increase in the price of a product leads on average to 1.4% increase in the market share of the products in the same segment and only 0.05% increase in the market share of the product in a different market segment.[8]

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:

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

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 (which is a product of market share of product j at time t and total market size at t, i.e. $q_{jt}=s_{jt}(p)M_t$, c_{jt} is the marginal cost of product j at

[8] 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.

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. Yet price competition might be a questionable assumption during the periods when firms face capacity constraints. As a result we compute markups based on both Bertrand and Cournot modes of competition for purposes of comparison.[9]

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

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

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

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

Eq. (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}.[10] This

[9] For example, a Harvard Business School case study by Yoffie (1991) 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 Tyson (1992) reports that industry sources claim that capacity constraints were not binding during the 1980s. An unpublished appendix available on the authors' web sites derives the equilibrium for Cournot competition.

[10] Note that the above equilibrium ignores the fact that a firm's actions will affect its profits via the effect on the other firms' future optimal output decisions.

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 0. Eq. (4) would then equate marginal revenue to current marginal cost, and dynamic marginal cost would equal to current marginal cost (i.e. $c = c^*$). Thus, Eq. (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 Z_{jt}:

$$c_{jt} = A_j Z_{jt}^{\theta} \qquad \text{with } Z_{jt} = \sum_{s=1}^{t-1} q_{jt} \text{ and } Z_{j1} \equiv 1 \tag{5}$$

where A_j is a firm specific cost parameter and parameter θ measures the learning rate.[11] The estimation of Eq. (5) ideally requires information on unit cost of production and cumulative output. Unfortunately, we do not have access to detailed cost data (as, for example, in Benkard, 2000, 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. 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 2–3 years following the introduction of a plane (see Fig. 6 in his paper).[12] 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

[11] The learning rate is calculated as $1 - 2^{\theta}$. For example, a 20% learning rate (associated with θ of -0.33) implies that a doubling of output reduces unit cost of production by 20%.

[12] 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 2 or 3 years after introduction (the Boeing 777 took 4 years to reach that level), while most Airbus aircraft reach this figure within the first 4–5 years after the initial launch.

compute the ratio between dynamic marginal costs and current marginal cost, implied by cost function (5), $d_{jt} \equiv (c_{jt}^{*S}/c_{jt}^{S}) = (Z_{jt}^{\theta} + E_t[\sum_{n=1}^{\infty} \beta^n q_{jt+n} \theta Z_{jt+n}^{\theta-1}])/Z_{jt}^{\theta}$. 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.[13] We set the discount rate β of 0.95. 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.[14]

Second, we take our estimates of dynamic marginal costs implied by Eq. (4) as given. We then compute a measure of current marginal cost as $c_{jt} = c_{jt}^{*}/d_{jt}$ 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 -0.4, which correspond to learning rate of 0–25%.

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 multi-product Bertrand, single-product Bertrand, and multi-product Cournot competition. Several interesting findings emerge. Let us first focus on the markup margins when learning rate is 0, which correspond to markup margins obtained in static profit maximization. First, multi-product Bertrand estimates suggest that the average markup margins decline from 0.36 in the early 1970s to 0.15 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 (and not just the demand for its rivals' products). As a result, the markups accounting for multi-product firms are on average 12% higher than the single-firm markups in the 1990s. Finally, the markup estimates are not very sensitive to whether firms compete in prices or quantities. Cournot markup margins and display similar patterns as the Bertrand markup margins.

[13] Because our data ends in 1998, we obviously do not observe full 10 years of future production for product-year observations 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 0.7 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. We choose 0.7 because regression of current output on lagged output yields a coefficient of 0.7. 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.

[14] In fact, at 20% learning rate, our data suggest that the output weighted average of the ratio (over all aircraft) is 0.47 in the 1st year of production, 0.72 in the 2nd year, 0.8 in the 4th year, and 0.9 in the 10th year of production of the aircraft.

Table 4
Markup margins based on various learning rates

Period	Multi-product Bertrand (1)	Single-product Bertrand (2)	Multi-product Cournot (3)
$\theta = 0$			
1969–1973	0.361	0.361	0.382
1974–1978	0.270	0.270	0.292
1979–1983	0.250	0.248	0.266
1984–1988	0.226	0.213	0.241
1989–1993	0.176	0.166	0.189
1994–1998	0.155	0.141	0.164
$\theta = -0.1$			
1969–1973	0.272	0.272	0.297
1974–1978	0.207	0.207	0.231
1979–1983	0.199	0.197	0.217
1984–1988	0.168	0.153	0.184
1989–1993	0.123	0.113	0.137
1994–1998	0.105	0.089	0.114
$\theta = -0.2$			
1969–1973	0.197	0.197	0.225
1974–1978	0.141	0.141	0.167
1979–1983	0.154	0.152	0.173
1984–1988	0.108	0.092	0.125
1989–1993	0.097	0.086	0.111
1994–1998	0.055	0.038	0.064
$\theta = -0.3$			
1969–1973	0.144	0.144	0.174
1974–1978	0.074	0.074	0.102
1979–1983	0.118	0.115	0.137
1984–1988	0.046	0.028	0.065
1989–1993	0.062	0.051	0.078
1994–1998	0.009	−0.008	0.019
$\theta = -0.4$			
1969–1973	0.111	0.111	0.143
1974–1978	0.009	0.009	0.039
1979–1983	0.086	0.084	0.107
1984–1988	−0.017	−0.036	0.003
1989–1993	0.030	0.019	0.046
1994–1998	−0.030	−0.048	−0.019

θ denotes the learning rate used in calculation of current marginal cost. The reported markups are output-weighted period averages. In some instances the initial observation is omitted for 747, MD-11, and A330 because the model predicted negative ratio of dynamic to current marginal cost in the first year due to low first year output and high future output. This inflated the markup estimates in that year.

Given the importance of dynamics in early stages of production, let us now consider markup margins when we account for learning by doing, taking the learning parameter to be −0.3, corresponding approximately to a 20% learning rate suggested by industry sources.[15] Several interesting patterns emerge. First, accounting for dynamics often yields negative markup margins for individual products (not displayed in the table), especially during the first few years following the entry and in scenarios with higher learning rate. For example, our markup margins for individual products range from -1.1 to 0.37 at 20% learning rate. In addition, period averages reported in Table 4 suggests that in general, markups are lowest during the periods 1974–1978, 1984–1988, and 1990s. This pattern is consistent with the fact that those periods follow market entry and thus intensified competition. Anecdotal evidence suggests increased competition for the market share in both of these entry episodes.[16] Moreover, even when we account for dynamics we continue to find that multi-product 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).[17]

3. Aspects of Airbus–Boeing competition

The structural estimates from the previous section can be used to explore 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-

[15] This information is based on personal correspondence with the chief economist of Boeing, Bill Swan. Benkard estimates a learning parameter of -0.29 for the L-1011 (i.e. 18% learning rate). 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.

[16] For example, A-300 entered in 1974, following the entry of DC10 in 1971 and L-1011 in 1972. A-310 and Boeing 767 entered in 1982 and 1983, respectively. Moreover, A330 and A340 entered in 1993 and Boeing 777 entered in 1995.

[17] We can also compare these markup margins to estimates by Benkard (2003), who 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 0 or negative throughout its lifespan. Our estimates for L-1011 based on 20% learning rate yield markup margins between -0.19 and 0.2. 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 14–17% with occasional periods when markup margins drop to 3–5%. We find a similar pattern.

320 in the mid-1980s. After Air India cancelled an order for Boeing 757s when Airbus offered steep discounts on the A-320, the US 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 Pavcnik, 2002; Tyson, 1992). 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% 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, reducing the incentive for Airbus to cut price significantly to capture certain sales.

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 US–EU agreement on aircraft prices, our data enable us 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.[18] Since the estimated coefficients are not statistically different from each other when we estimate the separate narrow- 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 5a presents the results. The coefficients on the treaty indicator in columns 1–4 suggest that prices of aircraft have on average increased after the 1992 US–EU trade agreement. The estimates range from 9.4% to 3.7% 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). 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

[18] The characteristics of most planes do not vary during this period. Thus, aircraft fixed effect accounts for them.

Table 5a
The impact of the 1992 U.S.-E.U. agreement on the pricing of aircraft

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Treaty	0.094***	0.039**	0.075***	0.037*	0.052***	0.088***	0.032	0.066***	0.030	0.049**
	[0.015]	[0.016]	[0.012]	[0.021]	[0.017]	[0.019]	[0.020]	[0.017]	[0.024]	[0.019]
Treaty* airbus						0.019	0.018	0.024	0.020	0.007
						[0.020]	[0.018]	[0.020]	[0.018]	[0.018]
Herfindahl index	− 0.217*	0.211	− 0.267***	0.156	0.044	− 0.217*	0.211	− 0.267***	0.151	0.043
	[0.115]	[0.165]	[0.089]	[0.131]	[0.121]	[0.118]	[0.166]	[0.093]	[0.131]	[0.123]
GDP growth			− 0.001	0.000	0.005			− 0.001	0.000	0.005
			[0.010]	[0.011]	[0.009]			[0.010]	[0.011]	[0.009]
Price of petroleum			− 0.004***	− 0.001*	0.001			− 0.004***	− 0.001*	0.001
			[0.001]	[0.001]	[0.001]			[0.001]	[0.001]	[0.001]
Time trend		0.013***		0.012***	0.009***		0.013***		0.012***	0.009***
		[0.003]		[0.004]	[0.003]		[0.003]		[0.004]	[0.003]
N	160	160	160	160	151	160	160	160	160	151

Robust S.E.s adjusted for clustering on products are reported in parenthesis. ***, **, and * indicate significance at a 1%, 5% and 10% level, respectively. Dependent variable is ln price. All regressions are estimated using product fixed effects. The regressions includes wide- and narrow-body aircraft. Columns 5 and 10 are estimated without year 1985.

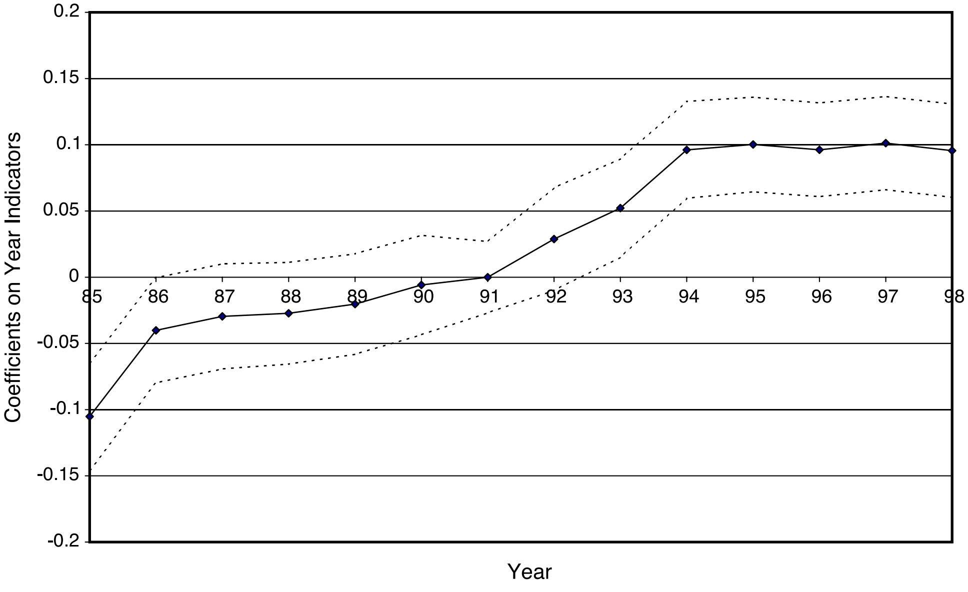

Fig. 2. Aircraft prices surrounding the 1992 agreement.

suggest that the agreement did not have a statistically differential impact on the pricing of Airbus. 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 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 relative to 1991 and their 95% confidence intervals are depicted in Fig. 2. The coefficients on year indicators for 1992 onwards are all positive. As a result, it is unlikely that one particular year is driving our findings.[19]

Overall, this evidence suggests that the 1992 US–EU agreement limiting aircraft subsidies raised the 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

[19] Columns 5 and 10 of Table 5a 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.

demand parameters, marginal costs c implied by Bertrand pricing equilibrium, predicted market share Eq. (1), and equilibrium pricing Eq. (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%. 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 (i.e. MD-11) 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. In fact, the weighted average of the ratio of dynamic to current marginal cost based on the calculations reported in Section 2.3 is 0.89 when learning rate is approximately 20%. This confirms that firms have already accumulated significant experience and that abstracting from future cost reductions associated with current output might not be problematic. Table 5b 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 3.7–7.5% price rise corresponds to about 5–10% increase in the marginal costs of firms.

3.2. Impact of A-380 entry

The most recent trade controversy centers on government funding for Airbus's super-jumbo aircraft, the A-380, whose first deliveries are expected in the year 2006 (see Pavcnik, 2002 for details on the controversy). As Fig. 1 indicates, the A-380 will be the world's largest passenger aircraft, designed to carry between 550 and 650 people, have a range of over 14,200 km (8000 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 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.

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% are being negotiated with potential buyers. Some reports even indicate that 35% discounts have been offered, but the industry

Table 5b
The stimulated effect of the 1992 trade agreement on prices

Marginal cost increase	No change	5%	7.5%	10%	12.5%	15%	17.5%	20%
Durable demand								
Average price	89.6	93.3	95.1	97.0	98.8	100.7	102.5	104.4
S.D.	(27.1)	(28.3)	(28.9)	(29.5)	(30.1)	(30.7)	(31.3)	(31.9)
Average % change in price	n.a.	4.09	6.14	8.19	10.24	12.30	14.36	16.42
S.D.	n.a.	(0.25)	(0.37)	(0.50)	(0.63)	(0.75)	(0.88)	(1.01)

Simulations are based on demand parameter from Table 2, column 2 and the assumption of multi-product Bertrand pricing. Simulations use aircraft characteristics and marginal cost estimates from 1992. The prices are expressed in million 1995 US Dollars.

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 had been ordered as of early 2001. The A-380 is designed to compete directly against 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. 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. A-340 unobserved quality does not fluctuate much over time and it follows a similar time path as the unobserved quality of 747 during the late 1990s (albeit unobserved quality of 747 is about 1.7 times higher).[20] Thus, focusing on the 1998 values is not likely to be problematic. In additional simulations, we allowed the A-380 quality to take values between the quality of A-340 and 747.[21] This did not change the main characteristics of simulated results reported below (albeit A-380 obviously gained greater market share).

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.[22] 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 Eq. (1) and the pricing Eq. (4), we simulate the new equilibrium prices and market shares for each of the existing products.

Airbus has an incentive to initially offer large price discounts (and potentially price below marginal cost) to secure a large market share for the A-380 and to take advantage of economies of scale. We thus explicitly consider how price discounts on A-380 affect the

[20] The unobserved quality of A-340 also follows a similar trend to the unobserved quality of A-330 with the exception of the initial 2 years. A-330 quality is low in the initial 2 years, it then increases, and then relatively levels off.

[21] These results are presented in the unpublished appendix available on the authors' web sites.

[22] One potential problem with this 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 terms are insignificant and the F-test of joint insignificance yields a P-value of 0.15. 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.

A-380 current market share and simulate the annual post entry market when the A-380 is sold at the list price, and at a 10%, 20% and 30% 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 0.92 (when we assume 20% learning rate; the ratio is above 0.96 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 4 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% discount. The no entry case always serves as the comparison group.

Several interesting findings emerge. First, the A-380 gains about 1% of the overall annual market (which translates into 38 aircraft), and 17.4% of the long-range market segment. Boeing 747, for example, controls 1.2% of the overall market prior to the A-380 entry (28.5% 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 1.6% (0.0002 decline in market share), while the overall market share of a medium-range plane (for example Boeing 767) declines only by 0.9% (0.0001 decline in market share). This translates into the total annual loss of seven sales by the existing long-range varieties and the total annual loss of 0.3 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%, while the declines in prices of existing Airbus wide-body aircraft are about 0.3%. 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 US producer and lead to future conflicts in US–EU 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.

Table 6
The effect of A380 entry on existing wide body planes

	No entry	List price		10% discount		20% discount		30% discount	
	actual	simulated	change	simulated	change	simulated	change	simulated	change
Market Share									
Long Range									
A380		0.0002		0.001		0.009		0.040	
747	0.0120	0.0120	0.0000	0.0120	0.0000	0.0118	−0.0002	0.0100	−0.0019
777	0.0167	0.0167	0.0000	0.0167	0.0000	0.0164	−0.0003	0.0140	−0.0027
MD11	0.0027	0.0027	0.0000	0.0027	0.0000	0.0027	−0.0001	0.0023	−0.0004
A330	0.0052	0.0052	0.0000	0.0051	−0.0001	0.0047	−0.0005	0.0034	−0.0018
A340	0.0054	0.0054	0.0000	0.0053	−0.0001	0.0049	−0.0005	0.0035	−0.0019
Medium Range									
767	0.0106	0.0106	0.0000	0.0106	0.0000	0.0106	−0.0001	0.0104	−0.0003
A300	0.0029	0.0029	0.0000	0.0029	0.0000	0.0029	0.0000	0.0028	−0.0001
A310	0.0002	0.0002	0.0000	0.0002	0.0000	0.0002	0.0000	0.0002	0.0000
Outside good	0.9442	0.9440	−0.0002	0.9430	−0.0012	0.9374	−0.0068	0.9133	−0.0309
Market share within each wide−body market segment									
Long Range									
A380		0.005		0.032		0.174		0.546	
747	0.285	0.284	−0.0012	0.277	−0.0080	0.240	−0.0446	0.137	−0.1481
777	0.398	0.396	−0.0017	0.387	−0.0112	0.336	−0.0623	0.191	−0.2068
MD11	0.065	0.064	−0.0003	0.063	−0.0018	0.054	−0.0101	0.031	−0.0335
A330	0.124	0.123	−0.0008	0.118	−0.0054	0.096	−0.0278	0.046	−0.0773
A340	0.129	0.128	−0.0009	0.123	−0.0056	0.100	−0.0290	0.048	−0.0807
Medium Range									
767	0.771	0.7705	0.0000	0.7706	0.0001	0.7709	0.0004	0.7721	0.0016
A300	0.213	0.2131	0.0000	0.2131	−0.0001	0.2127	−0.0004	0.2116	−0.0015
A310	0.016	0.0164	0.0000	0.0164	0.0000	0.0164	0.0000	0.0163	−0.0001
Price (million 1995 $)									
Long Range									
747	146.8	146.7	−0.0389	146.5	−0.2542	145.4	−1.3274	143.0	−3.7822
777	107.6	107.6	−0.0390	107.4	−0.2543	106.3	−1.3275	103.8	−3.7823
MD11	101.8	101.7	−0.0391	101.5	−0.2543	100.4	−1.3276	98.0	−3.7823
A330	105.7	105.7	−0.0113	105.6	−0.0732	105.3	−0.3698	104.7	−0.9827
A340	112.8	112.8	−0.0113	112.7	−0.0732	112.4	−0.3697	111.8	−0.9827
Medium Range									
767	75.3	75.3	−0.0010	75.3	−0.0068	75.3	−0.0394	75.2	−0.1458
A300	82.6	82.6	−0.0004	82.6	−0.0024	82.5	−0.0132	82.5	−0.0442
A310	67.5	67.5	−0.0004	67.5	−0.0024	67.4	−0.0132	67.4	−0.0443
Number of A−380 sold		0.9		6.1		37.6		177.3	
Decline in sales of LR aircraft		0.2		1.0		7.2		38.8	
Decline in sales of MR aircraft		0.0		0.1		0.3		1.6	

Table 6 (*continued*)

	No entry	List price		10% discount		20% discount		30% discount	
	actual	simulated	change	simulated	change	simulated	change	simulated	change
Price (million 1995 $)									
Decline in sales of outside good		0.8		5.0		30.1		136.8	

Simulations are based on demand parameter from Table 2, column 2 and multiproduct Bertrand pricing. The reported changes are differences between various scenarios relative to the base of no A380 entry reported in column 1. Simulations use aircraft characteristics from the last year of the data (1998). The changes in sales (i.e. change in number of planes sold) reported on the bottom of the table are calculated based on the 1998 market size (4424 planes). Market shares are based on quantities of planes sold.

While Airbus is only able to sell one A-380 per year at the list price (corresponding to 0.02% market share), the annual sales of the A-380 increase to six planes at a 10% discount (0.1% market share), 38 sales at 20% discount (1% market share), and 177 sales at 30% discount (4% 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.

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% 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 1500 super-jumbos 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 super-jumbos 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, if there are synergies in owning all Airbus (or Boeing) planes, the introduction of a long-range plane such as A-380 might 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. We began by estimating 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- and long-range wide-body planes, consistent with the anecdotal evidence on the near monopoly position enjoyed by the Boeing 747 in the long-range market until the early 1990s. Second, despite the small number of firms in the industry, market competition has intensified (we estimate higher demand elasticities and lower markups over time), especially with the entry of new aircraft varieties. 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. Fourth, 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.

Given that the aircraft industry continues to be the source of trade friction between the United States and the European Union, we evaluated two key trade issues. We find evidence that the 1992 US–EU agreement to limit subsidies resulted 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%. 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.

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.

5. 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- 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 US hourly manufacturing wages and the US 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 0.4), Germany (weight is 0.4), and Great Britain (weight is 0.2) 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 US dollars.

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References

Baldwin, R., Krugman, P., 1988. Industrial policy and international competition in wide-bodied jet aircraft. In: Baldwin, R.E. (Ed.), Trade Policy Issues and Empirical Analysis. University of Chicago Press for the NBER, Chicago.

Benkard, C.L., 2000. Learning and forgetting: the dynamics of aircraft production. American Economic Review 90 (September), 1034–1054.

Benkard, C.L., 2003. A dynamic analysis of the market for wide-bodied commercial aircraft. Review of Economic Studies (in press).

Berry, S., 1994. Estimating discrete-choice models of product differentiation. Rand Journal of Economics 25 (Summer), 242–262.

Berry, S., Levinsohn, J., Pakes, A., 1999. Voluntary export restraints on automobiles: evaluating a trade policy. American Economic Review 89 (June), 400–430.

Brander, J., Spencer, B., 1985. Export subsidies and international market share rivalry. Journal of International Economics 18, 83–100.

Goldberg, P.K., 1995. Product differentiation and oligopoly in international markets: the case of the US automobile industry. Econometrica 63 (July), 891–951.

Hendel, I., 1999. Estimating multiple-discrete choice models: an application to computerization returns. Review of Economic Studies 20 (April), 423–446.

Irwin, D.A., Klenow, P.J., 1994. Learning-by-doing spillovers in the semiconductor industry. Journal of Political Economy 102 (December), 1200–1227.

Klepper, G., 1990. Entry into the market for large transport aircraft. European Economic Review 34, 775–803.

Klepper, G., 1994. Industrial policy in the transport aircraft industry. In: Krugman, P., Smith, A. (Eds.), Empirical Studies of Strategic Trade Policy. University of Chicago Press for the NBER, Chicago.

Neven, D., Seabright, P., 1995. European industrial policy: the airbus case. Economic Policy 21, 313–358.

Pavcnik, N., 2002. Trade disputes in the commercial aircraft industry. World Economy 25, 733–751.

Tyson, L.D'A., 1992. Who's Bashing Whom? Trade Conflict in High Technology Industries. Institute for International Economics, Washington, DC. November.

Yoffie, D.B., 1991. Collision course in commercial aircraft: Boeing–Airbus–McDonnell Douglas. Harvard Business School Case. Harvard Business School, Cambridge, MA.