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Commercial Aircraft Pricing: Models, Applications, and Lessons Learned

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Abstract

The procurement of commercial items presents both opportunities and challenges for the Department of Defense. Among the challenges is the negotiation of “fair and reasonable” prices with suppliers where competitive sources are not relevant. This paper presents analyses to address this challenge for commercial aircraft that serve as the basis for military systems. Using insights from the economics literature on aspects of the commercial aircraft market, we develop estimating models for aircraft price that take into account both supply and demand drivers, across both aircraft models and time. These models are applied to the KC-46A airborne tanker program, prices of which are subject to negotiation. Other factors affecting the commercial aircraft market and aircraft used in these programs (Boeing variants) are also addressed. Lessons learned applicable to the general problem of negotiation of contracts for commercial items are enumerated.

Background

The procurement of commercial items presents both opportunities and challenges for the Department of Defense (DoD). Among the challenges is the negotiation of “fair and reasonable” prices with suppliers where competitive sources do not exist. The Institute for Defense Analyses (IDA) has performed a series of studies developing estimating relationships for the prices of commercial aircraft, variants of which figure in DoD acquisition programs (Harmon, Sullivan, & Davis, 2010). Unlike in the case of purpose-built military aircraft, DoD negotiators generally do not have access to the underlying costs or cost estimating relationships derived from historical costs for analogous items. Buying commercial aircraft is substantially different from buying military aircraft or commodity items from other types of commercial suppliers. Lessons learned from this past research can help inform current Air Force negotiations on the prices of current and future systems; of particular interest is the KC-46A program. The lessons learned also have implications for the broader portfolio of the DoD’s commercial items purchases, particularly those bought in thin markets, and/or markets dominated by sellers with market power where competitive sourcing is not relevant.

The Economics of the Commercial Aircraft Market

The market for commercial aircraft with a range greater than 3,000 nautical miles (NM) is currently a duopoly, with Boeing and Airbus the only producers. In a duopoly such as this, the participants have a degree of market power not evident in more competitive markets. The suppliers’ choice of quantity (price) has an effect on market price (quantity demanded), as each supplier contributes a large part to industry output. Also, given learning in the aircraft industry, the choice of quantity for a given time period affects costs in future time periods. This combination of attributes means that for any given product line and time period, price can be below marginal cost (startup period)[1] or above marginal cost (mature program). In addition, given market power (the supplier faces a downward sloping demand curve), price discrimination is also evident. This contrasts with a competitive market in which all firms are price takers; the cost of production for any given firm does not affect the market price. All of these factors contribute to the difficulty in arriving at fair and reasonable prices for commercial aircraft.

Overview of the Literature

These observations are drawn from substantial academic literature on the economics of the commercial aircraft industry, presented in Harmon et al. (2010), in which price determination is an important aspect of much of the research. This literature provides important insights regarding potential drivers of aircraft price levels and movements over time. These studies show that, although learning will not affect purchase price to the degree evident in a contracting environment—as in the military aircraft procurement, where prices are negotiated based on cost—there still can be some effect (Baldwin & Krugman, 1988; Benkard, 2004; Irwin & Pavcnik, 2004). This should be true for anything that affects the cost structure of the industry or a given product line. For example, estimated price increases that followed the 1992 reduction in government subsidies were coincident with calculated increases in producer costs (Irwin & Pavcnik, 2004). Other possible cost drivers that could show up in price include labor productivity, secular trends, and cyclical movements. Some fixed costs will be “quasi-fixed”—portions of labor inputs that are sticky relative to production rate. This was noted in Kronemer and Henneberger (1993), a Bureau of Labor Statistics (BLS) study of labor productivity in the aircraft industry. The BLS found that labor productivity was highly procyclical—higher output measures were associated with higher productivity growth as quasi-fixed portions of labor were spread over more units. Their data also show a longer-term upward trend in labor productivity of 1.5% to 2.5% per year.

Modeling Approaches

The models of the aircraft industry presented in the economics literature have, by necessity, been abstracted from a complex reality. They have at least four things in common:

- Use of a multi-period dynamic framework;
- Rules guiding the strategic behavior of suppliers in a duopoly/oligopoly situation in which game-theoretic approaches are used to solve for industry equilibrium;
- Inclusion of learning curves in the supply functions of the firms, while taking into account the dynamic effects of learning on firm decisions; and
- Demand relations reflecting the derived demand of aircraft as an input to the production of air services.

All the models take the manufacturers as value maximizers over an extended time horizon where the value function is, assuming a homogeneous product, for firm *j*,

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[1] Due to learning-by-doing, the first quantity produced has a very high cost. Prices in the startup period are usually observed to be below marginal costs.

$$V_j = \sum_{t=0}^{T} R^t (p_{jt} q_{jt} - c_{jt} q_{jt}), \tag{1}$$

where Vj is the net present value for firm j, R is a discount factor and p_{jt}, q_{jt}, and c_{jt} are the relevant price, quantity, and marginal cost.[2] Modifications to this basic setup were made by the different researchers to reflect additional assumptions. The firms' strategic behavior is portrayed either as quantity setting (Cournot game) or price setting (Bertrand game). The choice of q_{jt} will affect both the current price through the demand relation, $p_{jt}=f(Q_{jt})$, where $Q_{jt} = \sum_{j=1}^{J} q_{jt}$, and current and future costs, through the learning curve. In the Bertrand game, choosing p_{jt} will affect q_{jt}, which in turn will affect future costs through the learning curve. The models vary in complexity and realism. For the simplest model, stated in Baldwin and Krugman (1988), a single-period equilibrium solution for market price (p_t) was determined as

$$p_t = \frac{c_t + z_t}{1-(1\text{-}s)/E}, \tag{2}$$

where c_t is the marginal cost of the aircraft, z_t is the shadow value of current production arising from reductions in future costs due to learning, s is the market share of the subject firm, and E is the demand elasticity ($E > 0$).[3]

Example Program: KC-46A

In the KC-46A program, government-funded development includes the creation of a new minor model of the 767, the 767-2C, which was not previously available to commercial customers. The 767-2C includes a combination of features available in other Boeing commercial aircraft, including freighter floors and doors, convertible passenger capability, an upgraded cockpit, and higher maximum take-off weight (MTOW). In addition, tanker mission system provisions are also incorporated; although these features were not available on previous Boeing commercial aircraft, they are "of a type" changes that commercial customers might specify (e.g., added provisions for non-standard buyer-furnished equipment [BFE]). Boeing has applied for a Federal Aviation Administration "amended type certificate" (ATC) for the 767-2C. Given the ATC, the 767-2C will be commercially available to other customers. All of these factors add challenges to the negotiation of fair and reasonable prices, as pricing history for direct commercial analogs do not exist. The effects of these challenges are mitigated by an acquisition strategy in which the initial competition between suppliers (resulting in the choice of Boeing over Airbus in February 2011) provided for price discovery. The award covered a Fixed-Price Incentive Firm contract for Engineering and Manufacturing Development along with Firm Fixed Price contract options for Low Rate

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[2] The definition of marginal cost in most of this literature is not the cost of the last aircraft built during the time increment, but the average cost over that time period, implying the inclusion of recurring fixed costs.

[3] Denote demand with x. The price elasticity of demand is $-(\Delta x/\Delta p)\ (p/x)$, which measures the percentage change in demand in response to a 1% change in price.

Initial Production Lots 1 and 2, and Not-to-Exceed (NTE) contract options with an Economic Price Adjustment (EPA) clause for Full Rate Production Lots 3 through 13 (DoD, 2016). It is at Lot 3 (FY 2017) where negotiation becomes relevant.

Modeling Commercial Aircraft Prices

We use least-squares regression techniques to define and test specifications of the price estimating relationships. Prices are treated as dependent variables and related to independent variables, which we hypothesize to be price drivers. In the case of least-squares regressions, the functions are defined by parameter estimates on the independent variables, determined by minimizing the squared errors of the regression line from the actual data. The price estimating relationships take on the multiplicative form:

$$p_j = f(x_j, \beta)e^{u_j}, \tag{3}$$

where p_j is the value of the observed price for aircraft j, x_j is the vector of independent variables, □ is the vector of parameter estimates, and u_j is the error term. Without loss of generality, assume that the equation takes on the intrinsically linear form with an intercept, one regressor x_1 (price driver), and one dummy variable D,

$$p_j = \beta_o x_{1j}^{\beta_1} \beta_2^{D_j} e^{u_j}, \tag{4}$$

and then OLS regression techniques can be applicable. To do this, the equation is transformed to a log-log form:

$$\ln(p_j) = \ln(\beta_0) + \beta_1 \ln(x_{1j}) + \ln(\beta_2) D_j + u_j. \tag{5}$$

OLS will produce parameter estimates of $b_0 \equiv ln(\beta_0)$, $b_1 \equiv \beta_1$, and $b_2 \equiv ln(\beta_2)$. Both β_0 and β_2 can be recovered by taking an anti-logarithmic transformation of b_0 and b_2 (i.e., by calculating e^{b_0} and e^{b_2}). The parameter estimate b_1 has a natural interpretation of elasticity, measuring the percentage change in price with respect to a 1% change in x_1. The parameter b_2 represents a change in price ($\Delta p_j/p_j$) when the dummy variable switches its value from 0 to 1.

When describing the estimating relationships, information presented includes R^2, adjusted R^2, the standard error of the estimate ($\hat{\sigma}$), and the t-statistics (which are the ratios of the parameter estimates to their standard errors), as well as associated levels of statistical significance for each of the parameter estimates. We generally exclude variables whose parameter estimates are not significant at the 0.1 level, although some exceptions are made. In a linear model, R^2 measures the proportion of the total variance in the data explained by the model. Although this is not strictly true for most of our models because they are nonlinear, the R^2 analog provides useful information about the relative fit of the models. Adjusted R^2 presents this information adjusted for the number of independent variables in the regression. R^2 and adjusted R^2 are calculated from the data and model after they are transformed back from log space to arithmetic space. $\hat{\sigma}$ is calculated in log space; it can be converted into minus/plus percentages of price in the original space by calculating values for $(e^{-\hat{\sigma}}) - 1$ and $(e^{+\hat{\sigma}}) - 1$. Measures derived from the standard errors provide information regarding the uncertainty of the estimates.

Data

The IDA team used data from airline industry consultants to build price estimating relationships for commercial aircraft. Airlines and manufacturers withhold transaction price information from public release, and Department of Transportation transaction price data for contemporary experience are not available. Although list prices are available on Boeing and Airbus websites, aircraft are generally sold at a substantial discount from list. The airline consultants estimate prices for a variety of clients including aircraft purchasers, lessors, insurers, and investors. They are coy about their estimating methods; they seem to extrapolate from a limited number of actual data points (often from their clients) based on financial valuation models.

IDA's previous analysis of the KC-767 purchase price (Nelson et al., 2003) noted uncertainties associated with reported aircraft price data:

> The complexity of the transactions comes from two sources: the variation in content from one sale to another, and the nature of the contractual arrangements involved. Both sources of complexity make it difficult to interpret any known historical sales prices.
>
> The content included in a given sale may on the one hand include spare parts, training, and maintenance support. On the other hand, the sales price may not include buyer furnished equipment such as interiors, in-flight entertainment, seats and galleys. Additionally, 767 aircraft, like most commercial models, are sold with a wide range of features such as upgraded avionics, engines, fuel capacities, maximum gross takeoff weight and cargo handling systems.

This uncertainty was addressed for 767 pricing by collecting data from multiple sources, representing multiple years and transactions. This general strategy was expanded to the broader commercial aircraft market by statistically defining price estimating relationships. The goal was to abstract from the available data some reference value for a given aircraft model based on the consultants' pricing data, regardless of the conditions of specific transactions or possible measurement error associated with the individual data points used. The regression analyses employed generated the expected values of prices conditioned on measures of aircraft utility and other price drivers. The statistical analyses in turn provided measures of estimation error that partially reflect uncertainties in the data.

IDA price estimating research was first performed in 2009 to 2010 in Harmon et al. (2010) using data from Airline Monitor, AVITAS, and Morten Beyer & Agnew (MBA). These data included reported prices through 2009. The AVITAS and MBA data showed similar prices for the same aircraft model, while the Airline Monitor data showed consistently higher prices, particularly for wide-body (WB) aircraft. Also, Airline Monitor's time series data showed almost no price variability between years, and price data for discontinued aircraft models were reported after they ceased delivery. As AVITAS did not include time series data by aircraft model, we chose to update only the MBA data; the updated data used in modeling included reported prices through January 2016. MBA presented "Base Value" and "Current Market Price" data—in most cases the two values were the same, but when they were different, we used the Current Market Price value. Prices were for typical airline configurations, including interiors/BFE.

Table 2 shows the coverage by year for the MBA data used in the regression modeling. Note that there was a gap in data reporting in 2010 and 2011.

Table 2. Data Coverage

Manufacturer	Aircraft	Years in 2010 Study	Additional Years in 2016 Update
Airbus	A330-200	1998–2009	2012–2016
	A330-300	1996–2009	2012–2016
	A330-300F	NA	2014–2016
	A380-800	N/A	2012–2016
Boeing	737-600	1998–2006	N/A
	737-700	1998–2009	2012–2016
	737-800	1998–2009	2012–2016
	737-900	2001–2005	N/A
	737-900ER	2006–2009	2012–2016
	747-8	N/A	2012–2016
	747-F	N/A	2016
	767-200ER	1988–1991, 2000–2007	N/A
	767-300ER	1988–2009	2012–2013
	767-300F	NA	2014–2016
	767-400ER	2000–2002	N/A
	777-200	1995–2006	N/A
	777-200ER	1997–2009	2012–2014
	777-200LR	2007–2009	2012–2014
	777-300	1998–2006	NA
	777-300ER	2005–2009	2012–2016
	777F	NA	2014–2016
	787-8	N/A	2012–2014
	787-9	N/A	2016

All dollar amounts are measured in calendar year (CY) 2016 dollars. The inflation adjustment is made using the U.S. Gross Domestic Product (GDP) deflator as reported by the Bureau of Economic Analysis (BEA). The effect of other economic factors (fuel price, world GDP, cumulative aircraft quantity) are weighted based on estimates from panel data analyses that are described later.

Aircraft characteristics used as cost drivers in the regressions were open source data obtained primarily from the aircraft manufacturers' websites. Price drivers were aircraft characteristics fixed over time reflecting utility to airlines. Different independent variables and subsets of data were included in the resulting price estimating relationships. Either MTOW, Seats and Range (Seat Miles[4]), or Payload was used as the primary driver. These drivers are presented graphically for the aircraft in the data sample in Figure 1.

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[4] Seat Miles is a measure of an aircraft's passenger-carrying capacity. It is equal to the number of seats available multiplied by the maximum range in miles.

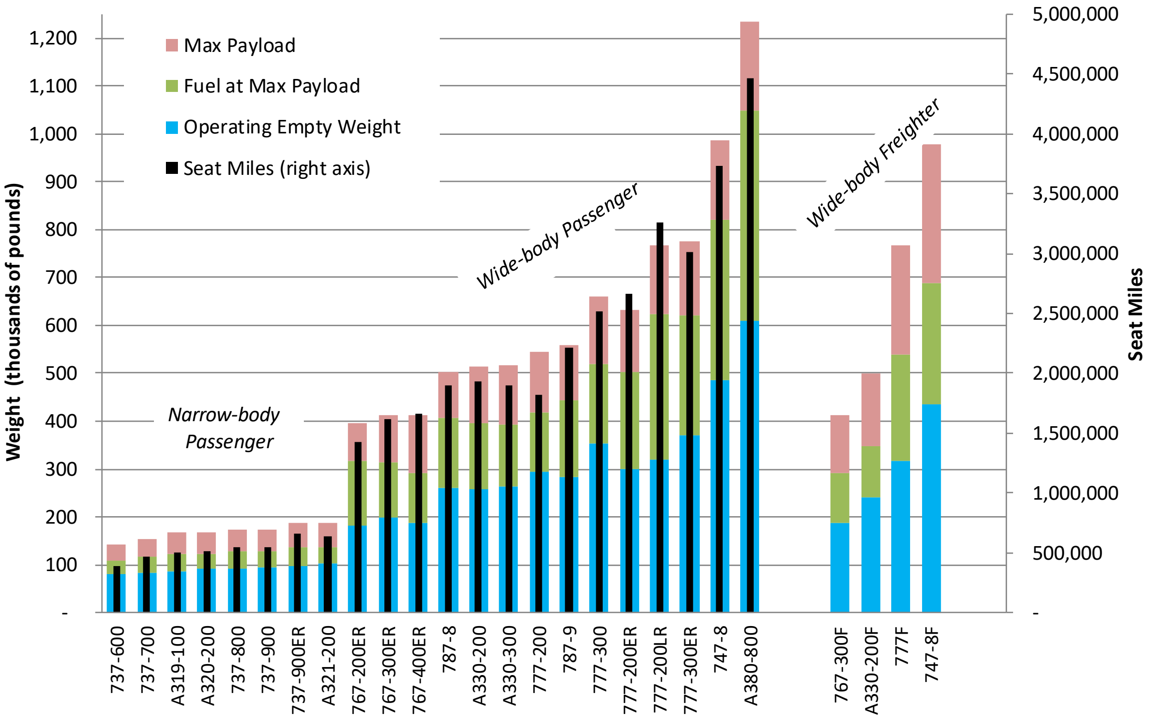

Figure 1. MTOW and Seat Miles for Commercial Aircraft Sample

Data can be further broken down by aircraft model. An aircraft model is introduced, manufactured, and phased out over time. Therefore, a given model is usually observed in multiple years over a specific range of years. Some drivers change over time and model. For example, the variables representing and measuring utility (demand) and cost (supply) affect prices over time. The economics literature informs our choice of independent variables.

Pooled OLS Models

Our data were a mix of cross-section (data by aircraft model) and time series (for a given model). The time series data sample included observations from 1988 to 2016, covering periods that vary by model; the data ranges are shown in Table 2. Our empirical regression took the logarithmic form:

$$p_{jt} = \mathbf{z}_j \alpha + \mathbf{x}_{jt} \beta + \varepsilon_{jt} \,, \qquad (6)$$

where the j subscript indexed each model, $\mathbf{z}_j$ was a vector containing a constant term and variables for each model that are fixed over time, and $\boldsymbol{x}_{jt}$ was a vector of regressors that varied over model and time.

In terms of the price estimating model, the aircraft-model-specific variables fixed over time (e.g., Seat Miles and MTOW) were contained in $\mathbf{z}_j$, while the x_{jt}s were the economic variables that changed over time and model (including delivery quantities to capture learning). If the observed aircraft-characteristic variables fully define $\mathbf{z}_j$, then OLS can be used to estimate the model (Greene, 2002). Given positive diagnostics regarding $\mathbf{z}_j$, we chose to estimate the price estimating relationships using OLS.[5]

For the aircraft model-specific variables (the z_js) we found either Seats and Range or MTOW to be statistically significant. The MTOW specification allowed us to include freighter aircraft in the sample. The MTOW model showed a substantially better fit than the Seats and Range model. One reason for this may be the ambiguity regarding seating configurations for the passenger aircraft. We also tried different combinations and transformations of the constituents of MTOW (e.g., empty weight, weights for payload and fuel), but we found that MTOW fit the best. For the updated data sample, we did not find a freighter effect.

For the economic variables, we experimented with different time lags and forms of world GDP growth (International Monetary Fund, 2016), fuel prices (U.S. Energy Information Administration, n.d.), delivery rates, and aircraft cumulative quantity, as well as a time trend. As there were already substantial correlations between time, cumulative aircraft quantity, and fuel price, we used the de-trended series for GDP growth.

The net effect of market cycles on aircraft prices is an interesting empirical question. There is a supply-side argument that higher production rates would mean lower unit costs and prices.[6] The demand-side argument is that higher economic growth would raise the utility of aircraft to the airlines and prices would rise. Although these are two different effects, they were highly correlated with one another in the data. We found that higher GDP growth is associated with higher prices, and that measures of delivery rate were either statistically insignificant when entered with GDP growth or carried the same sign. In the end, we chose de-trended world real GDP growth, lagged two years, to capture the effect of market cycles on prices.

The impact of other x_{jt}s were not ambiguous, as the demand and supply/cost effects were more clearly delineated. Fuel price was a demand-side driver, where higher fuel prices were expected to result in lower aircraft prices. Higher cumulative quantities should result in lower costs and prices. Long-term increases in productivity should lead to lower real prices over time for a given aircraft capability.

For our preferred baseline pooled OLS regression, we identified five price drivers: maximum takeoff weight ($MTOW_j$), cumulative quantity ($CumQ\_L1_{jt}$), de-trended world real GDP growth rate ($WGDP\_L2_{jt}$), fuel price ($FuelP\_L1_{jt}$), and calendar year ($Year_{jt}$), each of which is measured as explained below:

- $MTOW_j$ is described above;
- $4Engines_j$ is a dummy taking *1* if model *j* is a four-engine aircraft and *0* if it is a two-engine aircraft*;*

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[5] Although there was evidence in the regression results that assumptions required for OLS to be the best unbiased linear estimator were violated (unequal error variances across panels/heteroskedasticity and correlation of errors across time within each panel/serial correlation), we judged alternatives to address these problems (generalized least squares or the use of cluster robust standard errors) inappropriate, given our data sample.

[6] There were also offsetting supply-side arguments; production spikes may be associated with increased prices for inputs and increasing marginal costs.

- $CumQ\_L1_{jt}$ is the cumulative quantity for the aircraft family associated with aircraft model j at the end of the prior year;
- $WGDP\_L2_{jt}$ is world real GDP growth expressed as percentage deltas from the trend and lagged two years, where the trend is established using the Hodrick-Prescott filter (Hodrick & Prescott, 1997);
- $FuelP\_L1_{jt}$ is the real price of jet fuel lagged one year; and
- $Year_{jt}$ is the calendar year associated with each model j and time t.

When estimating the model, we included a dummy variable for WB aircraft, along with an interaction term with the $MTOW_i$ variable. This resulted in a unique slope coefficient on $MTOW_i$ as well as a different intercept for WB. This meant a separate model estimated for each of WB and narrow-body (NB) aircraft, as shown in the specification presented in **Error! Reference source not found.**. Variations on both the MTOW and Seat Miles pooled OLS models included production rate for each aircraft family as an additional independent variable. Our estimated models follow (standard errors are included under the parameter estimates):

- For WB aircraft:

$$ln(p_{jt}) = 13.01+1.147\ ln(MTOW_j)-0.253\ (4Engines_j) - 0.031\ ln(CumQ\_L1_{jt})$$

(.140) (.039) (.008)

$$+\ 1.371\ (WGDP\_L2_{jt}) - 0.038\ (FuelP\_L1_{jt}) - 0.011\ Year_{jt},$$

(.738) (.013) (.002)

- For NB aircraft, the interaction terms result in a unique intercept and MTOW coefficient, with the remaining coefficients remaining the same as for WB aircraft:

$$ln(p_{jt}) = 4.37 + 1.907\ ln(MTOW_j)$$

(.738)

Error! Reference source not found. compares MBA-reported data points to the projected prices using the estimated models.

$$p_{WB\,jt} = 447{,}111\; MTOW_j^{1.147}\, .777^{4Engine_j}\, CumQ\_L1_{jt}^{-.031}\, 1.371^{WGDPc\_L2_{jt}}\; 0.963^{FuelP\_L1_{jt}}\, 0.989^{Year_{jt}}$$

$$\left(p_{NB\,jt} = 79.4\, MTOW_j^{1.907}\right)$$

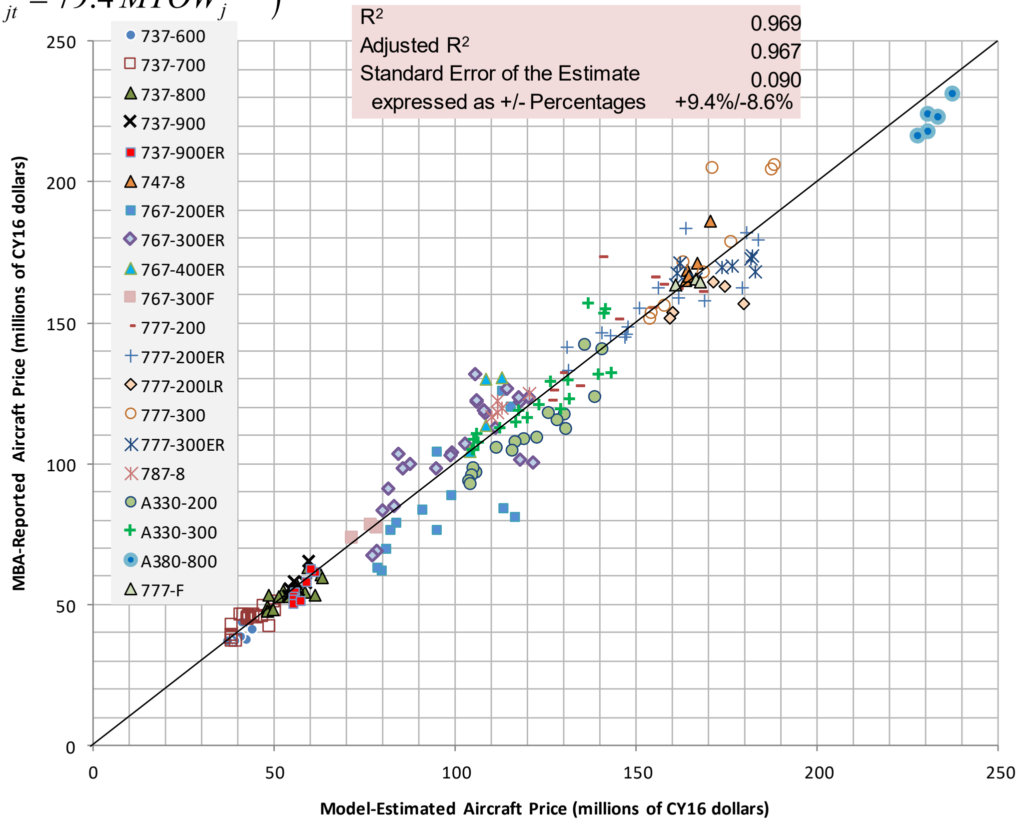

Figure 2. MTOW Panel Data Model

All of the parameter estimates for the preferred model shown in **Error! Reference source not found.** are significantly different from zero at *p* = .06 or better. Estimates for the coefficient on $CumQ\_L1_{jt}$ indicate equivalent price improvement curve slopes of 97.9%. This is much shallower than typical cost improvement curves and is consistent with the economics literature. The estimates on $WGDP\_L2_{jt}$ suggest that if world real GDP growth is 1 percentage point above trend two years prior to aircraft delivery (say, 4.4% versus the 3.4% growth trend estimated for 2017 using the Hodrick-Prescott filter), the price will be 1.4% higher than if GDP growth was at trend.

Estimates for the fuel price coefficients indicated that a $1 per gallon increase in fuel price one year prior to aircraft delivery results in a 3.8% decrease in price. The reasonableness of this estimate was tested by an approach similar to that taken in Markish (2002), where changes in fuel costs were related to changes in discounted life cycle costs associated with the aircraft. Predicted changes in aircraft price associated with changes in fuel cost were around 10% of the change in the discounted life cycle cost associated with the same fuel cost change. This seems reasonable, given that substantial portions of fuel price changes will be passed along to airline customers or result in changes in demand for seats as opposed to being absorbed by the aircraft manufacturers as price decreases. Also, only a portion of annual price changes will be interpreted by the market as affecting future prices.

The time trend parameters on *Year*$_{jt}$ indicated a decrease in real prices of 1.1% per year. Note that the GDP deflator was used to escalate nominal prices to constant 2016 dollars. For the recent period, this is consistent with a 1% annual rise in nominal prices.

Price Discounts From List Price and Boeing Financial Data

Estimates of transaction prices for commercial aircraft are often expressed as discounts from list prices. We calculated discounts from Boeing's 2016 list prices (which were unchanged from the published 2015 values) using both the MBA data and estimated prices from the models, including error bounds. An example using the pooled OLS MTOW model is shown in **Error! Reference source not found.**.

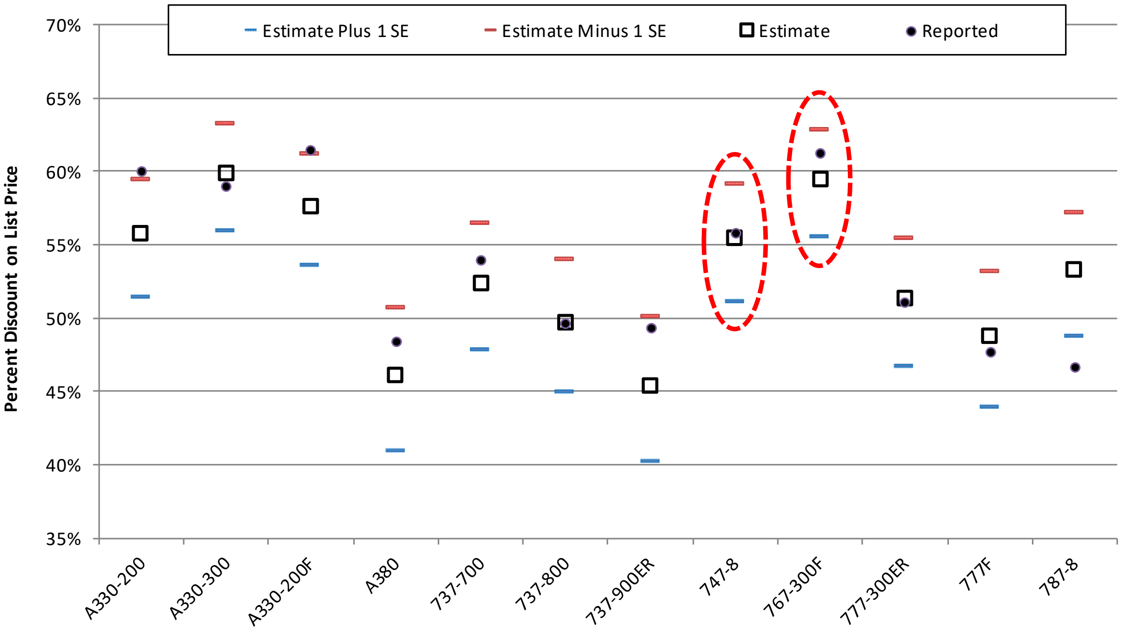

Figure 3. Discounts From 2016 List Prices: MTOW Model

For the WB aircraft, the average discount for Boeing aircraft was 53% for the MBA data and 52% for the MTOW model estimates. Over the entire Boeing portfolios, the average discount was 53% for the MBA data and 52% for the MTOW model estimates. For the Boeing portfolio, we also calculated weighted average discounts.

As a means of validating the models and the underlying MBA data, we calculated the weighted average discount for Boeing based on their reported financial data and aircraft deliveries for 2016. Boeing reported revenue by Segment including Commercial Airplanes (BCA), where revenue was booked at aircraft delivery. A small portion of BCA revenue is from commercial after-sales support (CAS) and was estimated to be $6.5 billion in 2014 (Broderick, 2014). Extrapolating this value forward using the annual growth rate from 2011 to 2014 of 6.4%, we arrived at a value of $7.355 billion for 2016.

We calculated aircraft sales revenues by subtracting CAS revenues from total BCA revenues for 2016:

$$R_t = \$65{,}069\text{M} - \$7{,}355\text{M} = \$57{,}714\text{M}.$$

Annual delivery quantities by model (q_{jt}) and list prices by model ($\overline{p}_{jt}^{\,*}$) are available for each model from Boeing's website. Given these values, the weighted average 2016 discount (D_t) was

$$D_t = \frac{R_t}{\sum_j \overline{p}_{jt}^{\,*}\mathrm{q}_{\mathrm{jt}}} - 1 = \frac{\$57{,}714M}{\$121{,}453M} - 1 = 52.5\%\,. \tag{7}$$

Replacing $R_t$with the model estimates for each model $\hat{p}_{\mathrm{jt}}$ yielded the estimated weighted average discount ($\hat{D}_t$):

$$\hat{D}_t = \frac{\sum_j \hat{p}_{\mathrm{jt}}\mathrm{q}_{\mathrm{jt}}}{\sum_j \overline{p}_{jt}^{\,*}\mathrm{q}_{\mathrm{jt}}} - 1\,. \tag{8}$$

$\hat{D}_t$ varied between 50.2% and 51.3%, depending upon which models were used to estimate $\hat{p}_{\mathrm{jt}}$. When the MBA values were used for $\hat{p}_{\mathrm{jt}}$, $\hat{D}_t$ = 50.1%. These results give some assurance, that at least at the top level, the MBA data and the models are consistent with Boeing's revenue derived from aircraft sales.

Another important result from the models was the estimated downward trend in real transaction prices over the sample period. Boeing applies a weighted average of input price inflation rates when escalating list prices from year to year. Given this, and the model results, we should expect calculated discounts from list prices to be increasing over time as list prices rise at a higher rate than transaction prices. This is what we see where D_t increased from 34–39% (depending on assumptions regarding CAS revenue) in 2004 to 52.5% for 2016 as calculated in Equation 7. These additional calculations using publicly available Boeing data also confirm modeling results and the underlying data used.

Example Application: KC-46A

In this chapter, we apply information from the economics literature, our modeling results, and other relevant data to help estimate "fair and reasonable" prices for the commercial aircraft platforms used for the KC-46A.

The KC-46A's commercial platform, the 767-2C, has features that have no direct analog in the commercial aircraft database. Boeing considers the platform to be based on the 767-200ER passenger aircraft, even though it has freighter floors and doors associated with the longer 767-300F. While the 767-300F is still in production, the last 767-200ER was delivered in 2008. The price estimating models do provide some flexibility in producing estimates of transaction prices. The model can take into account the implied value to the market of some characteristics of the 767-2C, such as the increased MTOW (415,000 lbs. versus 396,000 lbs. for the 767-200ER and 413,000 lbs. for the 767-300F).

The competitive nature of the initial down-select, including NTE prices for production lots through the end of the planned program, meant that the fair value of all 767-2C features was revealed and should guide future prices. In other situations, one approach to addressing the value of like-type features would be to add their cost basis along with a representative mark-up to price. The costs could be based on analogies, cost estimating relationships, or cost data from the seller. The government has the right to ask for seller cost data, although it need not be TINA-compliant.

However, the overall market conditions and the specifics of the 767 production that were obtained at the time of the 2011 competition (including expectations regarding the future) are likely to be different now. The MBA data, price estimating models, and Boeing financials show a continuing downward trend in real prices. Also, given additional 767-300F orders and deliveries for Federal Express, the overall 767 program is delivering aircraft at a rate higher than planned in 2011; given the relationship between cost and price for a mature program (where the z_t argument goes to 0 in the $p_t = \frac{c_t + z_t}{1-((1-s)/E)}$ equilibrium relation, and the denominator is less than 1), the delivery rates indicate a lower price, as fixed costs are allocated over more units in a given year.

We are able to capture the overall price trend by applying the pooled OLS model using 767-2C characteristics and time series inputs, including projections to 2020. Projections for GDP growth and fuel prices are taken from International Monetary Fund (IMF) forecasts (2016), while additional deliveries reflect Boeing planned 767 delivery rates of two aircraft/month (up from prior values of one aircraft/month). This is shown in **Error! Reference source not found.**, along with data and model results from the 767-200ER, model estimates of the 767-2C, as well as data for the 767-300F.

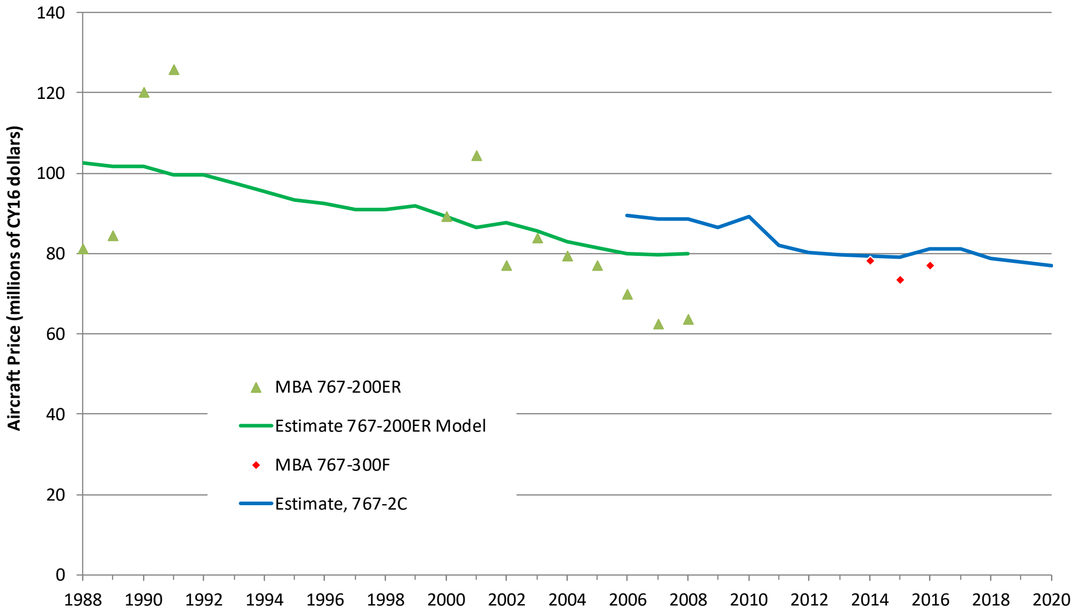

Figure 4. Panel Data Model Estimates for the 767-2C With Comparisons

The 2016 estimate for the 767-2C is $81.3 million in CY2016 dollars (note that this excludes KC-46A-specific provisions that are not captured in the model). Comparing this value to the model-predicted 2011 value shows an estimated decrease in price of 1.3%. In the case of 2017, the longer-term decrease in real prices is offset by price increases indicated by the model due to decreases in the fuel prices. This effect dissipates for future years with estimated prices decreasing to 6% below the 2011 value by 2020.[7] This indicates that there is room for negotiation below the NTE values determined in the 2011 competition. For later lots where the NTEs are subject to adjustment based on an EPA clause, if the price trends indicated by the data and model (including evidence from Boeing's financial data) diverge from the price index specified in the EPA clause, there is additional potential to negotiate prices below the NTEs (as adjusted by the EPA).

As mentioned in the description of the regression analyses, we cannot separate out the supply-side effects on price of increases in production rates from the demand-side effects (GDP growth in our preferred models) using the MBA data. However, given general knowledge of aircraft industry cost structures as well as specific information from Boeing's financial reporting, we can analytically derive an estimate of cost effects of the higher production rates. The cost/price effects of increased 767 production rates can then be approximated by employing a "rate slope" term as estimated in DoD programs where price is based on cost.[8] Information from Boeing financial statements regarding the cost of reducing 747 production rates provides a way to calibrate the rate slope model for commercial aircraft production. With this information, estimates of unit costs and fixed cost percentages at different delivery rates can be calculated. This is shown in **Error! Reference source not found.**, where delivery rates from 6/year to 18/year are included, consistent with 2015 experience and forecasts through 2021.

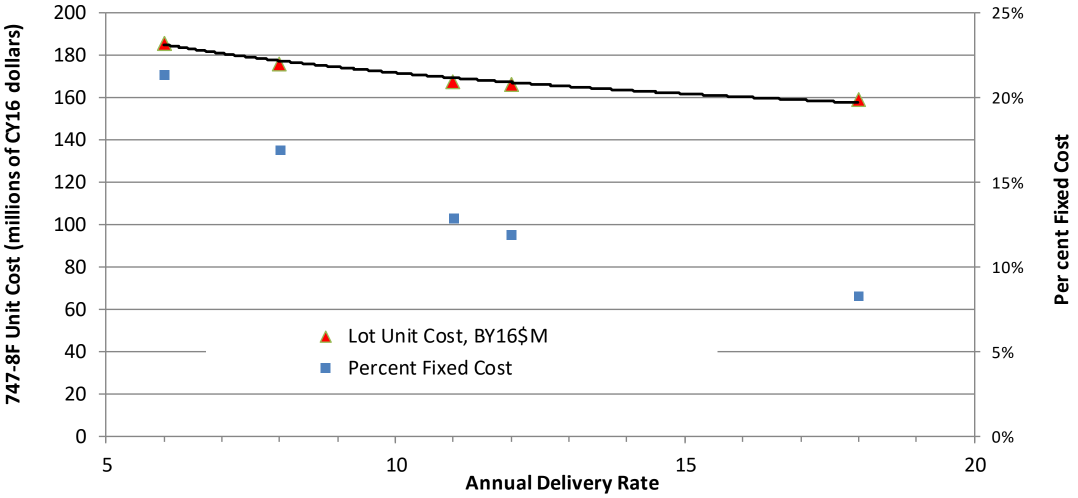

Figure 5. Unit Cost and Fixed-Cost Percentage Estimates for 747 Production

The curve fitted to the unit costs generalizes the relationship between annual quantities and unit costs; it is known as the "rate curve" relation,

$$c_t = \alpha \boldsymbol{q}_t^{\beta}, \qquad (9)$$

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[7] This estimate is based on IMF forecasts of the price of Brent crude, which is projected to increase from an average of $43/barrel in 2016 to $54/barrel in 2019 (all nominal dollars).

[8] This approach was suggested by Dr. David Marzo of CAPE/CA.

where q_t is the annual delivery rate. For the 747 example above, the estimated □ coefficient is -.146, corresponding to a 90.4% rate slope; this is within the range of parameters estimated for military aircraft programs.

Taking model-estimated prices for the 767-2C and insights from the above 747 analyses, we can estimate cost decreases driven by increases in production rates between the plan at Boeing's 2011 bid and the current plan. These differences indicate a 38% steady state increase in production rate. Baselining cost values to 767-2C price estimates for 2015 and applying the 15% margin assumption allows us to generate estimates of cost savings associated with the higher production rates. Using the 90.4% rate slope, we estimate annual unit cost savings of around $3 million (CY16) for the steady state years (2017 to 2026), corresponding to a 2% decrease in cost.

The 767-2C presents a special case, as price discovery at the time of competition between alternative tankers means that there is less uncertainty for future purchases. However, we see in the application of our models and other information that there are both program-specific factors (higher than previously planned production rates) and overall industry trends (increases in nominal prices over time that are less than overall inflation) that would indicate prices below the NTEs could be negotiated for future lots.

The long time horizon for the KC-46A program means that it is important to take into account both the effect of general industry pricing trends and changes in the specifics of 767 production economics. Our analyses of both of these effects indicate that the government may be able to pay lower prices than the NTE prices set in the original competition.

Commercial Aircraft Pricing Lessons Learned

Commercial Aircraft Pricing Tools

Price determination by negotiation for commercial items will generally only occur if the supporting markets are not purely competitive. In the case of commercial aircraft, the market is a duopoly where prices are above those that would be paid if the market were purely competitive. The specifics of this market have been explored in some detail in the economics literature. The resulting game-theory models are insightful but without much empirical gain. We were able to make use of the consultant-reported transaction prices to quantify price drivers, both on the demand and supply side of the market, through least-squares regression analyses. These models explain most of the variance in prices across aircraft models and time; utility associated with commercial airline services, moving people and goods speedily across long distances, can be proxied effectively by a small number of variables, while supply/cost effects can be mostly captured in a few dimensions. An important insight from the models and supporting data is the long-run decrease in real commercial aircraft prices. This could have an important impact on the pricing of future KC-46A procurements.

The models are useful in establishing baseline values for commercial aircraft used by the military. In our application of the models to the KC-46A program, we needed additional tools and data to address specifics of that program/aircraft. This included cost drivers not captured in the models (production rate effects).

Implications for Other Commercial Items

Several steps in the analysis of the commercial aircraft pricing for military applications would be relevant in negotiating prices for other commercial items:

- Understand the market in which the seller operates. This would go beyond “market research” and should address market dynamics as described by economic theory.
- Model market prices as they relate to both supply-side (cost) and demand-side (utility) drivers. This will be challenging in that most commercial items bought by the DoD and subject to price negotiation will not be as homogenous as commercial aircraft.
- Make use of the seller’s publicly available financial data to put available pricing data into perspective—and to better understand the seller’s business model.
- Given the existence of “like-type” modifications to items available on the commercial market, it may be advantageous to estimate the discrete costs of these modifications.

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