Massachusetts Institute of Technology
Engineering Systems Division

Working Paper Series

ESD-WP-2008-15

TAMING THE BUSINESS CYCLES IN COMMERCIAL AVIATION:

TRADE-SPACE ANALYSIS OF STRATEGIC ALTERNATIVES USING SIMULATION MODELING

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May 2008

Taming the Business Cycles in Commercial Aviation: Trade-space analysis of strategic alternatives policies across stakeholders using simulation modeling

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The delivery of air transportation services relies on the collaboration of a complex value chain. The primary stakeholders span the spectrum from end user (travelers and shippers) to service provider (airlines) and equipment manufacturer (aircraft integrators) while it includes enabler stakeholders (regulators, financiers and aircraft lessors). The interactions among these stakeholders and their collective response to external shocks have historically generated an industry that is notoriously cyclical.

This cyclicality comes at a price for shareholders, employees, and users. Historically, the industry-wide rate of returns on investment has been very low with the most recent losses erasing in nominal terms the total profits since the beginning of the industry. Employees in the airline or aircraft manufacturing sectors are, of course, affected by the intense hire/fire cycle[1]. As an indicative example, Boeing's workforce has fluctuated from more than 100,000 employees in 1967 to less than 40.000 in 1971, just four year later or a layoff rate of about 15,000 a year. Similarly, between 1992 and 1995, the layoff rate was about 7,000 employees a year ((Boeing 2005) and previous years, (Pope and Nyhan 2001)). The growth periods, while good for newly hired employees, are far from trouble-free; efforts to ramp-up production can backfire which was illustrated by the 1997 $2.6B write-offs by Boeing and the consequent stock tumble when several production lines had to temporarily shut down unable to meet the ambitious production targets due to lack of parts (Newhouse 2007). The resultant periodic over- and under-capacity creates issues for the planning of airports and air-traffic control capacity while passengers perceive (and receive) inconsistent levels of service (LOS) and pricing between periods. In summary, there are economic and societal costs involved with such cycles and mitigating their effects can provide benefits for the majority of the involved stakeholders.

In this paper we explore the relative effectiveness of a diverse set of strategic alternatives to mitigate the effects of the business cycle in commercial aviation and by doing so improve the long-term position of both the stakeholder that takes action as well as the aviation enterprise as a whole. Using simulation experiments, we find that such "symbiotic" alternatives exist even in the face of deregulated highly competitive markets. The key for unlocking the symbiotic potential lies, in this case, with the aircraft manufacturers as a central and consolidated node in the aviation value chain. A winning strategic alternative dictates that both the two remaining large commercial aircraft (LCA) manufacturers, Boeing and Airbus, maintain a policy of slow rather than quick response to the orders received by airlines. There are combinations of strategic alternatives that improve the outcome but the above is shown to be both robust and feasible.

This paper starts by presenting a review of the industry cycles literature in Section 1 that summarizes the hypotheses about the causal effects that drive the generation of cycles. Section 2 presents how the specific characteristics of the aviation industry can drive the

[1] The hire/fire cycle is of interest as it varies by firm as we shall see in Section 2.

aviation industry cycle and lists specific strategic alternatives that would address these drivers. Section 3 describes the commercial aviation simulation model that was developed to reproduce historical cyclical dynamics and project them into the future. Finally, Section 4 presents the strategic alternatives considered and the results of the experiments conducted to identify the relative effectiveness of how the different alternatives perform in mitigating the negative impacts of the aviation business cycle.

1. Economic, Industrial and Supply Chain Cycles

The business cycle for an industry can be loosely defined as a recurring non-seasonal variation in output that is usually accompanied by correlated changes in characteristic measures including profitability, equipment utilization, employment etc[2]. For most industries there is a correlation between economy-wide cycles and the industry-specific ones and few, if any, industries could claim immunity from the business cycle[3].

The observation that industry cycles are correlated to economy-wide cycles led economists to study how the different industries and economic functions interacted to produce the observed oscillations. Economic literature on business cycles traces back to the early 19th century and so does the theoretical basis for its causes. Among the recurring themes found in these hypotheses, external shocks and mass market psychology are the more prominent ones. The effect of external shocks as the reason for why economies oscillate was first submitted by Jevons in the late 19th century when he suggested that sunspot activity coincided with economic cycles. Although Jevon's conjecture was soon discredited, external shocks to a system remain a key initial hypothesis for explaining economy cycles. Pigou was among the first to suggest that the psychology of investors that make self-reinforcing errors of optimism and subsequent errors of pessimism[4], an internal rather than an external force, can also be considered as a driving force for the business cycle (Pigou 1929).

Most of the hypotheses that were proposed in order to explain business cycles are variants or refinements of these two ideas. Yet there are other contributing factors, for example, the lack of perfect information and the inability to forecast accurately as proposed by Metzler Abramovitz (Metzler 1941) (Abramovitz 1950). Imperfect information and delays between action and effect lie at the center of the mechanism called the "cobweb theorem;" it was described by Kaldor in order to explain commodity

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[2] One more formal definition of the business cycle for the economy given by Burns and Mitchell: "*a type of fluctuation found in the aggregate activity of nations that organize their work mainly in business enterprises: a cycle consists of expansions [,] recessions, contractions and revivals which merge into the expansion phase of the next cycle; this sequence of changes is recurrent but not periodic…*"
[3] In fact, cyclicality is considered integral to capitalistic economies by theorists. Schumpeter (1939), an economist who studied the macroeconomic cycles intensively, proclaimed that "[c]*ycles are not, like tonsils, separable things that might be treated by themselves, but are, like the beat of the heart, of the essence of the organism that displays them.*"
[4] Pigou noted that bankruptcies are not very effective in destroying capital, as the capital investments simply changes owners but instead, he suggested, it is fear of undertaking new investments that delays the optimal allocation of resources to be prepared for the next cycle.

market cycles (Ezekiel 1938). Commodity producers, the theorem went, can only perceive the prices in the market; as the prices for a given commodity are high and absent coordination every producer will spontaneously rush to fill that "opportunity" but they will not be able to discover this until the next year's crop is supplied and the market glut depresses the prices. Albeit idealized, this is a good description of how markets with multiple competing actors and large delays react even today.

Unlike commodities for which the production/consumption cycles are fairly short, durable goods like automobiles, ships and aircraft have a longer useful life. This characteristic implies that if for some reason there is a spike in the demand for a durable widget, this spike in orders will tend to be reproduced when the durable widgets delivered in a wave reach the end of their useful life in what was termed a reinvestment cycle.

Tinbergen was the first to describe the "durable goods" cycle in the Norwegian shipping industry in 1931. He attributed the cyclicality in the orders to delayed feedback between orders and rates (Tvedt 2003). When freight rates increased orders followed, yet as the delay of construction intervened, freight rates could reach very high levels triggering even more orders for ships. Expectedly, when the orders materialized they could create a glut and even a depression in cycles.

Continuing the research in the shipping industry, Einarsen observed a reinvestment cycle but he also noted that since the useful life of machinery can be extended through repairs, capital replacement should be elastic. This would imply the existence of what he called the *secondary reinvestment cycle*. These cycles "*owe their existence to the fact that the replacement of the machinery, which during depression becomes ripe for renewal, will to a great extent be neglected or postponed"* (Einarsen 1938). Therefore, he expected the reinvestment cycles to synchronize with the economic cycle as the new orders plus the replacements can be delayed until the post-recession growth.

Tinbergen's observations on the oscillation-inducing effect of the delay between orders placed by shipping companies and deliveries by shipyards pointed to a key mechanism of a phenomenon characterizing multi-tier supply chains known as the "bullwhip effect." The bullwhip effect was defined by Forrester as "*the amplification of order variation moving upstream in the supply chain"* (Forrester 1961). This effect has been observed in diverse supply chains (with examples including baby diapers (Lee, Padmanabhan et al. 1997), pasta (Hammond 1994), and even found in the difference between inbound and outbound inventories of a single warehouse (Svensson 2003).

Industry level observations have confirmed similar effects in the automotive industry (Blanchard 1983), the machine tool industry (Anderson, Fine et al. 2000), and in the electronics industry (Terwiesch, Ren et al. 2005). In fact, on the industry level, the bullwhip effect had been observed and described by classical economists who dubbed it the "***acceleration principle***" since the beginning of the 20th century (Clark 1917).

The causal mechanisms that drive the bullwhip effect in a given supply chain may include long lead times, imperfect forecasts, order batching, price variations, and the interaction of rationing and shortage gaming ((Lee, Padmanabhan et al. 1997), (Simchi-Levi, Kaminsky et al. 2003)). Yet, Croson and Donohue replicated experimentally the bullwhip effect in the beer game setting (Sterman 1989) even when all the other identified operational causes of the bullwhip effect were removed with the exception of lead time (Croson and Donohue 2006).

Given the convergence in the hypotheses behind the driver of oscillations in supply chains of durable goods, it is not surprising to note significant qualitative similarities in the behavior of very different markets. Figure 1 showcases the similarity in pattern behavior of the shipbuilding industry in Norway at the end of the 19th century and early 20th century and the commercial aircraft industry at the second half of the 20th century. The total orders for aircraft-seats are superimposed over Einarsen's observations of orders for ship capacity in tons and while the underlying economy, location, external shocks are quite different, they still seem to generate strikingly similar behavior indicating that internal dynamics may shape system behavior. The next section describes the key internal and external dynamics present in the commercial aviation industry.

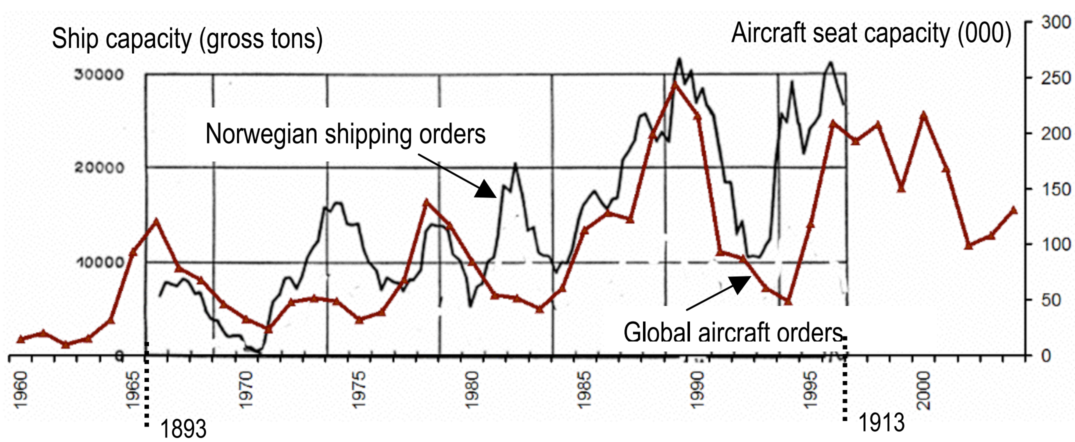

Figure 1: Illustration of similarities in the cyclical behavior of the shipping ordering cycle in Norway between the years 1893-1913 and the global aircraft ordering cycle ((Einarsen 1938), Boeing and Airbus databases)

2. The Commercial Aviation Business Cycle

Commercial aviation business cycles have a period of 7-10 years similar to the Juglar equipment investment cycle as described by Schumpeter (Schumpeter 1939). In this type of cycles, economic growth as a driver of demand, the ordering and retirement of equipment, and the entry and exit of firms in the different markets are the key variables that need to be considered which reflects similar observations for the shipping industry (Stopford 1997)(pg 62). The cyclicality is illustrated by two key industry metrics airline profitability and order rates plotted in Figures 2 and 3 respectively.

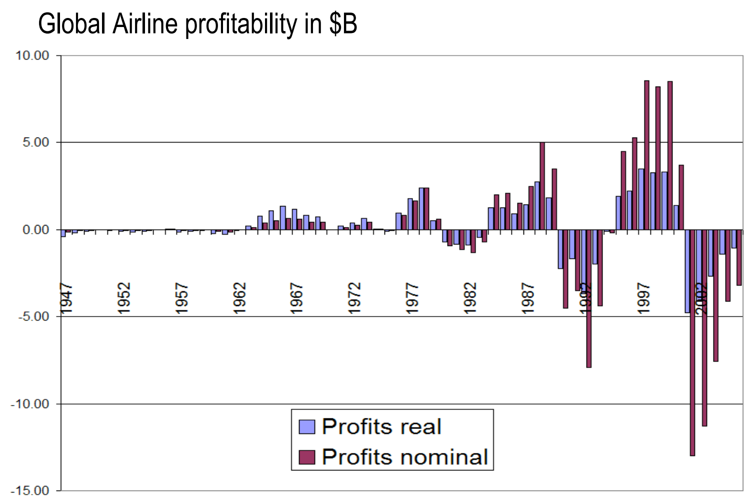

Figure 2: Global Airline Profitability in Billion Dollars (data source: (ATA 2006))

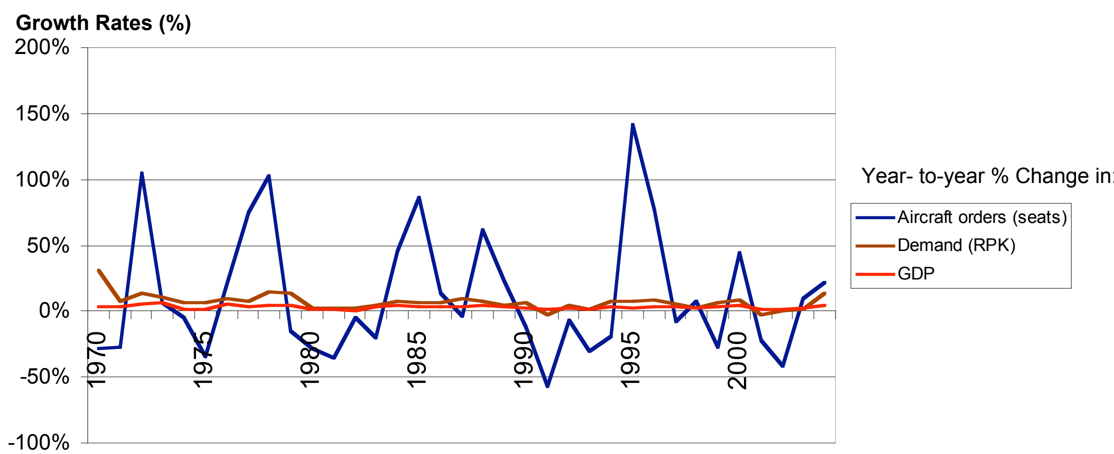

Figure 3: Year to year change in global large aircraft orders compared to changes in demand for air travel (revenue passenger kilometer or RPK) and the gross world product (Data source: Boeing and Airbus (orders), ATA 2006 (air travel), World Bank (GDP))

In the transitory period after the Airline Deregulation Act in 1978, the following commoditization dynamics could be seen as driving the oscillations in the industry. The first effect of deregulation was to allow a number of new entrants. These new entrants had lower operating costs than incumbent airlines as they operated younger fleets and their employees had low seniority and commensurate salaries. What they lacked was network size – a key parameter for attracting passengers. Therefore, a race began to gain market share and utilize capacity at a disregard for short profitability. This behavior, although rational in the short-term for a single player, created the illusion that even more capacity is needed as the lowered prices boosted demand; this was exacerbated by a growing economy. Airframe manufacturers and, later, leasing firms were happy to oblige in providing the capacity that was being ordered, despite the mismatch between demand growth and the much higher capacity growth, as that also helped them reduce their unit costs faster and compete for market share in an oligopolistic market. In addition, airframe manufacturers, trying 1) to establish market lock-in and 2) go down the steep learning curve that would give them an edge over their competitors, were engulfed in their own price war further inducing demand and adding another factor of overcapacity.

Overcapacity inevitably led to price wars and substantial losses but subsidies, mergers, and bankruptcy protections (Chapter 11 or nationalization) created barriers to exit, thus retaining a level of overcapacity and allowing for a continuation of the high unit cost practices by the legacy carriers. Even when carriers failed, their aircraft was re-circulated as leased or sold to new entrants willing to try their chances. Investors willing to finance these ventures facilitated this effect.

Two other factors dictated the retention of capacity by airlines: high midterm fixed costs and the sophisticated pricing capability offered by revenue management systems to maximize flight passenger revenue. The significant medium-term fixed costs faced by their operations included the need to "hoard" or retain highly trained employees if the airline was to remain competitive at the next market upturn while the costs for long-term leases, owned equipment and gate leases were also fixed in the medium-term. The high fixed costs made the prospect of price wars more palatable to airline managers as at least these would ensure a source of badly needed short-term liquidity even at the expense of profitability and long-term viability (which was usually longer than the time horizon of high-level management). Revenue management systems also provided a way of filling up the aircraft at ever higher load factors but at prices that sometimes did not cover the costs of the operation; the belief that the marginal cost of a seat is zero obscured the fact that in some cases the prices charged meant that the break-even load factor exceeded one.

In the description above, the key factor in the oscillation is the repeated mismatch between available capacity and demand in the industry with tight capacity matched by increased demand and high returns and vice versa. Airlines have flexibility in reducing available capacity; depending on the time horizon of the decision maker, schedules can be cut back in the short term and aircraft can be parked, returned to the lessor, sold, or scrapped in the medium and long term while airlines can go out of business. Yet, this flexibility is limited by several factors: firstly, an airline's frequency and network coverage is a key competitive advantage which is only reluctantly forfeited; secondly, aircraft are expensive assets that do not produce if underutilized while their lease or interest and capital payments continue; thirdly, even when an aircraft is returned to the lessor or sold it will return in the market sooner rather than later; fourthly, airlines worldwide are recipients of subsidies in different shapes and forms that creates high barriers to exit.

As a result, aircraft manufacturers emerge as a key stakeholder with the ability to moderate the influx of capacity in the market. This ability would be moot in a perfectly competitive market with multiple suppliers but becomes highly influential in a consolidated market setting. As described earlier, aircraft manufacturers have their own set of incentives for competing intensely. These include: establishing vendor lock-in for airlines that gain from lower operating expenses by flying single-type fleets, fast tracking the learning curve gains from higher rates of production, and establishing economies of scale by spreading the high upfront development costs over large productions runs and economies of scope that support varied product lines. Airlines negotiating for a new contract can leverage these points in order to play-off the offers between the manufacturers driving towards competitive pricing similar to a Bertrand equilibrium outcome[5].

In practice though none of the competitive incentives for manufacturers described above is overwhelmingly effective as that would have led the market to a natural monopoly equilibrium. In practice, airlines with history of loyalty to one manufacturer may switch to the other[6] while annual production rate change as opposed to cumulative production is shown to be a better indicator of the learning curve effect as shown by Benkard in the study of the Lockheed Tristar (Benkard 2004) and empirically demonstrated by Boeing's 1997 production problems.

In fact, looking more closely to how Boeing and Airbus adjust their production rates is revealing a different strategic approach. Piepenbrock pointed to several fundamental differences between the two manufacturers and argued that there is consistent pattern in other industries (Piepenbrock 2004). Here we will focus only on the production rate change strategy difference without consideration of which aspects in their organizational structure led the respective CEOs to conceive and abide by them in the first place.

In summary, Boeing has historically been oriented towards adjusting production rates to meet market needs as flexibly as possible while Airbus, on the contrary, has not. This difference is illustrated in Figure 3 which shows how the volatility of Airbus and Boeing orders received is similar (Airbus has in fact been receiving more volatile orders) but Airbus delivery rates are substantially less volatile than Boeing's. This is corroborated by the higher backlog[7] maintained by Airbus which is allowed to balloon to 12 years or higher compared to Boeing's three to four years average. While this difference certainly impacts the firms themselves and their competitive position, it is not immediately apparent how it impacts the aviation enterprise as a whole now and in the future and whether one or the other approach can be leveraged to alleviate some of the worse effects of the aviation business cycle. To investigate this and a set of alternatives that encompass the other mechanisms mentioned previously we built the system dynamics simulation model described below.

[5] This is a simplistic description as the negotiating power shifts between airlines and manufacturers.
[6] To provide two recent examples, British Airways, a loyal Boeing customer ordered Airbus A380 aircraft while JetBlue, a low-cost-carrier that operated an Airbus-only fleet, ordered Embraer ERJ-190 aircraft.
[7] Defined here as years of production needed to deliver existing orders at current production rates.

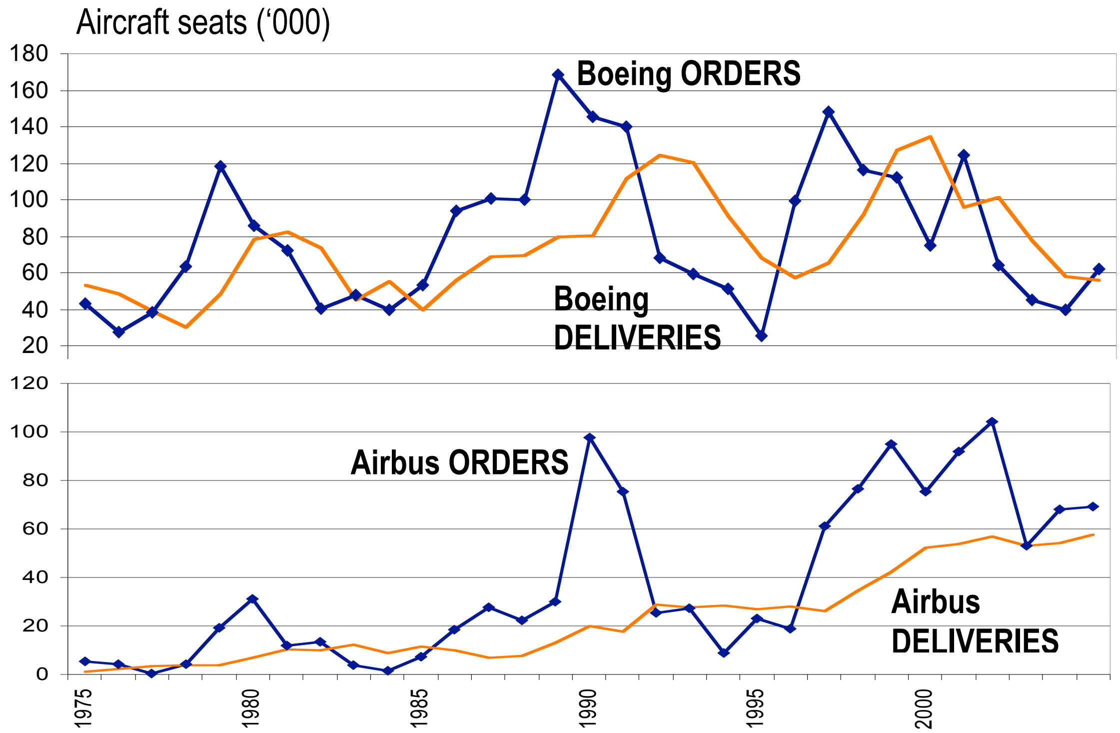

Figure 4: Juxtaposition of Boeing and Airbus order and delivery data in total number of seats (Data source: Boeing and Airbus databases)

3. Modeling the Commercial Aviation Business Cycles

3.1 Existing System Dynamics Modeling Efforts

Given the number of potential factors that can trigger or propagate and amplify oscillations, it is necessary to model the aviation enterprise in order identify which factors have the greatest impact and following from there which alternative policies are more effective. For this purpose, we based our modeling of the industry on the tried structures used by previous researchers enhancing them with the characteristics needed for our purpose as described in this section.

Weil adapted a generic commoditization model to represent the commercial aviation industry. Based on the generic industry model, Weil attributed the excess capacity to the following set of causes (Weil 1996):

- Over-estimation of demand growth
- Amplification of planning and forecast errors
- Large and increasing number of players
- Lack of adequate financial constrains
- Market liberalization

Skinner et al. also developed an SD model of the airline industry and focused on devising "cycle management strategies" for a single firm through cycle anticipation, corresponding growth and competitive behavior, and adding flexibility in areas like aircraft mix, options ordering, and labor (Butler and Keller 1999). Among the strategic alternatives they proposed were:

- Wet leases
- Fleet age stratification
- Fractional ownership
- Profit-sharing programs
- Code-sharing and alliances to coordinate changes in capacity

Lyneis used a more detailed version of the Weil structure that modeled the used aircraft markets, leasing firms, and the manufacturers (Lyneis 2000). Using this proprietary model, Lyneis observed that the reasons for cycles revolve around the inability of the individual airlines to perceive and act on the information of the industry as a whole as the significant delays in the major negative feedback loop amplify the variation in economic conditions by preventing airlines in total to account for the aircraft that are in backlog. This error is compounded by the use of extrapolation forecasting by airlines and competition for market share in the upcycle create a situation where the total expected market share by the airlines exceeds significantly the actual market.

Finally, Liehr et al. developed a parsimonious SD model using similar feedback structures as the other researcher and, like Skinner et al., focused on the alternatives available to an individual client airline (Lufthansa) for managing cyclicality (Liehr, Grossler et al. 2001). They stressed the creation of an organizationally independent business unit to manage capacity as a prerequisite in any meaningful cycle management strategy within an airline. In addition, strengthening alliances as a way of introducing wider capacity controls in the industry was seen as critical if network planning in the alliance and equalization across regions were to be implemented.

3.2 Expanded Commercial Aviation System Dynamics Model

The model that we developed is based on the tested structures used by the researchers referenced in Section 3.1. The model represents the dynamic interactions between the primary stakeholders shown in Figure 5 (aircraft manufacturers, airlines, passengers etc.).

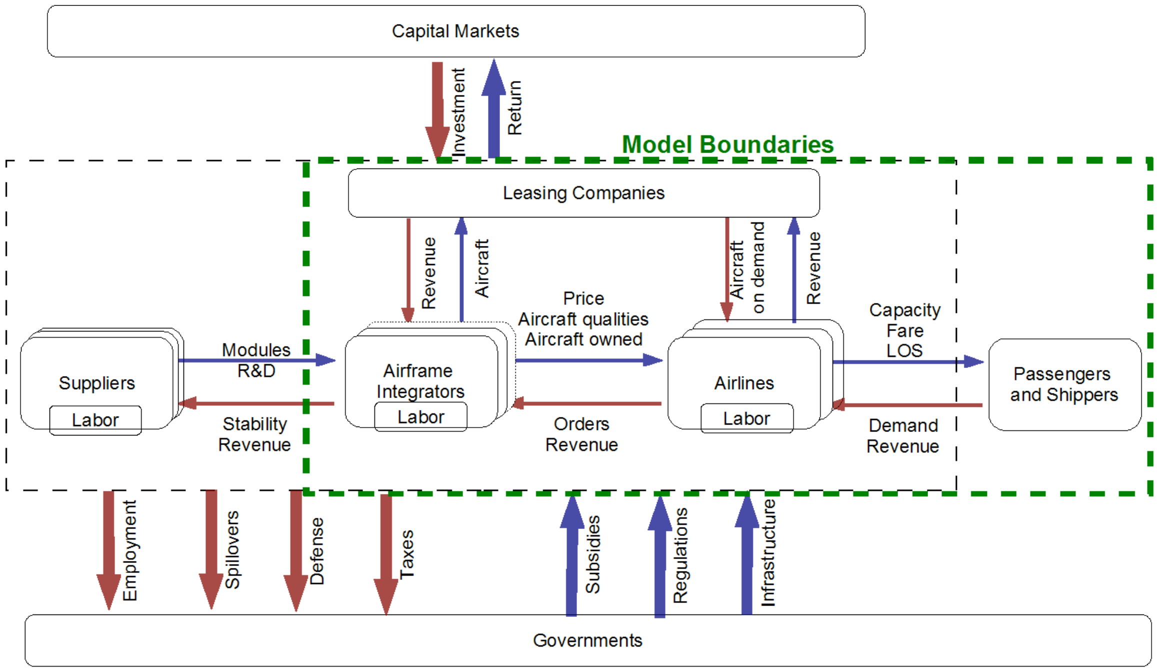

Figure 5: Commercial Aviation Enterprise Structure and Model Boundaries

The model is intended to adequately simulate the key dynamics of the industry identified in the previous section while also allowing for experimentation with alternatives that would structurally change the system. As a consequence some of the interactions modeled include:

- the competitive dynamics of a duopolist market for aircraft manufacturers that includes aircraft pricing, and the effects of economies of scale, scope, and vendor lock-in.
- the market dynamics of the global airline industry; differing competitive dynamics affected by the relative barriers to entry and exit and the profitability of the industry where high level of profitability induces higher entry rate which in turn suppresses fare prices as competition intensifies. Similarly, orders, utilization, and retirement of aircraft are dependent on the competitive dynamics; in a more competitive industry, the desire to fill the available aircraft and increase load factors in the short term will override the propensity to reduce capacity in an effort to improve profitability.
- The demand for air transport is dependent on economic and population conditions on one hand and on the reaction to price levels as demonstrated by the price elasticity of the consumers of the transport service.
- External effects not captured by the dynamics described previously like fuel prices and events that disproportionately affect air travel (e.g. a terrorist attack, regional war, or a pandemic) compared to their impact on the economy as a whole.

These dynamics are presented in a causal loop diagram format in Figure 6.

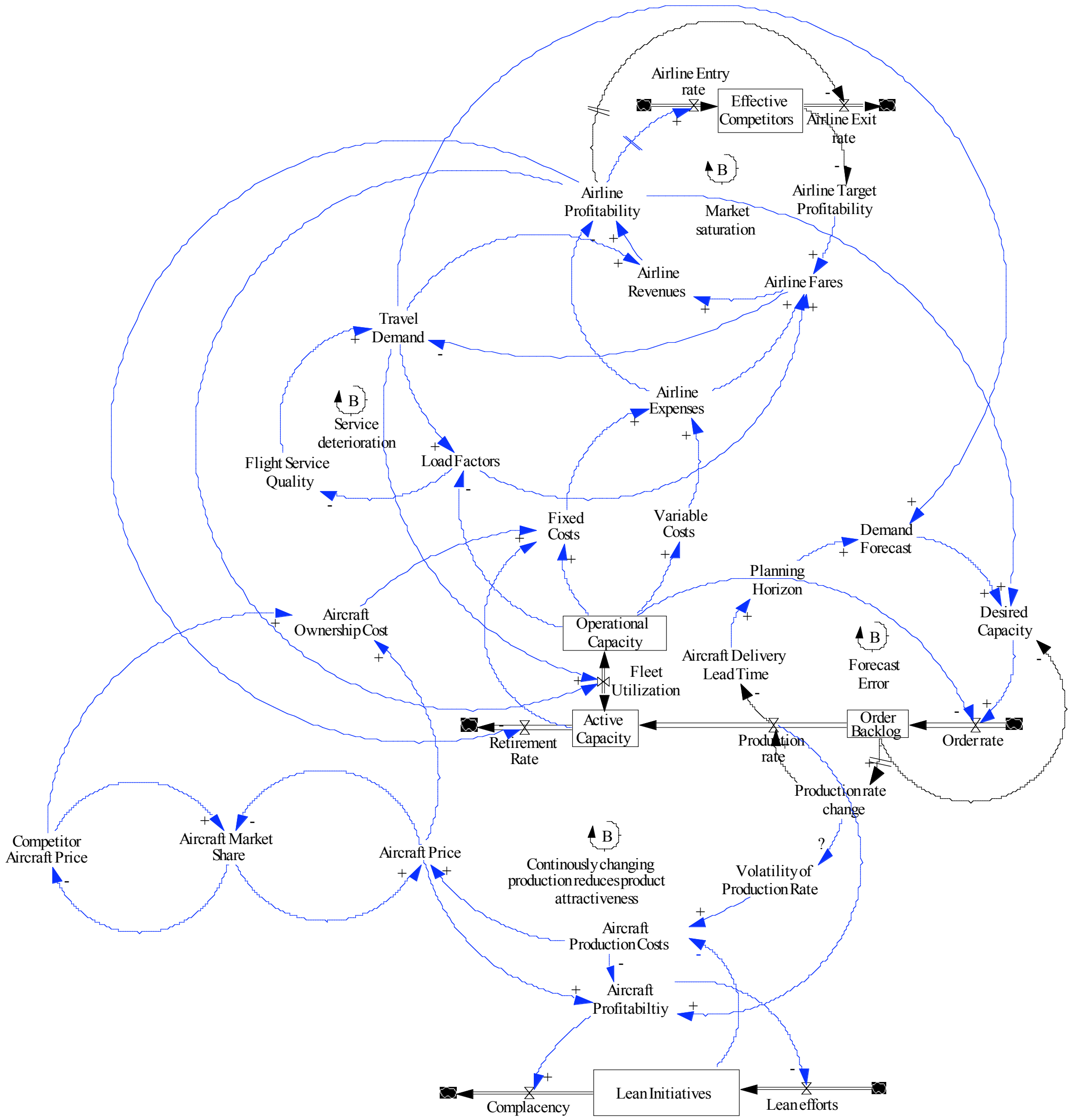

Figure 6: High level causal loop diagram of the major interactions in the commercial aviation model

3.3. Calibration and Validation of the System Dynamics Commercial Aviation Simulation Model

The commercial aviation system dynamics model that was summarized in the previous section was intended for high level policy analysis rather than detailed forecasting. The calibration process used a combination of historical data-derived parameter values based on econometric estimation, published estimates of specific parameters, and, in the case of parameters where existing estimates were not available or were qualitative in nature, a reasonable estimate was used accompanied by sensitivity analysis. In addition, the model's modular structure allowed for a sequential calibration/verification of each module by separating them and feeding historical data as inputs and monitoring the outputs compared to the historical expected values. Given the tight interactions between modules, this was an iterative convergence process.

The calibration against historical data used 1984 as the starting year as by that time many of the current features of the industry were in the process of being established:

- airline deregulation in the US market was well under way,
- LCCs were introduced and growing (Southwest, People Express etc)
- Yield management systems started to become widespread
- Airbus had carved a niche for itself in the widebody aircraft category and was about to introduce its narrowbody family

For this reason the mid-eighties is a good starting point for the system dynamic model as it gives ample historical data for further calibration and does not have to account for big differences in industry structure.

The key parameters used for calibration against historical data were:

- Airline total demand, operating capacity, and load factors
- Airline revenues, costs, and profit margins
- Airline orders and manufacturer backlog (aircraft delivery lead times are captured with backlog)

In Figure 7, we show a sample of these parameters for airlines comparing model results against the historical data.

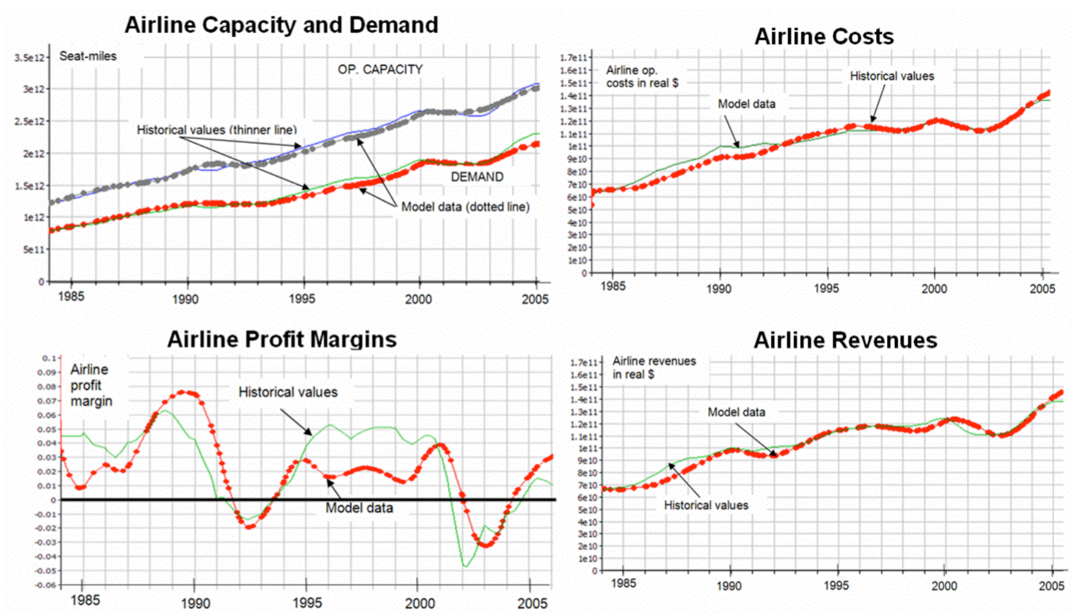

Figure 7: Historic vs. model output data used for model calibration and validation

To confirm the visual indications of close similarity between the modeled and historical data, we also conducted a set of statistical tests for these key parameters summarized in Table 1. For all parameters the hypothesis that the model results are not significantly different statistically than the data distribution could not be rejected. We also notice from the fact that the U_c Theil statistic is greater than U_m and U_s that there is a phase shift between the model results and the historical data but does not give information as to the relative magnitude. By inspection, this phase shift is less than one year which is a small time frame for the time-scales that we are considering. On the same topic, Sterman (p. 877) notes that the system type we are considering -- a combination of supply chains and commodity markets – "*selectively amplify certain frequencies in the random shocks that constantly perturb them. Since no model can capture all the random variations in the environment, model dynamics can diverge from the data* ***even if the model is perfectly specified***" (emphasis in the original) (Sterman 2000).

Table 1: Statistical tests comparing the Historic Data Distribution (d) with the model output data (m)

Variable	Mean d	Mean m	Sqrt (MSE)	R sq.	Theil statistics *Um*	*Us*	*Uc*	P(T<=t) two-tail	Statistically significant difference at 0.05
Capacity (in trillion op. ASM)	2.03	2.03	0.077	0.981	0.001	0.153	0.845	0.986	**No**
Demand (in trillion RPM)	1.39	1.39	0.061	0.975	0.004	0.007	0.989	0.976	**No**
Load factors	0.68	0.68	0.02	0.430	0.019	0.002	0.979	0.718	**No**
Airline costs in ($B)	101	98.9	5	0.959	0.172	0.246	0.582	0.730	**No**
Airline revenues	103	101.1	5.2	0.949	0.152	0.185	0.663	0.735	**No**
Airline profit margins	0.026	0.027	0.018	0.663	0.003	0.000	0.997	0.916	**No**
Aircraft orders (in trillion ASM)	0.21	0.19	0.067	0.628	0.081	0.095	0.824	0.531	**No**
Aircraft backlog (in trillion ASM)	0.61	0.63	0.164	0.636	0.019	0.111	0.871	0.771	**No**

Finally, in order to create a meaningful background for experiments, we projected the key driving parameter variables (i.e. gross world product and population, fuel prices and external factors) to 2024 using three scenarios named Global Village (a continuation of the current status with historical growth rates and relatively stable fuel prices), Islands of Sufficiency (a reduction in GWP historical growth rates and an increase in fuel prices that drive more regional reliance and a reduction in demand for long-distance travel), and Growth and Overshoot (the fast paced growth continues for some years until it reaches hard resource constraints causing a dramatic collapse in economic output and desire to travel). We used these scenarios as a way to conduct sensitivity analysis for the effectiveness of the different strategic alternatives that tested as described in the following section.

4. Mitigating the effects of the business cycle in Commercial Aviation

We structured our experimental investigation into two sections; one focused on understanding the relative impact of the endogenous structure of the industry as opposed to the exogenous influences while the second specifically examined the effectiveness of different potential strategic alternatives in mitigating the effects of the business cycle that is generating higher value for the different industry stakeholders than the baseline.

4.1 Endogenous vs. Exogenous Effects

We experimented with the relative effect of external factors versus the endogenous structure of the industry. The experiments consisted of stabilizing all but one exogenous parameter at a time and comparing in turn, their relative impact on the industry cycle. We also considered the impact of differences in the internal structure of the industry. We used the coefficient of variation in airline profitability and ordering rates as the metrics for comparison and the results are summarized in Table 2, where a higher value indicates a more volatile environment.[8]

Table 2: Coefficient of variation* of airline profitability and aircraft orders investigating the relative effect of external factors and industry structure

Experiment	Airline Profitability	Aircraft Orders
1. All exogenous factors variable (baseline)	1.10	0.86
2. Only fuel prices variable	0.88	0.53
3. Only economic output variable	0.74	0.71
4. Only external events variable	0.67	0.58
5. No exogenous factors variable and consolidated airline industry	0.56	0.53
6. No exogenous factors variable and competitive airline industry	0.64	0.53

* A higher value of the coefficient of variation indicates a more volatile/cyclical behavior

We found that the volatile fuel prices impact airline profitability but not aircraft orders as much. This is because in a competitive industry, a large fraction of the downward fare fluctuation is absorbed as losses and do not seriously impact customer demand that is the primary driver for aircraft orders. The economic cycle on the other hand has a deeper effect upstream in the supply chain while the external events (terrorism etc) are a distant third in their impact as drivers of a cycle.

More importantly, we show that for a consolidated industry, an industry that effectively acts as an oligopoly that allows for economic profits, the disequilibrium of the initial conditions is dampened. This is not the case if the airline industry is competitive and with active entries and exits in the industry. In this case, even in the absence of other external factors the structure of the industry perpetuates a endogenous cycle in profitability. The effects of these internal dynamics amplify external signals generating the status quo of a notoriously cyclical industry. Liehr et al. (2001) had reached a similar conclusion running contrary to the conventional wisdom of industry leaders that attributed the plight of the industry to the exogenous rather than the endogenous drivers. The significant potential of endogenous change is highlighted in the following sections.

4.2 Evaluating strategic alternatives for mitigating the effects of the commercial aviation business cycle

A prerequisite step in evaluating the impact of strategic alternatives on the value delivered to different stakeholders is the definition of representative value functions for

[8] As the experiments are deterministic and replicable probabilistic analysis was not necessary in this case.

the stakeholders and metrics that reflect them. In our case, these are summarized in Table 3.

Table 3: Representative value functions and metrics for the key commercial aviation stakeholders

Constituent Enterprise/ Stakeholder	Values	Metrics
Passengers/ Shippers	Availability of air travel	ASK / year
	Affordability of air travel	Average fares
	Level of Service	Frequency, reliability, amenities (load factors as proxy)
Carriers	Economic Return	Economic Value Added (EVA: Op. Profit – Taxes – Cost of Capital) Discounted to NPV
	Stability of Return	Coefficient of variation (CV)
	Downturn time	Average time with negative returns
Airframe Manufacturers	Economic Return	Economic Value Added (EVA: Op. Profit – Taxes – Cost of Capital) Discounted to NPV
	Stability of Aircraft Deliveries	Coefficient of variation (CV)
	Downturn time	Average time with negative returns
Capital Markets	Return on investment	Combination of airlines and airframe manufacturers returns
	Defaults avoidance	Economic losses due to defaults
Governments	Availability of air travel	ASK/year
	Returns of domestic industries	EVA
	Min. subsidies	Amount of assistance in support of airlines and aircraft manufacturers
	Employment stability	Employment numbers

For this paper, we assume that long-term returns are prioritized for the capital marketsand and for the government stakeholders. For the latter, the combination of long-term economic return stability and high availability of air travel also implies employment stability for an industry where labor input per aircraft flight is regulated by minimum requirements. As a result, the value functions for these two stakeholders can be derived from the satisfaction of the value functions of the top three stakeholders in Table 3, which we use as proxies for evaluating the different strategic alternatives.

Based on the dynamics discussed in Section 2, we considered a number of conceivably feasible strategic alternatives, which we summarize in Table 4. The evaluation process consisted in running experiments of activating a single alternative at a time. Next, a set of experiments with promising combinations of strategic alternatives was tried. In order to explore as large a portion of the solution space as possible, an automated optimization process was implemented to generate a solution space of multiple combinations of strategic alternatives and clarify how individual alternatives fared against bundles of alternatives. The final step was to consider the feasibility of strategic alternatives given non-modeled considerations (e.g. political will, probability of successful deployment, coordination levels required across stakeholders that could be considered as collusion and not viable in a regulated free market environment etc.). In all cases, the desired objective was to 'satisfice' with a solution that performs well across stakeholders (symbiotic) and requires minimum, if any, political intervention or collaboration among actors.

Table 4: List of strategic alternatives evaluated

	Mechanism	Strategic Alternative Description
Flexibility in Airline Operations	**Fixed to variable costs**	*Profit Sharing and Outsourcing*: Investigates the transfer of fixed operating costs to variable via profit-sharing agreements and service outsourcing as a way to defer costs in a downcycle.
		Leasing Variation: Investigates the effect of more flexible ownership costs offered by leasing
	Operational fleet management	*Flexibility in Aircraft Fleet Utilization:* Investigates how different aircraft utilization strategies affect cyclicality.
		Aircraft retirement patterns: Investigates how a change in the aircraft retirement patterns affects the commercial aviation enterprise.
	Aircraft ordering patterns	*Supply chain visibility*: Investigates reductions in 'supply chain discounting' or the observed phenomenon (acutely in the airline industry) of collectively ordering as if the backlog of orders in the supply chain is non-existent.
		Demand Forecasting: Investigates changes in forecasting: how smoother forecasts affect the cycle.
		Adjusting the Effect of Profitability on Order Patterns: Presents the effects of moderating ordering 'exuberance' in profitable for airlines periods and commensurate dearth of orders in a high loss period.
Airline Competitive Environment	**Yield management policies**	Investigates how different assumptions in the airline yield management strategies may influence cyclicality.
	Changes in airline barriers to entry and exit	Examines the effect of changing the barriers to enter and exit the airline industry which are controlled by the regulators and financiers: Competitive vs. regulated markets: Lower barriers to entry and higher barriers to exit Higher barriers to entry and lower barriers to exit
Aircraft Manufacturer Competitive Environment	**Competitive strategies**	Considers individual manufacturer action that does not require any leader/follower game.
	Coordinated strategies	Assuming manufacturer cooperation
	Aircraft pricing	Investigates the effect of coordinated and competitive changes in aircraft pricing: Monopolistic pricing Signal pricing: attempt to induce airlines to buy more or less by drastic changes in aircraft price Competitive: highly competitive pricing
	Production rate adjustments	Investigates the effect of coordinated and competitive changes in aircraft production rates: Just-In-Time delivery (very responsive aircraft deliveries) Quick production rate adjustments (similar to the current Boeing production strategy) Slow production rate adjustments (similar to the current Airbus production strategy) Pre-determined production schedules pegged at long-term aviation growth rates

A striking conclusion from evaluating the different strategic alternatives is that controlling capacity was *in all cases* instrumental for positive outcomes. Interestingly, the one solution that did not require either explicit collusion or changes in the regulatory environment was the implementation by the manufacturer that represented Boeing to follow a slow to adjust production planning strategy similar to the one used to model

Airbus's behavior as shown in the selective results summary in Table 5. In Table 5 we present the results that provided significant (>3% difference) changes from the baseline results.

Table 5: Indicative results summary for strategic alternatives with positive impacts

	Airline		Manufacturers		Passengers	
	NPV Change	CV change	NPV Change	Order CV Change	Fare Change	LF change
75% SC visibility	**256.4%**	**54.0%**	**-45.6%**	**41.8%**	**2.6%**	**13.8%**
50% SC visibility	**168.7%**	**47.3%**	**-38.9%**	**31.5%**	**2.7%**	**9.5%**
MF fixed prod. Rate	**49.6%**	**-23.4%**	**123.3%**	**N/A**	**-0.3%**	**2.8%**
Slow prod rate change	**25.6%**	**-2.6%**	**63.7%**	**-43.5%**	**-0.8%**	**1.3%**
Slow prod rate change + 25%SC visibility	**142.2%**	**50.5%**	**4.3%**	**5.3%**	**2.2%**	**7.4%**
MF JIT+ lean + 25% SC visibility	**90.6%**	**41.9%**	**-40.2%**	**25.4%**	**3.6%**	**5.2%**

Notes:
Results that are significantly positive are shaded darker (green) and those that were significantly negative shaded lighter (yellow).
NPV: Net Present Value
CV: Coefficient of Variation for the metric. A positive CV change means that the metric is more volatile (cyclical) than its baseline value

The positive impact of the adoption of slow production rate adjustments by Boeing and the continuation of that strategy by Airbus provides strong positive returns for both manufacturers and airlines while only marginally affecting the passenger welfare by reducing ticket prices (primarily as a result of lower production costs) and slightly increasing load factors (a relative disadvantage if used as proxy for service levels but at the same time performing much better than the other promising solutions in that metric).

Another important observation that can be drawn from these results is that the just-in-time aircraft delivery strategic alternative that calls for lead times of less than six months from order placement to aircraft delivery, even when bundled with other positive strategic alternatives like lean manufacturing to ensure reductions in manufacturing costs and supply chain visibility, fails to offer a symbiotic outcome as it provides benefits to airlines but it still takes a toll on the manufacturers that cannot reduce their costs fast enough to compensate for the erratic order placement of the airlines and at least in the timeframe that we examined, there does not seem to create a positive reduction in the cyclicality of the industry.

These results are robust even against the large solution space provided by bundling of strategic alternatives as shown in Figure 8. There the strategic alternative that calls for Boeing to adapt Airbus's production strategy is dominated by only a handful of bundles while the (unrealistic and costly for passengers) fixed production strategy is clearly on the Pareto front.

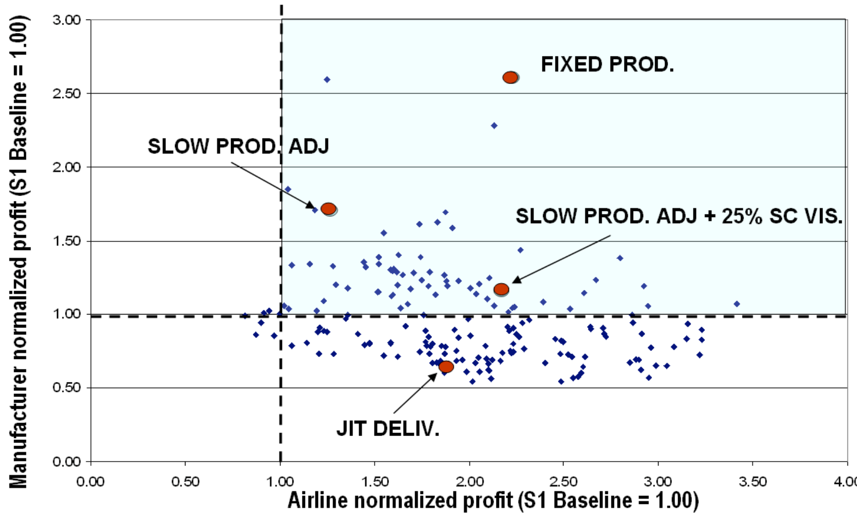

Figure 8: Impacts of bundled strategic alternatives in two dimensions for the airline and aircraft manufacturer stakeholders against single the symbiotic

Note: Symbiotic solutions reside on the upper right quadrant as it is there that the benefits are positive for both the airlines and the manufacturers compared to the baseline.

4.3 Discussion

Aircraft manufacturers face a prisoner's dilemma kind of problem in their decision to adjust capacities independent of orders to optimize for long-term performance. They have an incentive for adjusting production rates fast enough so that they can cater to airline demand and avoid losing orders due to delays. On the other hand, they would both be better off if they adjusted production rates slowly. The emergence of a third manufacturer for large scale aircraft facilitated by both incumbents following the same slow adjustment strategy and carrying large backlogs was not modeled. It is an unlikely event for the immediate future based on technical and economic considerations constraining credible entry proposition but cannot be dismissed in the long-term. The key to compete effectively even with large backlogs may lie with the uncertainty of orders in the backlog; as airlines place phantom orders, their slots may be exchanged or auctioned if and when they are cancelled.

There were other strategic alternatives that provided relatively strong positive results for one group of stakeholders. These alternatives included the consolidation of the airline industry, the consolidation of aircraft ordering to more closely match demand growth rates, reduction of aircraft delivery lead times, or price collusion between the two aircraft manufacturers. In all of these cases, the positive results were counterbalanced by deterioration in the metrics for the rest of the industry stakeholders.

The attractiveness of the most promising strategic alternative that we identified, the slower production adjustment for the manufacturers, lies with i) its simplicity, as it does not involve coordinated action and rests only with one set of stakeholders – the manufacturers, ii) its Pareto efficiency, as we discuss above it is the only single alternative that does not significantly diminish the benefits to other stakeholders, and iii) its effectiveness, as the resulting effect is close to the Pareto front of combination alternatives. Given that Airbus has historically followed this alternative, it should be stressed that the simulated Boeing gained significantly when it follows this alternative; in our experiments this benefits amounted to slightly less than 90% increase in the net present value of its gross profitability for the 1984-2025 period over the baseline. For Airbus the effect of this action is also positive but expectedly offering less of an improvement.

In the beginning of 2008, we high order backlogs across the board for bothe manufacturers. These backlogs can be attributed to the recent delays in the major new aircraft programs for both manufacturers, the Airbus A380 and A350XWB and the Boeing 787, as well as the surge in orders that was fueled by the rapid growth of the developing world markets in China, India, and the Middle East and the profitable 2005-2007 period for the US and European airlines. Given this situation, it is possible that both manufacturers are pressured to increase production rates. Evidence to this effect can be seen by recent increases in the production capacity for the A320 line by Airbus. If Boeing follows suit with ramping capacity in the 737 line and especially the 787 line then it is possible that the industry is setting itself up for another big swing of the cycle. This may come in a time where demand for air travel is affected by fare prices that have to follow the rising fuel prices, potential carbon regulations that impact aviation, and a generally slow economic climate. Based on the above, our recommendation would be for both manufacturers to resist the temptation of quickly ramping up capacity even at the cost of penalties for promised deliveries – it may be the more beneficial path across the aviation stakeholder board in the long term.

5. Conclusions

We demonstrated experimentally, using a customized system dynamics model of the commercial aviation industry, that reducing the lead times of delivery, improving forecasting by smoothing it over longer periods to better capture the trend, greater number of cancellations, or even allowing for greater pricing power of the airlines all have substantially lower impact on modulating the profitability cycle than simply ordering with full accounting of the aircraft in backlog. If this function is carried out by airlines though, the outcome for aircraft manufacturers is not Pareto-efficient as their profitability is reduced and the actual volatility of orders is increased. Instead we found that the most promising symbiotic alternative lies with the adoption of slow production rate adjustments by both manufacturers and the rate of production adjustments is key in improving returns (and reducing cyclicality) in this system. It should be noted that passengers do not face deterioration of costs in this case as it is the increased production efficiency that contributes to the increased value rather than increases in fare prices. The probability of a new entrant in the large commercial aircraft industry is remote in the short term but can be an issue if this strategy is followed in the longer term, especially when combined with radical technological innovation.

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