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Real option analysis of aircraft acquisition: A case study

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ABSTRACT

This paper demonstrates that aircraft acquisition by airlines may contain a portfolio of real options (flexible strategies) embedded in the investment's life cycle, and that if airlines rely solely on the static NPV method, they are likely to underestimate the true investment value. Two real options are investigated: i) the "shutdown-restart" option (a carrier may shutdown a plane if revenues are less than costs, but restarts it if revenues are more than costs), and ii) the option to defer aircraft delivery. We quantify the values of these options in a case study of a major U.S. airline. The economic insight could help explain observed capital expenditures of airlines, and serve as a rule of thumb in evaluating capital budgeting decisions. A compound option (consisting of both the shutdown-restart and defer options) is also analyzed.

1. Introduction

The airline industry operates in a dynamic environment with a great number of uncertainties, with airline revenues and costs being influenced heavily by overall economic activities. How to evaluate investment projects in circumstances of uncertainty thus becomes crucial for airlines. Gibson and Morrell (2005) find that airlines predominantly use the static NPV (net present value) method[1] as their capital budgeting tools. The static NPV method is based on the traditional discount cash flow (DCF) approach, which has an implicit assumption that the investment will, once undertaken, be operated until the end of its useful life set at the very beginning. Under the predetermined scenario, cash flows are estimated based on predicted future revenues, costs, follow-up investments, etc., regardless of the changing circumstances in the future and likely managerial responses to some realized uncertainty outcomes. The DCF methodology thus implies a rigid managerial strategy that may not reflect real business decision-making of most firms, particularly those operating in a multiple risk environment like airlines. To survive in the dynamic environment, airlines' business strategy must be more flexible.

Real options analysis, on the other hand, combines the inherent uncertainty in the business environment with "managerial flexibilities", that is, firms would, in practice, adopt appropriate strategies from the options presented to them as time progresses and conditions change. In other words, firms are likely to actively alter their business strategies (e.g., expand or contract production scale, shutdown and restart a project, and defer or abandon the investment) in response to changing circumstances and new information. Such managerial flexibilities provide the management opportunities not only to minimize risk exposure and reduce losses, but also to capture profit potentials. In general, real option analysis provides more appropriate project evaluation than would the DCF method.

This article examines how airlines can correctly evaluate aircraft investment by comparing the static NPV (traditional DCF) method with real option valuation (ROV).[2] We demonstrate that aircraft

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[1] Gibson and Morrell (2005) survey the investment criteria, such as NPV, used by airlines, and report data on actual discount rates used at airlines. In particular, they find that airlines prefer the NPV method to the ARR (accounting rate of return) method. The reason is that while cash-based NPV techniques take the time value of money into consideration, ARR does not. They conclude, nevertheless, that finance departments of airlines do not necessarily capitalize on all useful methods available. For an empirical (field) study on the preference of capital budgeting tools of companies in a wide range of sectors, see Graham and Harvey (2001).

[2] Since the present paper is concerned primarily with the ROV process we shall, in the remainder of the paper, use ROV for "real option valuation" or, in some contexts for "real option analysis" (which may be abbreviated as ROA; but as pointed out by an anonymous referee, such an abbreviation could be misleading since ROA is closely associated with "return on assets" in the context of valuation).

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acquisition may contain a portfolio of real options embedded in the investment's life cycle. If airlines rely solely on static NPV analysis, they would underestimate the true investment value. Two basic real options are investigated: i) the "shutdown-restart" option, that is, a carrier shutdowns an airplane if revenues are less than costs, but restarts the plane if revenues are more than costs; and ii) the option to defer aircraft delivery (the defer option). We quantify the values of these options in a case study of a major U.S. airline. The economic insight could help explain observed capital expenditures of airlines and serve as a rule of thumb in evaluating capital budgeting decisions. We further examine a compound option that combines the shutdown-restart and defer options. The analysis shows that the value of the defer option depends on whether the option is considered as an independent option or as a part of the compound option.

Real option analysis has been used in the valuation of large transportation capital acquisitions such as aircraft and containerships. Stonier (1999, 2001a, 2001b) applies the pricing model of binomial tree to evaluate the aircraft option, and obtain a set of potential expected NPVs under Monte Carlo simulation. Gibson and Morrell (2004) apply the same model to value an aircraft family conversion option. Bendall (2002) and Bendall and Stent (2003, 2005, 2007) examine, in the container shipping industry, values of the option to expand or contract operations and the option to switch the introduction mode (build or charter a ship) in the usual fashion of bivariate geometric Brownian motions. For example, Bendall and Stent (2005) find that shipping companies value flexibility when making ship acquisition decisions under uncertainty. Following a similar ROV, the present paper complements the existing literature that utilizes mainly the Monte Carlo simulation and closed-form equations approaches. We explore a binomial-tree model in which the NPV of aircraft acquisition is used as the value of underlying asset. Furthermore, the paper examines a compound option with the shutdown-restart and defer options as its components. We note that such a compound option has yet been analyzed in the airline literature.[3]

Our paper also complements the extant literature investigating the question of whether airlines invest in aircraft capacity efficiently or not. For instance, Wojahn (2012) examines the causes for the well-documented phenomenon of capacity over-investment in the airline industry based on a data set covering all publicly listed airlines. He finds that agency problems (e.g., myopia and empire building) and the shift toward low-cost and Asian carriers coupled with remnants of capital in legacy airlines, as well as economies of scale, are all associated with over-investment. An important feature that is not investigated in his paper is the oligopoly rivalry examined by, e.g., Brander and Lewis (1986) and Oum et al. (2000a): i.e., with the limited-liability effect investment with debt financing serves as a "top dog" strategy in airline output rivalry, leading to over-investment in capacity. Our analysis quantifies the option values that appear to have been ignored by airlines in their aircraft investment decisions with the use of DCF method. On the other hand, in practice airlines do seem to exercise these options by adjusting their flight schedules and overall capacity with the changes of business environment. Taken together, our results, while seemingly being in the opposite direction of explaining the observed over-investment anomaly, suggest that the anomaly may be more pronounced than was thought previously.[4]

The paper is organized as follows. Section 2 discusses key issues in ROV and aircraft investment valuation. Section 3 sets out decision scenarios of the case study. Section 4 conducts ROV for the case and presents the main results, which are then followed by a sensitivity analysis in Section 5. Finally, Section 6 contains concluding remarks.

2. Real option analysis in aircraft investment

2.1. Valuing real options

The central insight of ROV is that a (potential) project should be valued fully by including options embedded in the project, which can be viewed as managing a portfolio of options (Luchrman, 2001). Some options are taken simultaneously while others sequentially. When moving along with the project, managers can implement strategies that are adaptable to the revelation of uncertainties. Further, project options (strategies) are asymmetric in nature, in the sense that management can reduce losses and maximize gains by intervening at the right time (Yao and Jaafari, 2003). Thus the static NPV approach is more suitable for a project that, once undertaken, requires no further decisions or actions by management. The project value will rise if real options exist, however.

ROV is related to the important advancement in the research on financial-option pricing in the 1970s. Black and Scholes (1973) and Merton (1973) developed the quantitative methodology of pricing financial options. The Black-Scholes model, however, is "complex and off-putting to many practitioners" (Cox and Ross, 1976). Cox et al. (1979)'s binomial approach presented a simplified valuation of financial options in discrete time. Cox and Ross (1976) recognized that an option can be replicated (to create a "synthetic" option) from an equivalent portfolio of traded securities, and facilitated further the actual valuation of options.[5]

Mason and Merton (1985) and Kasanen and Trigeorgis (1993) maintain that real options can in principle be valued in a manner similar to financial options, even though they may not be traded as are the financial options. This is because the course of capital budgeting determines the value of the project's cash flows in the market. The replicating portfolio approach is based on the "law of one price:" that is, to prevent arbitrage (riskless) profits, two assets with the same risk characteristics ("twin securities") in every state of nature are perfectly correlated with the underlying risky asset and, therefore, the non-traded real asset in complete market is sufficient for real-option valuation. Copeland and Antikarov (2001) suggest that, since finding a market-based twin security that is perfectly correlated with the underlying asset would be difficult, the NPV of the project itself be used as the value of underlying asset (rather than searching for a perfectly correlated asset in the market). It is this approach that will be taken in this paper. The full value of a project is thus the sum of the static (inflexible) NPV and the value for managerial flexibilities (real options):

[3] More generally, the early ROV literature focused on the theoretical issues or valuation of a specific real option, such as the options to defer or abandon or to switch use, in a wide range of fields (natural resource, real estate, research and development, etc.). This one-at-a time approach can be limited however, as the combined value of a collection of operating options may differ significantly from the sum of separate option values (e.g., Cox et al., 1979; Schwartz and Trigeorgis, 2001; Trigeorgis, 2001).

[4] That is, the results may in effect provide some support to the hypothesis that airlines overestimate values of the shutdown-restart option and other options. The paper is also related to a branch of literature on aircraft investment concerning the choice between ownership and lease (e.g., Gritta et al., 1994; Littlejohns and McGairl, 1998; Oum et al., 2000b; 2000c; Gibson and Morrell, 2004; Allonen, 2013). Gibson and Morrell (2004) indicated that 25% of airlines' aircraft are leased, of which about 80% are operating leases (Gritta et al., 1994). A very useful general reference on airline finance is Morrell (2007).

[5] See Gibson and Morrell (2004) who introduce NPV, stochastic NPV and real-options approaches to aircraft financial evaluation.

$$\text{Value of project with flexibility} = \text{Value of project without flexibility} + \text{Value of managerial flexibility(real options)} \quad (1)$$

The formula is equivalent to:

$$\text{Expanded NPV(ENPV)} = \text{Static NPV(SNPV)} + \text{Value of real options} \quad (2)$$

The value of real options is then the difference between ENPV and SNPV. With the full project value consisting of the static NPV and the value of any embedded options, ROV is seen as complementing rather than replacing the static NPV analysis (Vanputten and Macmillan, 2004).

2.2. Aircraft acquisition valuation

Amram and Kulatilaka (1999) discuss situations where ROV is needed for investment evaluation: e.g., the investment has a long lifespan, faces a great deal of uncertainty, and involves contingent decisions. An aircraft investment project seems to comply with these conditions. In our ROV application, as indicated above, the project itself is taken as the twin security, and the price of the project is estimated to be its NPV. Following Corjidooz and Vasigh (2010) and Vasigh et al. (2012), the NPV of aircraft can be expressed as:

$$NPV = \sum_{t=0}^{n} \frac{CF_t}{(1+k)^t} + \frac{RV_n}{(1+k)^n} - I \quad (3)$$

where CF stands for the free operating cash flow generated from the aircraft, RV is the residual value, I is the (fixed) acquisition cost (including aircraft purchase and other initial-investment costs on spare parts and pilot training), k is the cost of capital, t indexes year, and n is the (expected) "economic life" of aircraft. Equation (3) can be rewritten as:

$$NPV = \sum_{t=0}^{n} \frac{TR_t - TC_t}{(1+k)^t} + \frac{RV_n}{(1+k)^n} - I \quad (4)$$

where total revenue TR (including passenger, freight and ancillary revenues) is given by:

$$TR_t = ASM_t \times Yield_t \quad (5)$$

with *Yield* denoting revenue per ASM (available seat mile). Further, TC in (4) represents total costs, which are the sum of fuel and other costs.

Note, from Equations (3)–(5), that volatility of the aircraft NPV mainly comes from three sources: i) *Yield*, ii) fuel cost, and iii) RV (residual value). Our examination of ten airlines in the world (which are randomly selected, including both full-service airlines and low-cost carriers) shows airline *Yield* is highly volatile.[6] Similarly, fuel prices fluctuate a lot and seem difficult to predict. RV can be another source of NPV volatility. For example the residual value of less fuel efficient aircraft like A340 or B747 have deteriorated markedly with higher fuel prices and the introduction of more fuel efficient aircraft like A350 and B787. Predicting this decline would require a correct prediction of fuel prices.[7]

Although all three variables (*Yield*, *RV* and fuel cost) are impacted by, among other factors, overall business cycles, *Yield* appears most unpredictable (Littlejohns and McGairl, 1998).[8] First, residual value can be expressed as:

$$RV_n = \sum_{t=n+1}^{m} \frac{CF_t}{(1+k)^t} + \frac{DV_m}{(1+k)^m} - C \quad (6)$$

where m refers to the entire aircraft lifespan and so the first part on the right-hand side of Equation (6) is its value as a second-hand aircraft. Further, DV is the disassembly and dismantle value (so-called "scrap," including the value of waste aviation materials and second-hand aviation spare parts) and C is the trading and disposal cost of second-hand aircraft before disposal (resale or demolition). Both DV and C are small (and are negligible relative to purchase price I) and so may be considered as constant in relation to the overall NPV. Further, in the trade of second-hand aircraft the sellers and buyers may, sometimes with the help of third-party institutions that specialize on aircraft appraisal, reach a predetermined price. In some cases, aircraft manufactures provide airlines or air leasing companies with a guarantee of aircraft residual value, and hence undertake the risk of residual value, in order to promote sales and marketing.

Second, fuel price affects economic performance of all industries including air transportation. As a consequence, nowadays in the financial market there are many mature fuel derivatives tools and strategies to directly and efficiently hedge the volatility of fuel price. In addition, many countries allow their airlines to levy fuel surcharges that bear a close linear relationship with fuel price. On the other hand, the airline industry does not have an open traffic price trading market – this is in contrast to the shipping industry where ship holders can utilize the derivatives tools of traffic price to hedge the yield volatility. As a result, airlines lack direct and efficient tools to hedge the risk from *Yield* fluctuations.[9]

3. Case study: the scenario

We have chosen, as a case study, a proposed investment project of a large U.S. airline, namely, acquisition of new aircraft. The hypothetic scenario is based on an actual transaction with real data. As to be seen below, it provides an appropriate setting to understand and help aircraft-investment decision-making faced by airlines, and to demonstrate the efficacy of ROV as an appropriate valuation method and risk management tool.

Airline X, a major U.S. carrier, has a fleet of over 500 large aircraft. The carrier earns roughly half of its revenue from the domestic market, and majority of its fleet servicing the domestic market are the single-aisle jet planes. While the carrier has a sizable

[6] The data are available upon request. The ten airlines are Delta, United (United Continental), Southwest, JetBlue, British Airways, Lufthansa, Cathay Pacific, Singapore Airlines, Emirate, and EasyJet, and the time series of data span between 10 years (2004–2013 for EasyJet) and 40 years (1974–2013 for Southwest) depending on the data availability. We also found that in general the low-cost carriers have a lower *Yield* volatility than the full-service airlines.

[7] We thank an anonymous referee for suggesting this observation.

[8] See also Liehr et al. (2001) for analysis and management of airline business cycles using the system dynamics approach in combination with a statistical forecasting model, and Chin and Tay (2001) for analysis of profit cycles and their effect on airplane investment decisions.

[9] Furthermore, Vasigh et al. (2012) conducted sensitivity analysis on aircraft value, and found that passenger yield is a major contributor to the present value of aircraft: a 1% increase in passenger yield leads to an approximate 18% increase in present value.

B737 next-generation (NG) fleet, more than one half of its one-aisle fleet are the types that are no longer produced by Boeing (MD90s and B737 classics). To improve the fleet's operating economy, X plans to launch an upgrading program to replace its aging and outdated planes with B737 NGs.[10]

The airline has determined 737–700 as the main model in its upgrading program.[11] It has signed the purchase contract and confirmed the aircraft introduction plan after some hard negotiations with Boeing. The first batch of ten 737–700 aircraft have a single economy-class layout with 137 available seats, and will be delivered and immediately put into service one year later (in January 2013). The trade price is $34.68 million per aircraft.[12] In view of the large amount in carrier X's purchase (and X's importance in the airline industry), Boeing has provided X a "defer" option, that is, X (the buyer) has the right to delay the aircraft-receiving date for two years, with the price rising to $35.71 million as a result. In addition, Boeing provides X with a guarantee of aircraft residual values at the end of 20 years after purchase ($9.26 million and $9.49 million at the end of 2033 and 2035, respectively). In the course of reaching this pact, Ascend, a leading provider of expert advisory and valuation services to global aviation industry, has played an important role.

These 737-700s are proposed to be put into service on U.S. domestic routes, with average traffic capacity of 700 miles per route, 6 flights per day and 360 available days per year. With these figures, the proposed one-jet traffic capacity can be calculated as 207.144 million seat-miles per year. It is carrier X's practice that the firm's operating and financial data are analyzed continuously. Further, the carrier uses the fuel surcharge and fuel derivative tools to hedge the volatility of fuel price. In particular, it is able to lock the aviation kerosene cost at the level when the light sweet crude oil price stays at $100 a barrel. Under these conditions of traffic capacity and fuel price, X has the variable "cash operating cost" (COC) at about $0.060 per ASM and the fixed COC at about $0.015 per ASM. These costs are subject to a 1% annual increase, owing to inflation.[13] The carrier exhibits an annualized volatility of 5% for its *Yield* in the domestic market.[14] Based on X's accounting policy, the airframe and engine have a depreciation period of 25 years, with the residual value at 5% of the initial purchase (book) value. X usually takes 20 years as its aircraft's (economically) useful years in its acquisition decision, and uses the higher figure between the book-value and appraisal-market methods as the residual value.[15] Carrier X uses the current rate of 10-year U.S. Treasury Note, 2%, as the risk-free rate, and its current margin income tax rate is 38.5%. A sensitivity analysis for alternative risk-free rates is conducted in Section 5.

As indicated above, there are three main risk factors affecting the NPV of the aircraft acquisition project, namely, *Yield*, aircraft residual value and fuel prices. For the specific case at hand however, the manufacturer has already provided the carrier with a guarantee of residual values; further, the risk of fuel prices has been hedged by fuel derivatives and fuel surcharges. As a result, *Yield* becomes the uncertain factor affecting *CF* which in turn will, through Equation (3), affect the project's NPV. Their volatilities can be considered to be the same, expressed as:

$$\sigma(Yield_t) = \sigma(NPV) = \sigma(CF_t) \tag{7}$$

This condition will, with the NPV as the underlying asset, significantly simplify our ROV analysis in what follows. More specifically, under the premise that the airline is able to continually hold its flight time for the fleet, if its operating revenue cannot cover the fixed COC, then the manager will probably seal part of the fleet up for safekeeping for a period of a year or more. According to the contracts with airports holding idle planes, X needs to pay $0.10 million as the expense of sealing a plane up for a year, and then pay $0.25 million to unseal a plane (this unsealing expense includes the cost to repair the plane so as to restore to airworthiness). Similar to the case of operating costs, there is a 1% annual growth rate for the sealing and unsealing expenses (owing to inflation). Furthermore, to simplify the calculation process, the amount of initial investment includes only the aircraft purchase price, and sealing up aircraft is assumed to have no impact on the appraisal value.[16] Finally, to comply with the assumption of the binomial tree and Black-Scholes models we assume, following Hallerstrom (2013), that the logarithmic price of the underlying asset follows a random walk with drift (geometric Brownian motion).[17]

4. Analysis and results

4.1. Static NPV

Following the discussion in Sections 2 and 3, the underlying asset is the project of acquiring the first batch of B737-700 jets. To compute the project's static NPV, carrier X first uses the binomial-tree model to obtain the distribution of *Yield*, which is denoted $f_{i,\,t}$ and given in Fig. 1. This is followed by the calculation of *CF* for each term and scenario $CF_{i,\,t}$ (Fig. 2), with *CF* including the revenue from aircraft residual value.

Next, the binomial-tree formula is used to calculate the SNPV of *CF* in the project:

[10] The improved CFM56-7 turbofan engine in B737 NGs is 7% more fuel efficient than the previous CFM56-3 turbofan engine in B737 classics. New-technology "blended winglets" are available on most B737 NGs, which enhance range, fuel efficiency and take-off performance while lowering carbon emissions, engine maintenance costs and noise (http://www.boeing.com/boeing/commercial/737family/background.page).

[11] B737-700, the first plane in the NG series, was launched in November 1993. After receiving the type certification by the US Federal Aviation Administration (FAA), the first delivery took place in December 1997. In the following years, the B737 NG program has encompassed the −600, −700, −800, −900 and −900 ER.

[12] All amounts in this paper are in U.S. dollar.

[13] The 1% growth rate is obtained after we have examined a data set of seven airlines in the world (including airline X); the analysis is available upon request. Sensitivity analysis for alternative growth rates (0.5%, 0.75%, 1.25% and 1.5%) is given Section 5.

[14] This result is obtained as part of the analysis noted in footnote 6.

[15] In general, the designed life of a jumbo jet is 30 years. In practice however, its useful life is mostly less than the designed life due to various factors (safety, maintenance, etc.), and so airlines often set 20–25 years as the depreciation period for the airframe and engine. Meanwhile, because the economic life of the airframe is influenced by a variety of factors, especially during recent years since a great number of new aircraft types have entered into service and the fuel price has been at a high level, most airlines are forced to retire old aircraft ahead of their useful life. As a result, airlines now appear to prefer the use of the economic life as the investment period in their evaluation of aircraft acquisition.

[16] Sealing up aircraft may reduce tangible damages to the aircraft, but the residual value of a plane depends mainly on the supply and demand of the aircraft market. Further, the intangible loss has more influence on the appraisal value of second-hand aircraft. Therefore, this assumption has no material impact on our results in the remainder of the paper. If the impact of sealing up aircraft were taken into consideration, the value of embedded real options would be greater, especially for the value of the shutdown-restart option.

[17] In particular, the variable *Yield* is assumed to follow a random walk. Hallerstrom (2013) introduces geometric Brownian motion (GBM), rather than "mean reversion" (MR), to simulate the path of the "base value" of aircraft, although he also recognizes that it may be appropriate to include an MR in the random walk. The aircraft base value is some kind of "through-the-cycle" value, unaffected by imbalances in supply and demand or business cycles. Although few aircraft trade at the base values, the base-value concept may be helpful in constructing the "current market value" (a spot-market value) projections. Pindyck (1999) suggests that while price behavior seems consistent with a model of slow MR in the long run, for irreversible investment decisions for which energy prices are the key stochastic state variables, the GBM assumption is unlikely to produce large errors in the optimal investment rule. We discuss the issue further in the concluding remarks.

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	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
																				0.217
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																	0.187		0.187	
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															0.169		0.169		0.169	
														0.161		0.161		0.161		0.161
													0.153		0.153		0.153		0.153	
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									0.125		0.125		0.125		0.125		0.125		0.125	
								0.119		0.119		0.119		0.119		0.119		0.119		0.119
							0.114		0.114		0.114		0.114		0.114		0.114		0.114	
						0.108		0.108		0.108		0.108		0.108		0.108		0.108		0.108
					0.103		0.103		0.103		0.103		0.103		0.103		0.103		0.103	
				0.098		0.098		0.098		0.098		0.098		0.098		0.098		0.098		0.098
			0.093		0.093		0.093		0.093		0.093		0.093		0.093		0.093		0.093	
		0.088		0.088		0.088		0.088		0.088		0.088		0.088		0.088		0.088		0.088
	0.084		0.084		0.084		0.084		0.084		0.084		0.084		0.084		0.084		0.084	
0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080
	0.076		0.076		0.076		0.076		0.076		0.076		0.076		0.076		0.076		0.076	
		0.072		0.072		0.072		0.072		0.072		0.072		0.072		0.072		0.072		0.072
			0.069		0.069		0.069		0.069		0.069		0.069		0.069		0.069		0.069	
				0.065		0.065		0.065		0.065		0.065		0.065		0.065		0.065		0.065
					0.062		0.062		0.062		0.062		0.062		0.062		0.062		0.062	
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								0.054		0.054		0.054		0.054		0.054		0.054		0.054
									0.051		0.051		0.051		0.051		0.051		0.051	
										0.049		0.049		0.049		0.049		0.049		0.049
											0.046		0.046		0.046		0.046		0.046	
												0.044		0.044		0.044		0.044		0.044
													0.042		0.042		0.042		0.042	
														0.040		0.040		0.040		0.040
															0.038		0.038		0.038	
																0.036		0.036		0.036
																	0.034		0.034	
																		0.033		0.033
																			0.031	
																				0.029

Note: Numbers used in the binomial-tree model:

$u = e^{5\%\sqrt{1.0}} \approx 1.051;\ d = e^{-5\%\sqrt{1.0}} \approx 0.951;\ \delta_t = 1.0;\ p = (e^{2\%\times 1.0} - d)/(u-d) \approx 0.69;$
$f_{1,0} = 0.08u \approx 0.084;\ f_{1,1} = 0.08d \approx 0.076;\ f_{20,20} = 0.08d^{20} \approx 0.029.$

Fig. 1. Binomial-tree model of *Yield.*

$$SNPV\ of\ CF = e^{-r_f\delta_t i}\sum_{t=0}^{i}\left[\frac{i!}{t!(i-t)!}p^{(i-t)}(1-p)^{i}CF_{i,\,t}\right] \qquad (8)$$

where r_f is the risk-free interest rate, δ_t is the span per term, i is the number of *Yield* falling and is the same as t_i in Equation (3), and $i-t$ is the number of *Yield* rising. In addition, we have

$$p = \frac{e^{r_f\delta_t} - d}{u-d},\ u = e^{\sigma\sqrt{\delta_t}},\ d = e^{-\sigma\sqrt{\delta_t}} \qquad (9)$$

with σ being the standard deviation (volatility) of *Yield*. *CF* for each year is then given in Table 1, further yielding a present value of $39.8673 million. SNPV of acquiring one 737–700 is thus the difference between $39.8673 million and aircraft purchase price $34.68 million, or $5.1873 million. SNPV of ten 737–700 jets is then equal to $51.873 million.

4.2. Value of the shutdown-restart option

With the shutdown-restart option, a plane will be shutdown if in a single period *Yield* is less than the variable COC per ASM (denoted *VCOC*) minus the sealing expense. The plane will be restarted if *Yield* is greater than *VCOC* plus the unsealing expense. Specifically for the case at hand, the point of shutting down a plane equals $0.0595 per ASM in 2012, which is calculated by *VCOC* minus the ratio of sealing expenses divided by traffic capacity (i.e., total ASM). The point of restarting a plane is $0.0624 per ASM in 2012, calculated by *VCOC* plus the ratio of unsealing expenses over traffic capacity.

Airline X must hold a minimum flight execution rate α (i.e., maintain its minimum flight times in a given year) so as to keep its airport slots. If X needs to continue to use all recourses of flight times, it utilizes the shutdown-restart (*SR*) option only on part of its operating fleet. As indicated earlier, carrier X will put new aircraft into flight operation immediately after receiving them, and then shutdown or restart planes according to the conditions discussed above.[18] We set 70% for α, the minimum flight execution rate

[18] Please see the calculation procedures with examples in Figs. 3 and 4.

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0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
																				16.552
																			15.317	
																		14.146		13.916
																	13.036		12.809	
																11.986		11.760		11.531
															10.990		10.767		10.540	
														10.048		9.827		9.602		9.372
													9.156		8.937		8.714		8.487	
												8.311		8.095		7.874		7.649		7.419
											7.512		7.298		7.079		6.856		6.629	
										6.756		6.544		6.328		6.107		5.882		5.652
									6.041		5.831		5.617		5.398		5.175		4.948	
								5.365		5.157		4.945		4.729		4.508		4.283		4.053
							4.726		4.520		4.310		4.096		3.877		3.654		3.427	
						4.122		3.918		3.710		3.498		3.282		3.061		2.836		2.606
					3.552		3.350		3.144		2.934		2.720		2.501		2.278		2.051	
				3.013		2.813		2.609		2.401		2.189		1.973		1.752		1.527		1.297
			2.504		2.306		2.104		1.899		1.689		1.474		1.256		1.033		0.805	
		2.024		1.828		1.628		1.425		1.217		1.004		0.788		0.567		0.342		0.112
	1.571		1.377		1.179		0.978		0.772		0.562		0.347		0.129		(0.094)		(0.322)	
1.144		0.952		0.756		0.557		0.353		0.145		(0.067)		(0.284)		(0.505)		(0.730)		(0.959)
	0.552		0.358		0.160		(0.042)		(0.248)		(0.458)		(0.672)		(0.891)		(1.114)		(1.341)	
		(0.018)		(0.213)		(0.413)		(0.617)		(0.825)		(1.037)		(1.254)		(1.474)		(1.700)		(1.929)
			(0.565)		(0.763)		(0.964)		(1.170)		(1.380)		(1.595)		(1.813)		(2.036)		(2.264)	
				(1.091)		(1.291)		(1.495)		(1.703)		(1.915)		(2.131)		(2.352)		(2.577)		(2.807)
					(1.597)		(1.799)		(2.005)		(2.215)		(2.429)		(2.648)		(2.871)		(3.098)	
						(2.085)		(2.289)		(2.497)		(2.709)		(2.925)		(3.146)		(3.371)		(3.601)
							(2.555)		(2.760)		(2.970)		(3.185)		(3.403)		(3.626)		(3.854)	
								(3.007)		(3.215)		(3.427)		(3.644)		(3.864)		(4.090)		(4.319)
									(3.444)		(3.654)		(3.868)		(4.087)		(4.310)		(4.537)	
										(3.865)		(4.077)		(4.294)		(4.515)		(4.740)		(4.970)
											(4.272)		(4.487)		(4.705)		(4.928)		(5.156)	
												(4.666)		(4.882)		(5.103)		(5.328)		(5.558)
													(5.046)		(5.265)		(5.488)		(5.715)	
														(5.414)		(5.635)		(5.860)		(6.090)
															(5.771)		(5.994)		(6.221)	
																(6.117)		(6.342)		(6.572)
																	(6.452)		(6.680)	
																		(6.778)		(7.007)
																			(7.094)	
																				(7.402)

Note: Numbers used in the binomial-tree model:

Depreciation and amortization amount per term, $D\&A = (1-5\%) \times 34.68 \div 25 \approx 1.3178$;

Income tax rate, $T = 38.5\%$;

COC per ASM at term 0, $COC_0 = VCOC_0 + FCOC_0 = 0.060 + 0.015 = 0.075$, where $VCOC$ and $FCOC$ are the variable and fixed COC per ASM, respectively;

$COC_1 = 0.075 * (1+1\%)^1 = 0.07575;\ COC_{20} = 0.075 * (1+1\%)^{20} \approx 0.0915$

$CF_{1,0} = \left[\left(f_{1,0} - COC_1\right) \times 207.144 - D\&A\right] \times (1-T) + D\&A \approx 1.571;$

$CF_{20,20} = \left[\left(f_{20,20} - COC_{20}\right) \times 207.144 - D\&A + RV\right] \times (1-T) + D\&A \approx -7.402.$

Fig. 2. Binomial-tree model of *CF*.

required by the U.S. Federal Aviation Administration:

$$ENPV^{SR}_{fleet} = (1-\alpha) \times N \times ENPV^{SR}_{1-\alpha} + \alpha \times N \times SNPV_{\alpha},$$
$$SR_{fleet} = (1-\alpha) \times N \times SR_{1-\alpha} \quad (10)$$

where $ENPV^{SR}_{fleet}$ is the expanded NPV of fleet acquisition embedded with the *SR* option, $ENPV^{SR}_{1-\alpha}$ is the ENPV of one-jet acquisition embedded with the *SR* option, $SNPV_{\alpha}$ is the SNPV of one-jet acquisition without the *SR* option, $SR_{1-\alpha}$ (SR_{fleet}) is the *SR*-option value of one-jet (fleet) acquisition, and N is the number of aircraft (10 in the present case).

With these points and following Guthrie (2009), the carrier can obtain the distribution of *Yield* (denoted $f^{SR}_{i,t}$) and the distribution of *CF* with the *SR* option ($CF^{SR}_{i,t}$). These two distributions are given in Figs. 3 and 4, respectively.

Based on the results of Figs. 3 and 4, airline X can obtain the ENPV of the project's *CF* with the *SR* option. This is done by first calculating the ENPV with the formula of binomial-tree model, which equals \$43.7504 million (Table 2). The ENPV of \$9.0704 million then follows by subtracting \$43.7504 million from the aircraft purchase price.

Together with the above SNPV analysis, the value of the SR option is therefore equal to \$3.8831 million, which is, according to Equation (2), the difference between ENPV \$9.0704 million and SNPV \$5.1873 million. Essentially, for its acquired aircraft the airline has the decision power over whether or not to exercise the option

Table 1
Static present value of cash flows (*CF*) in the project.

Unit: $ mn

t	Year	Amount	t	Year	Amount
1	2013	1.2298	11	2023	2.0441
2	2014	1.3146	12	2024	2.1215
3	2015	1.3985	13	2025	2.1983
4	2016	1.4818	14	2026	2.2744
5	2017	1.5643	15	2027	2.3498
6	2018	1.6461	16	2028	2.4246
7	2019	1.7271	17	2029	2.4986
8	2020	1.8074	18	2030	2.5720
9	2021	1.8870	19	2031	2.6447
10	2022	1.9659	20	2032	2.7168
TOTAL			39.8673		

Note: The SNPV of one-jet acquisition is the difference between the present value of *CF* $39.8673 million and aircraft purchase price $34.68 million, and is thus equal to $5.1873 million.

to shutdown and restart a plane, and will, if it can, avoid part of the recession risk (owing to business cycles). We further note that the *SR*-option value for the 10-jets fleet is, by Formula (10), equal to $11.6493 million, which accounts for 0.93% of the 2013 operating income of United Continental.[19] While the value is not huge in absolute term, it is nevertheless appreciable especially considering the number of such acquisitions for a major airline over the years.

4.3. Value of the defer option

MacDonald and Siegel (1986) study the optimal timing of investment in an irreversible project (i.e., without abandonment flexibility) in which the gross project value, and possibly the investment cost, follow continuous-time process. In the present case, the option to defer aircraft delivery is an American call option in which carrier X can determine the receiving date. But with the option period of two years, there is not much room for X to choose the receiving date before the deadline. Carrier X may continue to use the binomial-tree model to compute *CF* in each term and scenario and obtain ENPV with the "compound option" that consists of the *SR* and defer options as components. The ENPV with the compound option equals $13.5598 million. This number is greater than the ENPV with the *SR* option of $9.0704 million, which was obtained in Section 4.2, suggesting that the more the managerial flexibilities (embedded in the compound option, vs. the *SR* option alone), the greater the option values. The difference of the two values ($13.5598 million vs. $9.0704 million) is the defer-option value of $4.4894 million.

Alternatively, carrier X can use the Black-Scholes (BS) model to calculate the value of the option. With the minimum flight execution rate, the carrier must distinguish the characteristics of the defer option between the compound option (*CO*) and the independent option (*IO*):

$$ENPV_{fleet} = (1-\alpha)\times N\times ENPV^{CO}_{1-\alpha} + \alpha\times N\times ENPV^{IO}_{\alpha},$$
$$D_{fleet} = (1-\alpha)\times N\times D^{CO}_{1-\alpha} + \alpha\times N\times D^{IO}_{1-\alpha} \quad (11)$$

where $ENPV_{fleet}$ is the ENPV of fleet acquisition embedded with the options, $ENPV^{CO}_{1-\alpha}$ is the ENPV of one-jet acquisition embedded with the compound option, $ENPV^{IO}_{\alpha}$ is the ENPV of one-jet acquisition embedded with the defer option as independent option, D_{fleet} is the defer-option value of fleet acquisition, $D^{CO}_{1-\alpha}$ is the defer-option value of one-jet acquisition as part of the compound option, and D^{IO}_{α} is the defer-option value of one-jet acquisition with the defer option as independent option.

In the use of the BS model, the current stock price and the exercise price in the financial option are replaced, respectively, by the ENPV of *CF* with the *SR* option and the initial investment cost in the valuation of the defer option. Unlike the *SR* option, an airline usually acquires, actively or passively, the defer option through transactions. As the *SR* option is an intrinsic option, the airline needs to examine other real options based on an analysis in which the *SR* option is part of the compound option (rather than just an independent option). The ENPV with the compound option and the value of defer option are $9.7663 million and $0.6958 million, respectively, calculated by the BS model (Table 3).

There appears a large difference in the ENPVs between these two models. This is because the excessive period interval leads to the less term number of the binominal-tree model, thereby producing much larger deviation. Unfortunately, airlines basically cannot resolve the problem owing to the financial budget cycle, the strong industrial cycle and the tremendous amount of computation work. As a result, the BS model is preferred as the valuation model of the defer option to the binomial-tree model, thereby resulting in the defer-option value as $0.6958 million in the scenario (rather than $4.4894 million).

When the *SR* option cannot be used in the aircraft investment, the defer option becomes an independent option and so the carrier can directly value the option. In applying the BS model, the current stock price and the exercise price in the financial option are replaced, respectively, by the SNPV of *CF* and the initial investment cost in the valuation of the defer option. The ENPV with the defer option and the defer-option value are $5.8938 million and $0.7065 million, respectively. As expected, the value of the defer option is higher if the *SR* option is absent. Nevertheless, the value of the defer option as an independent option is, for one jet, only $0.0106 million higher than value of the defer option as part of the compound option. The difference is small and negligible. The ENPV of the entire fleet acquisition is $18.6822 million including the defer-option value of $7.0329 million by Formula (11) and the *SR*-option value of $11.6493 million.

5. Sensitivity analysis

The sensitivity analysis is first conducted for five important factors, namely, *Yield*, risk-free interest rate, option period, volatility of *Yield* and aircraft purchase price. We examine how each factor affects the values of the shutdown-restart option, the defer option, and the compound option. The result for factor *Yield* is given in Fig. 5. As can be seen, there is a significant negative relationship between the option values and *Yield* for yield less than 0.080, but there is virtually no impact of *Yield* on the option values for yield greater than 0.080.

Next consider the impact of risk-free interest rate *r*. As can be seen from Fig. 6, the value of the *SR* option is, as expected, negatively related to *r*. But the figure shows a concave curve between the value of the defer option (as independent option) and *r*: a significant negative relationship between the defer-option value and *r* when *r* is less than 2% and then a positive relationship for *r* greater than 2%. Taken together, the sum of the option values shows a concave relationship with *r*.

The impact of the other three factors can be similarly examined; to save space, the corresponding figures are omitted here (but are available upon request from the authors). Briefly stated, the option

[19] In 2013, United Continental's mainline and regional businesses had traffic capacity of 245,354 million ASM and a fleet of 1265 aircraft including 693 mainline aircraft and 572 regional aircraft.

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
																				0.217
																			0.207	
																		0.197		0.197
																	0.187		0.187	
																0.178		0.178		0.178
															0.169		0.169		0.169	
														0.161		0.161		0.161		0.161
													0.153		0.153		0.153		0.153	
												0.146		0.146		0.146		0.146		0.146
											0.139		0.139		0.139		0.139		0.139	
										0.132		0.132		0.132		0.132		0.132		0.132
									0.125		0.125		0.125		0.125		0.125		0.125	
								0.119		0.119		0.119		0.119		0.119		0.119		0.119
							0.114		0.114		0.114		0.114		0.114		0.114		0.114	
						0.108		0.108		0.108		0.108		0.108		0.108		0.108		0.108
					0.103		0.103		0.103		0.103		0.103		0.103		0.103		0.103	
				0.098		0.098		0.098		0.098		0.098		0.098		0.098		0.098		0.098
			0.093		0.093		0.093		0.093		0.093		0.093		0.093		0.093		0.093	
		0.088		0.088		0.088		0.088		0.088		0.088		0.088		0.088		0.088		0.088
	0.084		0.084		0.084		0.084		0.084		0.084		0.084		0.084		0.084		0.084	
0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080		0.080
	0.076		0.076		0.076		0.076		0.076		0.076		0.076		0.076		0.076		**0.076**	
		0.072		0.072		0.072		0.072		0.072		**0.072**		**0.072**		**0.072**		***0.072***		0.072
			0.069		0.069		0.069		**0.069**		***0.069***		***0.069***		***0.069***		0.069		0.069	
				0.065		0.065		***0.065***		0.065		0.065		0.065		0.065		0.065		0.065
					0.062		0.062		0.062		0.062		0.062		0.062		0.062		0.062	
						0.059		0.059		0.059		0.059		0.059		0.059		0.059		0.059
							0.056		0.056		0.056		0.056		0.056		0.056		0.056	
								0.054		0.054		0.054		0.054		0.054		0.054		0.054
									0.051		0.051		0.051		0.051		0.051		0.051	
										0.049		0.049		0.049		0.049		0.049		0.049
											0.046		0.046		0.046		0.046		0.046	
												0.044		0.044		0.044		0.044		0.044
													0.042		0.042		0.042		0.042	
														0.040		0.040		0.040		0.040
															0.038		0.038		0.038	
																0.036		0.036		0.036
																	0.034		0.034	
																		0.033		0.033
																			0.031	
																				0.029

Note: Numbers used in the binomial-tree model:

Point of sealing at term 0, $SP_0 = 0.060 - 0.1/207.144 \approx 0.595$;

Point of restarting at term 0, $RP_0 = 0.060 + 0.25/207.144 \approx 0.625$;

$SP_7 = 0.060 * (1+1\%)^7 - 0.1 * (1+1\%)^7/207.144 \approx 0.0638$; $SP_8 = 0.0644$; $SP_9 = 0.0651$;

$RP_7 = 0.060 * (1+1\%)^7 + 0.25 * (1+1\%)^7/207.144 \approx 0.0656$; $RP_8 = 0.0663$; $RP_9 = 0.0669$;

$f_{7,6}^{SR} = 0.08u^1d^6 \approx 0.062 < SP_7$, which means the jet will be under the sealing situation;

$f_{8,6}^{SR} = 0.08u^2d^6 \approx 0.065 \in (SP_7, RP_7)$, which means the jet will be under the sealing situation or continual operating situation;

$f_{9,6}^{SR}$: $0.08u^3d^6 \approx 0.069 > RP_7$, which means the jet will be under the restarting situation or continual operating situation.

In Figures 3 and 4 (below), the cell with background color means the sealing situation; the cell in bold and italic type with background means the sealing or continual operating situation; and the cell in bold and underscore with background means continual operating or restarting situation.

Fig. 3. Binomial-tree model of *Yield* with shutdown-restart option.

period, while having no impact on the *SR*-option value, has a positive impact on the defer-option value, both of which are expected. There are significant positive relationships between the *SR*-option value and the volatility of *Yield* (Sigma), and between the defer-option value and Sigma. Consequently, the sum of the option values rises as Sigma rises. Finally, there is a significant negative relationship between the defer-option value and the (future) aircraft price.

In general, the value of the defer option, as the independent option, exhibits greater fluctuation than the value of the defer

0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032
																				22.247
																			15.317	
																		14.146		19.611
																	13.036		12.809	
																11.986		11.760		17.226
															10.990		10.767		10.540	
														10.048		9.827		9.602		15.067
													9.156		8.937		8.714		8.487	
												8.311		8.095		7.874		7.649		13.114
											7.512		7.298		7.079		6.856		6.629	
										6.756		6.544		6.328		6.107		5.882		11.347
									6.041		5.831		5.617		5.398		5.175		4.948	
								5.365		5.157		4.945		4.729		4.508		4.283		9.748
							4.726		4.520		4.310		4.096		3.877		3.654		3.427	
						4.122		3.918		3.710		3.498		3.282		3.061		2.836		8.301
					3.552		3.350		3.144		2.934		2.720		2.501		2.278		2.051	
				3.013		2.813		2.609		2.401		2.189		1.973		1.752		1.527		6.992
			2.504		2.306		2.104		1.899		1.689		1.474		1.256		1.033		0.805	
		2.024		1.828		1.628		1.425		1.217		1.004		0.788		0.567		0.342		5.807
	1.571		1.377		1.179		0.978		0.772		0.562		0.347		0.129		(0.094)		(0.322)	
1.144		0.952		0.756		0.557		0.353		0.145		(0.067)		(0.284)		(0.505)		(0.730)		4.735
	0.552		0.358		0.160		(0.042)		(0.248)		(0.458)		(0.672)		(0.891)		(1.239)		**(1.429)**	
		(0.018)		(0.213)		(0.413)		(0.617)		(0.825)		**(1.120)**		**(1.338)**		**(1.560)**		***(1.805)***		5.940
			(0.565)		(0.763)		(0.964)		**(1.250)**		***(1.596)***		***(1.693)***		***(1.792)***		(1.829)		(1.876)	
				(1.091)		(1.291)		***(1.587)***		(1.671)		(1.715)		(1.760)		(1.805)		(1.852)		5.940
					(1.597)		(1.607)		(1.650)		(1.693)		(1.737)		(1.783)		(1.829)		(1.876)	
						(1.586)		(1.628)		(1.671)		(1.715)		(1.760)		(1.805)		(1.852)		5.940
							(1.607)		(1.650)		(1.693)		(1.737)		(1.783)		(1.829)		(1.876)	
								(1.628)		(1.671)		(1.715)		(1.760)		(1.805)		(1.852)		5.940
									(1.650)		(1.693)		(1.737)		(1.783)		(1.829)		(1.876)	
										(1.671)		(1.715)		(1.760)		(1.805)		(1.852)		5.940
											(1.693)		(1.737)		(1.783)		(1.829)		(1.876)	
												(1.715)		(1.760)		(1.805)		(1.852)		5.940
													(1.737)		(1.783)		(1.829)		(1.876)	
														(1.760)		(1.805)		(1.852)		5.940
															(1.783)		(1.829)		(1.876)	
																(1.805)		(1.852)		5.940
																	(1.829)		(1.876)	
																		(1.852)		5.940
																			(1.876)	
																				5.940

Note: Numbers used in the binomial-tree model:

$FCOC_7 = 0.015 * (1 + 1\%)^7 \approx 0.0161;\ FCOC_8 \approx 0.0162;\ FCOC_9 \approx 0.0164;$

$VCOC_8 = 0.060 * (1 + 1\%)^8 \approx 0.0650;\ VCOC_9 \approx 0.0656;$

Sealing expense at term 7, $S_7 = 0.1 * (1 + 1\%)^7 \approx 0.1072;\ S_8 \approx 0.1083;\ S_{20} \approx 0.1220;$

Unsealing and restarting expense at term 9, $R_9 = 0.25 * (1 + 1\%)^9 \approx 0.2734;\ R_{20} \approx 0.3050;$

$CF_{7,6}^{SR} = (-FCOC_7 \times 207.144 - S_7 - D\&A) \times (1 - T) + D\&A \approx -1.607;$

$$CF_{8,6}^{SR} = \{[(f_{8,6}^{SR} - FCOC_8 - VCOC_8) \times 207.144 - D\&A] \times (1 - T) + D\&A\} \times (1 - p) + [(-FCOC_8 \times 207.144 - D\&A - S_8) \times (1 - T) + D\&A] \times p \approx -1.587;$$

$$CF_{9,6}^{SR} = \{[(f_{9,6}^{SR} - FCOC_9 - VCOC_9) \times 207.144 - D\&A] \times (1 - T) + D\&A\} \times [(1 - p) + (1 - p) \times p] + [(-FCOC_9 \times 207.144 - R_9 - D\&A) \times (1 - T) + D\&A] \times p^2 \approx -1.250;$$

$CF_{20,20}^{SR} = (-FCOC_7 \times 207.144 - S_{20} - R_{20} - D\&A + RV) \times (1 - T) + D\&A \approx 5.940.$

Under the sealing situation, if aircraft need to be sold and leased as second-hand aircraft, they will be unsealed and repaired to restore to airworthiness so as to conform to corresponding contracts. So the airline needs to undertake the sealing expense for term 20 and pay for the unsealing and restarting expense for sales.

Fig. 4. Binomial-tree model of *CF* with shutdown-restart option.

option as a part of compound option, due to the absence of additional flexibility by the *SR* option. Given the minimum flight executive rate, there is only a small part of fleet operations possessing the shutdown option. As a result, the change of overall option value is influenced mainly by the change of defer-option value.

To summarize, *Yield*, risk-free rate of interest and volatility of

Table 2
Expanded present value of *CF* with shutdown-restart option.

Unit: $ mn

t	Year	Amount	t	Year	Amount
1	2013	1.2298	11	2023	2.0433
2	2014	1.3146	12	2024	2.1227
3	2015	1.3985	13	2025	2.2004
4	2016	1.4818	14	2026	2.2772
5	2017	1.5643	15	2027	2.3538
6	2018	1.6465	16	2028	2.4283
7	2019	1.7280	17	2029	2.5012
8	2020	1.8074	18	2030	2.5761
9	2021	1.8873	19	2031	2.6495
10	2022	1.9677	20	2032	6.5720
TOTAL			43.7504		

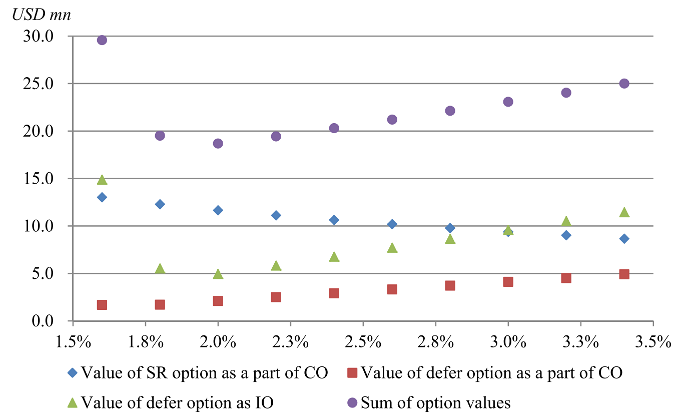

Fig. 6. Sensitivity of risk-free interest rate on option values.

Yield affect the values of both the *SR* option and the defer option. Besides, the defer-option value is affected by the option period and aircraft purchase price. Among these five factors, our analysis shows that the purchase price and *Yield* have the greatest impact on the value of the compound option. These are then followed by the volatility of *Yield* and the option period. The risk-free interest rate has the least impact of the five factors.

We have also conducted sensitivity analysis for the minimum flight execution rate (Fig. 7) and the inflation rate of operating costs (Fig. 8). Both rates have a fairly large impact on the ENPV and the option value of fleet acquisition. When the airline increases its minimum flight executive rate, it will have less managerial flexibility in the *SR* option, losing its option value as a result. If the airline has more power in controlling the growth of its operating costs, it will earn greater operating income. The cost-control ability plays a crucial role in the option value of fleet acquisition.

Table 3
Value of defer option under Black-Scholes model.

	Number	Unit
ENPV of CF with SR option	43.7504	USD mn
Aircraft purchase price	35.3712	USD mn
Sigma of Yield	5.0%	
Risk-free rate of interest	2.0%	
Option period	2.00	year
ENPV with compound option	9.7663	USD mn
ENPV with SR Option	9 0.0704	USD mn
Value of defer option	0.6958	USD mn

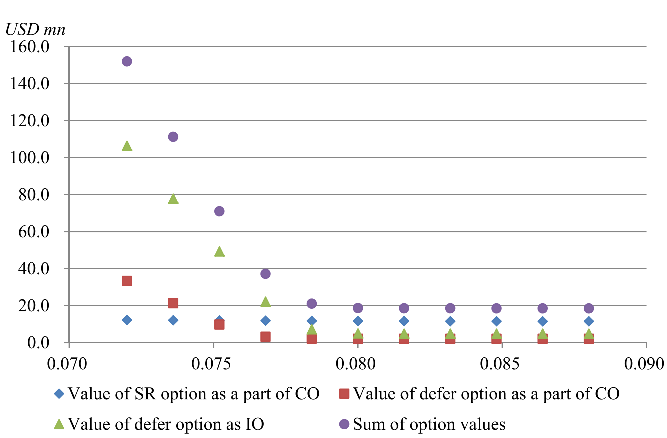

Fig. 5. Sensitivity of *Yield* on option values.

6. Concluding remarks

Our primary objective in writing this article is to demonstrate that if airlines rely solely on the static NPV analysis, they are likely to underestimate the true value of investment, with the difference being the value of real options (flexible strategies) embedded in the investment's life cycle. We illustrated this point by quantifying the shutdown-restart option in relation to the static NPV. While the value is not a huge amount, it is nevertheless appreciable especially considering the number of such acquisitions for a major airline over the years. The insight could help explain observed capital expenditures of airlines and serve as a rule of thumb in evaluating capital budgeting decisions. Furthermore, we analyzed a compound option that has the shutdown-restart and defer options as components. The analysis showed that the value of the defer option depends on whether the option is considered as an independent option or as a part of the compound option, suggesting the importance of specifying the context when a real option is evaluated.

Two issues may be incorporated in future work. First, we assumed a geometric Brownian motion (GBM) for the logarithmic price of the underlying asset in our application of the binomial tree and Black-Scholes models. It will be important to verify whether the distribution is of GBM or some other type (e.g., "mean reversion"). This would require the estimation of relevant prices in a deregulated airline market, a task that necessitates more detailed historical data. Although airline markets have been gradually

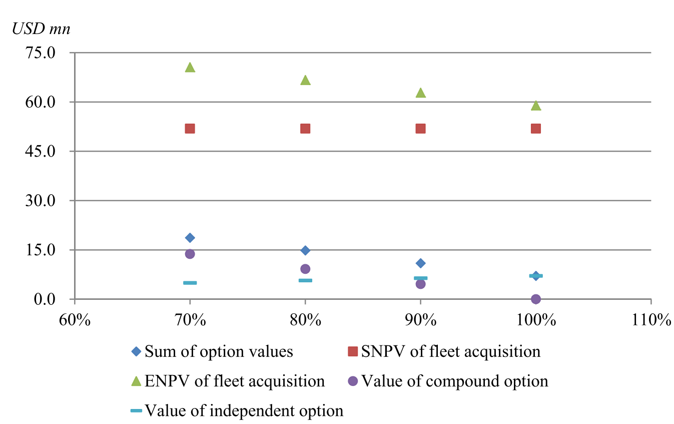

Fig. 7. Sensitivity of minimum flight execution rate on option values.

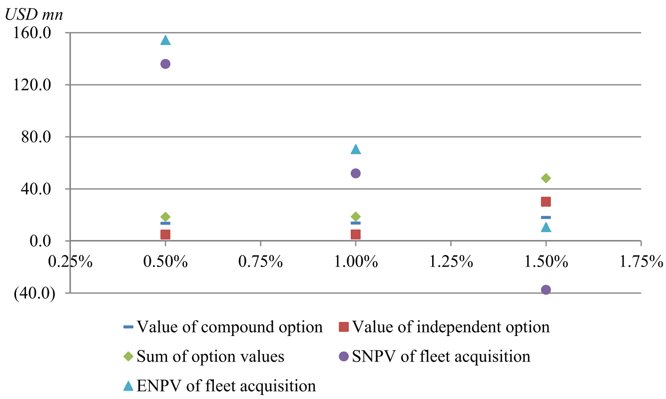

Fig. 8. Sensitivity of inflation rate of operating costs on option values.

deregulated and liberalized and thus moved to a more competitive market environment (since airline deregulations in the United States in 1978, Canada in 1988 and the European Union in 1997 for instance; see e.g. Zhang et al., 2011), the history of the deregulated airline industry is limited in view of an aircraft lifespan of over 20 years. Second, it is important to see what the results would be if, in addition to airline yield, there are uncertainties for aircraft residual value and fuel cost. We see these exercises as a natural extension of the analysis presented here, although beyond the scope of the present article.

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