Options Valuation of Architectural Flexibility:
A case study of the option to convert to office space

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Abstract

Corporate facility managers and real estate developers recognize the potential value in spaces that have the flexibility to serve a variety of functions. Investments in architectural flexibility are currently guided by the design team's judgment and refined by the architect's knowledge of building code allowances. More formal valuation of flexibility in architectural design would help inform rational levels of investment in the design process and resulting construction to address relevant uncertainties. This research addresses the assumptions needed to apply financial-type real options models to physical design questions. One major conclusion is that the governing uncertainty must be a market-based factor such as the price of rent in a competitive market. For a case study for a corporate campus, it is assumed that the price of a lease for office space in its geographic area meets this requirement. A model is developed to determine the option value to convert a space to *office space*. The date at which change occurs as well as the future prices of renting (the alternative to renovating) are stochastic variables. The model provides results in the following form: it is worth *$C* to invest in the design and construction of a space that can be renovated for *$X* over a specified time horizon. The results help decision-makers justify increased investment in flexible designs, as discussed for the design of a new laboratory.

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1 Introduction

Flexibility is a common design goal in many of today's architectural projects. Corporate facility managers and real estate developers recognize the potential value in spaces that can be reconfigured to accommodate different activities or that can be easily renovated for different uses, such as changing from a laboratory to an office. Key drivers of the need for flexible space are the rapid pace of changing business needs, mobile employees, and uncertain real estate markets. As suggested by anecdotal evidence, flexible space may also facilitate greater productivity and reduced long-term costs. However, facilities management and designers typically do not proactively address the consequences of change. Two of the primary barriers hindering consideration and implementation of more flexible space are higher first-cost and reluctance to depart from traditional, less flexible interior build-outs, such individual offices. To plan for and justify investment in the flexibility to change the use of a space, there is interest in assessing the option value of architectural flexibility.

In moving towards a strategic view of space as a flexible asset, real options methodologies are promising candidates for informing decisions in the design process. Currently, efforts to invest in space-type flexibility are guided by intuitive judgment and shaped by the design team's knowledge of allowances within the realm of building codes. More formal valuation of flexibility in architectural design would help inform rational levels of investment in the design process and the resulting construction to address relevant uncertainties. Valuation may also help address selection of specific elements of flexibility.

For valuation of managerial flexibility, financial-based real options methodologies, such as binomial-lattice models, are advantageous over decision tree methodologies under two conditions:

1. Large number of time periods, and
2. Major source of uncertainty is market-based.

Furthermore, when data is available to quantify the market-based uncertainty, real options methodologies are the more theoretically correct approach as compared to decision trees. However, when the major uncertainties are technical or private in nature, other methodologies are needed, such as simulation or combined options-decision tree approaches. Financial methodologies, as defined for this research, make the basic assumption that the uncertainty in the value of the underlying asset is characterized by a normal or lognormal probability distribution and that changes in value are described by geometric Brownian motion (GBM). Therefore, use of financial-based methodologies requires justification of market-based behavior.

For real estate, the future market rate of rent may be characterized as market-based when there exists a well-functioning, liquid market for the type of space. To date, the real options literature has considered applications of options theory to several relevant questions for real estate development. Geltner (1989) applied a financial option-pricing model to explain the phenomenon of vacant urban land. Geltner et al. (1996) used a perpetual option model to provide insights on the effect of land-use choice. Patel and Paxson (2001) use a perpetual American call option model treated as an exchange option to value a) properties under construction and b) properties held for development at the Canary Wharf development project (prime office space) in London. Each of these authors supported the argument that the underlying assets of land and property value follow a GBM process.

Application of decision-making tools to building design is complicated by the governing physical properties and system interactions affecting the decision variables of interest, such as energy consumption. Several authors have introduced decision-making under uncertainty to the field.

Zmeureanu and Pasqualetto (2000) consider selection of energy conservation measures when design inputs are uncertain, which differs from evolution of uncertain events with which real options is concerned. Kalligeros (2003) poses an algorithm for optimizing the design lifetimes of a set of buildings on a corporate campus that are expected to contract over the next few decades. The author uses real options and dynamic programming to address uncertainty in individual building demand and subsequent building value. Technical issues of structural design are not addressed in the model (Kalligeros, 2003). Overall, valuation of flexible design for architectural and building systems, including real options valuation, remains largely unaddressed in the literature as well as in practice.

To introduce flexible strategies into architectural design, it is useful to define two broad categories of flexibility: macro level (e.g. space-type) and operational level (e.g. work activities). The motivation for this research comes from a corporation whose campus has seen many of its buildings change at the macro-level, including conversions of laboratories to offices, pilot plants to laboratories, and closed offices to open-plan type offices. Another macro-level example comes from Arrowstreet Architects in Cambridge, MA who designed a telecom server building with the option to convert to an office building. The flexible design was motivated by the uncertainty in future demand for server-type buildings, which the designers knew would become better understood as the design process evolved (Batchelor, 2003). In the operational category, examples include changing the type and scale of experiments in a laboratory and reconfiguring office space (without major renovation). Millennium Laboratories, designed by Elkus-Manfredi Architects and shown in Figure 1, won the *R&D Magazine's* 2003 Award for Laboratory of the Year owing primarily to its flexible design concept (Mallozzi, 2003). The design melded the distinct functional requirements of chemistry and biology labs into a single design that allows for both types of experimental work, thereby facilitating productive changes as business-needs fluctuate. In summary, many examples of the need for architectural flexibility are apparent at both the macro and operational levels, and modern building design is beginning to embrace the concept.

1.1 Research objectives

This research explores the valuation of macro level, or space-type, flexibility with two goals. The first goal is to elucidate the assumptions needed to apply financial-type real options models to physical design questions. Through a case study with BP Inc. and its suburban Chicago corporate campus, the relevant drivers (of space changes), uncertainties, and applicability of financial options models are explored, as presented in Section 2. BP is currently designing a new laboratory space, and the company has identified flexibility in space-type, in the form of possible conversion to office space, as a design goal. Thus, the second research objective is to develop a model to value the flexibility to convert to office space. The model structure is presented in Section 3, and the case study results are given Section 4. The option value results help the design team and other corporate decision makers choose a rational level of investment in the up-front design and construction expenditures needed to be able to convert a space to office-space for a specified renovation cost in the future. Conclusions on real options applied to architectural and building design are presented in Section 5, along with a discussion of future work.

Figure 1. Millenium Laboratories used flexible concepts to achieve dual use laboratories. Photo by Justin Maconochie. Source: (Mallozzi, 2003).

2 Applicability of financial-type real options models to space-use and design

Real options valuation methodologies can be generally classified by the assumptions made and mechanics of applying the approach[1]. The type(s) of uncertainty considered and the availability of data fundamentally determine the necessary assumptions and mechanics of a model. Financial-type real options models are those that are used to value options traded in financial markets (e.g. options on buying/selling stocks); they include mathematically derived formulas (e.g. the Black-Scholes formula), binomial lattice models, and other numerical solutions to mathematical descriptions of the option. Financial options are characterized by random fluctuations in the value of the underlying asset that can be described using the random walk theory of geometric Brownian motion (GBM) (see Dixit and Pindyck, 1994). The volatility of the underlying asset is one of the fundamental inputs to financial-type models. Volatility is derived either from historical data or from a separate model of the value of the underlying asset.

Turning to physical projects and the use of financial-type real options models, the first step is to identify the underlying asset and the nature of its uncertainty. Next, to justifiably apply a financial-type real options model to valuation of flexibility, it must be established that

1. Changes in the value of the underlying asset are (at least partially) random, and
2. A replicating portfolio can be constructed.

Even when these factors are established, the analysis should clearly point out that the analogy between real options and options on stocks is not exact. According to Trigeorgis (1996), several of the distinguishing characteristics of real options as compared to stock options are non-exclusiveness of ownership, competitive interaction, non-tradability, and compoundness. Thus, the replicating portfolio justification is the assumption that is generally farthest from the theoretically correct application of real options models.

A replicating portfolio is used to establish a risk-free preference between holding the option and holding a certain quantity of the underlying asset financed by selling risk-free bonds[2]. The payoffs to the portfolio are risk-free, and thus the risk-free rate of return can be used to value the option[3]. The return on the replicating portfolio exactly matches the return of the real option if the following two assumptions hold: market completeness and no arbitrage opportunities. Market completeness means that the project does not expand the investors' opportunity set and that there exists sufficient possibilities for substitute investments (Trigeorgis, 1996). The most acceptable way to satisfy the complete market requirement is to establish that a competitive, liquid market exists for the underlying asset. For example, consider the difference between office buildings and laboratory buildings. While many urban and suburban areas have dynamic markets for office space, the same argument is difficult to make for specialized buildings such as laboratories.

Laboratory space is a specialized real estate market, and is thus less liquid than office space. Prices would not be characterized as random, and prices would include significant, individualized interior build-out costs. Thus, for lack of a market, it is generally not appropriate to value an option to convert to laboratory space with financial-type options theory. Nonetheless, as will be

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[1] See (Borison, 2003) for a discussion on classifying real options methodologies.
[2] This description of a replicating portfolio applies to a call option. For a put option, the risk-free preference is between selling an option and selling a certain quantity of the underlying asset combined with investing the proceeds in a bond that grows at the risk-free rate of return.
[3] Trigeorgis (1996) states that nontraded real assets may actually earn a return below the equilibrium rate of return expected in the financial markets. For the purposes of this analysis, the widely accepted use of the risk-free rate of return will be used, having justified complete markets and no arbitrage opportunities.

discussed in section 4.3, the concept of value in flexibility implies that a design should consider the possibility to convert to other types of space in the future. For example, in BP's new laboratory space ,the design aspects addressing flexibility for conversion to office space should include the possibility of reverting back to laboratory space. When the possibility for multiple conversions (at similar renovation costs) exists, the option value for a single conversion becomes a lower bound on the overall value of flexibility.

The absence of arbitrage profit opportunities, the second assumption behind the replicating portfolio concept, means that the investor cannot possibly make a profit without investing capital. The no-arbitrage postulate is a prerequisite for equilibrium valuation of the option, just as it is in standard discounted cash flow analysis (Trigeorgis, 1996). Thus, this assumption is generalizable to most valuation questions. It describes a situation in which all investors have complete information. Assuming all else equal between leased and owned space, the no arbitrage assumption says that a space-seeker is indifferent between leased or owned space by economic and absence of arbitrage profit principles.

Just as it is difficult to justify application of financial type options models to options on laboratory and other specialized space at the macro-level, it is similarly difficult to justify their application to valuation of options at the operational level, such as to change *activities* within a space. Changes of activity are governed by uncertainties in business activities and objectives, which, in turn, are determined by expectations in revenues. Because of the multitude of factors contributing to stock price, it is difficult to correlate the price of a company's stock or other market-determined price with specific activities within a company. Even for a copper mine, there is debate as to whether or not the (randomly fluctuating) price of copper is the correct underlying asset to use to value the option to develop a mine. Other costs and factors contribute significantly to the value of the mine itself. Simulation (real options) methods may be applicable to options to change activities within a space, and further research is needed in this area. A major part of such research would be to identify the appropriate underlying asset(s). For example, although revenue expectations may be simulated, it would be difficult to directly correlate revenues with the specific activities that produce those revenues.

2.1 Space-change drivers and characterization of uncertainties

Space-type changes follow from changes in business needs. Likewise, people are moved as businesses reorganize and redefine business pursuits. At major corporations that are involved in scientific research and engineering activities, such as BP, necessary space-types include offices, laboratories, pilot plants, libraries, cafeterias, meeting rooms, and more. If a company determines that it needs (more of) a certain type of space, it may choose among a) renovating an existing space, b) leasing space on the market, or c) building a new facility. The costs of the first two choices are incremental while the cost of the third choice (constructing a new building) is a major investment. Renovations are generally driven by business needs (i.e. use looking for a space), as opposed to being driven by an empty space looking for a use.

To bring the concept of flexibility to facility planning and design, discussions early on in the conceptual design phase should determine the nature of flexibility which the design should accommodate. At BP, a common change that has occurred in the past and that is expected to continue in the future is conversion of many types of space into office space. Laboratories have been converted to office space, and office spaces are commonly renovated to accommodate differing business group needs. Most recently, this has meant converting closed, individual offices into open-plan offices; however, it is noted that this trend may reverse or change course to a not-yet imagined office-type in the future. For the current laboratory space under design, BP identified the flexibility to convert to office space as a design goal.

Choice of a real options valuation methodology depends on the nature of the uncertainties governing the underlying asset that the flexible design addresses. For the option to convert to office space, the two primary uncertainties are 1) the timing of the space need and 2) the cost of the alternative – a market rate lease. A decision tree depicting these uncertainties is shown in Figure 2. Timing corresponds to changes in business needs that result in the desire to convert some or all of a space to office space. By framing the renovation question as a question of space *need*, the company has a choice between a) renting office space on the market or b) renovating existing corporate space. In doing so, the value of a market-priced lease becomes the underlying asset. The renovation cost, which is a function of the original architectural design and assumed to be a known constant, is the strike price. So long as such space is available on and priced by the market and the company is theoretically indifferent between leased or owned space, a financial options model may be used to value the flexibility.

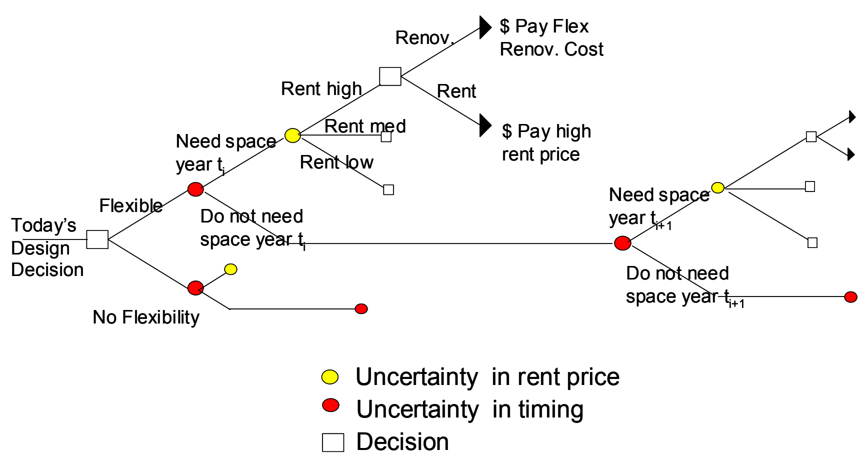

Figure 2. Partial decision tree representing the choices of flexible/inflexible design and renovating/renting with uncertainties in timing of space need and rental (lease) price.

In reality, there is a distinct preference for using on-campus space for a variety of reasons, including security and productivity due to proximity. However, by assuming indifference, the valuation is grounded to a market-based value. At BP, market-based values are used for charging internal rents to business units using office space, so it is a natural extension of this on-going practice. The company also holds several leases for office space in the nearby area. Furthermore, this suburban region has a well-functioning market for office space leases. Negotiation is sometimes possible for agreeing on the final price, but average prices for different classes of office space are tracked and available. Historical data covering many years or decades is available from consulting firms. These factors justify the existence of an applicable market for office space as the underlying asset.

3 Model for value of flexibility to convert to office space

A real options model, using the binomial lattice method, is developed to answer the following question:

> How much is it worth to invest in a space that could be renovated to *office* space for a specified renovation cost in the future?

The underlying asset is the price of a lease. The exercise date decision is framed as the economically rational choice between the price of a lease and the cost of renovating. The cost of renovating is the exercise price. The option to renovate is exercised if the renovation cost is less than the lease price. The option value is the savings from not paying for the lease, or zero if the lease is less expensive. As discussed in the previous section, the governing uncertainties are the future market price of a lease for office space and the timing of the space need, or exercise date. Use of a binomial lattice model to address uncertainty in rent price and value the option to renovate is discussed in the next section. The use of Monte Carlo simulation to model uncertainty in timing is discussed in section 3.2.

Renting space on the market means leaving a vacant space on campus. However, it is assumed that the company would pay the same operating costs on the owned space, such as taxes, depreciation, and basic utilities, regardless of the choice. According to BP, basic utility costs do not vary greatly with space occupancy. Thus, the decision to renovate or rent depends primarily on the relative costs, all other things equal. Also, although, the company may be able to find another use for the unrenovated, otherwise vacant space, this value is not considered in the basic model.

3.1 Binomial lattice model

The evolution paths of the price of a lease are modeled with a binomial lattice. Assuming a lognormal distribution of possible values, the binomial lattice parameters are specified to model geometric changes in price. Shown in Figure 3, each node of the binomial lattice represents a possible value of the price of rent at that particular point in time. Starting at the current time (time 0), the possible values in the next time step (Δt) are determined by multiplying the previous node by the size of the up (u) or down (d) movement, which are calculated from the historical estimate of volatility (σ) in the lease price as follows (Copeland and Antikarov, 2001)[4]:

$$u = e^{\sqrt{\sigma \Delta t}} \qquad \textit{(Eq. 1)}$$

$$d = 1/u \qquad \textit{(Eq. 2)}$$

With a sufficient number of branches in the node for rental price uncertainty, the decision tree in Figure 2 could accomplish a similar model of rent price evolution. However, the recombining property of the binomial lattice means that it grows linearly with the number of time steps which is a useful property for computational efficiency.

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[4] Note that a growth rate (i.e. trend or expected rate of return) (α) of the underlying asset could be modeled with the binomial lattice by setting $u = e^{\alpha t + \sqrt{\sigma \Delta t}}$ and $d = e^{\alpha t - \sqrt{\sigma \Delta t}}$. However, because the growth rate does not affect the value of the option, as it is conceptually replaced by the risk-free rate of return, it is common practice to leave it out of the model.

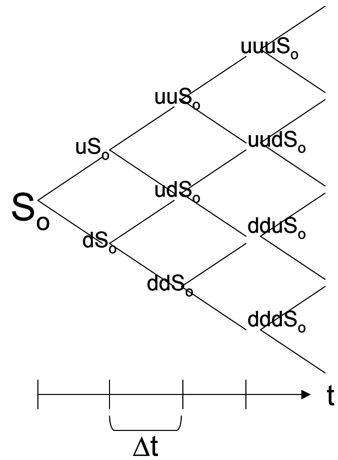

Figure 3. A binomial lattice is used to model a geometric evolution of rent price (S).

Whereas the binomial lattice represents the price of renting *per year*, the actual underlying asset should represent the full price of a lease, which is typically more than one year. According to BP, a typical lease term is five years. To calculate the present value of a multi-year lease, the continuously compounded present value factor (P_{lease}) is used,

$$P_{lease} = (1-e^{(-rl)}) / r \qquad \text{(Eq. 3)}$$

where r is an estimated annual discount rate, generally the company's weighted average cost of capital, and l is the length of the lease in years. The price of a lease at any time (S_{lease}), assuming l-years of constant rent payments (S_t) is then calculated as

$$S_{lease,\,t} = P_{lease}\, S_t \qquad \text{(Eq. 4)}$$

Renovation cost, or exercise price, is assumed to be fixed over the duration of the option. A range of cost scenarios is used to represent varying levels of flexibility. A low renovation cost represents a highly flexible, easy to change space, while a high cost represents a less-flexible, more intensive change scenario. For example, an office space with a moveable wall system has a low renovation cost to convert to a new office configuration. An inflexible office space consisting of enclosed offices with stud walls and sheetrock would have a higher cost of renovating to achieve a different configuration.

A second binomial-lattice is used to determine the option value. As shown in Figure 4, the second lattice uses the corresponding node values of the first lattice to make the exercise decision. The option to renovate is exercised if the cost of renovating (X) is less than the cost of renting ($S_{lease,\,t}$). The value of the option to renovate is the savings ($S_{lease,t}$ - X) enjoyed by not having to rent. Alternatively, if renting is cheaper than renovating, then the value of the option is zero, and the company would choose to rent office space rather than renovate its own space. Thus, the decision rule for each node at the exercise date is

$$\min\,[\text{ renovate } (X), \text{ rent } (S_{lease,\,t})] \qquad \text{(Eq. 5)}$$

which corresponds to

$$\max [\text{savings of renovating v. renting}, 0] = \max [(S_{lease,\, t} - X), 0] \qquad \textit{(Eq. 6)}$$

After the decision rule is applied to each node at the exercise date, the option value (C) is determined by rolling back the lattice using the risk-neutral probability (q), a factor based on the risk-free rate of return (r_f) and the up and down movements in the underlying asset (u, d):

$$q = (1+r_f-d)/(u-d) \qquad \textit{(Eq. 7)}$$

The risk-neutral probability (q) is derived by constructing a replicating portfolio, as was discussed in the previous section[5].

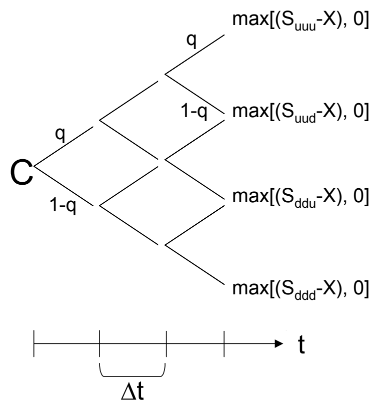

Figure 4. A second binomial lattice is used to calculate the value of the option to renovate.

3.2 Monte Carlo simulation

The second major uncertainty governing the option to renovate is the timing of the space need. This is modeled as a stochastic variable using Monte Carlo simulation. A probability distribution is needed to describe the possible outcomes of the timing of the space need. The PDF may be derived from historical values, expert opinion, or from a known mathematical model. A mathematically described two-parameter exponential PDF is used to validate the model and a judgment-based distribution is used in the case study.

During each run of the Monte Carlo simulation, a time is randomly chosen from the defined probability distribution. The option value is calculated using the binomial lattice model, the Monte Carlo chosen time, and the prespecified renovation cost. This is repeated for 10,000 trials. The mean of the resulting distribution is the option value for that scenario.
Figure 5 illustrates the steps in running the model.

[5] See (Trigeorgis, 1996) for derivation of the risk-neutral probability based on the replicating portfolio assumption.

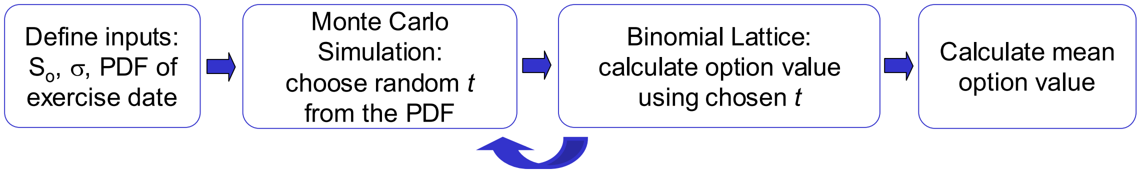

Figure 5. Steps in running the model. The Monte Carlo simulation chooses the exercise date (t) and the binomial lattice calculates the option value.

3.3 Model validation

Jennergren and Naslund (1996) derived a closed-form solution for a European option with a stochastic expiration date, where the probability distribution of the exercise date is a two-parameter exponential distribution. This closed-form solution was used to validate the model. The exponential distribution shown in Figure 6 is described by the parameter λ, where λ is set equal to the inverse of the maximum time horizon *T*. The Jennergren-Naslund formula gives an option value of $17.85 using the following inputs: λ *(0.1 years*$^{-1}$*)*, r_f *(10%/year), T (10 years), S ($39.35), X($50),* and σ *(0.3935/year)*.

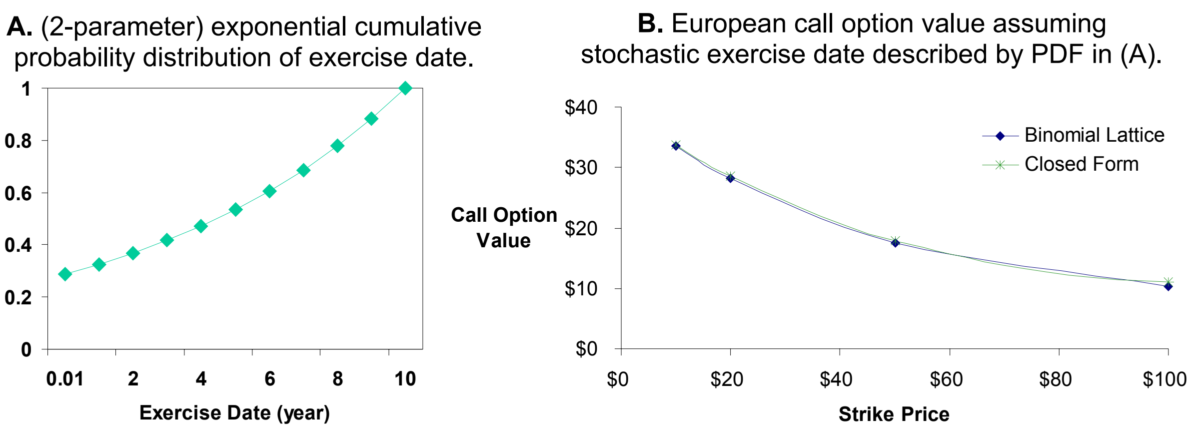

Figure 6. A closed-form solution, based on the cumulative distribution function shown in panel (A) was used to validate the model (panel B).

Using the same exponential PDF and other input parameters in the binomial lattice-Monte Carlo simulation model, the result is a mean option value of $17.50, or 2.0 percent less than the closed-form solution. For a strike price (*X)* of $10, the closed-form solution yields an option value of $33.70 and the model gives a mean value of $33.47, or 0.7 percent less than the closed-form solution. Results for a range of strike prices are shown in Figure 6. The binomial lattice model shows excellent agreement with the closed-form solution. The advantage of the model over the closed-form solution is that it can accommodate any type of PDF on the timing of the space need, not only a two-parameter exponential distribution with $\lambda = 1/T$. A unique description of a PDF is presented in the following case study.

4 Case Study Results and Discussion

The real options valuation methodology for the flexibility to renovate a space to office-type space was applied to a case study for BP's corporate campus in the suburban Chicago area. Input data, collected through discussions with facility managers, research of the local office rental market, and independent assumptions later checked by sensitivity analysis, are presented in section 4.1. The model results and sensitivity analysis are given in section 4.2. A discussion of application of the results to the design of a new laboratory currently underway is presented in section 4.3.

4.1 Input Data

A summary of the model inputs for the BP case study is given in Table 1, and a summary of calculated parameters is given in Table 2. The model inputs are current annual rent price of office space, standard deviation of rental prices, the risk-free rate of return, length of a lease, OCC for discounting lease payments, and a probability distribution of the exercise date. To represent a range of flexibility scenarios, renovation costs of \$25/SF, \$50/SF, and \$125/SF, or ratios of 1:1, 2:1, and 5:1 of renovation cost to current annual rent price, were chosen[6].

The current value of office space rent is deduced from several sources. According to BP, the gross rents for external (off-campus) space that they currently lease range between \$18-26/SF, and they estimate that the current level of market rent is \$28/SF. According to Cushman & Wakefield, Inc. (2003), suburban area Chicago rents for Class A office space were \$22-23/SF in the first six months of 2003. CB Richard Ellis, Inc. (2003) provides values of \$15.40-\$15.60 for average asking prices for leases for suburban area Class A Chicago office space in the first half of 2003. In the East-West Tollway region where BP's campus is located, average rents were slightly higher than the suburban average at \$16.00-\$18.50/SF. The source of discrepancy between the reported data is not clear; thus they are provided simply to give added points of reference to BP's estimates, which are used in the model. Specifically, \$25/SF is the assumed current annual market rent for office space, which translates to \$98.37 as the present value of a 5-year lease, discounted continuously at 10 %/year according to Eq.'s 3 and 4.

Table 1. Input parameters for BP case study

Variable	Options Language	Description	BP Case Study Value
S_o	Underlying asset	Current rental price of office space	\$25/SF/year
σ	Volatility (of underlying asset)	Annual volatility of market rental prices	0.10/year
X	Strike price	Renovation Cost	\$25/SF, \$50/SF, and \$125/SF $\longrightarrow$ *Decreasing Flexibility*
r_f	Risk free rate of interest		5%/year
l	---	Length of lease	5 years
r	OCC for discounting lease payments to value at time of signing lease		10%/year
T	Exercise date	Likelihood of timing of renovation (space need)	See CDF's in Figure 7

[6] To gauge the cost of renovating, BP provided recent figures for renovation costs in two cases: a) office space to new office space (\$30-40/SF), and b) laboratory to office space (\$300/SF).

An estimate of the volatility is used, and a sensitivity analysis showed that the option value is not highly sensitive to volatility. Data sets would need to be purchased, at considerable charge, to calculate volatility. The publicly available data from the aforementioned sources only cover a snapshot of time, usually one to one and a half years. The risk-free rate of return comes from the rate of return on 10-year U.S. Treasury Bills in January 2004. The 10-year value was chosen because it is closest to the 8-year time horizon base case; however, the values did not vary significantly across other Treasury Bill time horizons.

Table 2. Calculated parameters for BP case study.

Variable	Options Language	Description	Formula	BP Case Study Value
P_{lease}	Present value factor to calculate revised underlying asset and volatility		$P_{lease} = (1-e^{(-rl)}) / r$	3.9347
S_{lease}	(revised) Underlying asset	Lease price (present value of *t* years of constant payments of S_o)	$S_{lease,\,t} = P_{lease}\, S_t$	\$ 98.37 /SF/5-yr lease
σ_{lease}	(revised) Volatility	Volatility of market lease	$\sigma_{lease} = P_{lease}\, \sigma$	0.3935/year
u	Up movement per time step		$u = e^{\sqrt{\sigma \Delta t}}$	1.13
d	Down movement time per step		d = 1/u	0.88
q	Risk neutral probability (up)		$q = (1+r_f\text{-}d)/(u\text{-}d)$	0.51
$1\text{-}q$	Risk neutral probability (down)		$1\text{-}q$	0.49

The estimated probability distributions of the timing of space need are shown in Figure 7. BP estimates that, for one of its newer office buildings, 100 percent of the total square footage of the space will be renovated over the next eight years according to the cumulative probability distribution (CDF) labeled ‘8-yr Horizon’ in Figure 7. The distribution describes the estimate that there is a 50 percent probability that the space need will occur within approximately five years. Some spaces may be renovated more than once and others never renovated, but the overall result (estimation) is that an area equal to the total square footage of the building will have been renovated by the eighth year. If every space is expected to be equally as likely as the next to be renovated, then the option value of flexibility applies to all spaces. Two other probability distributions were also modeled, one representing a maximum time horizon of five years and another of fifteen years. The same shape of the 8-year CDF was maintained in the other distributions. In the 5-year time horizon CDF, there is a fifty-percent cumulative probability that the space-need will arise after 3.5 years; the fifty-percent cumulative probability rises to 10 years for the 15-year case.

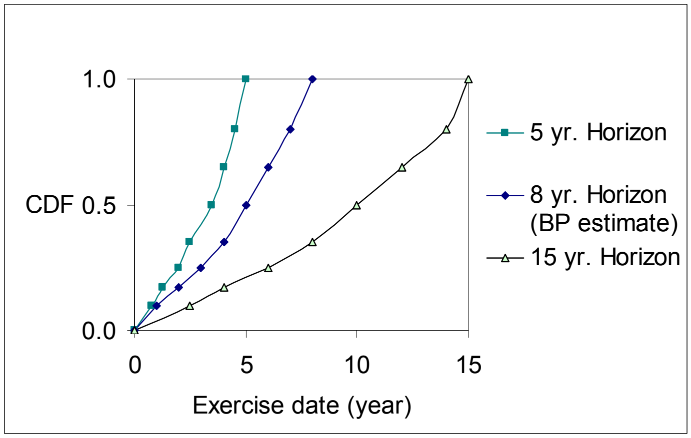

Figure 7. Three estimates of the probability distribution of the timing of office space needs at BP.

4.2 Results

The option value of the flexibility to convert a space to office space at strike prices (renovation costs) of \$25, \$50, and \$125/SF for the three time horizons are shown in Figure 8. The assumptions are those given in Tables 1 and 2, including current market rent of \$25/SF/year, volatility of annual rent of 0.10/year, and a five-year lease (\$98/SF current value). The probability distributions on the timing of the space need are those shown in Figure 7. The option value represents the expected savings of renovating as compared to having to pay for a market rate lease. Each bar in the graph represents the mean option value of the 10,000 Monte Carlo simulation trials for each scenario. Figure 9 shows the option value frequency distribution for the \$25/SF renovation cost scenario with the 8-year time horizon. The option value for a particular scenario is the mean of the Monte Carlo simulation. The results are interpreted as follows:

> In the 8-year time horizon scenario, a design that can be renovated for \$25/SF should cost no more than \$79/SF in design and construction expense above and beyond a baseline, inflexible (i.e. very high renovation cost) design.

Further discussion of the practical and technical issues of using the option value to aid decision-making is presented in section 4.3, while general behavior and sensitivity of the results are presented in the following paragraphs.

As with a standard option, the option value to renovate increases with a longer time horizon. This occurs for the same reason that the value of a financial call option increases with increased time to expiration: more time allows for a wider range of possible future rents (Brealey and Myers, 2000). Higher rents translate to greater savings attributable to the option to renovate for a fixed cost. The sensitivity of option value to time horizon increases with the strike price. At a highly flexible renovation cost of \$25/SF, the option value is not very sensitive to the time horizon, ranging only slightly from \$76.63/SF to \$83.12/SF for time horizons of 5 to 15 years respectively. However, at a less flexible renovation cost of \$125/SF, the option value has a much wider range: \$22.47/SF to \$46.88/SF for time horizons of 5 to 15 years respectively.

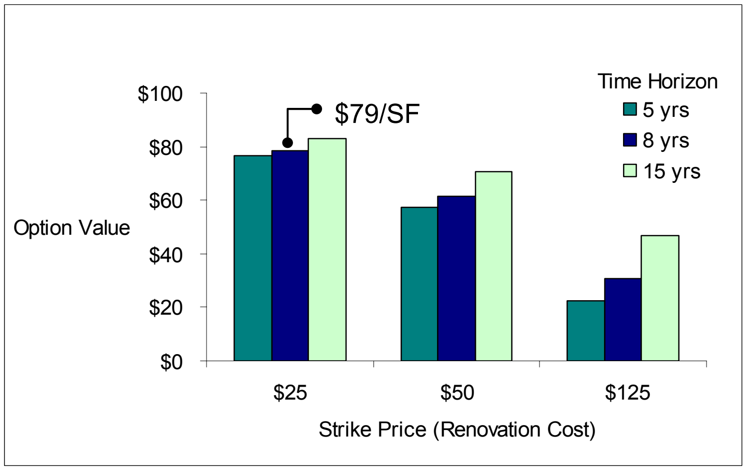

Figure 8. Results of the option value to renovate for 5-, 8-, and 15-year time horizons. The current present value of a 5-year lease is $98/SF and the volatility of the lease is 0.39/year.

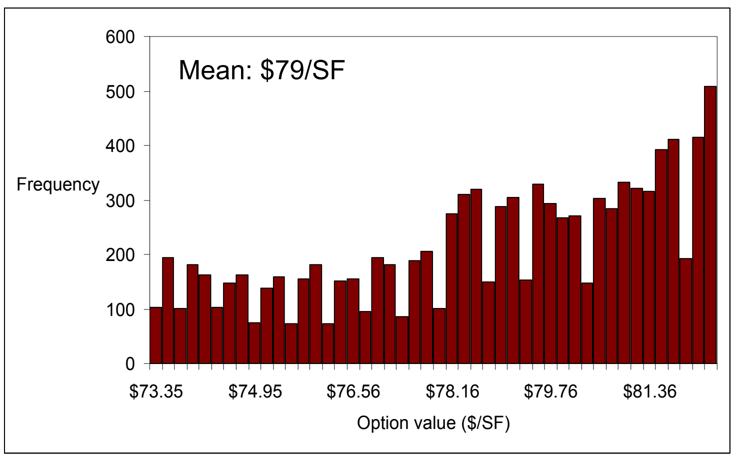

Figure 9. Frequency distribution output of the Monte Carlo simulation for the scenario of $25/SF renovation cost over the 8-year time horizon. The mean of this distribution is $79.[7]

The value of the flexibility to renovate is sensitive to the opportunity cost of capital of the lease (r) and the duration of the lease (l). The base case is an r of 10% for a five-year lease, which results in an option value of $79 for a $25 strike price (8-year time horizon). Increasing r to 15% per year results in a decrease in option value of 13 percent and decreasing the r to 5% results in an increase in option value of 16 percent. Changing the duration of the lease from 5 years to 2 years decreases the option value by 68 percent, as the quantity to which the cost of renovation is compared (i.e. the initial underlying asset value or initial lease price) is reduced from $98.37 to $45.32.

[7] The frequency distribution appears spiky because the binomial lattice model uses discrete time values, thus producing discrete option values. When those values are sorted into bins, some bins cover more discrete values than other bins. A model with infinitesimally small increments of time would approach a smooth frequency distribution result.

A useful property of the results is that they are scalable with constant ratios of strike price (renovation cost) to current underlying asset value (X/S_o). If renovation cost and current lease price are increased by a constant multiple, then the call option value also increases by that common ratio. For example, apply a factor of 10 to the X and S_o base case values for the 8-year time horizon, \$25/SF renovation cost result. The present value of a five-year lease is \$984 [=(10)(\$98.37)] and the renovation cost is \$250/SF [=(10)(\$25/SF)]. The resulting option value is equal to \$785 [=(10)(\$78.54)]. This scaling result helps generalize the results for different estimates of lease prices and renovation costs as long as the original ratio is maintained.

4.3 Application of results to design of new laboratory

In the decision-making process deliberating how much flexibility to include in a design, the results shown in Figure 8 are to be compared with cost estimates of architectural designs of varying levels of flexibility. The option value is but one of many factors that will be brought into the final decision, including functional requirements, aesthetics, and environmental impact. For BP's new laboratory space that is currently under design, the results apply to portions of space that may be renovated to office space in the future. The option value serves as a lower bound estimate of the value of flexibility, as it assumes only one renovation over a specified time period. The calculation does not include the value of converting back to laboratory space at some future time. However, this is where the concept of options, and specifically that of flexibility, can be used to guide the design.

It is not wise to "destroy" an option on a type of space that may be valuable. Thus, a conversion from laboratory to office space should not nullify the possibility of converting back to laboratory space some day. In other words, efforts should be made in the design so that the space could easily (i.e. inexpensively) be changed from one type to another and back again. This likely means maintaining the larger HVAC system that is needed for laboratory space even when the conversion to office space is made. The calculated option value for switching to office space is a good proxy for the value of flexibility of space that is initially designed to be laboratory space, because the higher cost provisions necessary for laboratory space will already be necessary as part of the base design. The opposite is true, however, for space that is initially designed to be office space but may some day be needed as laboratory space, as a larger investment would be needed, over and above the base design of office space, in elements like a larger HVAC system, structural specifications, and specialized materials, to be able to convert to laboratory space for a low cost in the future.

The analysis assumed that renovation costs are known, or constant for a specific design. In reality, renovation costs will vary depending on the specifications of the new space and will increase approximately with inflation. It may be possible for the company to enter into an agreement with a contractor to lock-in a fixed renovation cost, and the price of this contract would be included as one of the costs (including architectural, engineering, and construction) whose total sum should be no greater than the calculated option value. To incorporate this information into a life cycle costing analysis (LCCA), it must be assumed that the option will be exercised at some point in time, and an assumed exercise date is needed. Include the initial investment (e.g. no more than \$79/SF for a design corresponding to a \$25/SF renovation cost) and the renovation cost as an expenditure at the exercise date.

5 Conclusion

An understanding of the economic value of flexibility in space use is helpful in planning for and justifying investments in more flexible space. Real options is a growing field concerned with understanding the value of flexibility in physical systems using financial and other types of models. This work elucidated the assumptions needed to apply financial models to the valuation of space-type flexibility, primarily that an underlying asset be identified whose value varies randomly, much like that of a stock price.

By establishing that a market for office space in the proximity of a company's corporate campus exists, a model is created to determine the value of being able to renovate a space into office space using the price of a lease as the underlying asset. Uncertainty in the lease price is modeled using a binomial lattice, and uncertainty in timing of the space need is modeled using an estimated probability distribution and a Monte Carlo simulation. The resulting option values help inform the level of investment in design and construction of a space that could be renovated for a specific price to achieve office space. The option valuation in the case study for BP is but one of many factors the design team will use in the design and decision-making process for its new laboratory. Whereas previous decisions regarding flexibility were made on intuition and expert judgment, the real options valuation will be useful for guiding an economically rational level of investment. The valuation applies to the new laboratory under design to the extent to which it is desirable to have the flexibility to turn any fraction of its space into office space in the future.

As another goal of more flexible space is the potential of reduced throughput of materials, future work is needed to address the correlation of flexibility with environmental, health, and safety goals. Another area of future work is to apply options valuation to capital investment decisions in building technologies that offer operational flexibility. Such technologies include hybrid (mechanical and natural) ventilation and double skin facades. Approaches to valuing these technologies will combine physical models with economic real options models.

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