A Real Option Analysis Approach to Evaluating Digital Government Investment

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Real option analysis has been studied and applied in evaluating information technology (IT) investments for more than a decade. Its advantages over the traditional discounted cash flow techniques have been widely recognized in the information systems (IS) community. However real option analysis has yet to be seen in valuing digital government projects where the real option analysis and option thinking seem to be even more applicable. This study endeavors to fill this void by developing a digital government investment evaluation framework centered on real option analysis, and applying a recently developed option pricing model to a real world digital government project.

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1. INTRODUCTION

Worldwide IT spending will exceed $2.5 trillion in 2005, according to Gartner Dataquest. In the mean time, state and local digital government spending is expected to rebound in 2005 and double by 2008, based on a report from Input – a government market intelligence provider. The sheer amount of IT investments demands quantitative justification. However, traditional quantitative capital budgeting methods such as various discounted cash flow (DCF) techniques including net present value (NPV) and internal rate of return (IRR) are not used or widely used (Bacon 1992, Weill 1993) in IT investment decision making, partly due to their inability to recognize the management flexibility (Dixit and Pindyck 1995, Abel et al 1996).

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Enlightened by the successful application of option pricing theories in finance in the past three decades, researchers have developed real option theories and models, and apply them in a variety of investment valuation problems such as refinery and real estate developments (Paddock et al 1988, Quigg 1993). In IS, Clemons and Webber (1990) first suggest that real option analysis can be applied in IT investment evaluation. Dos Santos (1991) pioneers the application of option pricing model by using Margrabe's asset-for-asset model (Margrabe 1978) in a virtual two-stage project. Following Dos Santos' footstep, researchers have compared, extended, and developed different option pricing models and approaches (Kumar 1996, Schwartz and Zozaya-Gorostiza 2003, Fichman 2004), and applied them in real world IT projects (Benaroch and Kauffman 1999, Taudes et al 2000).

Despite the growing acceptance of real option analysis in IT investments evaluation, study has been lacking in digital government context where real option analysis could demonstrate even greater power. First of all, due to the distributed governing power among local, state, and federal governments, in most cases no one has the final say when it comes to build a collaborative information system. This is exactly the case in the Utah Statewide Parcel and Address Data Management Project (or parcel project hereafter). When Utah state government plans to build a statewide parcel and address system, some counties are supportive and some are not. As a result, the only alternative available to the state government is to build a base system to accommodate the data needs of the supportive counties, while holding the option that the system can be expanded to cover the whole state. Secondly, many of the digital government projects serve a wide spectrum of customers including citizens, private businesses, and local, state, and federal governments, therefore, there could be much greater number of growth options in comparison with IT projects in private sector. Those two characteristics of digital government projects make real option analysis a favorable tool.

In an IT real option, or in any real options to be exact, there is the issue of the existence of estimation errors of the underlying asset value. As discussed in Chen and Sheng (2004), unlike financial options whose underlying asset value is clearly observable as traded in the market, for real options, the underlying asset value is not known with certainty, the estimation errors are inevitable, and their magnitude can be particularly large for IT real options whose outcomes are usually not traded and often time hard to quantify. For digital government projects, the estimation errors could be even larger comparing to the IT projects in private sector because of the consideration of the welfare of the whole society, which dramatically increases the scope to cover and the proportion of unquantifiable benefits. Despite the tremendous effort and progress made by the researchers in real option analysis, before Chen and Sheng 2004, the effects of the estimation errors are at most partially examined using sensitivity analysis and largely ignored, and the systematic modeling and analysis of the estimation errors are surprisingly lacking in IS as well as in other disciplines.

We have discussed the characteristics of digital government projects, the differences between financial options and real options and the estimation errors of the underlying asset value in real option analysis. In Section 2, we illustrate the parcel project and propose a digital government investment evaluation framework. We then introduce a new option pricing model by incorporating the estimation errors as proposed in Chen and Sheng 2004 in Section 3. In Section 4, we empirically apply the new model to parcel project. We conclude by discussing contributions and limitations of this study and future research directions in Section 5.

2. PARCEL PROJECT AND EVALUATION FRAMEWORK OVERVIEW

Parcel and address records provide a common foundation of land information that is critical for a broad range of uses by both the public and private sectors. The Utah State Automated Geographic Reference Center and the State Chief Information Officer's Office have been working together to assess the potential for a comprehensive geographic system of parcel and address data for Utah, and have partnered with the University of Utah on this endeavor since 2003.

Based on the characteristics of parcel project, we have proposed and carried out an analysis framework that synthesizes applicable approaches in the literature to better address the evaluation issues we face in this project. This framework matches the evaluation method to the project's level of progression throughout the system development life cycle (SDLC), and consists of three key phases:

1. Preliminary analysis
2. Pre-pilot analysis
3. Post-pilot analysis

In the preliminary analysis we interviewed individuals from 14 organizations in Utah who represented data producers or data users of parcel and address data, and identified current problems, as well as benefits, features, concerns, and data needs of the proposed system. The data producers are mainly county recorders and assessors who collect, enter and validate parcel and other value-added land information. The data users are defined as any person or organization that uses parcel or address data in their work. Examples of data users that we interviewed include Bureau of Land Management Utah State Office, Utah Tax Commission, Utah Division of Emergency Services and Homeland Security, police department, and title company, etc. The preliminary analysis was completed on January 2004.

The second phase, a pre-pilot analysis, is the focus of this paper. It considers such options as varying implementation scopes and rollout approaches over time with an assumption that the pilot (base) system will cover limited numbers of counties and have some rather basic system functionalities. In this phase, we conduct structured interviews and surveys to gather both qualitative and quantitative costs and benefits information, estimate the parameters needed, and perform real option analysis. Currently we're at the final stage of this pre-pilot analysis. Collection of responses will end by April 2005. But, the data we have collected so far enables us to estimate the perceived benefits based on some assumptions, which we will discuss in details in Section 4.

In the third phase, after a pilot system is designed and implemented, we will find out the actual costs incurred and benefits realized from the pilot system, and decide whether or not to 'exercise' the options we hold with the base system.

The overall strategy is to gradually reduce risk and uncertainty of the proposed project, improve evaluation accuracy and user acceptance, and most importantly, leverage the managerial flexibility embedded as options.

3. OPTION PRICING MODEL CONSIDERING ESTIMATION ERRORS

Chen and Sheng 2004 developed a new option pricing model by extending Black-Scholes model with consideration to the estimation errors that are ubiquitously inevitable in a real option analysis. In this section, we will summarize the parameter definitions, closed form solution, and effects of the estimate errors as illustrated in Chen and Sheng 2004.

Consider an IT real option, assume that its investment cost (excise price) K is constant, its underlying asset value follows a geometric Brownian motion, the investment decision must be made at a fixed future time point T, and there are two types of estimation errors – the estimation error of the underlying asset value at the valuation time (or initial estimation error hereafter) and the estimation error of the underlying asset value at the excise time (or excise estimation error hereafter). Define

$$\begin{aligned} S_E &= (1+e)S \\ S_{TE} &= (1+e_T)S_T \end{aligned} \qquad (1)$$

where S_E denotes estimated underlying asset value at time of option valuation, S denotes intrinsic underlying asset value at time of option valuation, e denotes initial estimation error coefficient, S_{TE} denotes estimated underlying asset value at time of option exercise, S_T denotes intrinsic underlying asset value at time of option exercise, and e_T denotes exercise estimation error coefficient

Further define r as the risk-free rate of interest, s as the volatility of the underlying asset value, and the option value taking account of the estimation errors can be derived as

$$V = SN(d_1) - Ke^{-rT}N(d_2) \qquad (2)$$

where $N(.)$ is the standard normal cumulative density function, and

$$S = S_E/(1+e)$$

$$d_1 = \frac{\ln((1+e_T)S/K) + (r + s^2/2)T}{s\sqrt{T}}$$

$$d_2 = \frac{\ln((1+e_T)S/K) + (r - s^2/2)T}{s\sqrt{T}}$$

$$= d_1 - s\sqrt{T}$$

Formula (2) has the exact structure as the Black-Scholes (1973) model except for the differences introduced by the two estimation errors. In fact, when $e = e_T = 0$, V takes the Black-Scholes option value V_{BS}. Denote V_I as the option value taking account of e only and V_E as the option value taking account of e_T only, the analytic effects of the two estimation errors are summarized in Table I. Basically overestimating initial underlying asset value leads to overvalued option value, underestimating initial underlying asset value leads to undervalued option value, while overestimating and underestimating the underlying asset value at exercise time both lead to overvalued option value and could either magnify or minify the effect of initial estimation error depending on the sign of the initial estimation error.

Table I. Effects of Estimation Errors on Option Value

	$e_T = 0$	$e_T \neq 0$
$e = 0$	$V = V_{BS}$	$V_E < V_{BS}$
$e > 0$	$V_I < V_{BS}$	$V < V_I < V_{BS}$ $V < V_E < V_{BS}$
$e < 0$	$V_I > V_{BS}$	$V_I > V > V_E$ $V_I > V_{BS} > V_E$

4. EMPIRICAL STUDY

The proposed parcel system, when implemented fully, covers 29 counties, and has the potential to serve hundreds of government agencies and private business, and a much larger number of citizens in and out of the state of Utah. The sheer amount of data providers and data users forces us to do a lot of estimations with regard to the costs and benefits, therefore generates considerable estimation errors, especially on the benefit side. This aspect of the project makes option pricing model depicted in last section particularly favorable.

The overall process of option pricing analysis is similar to the traditional cost-benefit analysis except for the incorporation of the value of options. The objective of a real option analysis is to calculate:

$$NPV^A = NPV^P + V$$

where NPV^A is the active NPV, NPV^P is the passive NPV used in traditional cost-benefit analysis for the initial investment, and V is the value of options that embed in the base system. If the active NPV is positive, the initial investment is justified.

In the context of the parcel project, the initial investment could be to build a base system that covers a few counties and may provide flexible multi-county parcel/address data entries/uploads and lookups/downloads and basic data transformation, integration and reporting via the Web. Future growth options may include geographical expansion to cover the entire state, and functional expansion that outlines incremental additions of such system functions or services as seamless integration of statewide parcel/address database and data users' geographical information system (GIS). Although there are abundant growth opportunities with the base system, due to the data availability, we will only consider one option in this study, which is the option to expand the base system to cover the entire state of Utah that has 29 counties. Another rationale behind this treatment is that if taking one option into account makes the active NPV a significantly positive number and therefore justifies the initial investment, the objective to evaluate the initial investment is already achieved. Adding more options into the active NPV calculation will only reaffirm the decision, not change it.

In the pre-pilot phase, we collect the data separately for the two types of project stakeholders: the data producers and data users.

On the data producer side, using semi-structured and open-ended interview methodology, we interviewed county recorders, surveyors and assessors in five counties. We then designed and sent out the survey questionnaire, based on the interviews results, to the data producers in the rest of the 29 counties. So far we have interviewed or received responses from 14 individual or groups of data producers covering11 counties. Based on the data received, while most (13 out of 14) of the respondents recognized the potential risks, problems, or obstacles in creating and using a statewide parcel/address system, and there is not much benefit for the data producers per se, majority (about 64%, 9 out of 14) of the data producers are supportive of creating and using the statewide system, 3 respondents are not supportive, and 2 respondents are neutral. This result strengthened our belief that a statewide implementation at this stage is not only too risky technically and financially, but also politically infeasible due to the distributed governance and lack of consensus among the counties and the state. Consequently, investing in a pilot project that covers limited (supportive) counties would be a good, or maybe the only feasible, strategy, and therefore real option analysis is certainly the best theoretical framework to evaluate this investment.

On the data user side, first a short, 1-page survey was handed out to 60 data users at a GIS conference sponsored by the state government, raffle prize was drawn from those who completed the survey to encourage participations, resulting in 31 responses. Based on the results from the short survey, longer survey was designed and distributed via email to 170 data users. There were 26 responses for this survey so far. Data from both surveys showed that data users are more supportive of the system than data producers (77% vs. 64%), and data users could reap considerable monetary benefits when such a system is available. For example, one agency predicts to save $40,000-$50,000 a year in time and labor by not having to travel to county offices for ownership information. So far, 9 out the 26 respondents reported monetary benefit that adds up to around $130,000 a year, and we will use this number for benefit estimation based the following assumptions:

Assumption 1: The base system will cover five counties and the expansion will cover the entire state of 29 counties. The benefit is proportional to the number of counties covered.

Assumption 2: The data producers who haven't responded yet will have the same benefit as the ones who have responded.

Assumption 3: Both the base system and the expansion will have a lifetime of 10 years. The benefit will be discounted at an annual continuously compounded interest rate of 12% (as in Benaroch and Kauffman 2000).

Using these assumptions we estimate the benefit for the base system B = $905,656, and benefit for the expansion S_E = $4,347,149. We also estimate the cost of the base system C = \$905,656, and cost for the expansion K = \$2,158,145, considering the hardware, software, consulting, development, coordination, and ongoing costs.

For the base system, the passive NPV = $B - C$ = \$905,656 – \$944,382 = – \$38,726. Obviously the base system cannot be justified without taking account of the expansion option. Now let's move on to figure out the option value V.

Using risk-free rate of interest at 6% (as in Taudes et al 2000), we first conduct sensitivity analysis of the option value based different expiration time T and volatility s as depicted in Table II. The results show that in this particular case, the option value is not sensitive to either expiration time or the volatility.

Table II. Option Value Sensitivity Analysis

s	T (year)	V (\$)	s	T (year)	V (\$)
	1	2,320,118	10%		2,544,515
	2	2,462,354	20%		2,546,203
35%	3	2,598,151	30%	3	2,570,828
	4	2,725,180	35%		2,598,151
	5	2,841,717	50%		2,728,922

Given the huge magnitude gap between the option value (more than \$2 million) and the passive NPV (-\$38,726), without loss of generality, we take T = 3 years and s = 35%. Table III demonstrates the effects of the estimation errors with e and e_T ranging from –80% to +80%. The bottom right section of the table shows the option value in US\$. Practically, the estimation errors as high as –80% or +80% are unusual, but keeping them in the analysis gives us some ideas about the effects of the estimation errors under extreme conditions.

Table III. Effects of Estimation Errors on Parcel Project Option Value

		e_T						
		-80%	-20%	-5%	0%	5%	20%	80%
	-80%	19,297,911	19,933,068	19,933,126	19,933,128	19,933,127	19,933,121	19,933,112
	-20%	1,386,572	3,641,886	3,655,608	3,656,154	3,655,749	3,651,873	3,637,539
	-5%	809,645	2,799,081	2,817,884	2,818,679	2,818,072	2,812,005	2,786,816
e	0%	681,426	2,576,937	2,597,276	**2,598,151**	2,597,476	2,590,649	2,561,289
	5%	575,369	2,377,360	2,399,132	2,400,084	2,399,344	2,391,755	2,358,004
	20%	352,708	1,886,518	1,911,901	1,913,061	1,912,136	1,902,327	1,854,462
	80%	62,370	832,003	862,096	863,671	862,320	846,421	742,622

The results in Table III confirm the analytical effects of the estimation errors as illustrated in Section 3 originated in Chen and Sheng 2004. When the two estimation errors are in the –20% to +20% range, the option value (within the dotted line rectangular area) ranges from \$1,886,518 to \$3,656,154, which is far greater than the passive NPV of

-$38,726. When the estimation errors go extreme, though unlikely, for example when e = 80% and e_T = -80%, the option value can be as low as $62,370, only marginally covers the deficit of the base system, and renders the initial investment financially unattractive. But we believe that the estimation errors in parcel project wouldn't be so extreme, or at least not extreme in this way because of the wide coverage of our study and relatively conservative estimation of the initial underlying asset value (which implies that e is more likely to be negative, leading to a larger option value). As a result, we assert that the active NPV will be significantly positive, and the initial investment should be justified despite the fact that a passive NPV without taking account of option value suggests otherwise.

5. CONCLUSION

This study is the first to apply real option analysis in a digital government setting, we make three major contributions in this paper: (1) we propose a digital government investment evaluation framework that centers on real option analysis and impalement it, (2) we apply a recently developed option pricing model that takes account of the estimation errors into a real world digital government investment evaluation, and (3) we explain why real option analysis is a favorable tool to evaluate digital government investment. These contributions build a foundation for future real option analysis research in digital government, and provide guidance for practitioners as well.

The limitations of this study can be categorized to model limitations and data limitations. The option pricing model used here basically extends the Black-Scholes model, but the IT real options are generally more complex than the ones that Black-Scholes concerns (Schwarts and Zozaya-Gorostiza 2003) despite dominance of the Black-Scholes model in real world IT real option analysis studies (Benaroch and Kauffman 1999, Taudes et al 2000). From the model point of view, one limitation is that the investment cost is deterministic and without estimation errors, another limitation is that the cost and benefit are not broken down to components while in reality the heterogeneity of them may require further partition. From the empirical data point of view, due to relatively low response rate at this point, the benefit estimation error could be considerably high. Although on the flip side this limitation demonstrates the advantage of the newly developed option model, we should continue the data process and improve our estimations. Fortunately, in the parcel project, even high (not extreme) estimation errors cannot overturn the investment decision. This might not be the case if the passive NPV and the cost and initial benefit of the expansion option take different values.

Besides remedying the limitations, future research should explore the unique characteristics of digital government projects and develop or borrow appropriate real option analysis models to address them.

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REFERENCES

Abel, A.B., Dixit, A.K., Eberly, J.C., and Pindyck, R.S. "Options, the Value of capital, and investment", The Quarterly Journal of Economics, Aug 1996, 111:3, 753-777

Bacon, C. J. "The Use of Decision Criteria in Selecting Information Systems/Technology Investments", MIS Quarterly, Sep 1992, 16:3, 335-353

Benaroch, M. and Kauffman, R. "A case for using real options pricing analysis to evaluation information technology project investments", Information Systems Research, Mar 1999, 10:1

Black F. and Scholes. M. "The pricing of options and corporate liabilities", Journal of Political Economy, 1973, 81, 637-654

Chen, L., and Sheng, O., "Estimation Errors in Real Option Analysis", Working paper

Clemons, E.K. and Weber, B.W. "Strategic information technology investments: guidelines for decision making" Journal of Management Information Systems, Fall 1990, 7:2, 9-28

Dixit, A.K. and Pindyck, R.S. "The options approach to capital investment", Harvard Business Review, May/Jun 1995, 73:3

Dos Santos, B.L. "Justifying investment in new information technology", Journal of Management Information Systems, Spring 1991, 7:4, 71-90

Fichman, R.G. "Real Options and IT Platform Adoption: Implications for Theory and Practice" Information Systems Research, Jun 2004, 15:2, 132-154

Hayes, R.H. and Garvin, D.A. "Managing as if tomorrow mattered" Harvard Business Review, May/Jun 1982, 60:3, 70-79

Keen, P.G.W. "Value Analysis: Justifying Decision Support Systems", MIS Quarterly, Mar 1981, 1-15

Kumar, R. "A note on project risk and option values of investments in information technologies", Journal of Management Information Systems, Summer 1996, 13:1, 187-193

Luehrman, T.A. "Investment opportunities as real options: getting started on the numbers", Harvard Business Review, Jul/Aug 1998, 51-67

Margrabe W., "The value of an option to exchange one asset for another", Journal of Finance, Mar 1978, 33:1, 177-186

Paddock, J., Siegel, D., and Smith, J. "Option valuation of claims on physical assets: the case of offshore petroleum leases", Quarterly Journal of Economics, Aug 1988, 479-508

Post, G.V., Kagan, A. and Lau, Kin-Nam "A Modeling Approach to Evaluating Strategic Uses of Information Technology", Journal of Management Information Systems, Fall 1995, 12:2, 161-187

Quigg, L. "Empirical testing of real option-pricing models", Journal of Finance, Jun 1993, 621-640

Schwarts, E.S. and Zozaya-Gorostiza, C. "Investment under uncertainty in information technology: acquisition and development projects", Management Science, Jan 2003, 49:1, 57-70

Taudes, T., Feurstein, M., and Mild, A., "Options analysis of software platform decisions: a case study" MIS Quarterly, Jun 2000), 23:1, 227-243

Weill, P. "The role and value of information technology infrastructure: some empirical observations" in Strategic Information Technology Management: perspective on organizational growth and competitive advantage, R.D. Banker, R.J.Kauffman, M.A. Mahmood (eds), Idea Publishing Group, Harrisburg, PA, 1993, 547-572