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USING REAL OPTIONS ANALYSIS FOR EVALUATING UNCERTAIN INVESTMENTS IN INFORMATION TECHNOLOGY: INSIGHTS FROM THE ICIS 2001 DEBATE

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ABSTRACT

Business and information systems (IS) executives continue to grapple with issues of risk and uncertainty in evaluating investments in information technology (IT). Despite the use of net present value (NPV) and other investment appraisal techniques, executives are often forced to rely on instinct when finalizing IT investment decisions. Recognizing the shortcomings of NPV, real options analysis has been suggested as an alternative approach, one that considers the risks associated with an investment while recognizing the ability of corporations to defer an investment until a later period or to make a partial investment instead.

Responding to a growing interest in real options analysis among the IS community, a debate involving four prominent researchers was convened at the 2001 International Conference on Information Systems (ICIS). In addition to offering a tutorial overview of real options, the goal of the debate was to assess the state of research in this area and to identify avenues for future

research. This paper describes the outcomes of the debate, culminating in a series of research questions and topics that set the stage for future research in IT and real options analysis. A transcript of the debate and an overview of real options analysis are included as appendices.

KEYWORDS: Real options analysis, IT evaluation, investment risk, net present value, capital budgeting.

I. INTRODUCTION

Although growing numbers of business and information systems (IS) executives believe that investments in information technology (IT) help boost firm performance, issues of risk and uncertainty due to technical, organizational and environmental factors continue to frustrate efforts to produce meaningful cost-benefit analyses [Tallon et al., 2000]. As is typical of large capital outlays, IT investments are often evaluated using standard discounted cash flow techniques such as net present value (NPV), together with more traditional accounting-based measures such as return on investment (ROI). Despite the availability of such techniques, the uncertainties behind IT investment decisions and the inability of these traditional investment evaluation measures to address these uncertainties, force executives to rely heavily on instinct and gut feeling when finalizing an IT investment decision. A key problem with these evaluation techniques, it emerges, is their treatment of uncertainty[1] and their failure to consider that outside of a decision to reject an investment outright, firms may have an *option* to defer an investment until a later period or to consider an initial or small-scale pilot investment instead.

An approach that overcomes several of these shortcomings is real options analysis (ROA) – a technique usually associated with valuing options on traded financial securities[2]. An option, by definition, gives the holder, the right, but not the obligation to take ownership of an underlying asset at a future point in time. If future events remove or otherwise reduce the key sources of uncertainty to some satisfactory level, the firm may exercise its option and proceed with a full-blown implementation of the IT investment. If, however, the uncertainty continues or is not adequately resolved, the expiration period can be extended or the option may simply be allowed to lapse, thus limiting any downside exposure to future losses. If the firm does not acquire an option and instead makes a full-blown investment at the outset, the size of the loss (and thus the risk) would be much greater if the investment, rather than the option, fails.

Even in situations where an IT investment appraisal yields a negative NPV (usually taken as a signal that the investment should not proceed), an investment could still generate potentially valuable options, which in certain circumstances (e.g., technical risk or other sources of uncertainty are favorably resolved) could make an initial IT investment worthwhile [Kambil et al., 1993]. ROA recognizes, therefore, that a strict application of NPV could give a misleading indication of the total value of an investment[3]. ROA attempts to correct this error by computing an option value against which to compare the option cost. Even in cases where NPV is positive

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[1] For example, in using discounted cash flow (DCF) methods to evaluate high-risk investments, the discount rate is often increased above the corporation's cost of capital to take account of the heightened project-specific risk.

[2] Options on financial securities come in two forms: a call option describes an option to buy, while a put option describes an option to sell. In addition, a European call option can only be exercised on a specified expiration date whereas an American option can be exercised at any time up to and including the expiration date. In this paper, we focus on European call options, where the option is to acquire an IT asset at some future but definite, point in time.

[3] NPV provides a lower bound on the total value of the investment since NPV assumes that the value of the option is zero.

(meaning the investment is profitable and should proceed), there is still considerable merit to using ROA since options-thinking can allow executives to identify favorable opportunities that flow from a particular IT investment decision [Fichman, 2000].

Notwithstanding its attractiveness, however, ROA remains a controversial technique, one that has yet to gain widespread acceptance among U.S. firms. For example, a survey published in the Economist [2000] indicated that of those U.S. firms that had experimented with ROA, over 50% rejected it[4]. While there may be a host of reasons for this rejection, applying ROA in practice is inherently complex. For example, knowing the problems associated with estimating cash flows for inclusion in a traditional NPV calculation, executives may be reluctant to experiment with a technique that involves even more complexity – a requirement of applying ROA is to estimate the volatility of cash flows more so than just the size and timing of cash flows. Finally, researchers are beginning to question if the assumptions behind ROA and the Black-Scholes model, in particular, apply to IT investments. These key assumptions are briefly summarized below:

- Investors are risk-neutral
- An IT asset acquired through an option can be traded in the open market
- Exercising the option will not affect the value of the acquired IT asset
- The variance of the returns (or cash flows) from the IT asset are known
- Exercising an option is instantaneous

In the context of IT, some of these assumptions may be questionable. For example, few executives could assign a credible market value to an investment, especially where the investment is still undergoing implementation such as at the mid-point of an ERP installation, or where it is part of a multi-phase investment, such as upgrading network capacity as part of a wireless networking strategy.

Despite any initial misgivings, the benefits of ROA remain attractive to IT managers who are repeatedly faced with difficult investment decisions involving technical and organizational uncertainty, multiple forms of risk and incomplete information. Any technique that allows IT decision makers to consider risk and uncertainty factors in their decisions is a positive step. What remains unresolved, however, is the extent to which ROA represents an appropriate and useful tool for decision makers seeking to make more informed investment decisions. Given the low levels of ROA use among U.S. firms, it is particularly relevant to ask if the limitations of the technique render it ineffective when applied to IT or whether IS executives are still in a learning phase as to the usefulness of ROA.

To examine these and other issues of relevance to ROA, a debate was held among the top researchers in real options and IT investment evaluation – a debate whose goals were to examine the extent of ROA use in businesses, to discuss the appropriateness of using real options to evaluate IT investments, and to identify any unanswered research questions. To facilitate a lively discussion and to draw out both presenters' and audience members' views, the debate was entitled: "Real Options Analysis is Entirely Appropriate for Evaluating Uncertain IT Investments".

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[4] It is interesting to note that the early history of ROA is similar to that of NPV. When NPV was introduced in the mid 1960's, it was rejected for having unrealistic assumptions and for being overly complex. It was only later, when NPV became a standard function in fourth generation languages such as IFPS and Express that corporations began to slowly adopt the technique.

II. SUPPORTING AND OPPOSING VIEWS FOR THE DEBATE

Whether an individual considers ROA to be appropriate or inappropriate for evaluating IT investments, there is evidence in the literature to support each side of the debate. For example, those arguing that ROA is appropriate may cite the following areas of literature in support of their views:

- Kulatilaka and Venkatraman [2001] argue that opportunities in the digital economy are non-obvious and that by the time they become apparent, the window for investment opportunity may have closed. This argument suggests that in high-risk areas involving emerging technologies such as web-services or wireless telecommunications, both of which are viewed as critical elements of the digital economy, ROA is useful to discovering investment possibilities, particularly for firms seeking to acquire a first-mover advantage.

- While software platforms may not generate value directly, they nevertheless enable different value-generating applications to be implemented [Fichman, 2002]. Their value, therefore, lies in the options they create around building applications [Taudes, Feurstein and Mild, 2000]. Similarly, IT infrastructure projects may involve a "wait-and-see" component that directly follows the logic of ROA [Benaroch and Kauffman, 1999].

- IT related benefits include flexibility and increased responsiveness, both of which can be evaluated with ROA [Kumar, 1997].

- Kulatilaka, Balasubramanian, and Storck [1999] argue that ROA allows IT managers to understand the dynamic impact of risk and the contingent nature of follow-on investment decisions, both of which are likely to be of great value to IT executives.

- Benaroch and Kauffman [2000] note that ROA is useful for structuring executives' views of the strategic value of an investment involving an option and that the use of ROA enables a logical and intuitive interpretation of the investment outcomes. Similarly, Taudes, Feurstein and Mild [2000] note that through ROA, the value generated by an IT project can be explained plausibly and objectively.

On the opposing side of the debate, those who argue that ROA may not be appropriate for IT investments may cite the following in support of their views:

- Researchers question some of the assumptions underlying ROA, such as those involving the tradability and liquidity of the option [Zhu, 1999b] and risk neutrality on the part of the investor [Benaroch and Kauffman 1999, 2000]. If these assumptions are incorrect, ROA could lead to an erroneous IT investment decision.

- Like traditional NPV analysis, it is difficult to obtain accurate estimates of revenues and costs (i.e., cash flows) and in particular, to provide accurate estimates of cash flow volatility [Benaroch and Kaufman 1999, 2000; de Jong, Ribbers and van der Zee, 1999; Taudes, Feurstein and Mild, 2000]. In the absence of accurate estimates, ROA may lead to an erroneous decision.

- ROA may be too complex to communicate to business and IS executives. Relaxing some of the assumptions behind ROA, as Benaroch and Kauffman [2000] did for the Black-Scholes model, may simply create further complexity [de Jong, Ribbers and van der Zee, 1999].

Clearly, aspects of the existing IS literature can be used to support both sides of the debate. What is not in doubt, however, is that the application of ROA to IT investment decisions remains difficult. Despite this, a small number of published case studies have been able to assess the

option value of an IT investment. For example, Benaroch and Kauffman [1999, 2000] use real options to evaluate a point-of-sale deployment retrospectively while Taudes, Feurstein and Mild [2000] describe how an auto-parts manufacturer used ROA to support a decision to upgrade from SAP R/2 to R/3. In both cases, estimates of future cash flows and volatility were carefully considered. Finally, the identification of options that flow from a particular investment and understanding the timing of those options is a constant challenge facing IS executives. Equally important is whether the use of ROA will allow executives to identify and abandon failing IT investments before they escalate out of control [Keil, 1995; Fichman, 2002].

III. APPLYING THE BLACK-SCHOLES OR BINOMIAL MODELS

Although the Black-Scholes model is most often associated with valuing options on financial securities, it has been adapted to valuing call options on non-financial assets [Amran and Kulatilaka, 1999]. Accordingly, the model could be used to value a call option on an early-stage IT investment, though as indicated earlier, there are some concerns as to the validity of the assumptions behind the model.[5] As reference to the Black-Scholes model occurs throughout the debate, the precise functional form of the model appears below together with an overview of the variables in the model (analogous IT variables are shown in parentheses):

Stock price	(present value of cash flows from investment)	V
Exercise price	(extent of follow-on investment in IT)	X
Time to expiration	(length of time that decision can be deferred)	T
Risk-free rate of return	(yield on government bond)[6]	r_f
Volatility	(variance and standard deviation of cash flows)	σ

The Black-Scholes formula for computing the option value (C) is defined as:

$$C = V\,N(d_1) - X\,e^{-r_f T}\,N(d_2)$$

where:

$$d_1 = [\ln(V/X) + (r_f + \sigma^2/2)T] / [\sigma T^{1/2}]$$

$$d_2 = d_1 - \sigma T^{1/2}$$

N(.) = probabilities from the cumulative normal distribution

$V_T - X$ indicates the call option's terminal value

$V_T - e^{-r_f T} X$ indicates the call option's current value

An alternative model in the literature is the binomial model, also known as the Cox-Rubenstein Model. For example, Kambil et al. [1993] used the binomial model to evaluate an early-stage investment in handheld technology in a hospital setting, while in a side-by-side comparison

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5 The Black-Scholes model assumes that prior to exercising a call option, the option-holder does not have a right to receive dividends from the underlying asset. Although an early-stage IT investment may represent an option, a critical distinction is that it may provide benefits to the firm before the option is exercised; a pilot investment, for example, may realize short-term benefits. For this reason, Benaroch and Kauffman [1999, 2000] use Black's Approximation of the Black-Scholes model to represent a dividend paying IT asset.

6 The option value will be higher if a firm's cost of capital is used instead of the risk-free rate of return. Using the risk-free rate will, therefore, generate a lower bound on the option's value.

between the binomial and Black-Scholes models, Benaroch and Kauffman [1999] show that over a period of one year or more (meaning the time to expiration), the results of the binomial model will converge to those of the Black-Scholes model.

IV. KEY POINTS EMERGING FROM THE DEBATE

While a transcript of the debate is included in Appendix I, it is useful to isolate the key points from the debate and to aggregate the comments presented by the speakers and the audience into a series of points and counter points to:

- Present the current state of real options thinking among IS researchers, and
- Identify areas that could be interesting for future research and investigation.

Therefore, the main points raised by each of the four speakers are shown below.

1. Three "Images" in ROA Research Permit Us to Understand Its Potential for Managerial Impact (Rob Kauffman)

Real options research can be broken into three sequential images. The first image depicts the introduction of real options into the IS field, largely as a complement to NPV analysis. The second image reflects a period of intense research activity aimed at applying ROA to IT investment decisions. The third image, recognizing the many difficulties of applying ROA in practice, asks if alternative decision-making or game-theoretic models may be used instead. A number of new opportunities may lie with models that do not require some of the assumptions that accompany the Black-Scholes and other option pricing models.

2. There is a Time and a Place for Real Options Analysis (Hank Lucas)

While justifying IT investments is a complex task, it may not be universally necessary to justify all IT investments. If IT reaches a point where it is seen as a competitive necessity or a cost of doing business – for example, an ATM network in the case of a bank – a cost-benefit analysis is unlikely to sway an investment decision. Accordingly, some IT investments may be more suitable for evaluation than others – real options analysis or NPV need not be applied in all investment situations. Besides providing an option value, ROA should help IT executives to think about the future. The history of IT projects includes partial successes and, in some cases, total failure. In specifying the benefits to be realized from an IT investment, it would help to have those benefits realized within a relatively short period of time after the IT investment goes live. In the IT planning and evaluation phase, it would help to build in probabilities for these benefits so that IS (and business) executives are made aware that the benefits they expect from their IT investments are subject to variation.

3. Real Options Analysis: It's More than Just a Number (Kevin Zhu)

Traditional discounted cash flow (DCF) models ignore the role of active IS management in being able to change the scale or direction of an IT investment. ROA recognizes that management is an important variable in realizing benefits from IT. Fixating on the option value generated by Black-Scholes or other ROA models overlooks the reality that most of the time the number may be incorrect. Accordingly, it may be more important to use ROA to obtain investment insights rather than to dwell on the value computed. At the same time, it may be useful to investigate whether decision, simulation or game-theory models can yield further insights into the investment process.

4. ROA may Provide Insights but Precision is Important (Andy Whinston)

While the assumption of tradability makes it difficult to evaluate IT options, market valuation may still be possible in a small number of areas. For example, it may be possible to observe the market prices of technology services offered by application service providers (ASPs) and then to relate these prices to the value of an internal IT portfolio. In addition, for firms that use ASPs or other service providers, the question is how to structure contracts to take account of market and technological uncertainty, and in this respect, there is a significant element of ROA involved in managing and valuing technology services under contract.

V. CONCLUSION AND FUTURE RESEARCH

One of the goals for this debate was to identify areas of future research. As we consider the contributions of the four speakers (together with comments and questions from the audience reported in Appendix I), several possible areas for future research emerge for which we can offer the following research questions:

- How can real options become more useable or accessible to IS managers?
- In the same way that corporations have a portfolio of IT investments, they may also have a portfolio of real options. For example, a corporation may have made a series of small-scale investments in areas such as wireless telecommunications, web services or mobile computing. Exercising one of these options may impact the value of the remaining options, and so it is useful to ask if there is a way to model the interaction between decisions to exercise different options over time?
- How might strategic factors, such as competition, product innovation and technology substitution, be included in ROA?
- What other decision or game-theoretic models could be used to value real options? These models could explicitly embed options but might not require the same distributional or risk-neutrality assumptions as the Black-Scholes or other options pricing models.

Real options research has now evolved to a point where issues of risk and uncertainty can be incorporated into the decision process. Although ROA models tend to emphasize the calculation of an option value, IS researchers have been trying to steer business and IS executives away from fixating on a single number and instead to use ROA to gain insights into future possibilities enabled by an IT investment.

As we revisit the central theme of the debate as to the appropriateness of using ROA to evaluate uncertain investments in IT, it appears that researchers are largely supportive of using ROA and real options thinking, more broadly, to evaluate IT investments. ROA is not a panacea, however. Applying ROA remains difficult in practice. Its usability is likely to remain an issue for some time as firms struggle to overcome a sense that ROA is a magic bullet for evaluating uncertain IT investments. Research into other models could capture the options embedded in IT and provide further insights into how corporations can benefit from applying real options thinking, but the assumptions behind these models are, arguably, what will ultimately determine how these models are perceived and applied in the work place.

Clearly, the concept of real options and IT evaluation offers much promise for future research, and so we encourage our IS colleagues to accept the challenges that this debate posed.

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We would like to thank Dennis Galletta and Andrew Schwarz for providing a video recording of the debate (from which we created a transcript of the debate – see Appendix I) and ICIS 2001 who gave permission to include a transcript of the debate in this paper.

Editor's Notes:

1. This article was received on August 26, 2002 and was published on September 11,2002. It was with the authors 1 week for 1 revision.

2. Paul P. Tallon served as the moderator of the debate and is listed as the first author. The four panelists are listed as coauthors alphabetically

APPENDIX I: EDITED TRANSCRIPT OF THE DEBATE[7]

INTRODUCTION BY MODERATOR (PAUL TALLON, BOSTON COLLEGE)

Our first speaker is Professor Rob Kauffman who is Co-Director of the MIS Research Center and Chair of Information and Decision Sciences at the Carlson School of Management at the University of Minnesota. Rob's primary research emphasis is on economics of information systems and, in particular, on using economics as a way to evaluate IT investments. He is also looking at software engineering methods and metrics, and at the link between IT and financial services. His work has been published in the top journals such as MIS Quarterly, ISR, Communications of the ACM, and Organization Science, just to name a few.

Our second speaker is Professor Hank Lucas who is a Chaired Professor at the R.H. Smith School of Business, at the University of Maryland. Hank's research emphasis is on the impact of IT on organizations, justification for IT investments, strategy and technology, and more recently, Internet standards and technology adoption. His work has been published in the top research journals including MISQ, ISR, JMIS, and Communications of the ACM. Most recently, in 1999, he published a book entitled, "Information Technology and the Productivity Paradox," which is published by Oxford University Press.

Our third speaker is Professor Kevin Zhu who is an Assistant Professor of Information Systems in the Graduate School of Management at the University of California, Irvine. Like Rob, Kevin's research interests are in the economics of information systems and electronic markets with a focus on the economic and organizational impacts of IT. Recently he has been doing some work on the informational role of business-to-business (B2B) exchanges. He's also looking at strategic IT, evaluating IT investments using real options, network externalities and price competition in electronic markets. Kevin's work has been published in the Journal of Electronic Markets, and he has papers forthcoming in ISR and Communications of the ACM. He has also presented some of his research at WISE – the Workshop on IS and Economics.

Our fourth and final speaker is Professor Andy Whinston from the Graduate School of Business at the University of Texas at Austin, where he is also the director of the Center for Research on Electronic Commerce. Andy's research focuses on numerous aspects of electronic commerce, but in particular, the impact of e-commerce on business protocols and processes. He is also looking at organizational structure and corporate networks, and more recently at electronic publishing and education. He has a broad portfolio of publications, involving more than 250

[7] This edited transcript was prepared from video recordings of the ICIS debate, copies of which may be downloaded from aisel.isworld.org/Proceedings/ICIS/2001/panels/realoptions.asp.

papers. In addition, he is the editor of Decision Support Systems and the Journal of Organizational Computing & Electronic Commerce.

Each of our four speakers will be bringing unique perspectives to the debate but I'd just like to briefly allude to some of the things our speakers will be mentioning in their presentations. Rob and I had a phone conversation last week in which he mentioned that among the things he would like to bring to the debate are insights gleaned from some of his work on real options projects that firms have been working on, while he is also looking at how real options research is beginning to evolve and the direction that the research is taking as we move forward.

Because of Hank's interests in IT business value, we can expect him to allude to the link between real options and measures of IT business value. Kevin will talk about the advantages and pitfalls of using real options analysis, among other things. Finally, Andy will identify some practical limitations with using real options to evaluate uncertain IT investments, but he will then turn around and identify solutions to those practical limitations.

When we were putting together the proposal for this panel and debate originally, one of the reviewers commented that real options is a specific niche area within the IS field and that people in the audience may not necessarily understand what real options are all about. So to make it a little easier, we have taken the liberty of preparing a two-page handout, which you'll find on the seats around the room. [This handout is included as Appendix II of this article]. What the handout is designed to do is to provide you with an overview of real options, particularly in the context of IT investments, and to point you to areas in the literature – books and research papers – which if you are interested in looking closer at real options, you might wish to consider.

SPEAKER 1:
Rob Kauffman, University of Minnesota

Thank you very much, Paul. I have been at this work for quite a while, and during that time I've had the opportunity to watch this area of research evolve in a first-hand way. What I want to do today is point out some of that evolution so that our audience will be able to take away a framework for thinking about real option analysis.

To start out, I want to share with you some of the words of people who have been influential in the development of ROA as a new methodology for IT projects and investment evaluation. First, a quote from Judy Lewent, an MBA graduate from the Sloan School of Management and one-time CFO of Merck & Company, the pharmaceutical concern, from a Harvard Business Review article in 1994:

> *"When you make an initial investment decision in an R&D project, you're paying for an entry. You're paying for the right to enter, and to me, all business decisions are options."*

Then, in that same time frame, Stephen Ross, the Yale University Sterling Professor of Finance said something that really captured my own interest:

> *"I have become convinced that it's time to revisit the usefulness of NPV and to reconsider how much stock we want to place in it. For most investments, the usefulness of the NPV rule is severely limited. If modern finance is to have a practical and salutary impact on investment decision making practice, then it's also obligated now to treat these kinds of major investment decisions as option pricing problems."*

These pronouncements are what I associate with the first image of real option pricing. Our understanding of ROA was based on first glimpses at the new ideas being imported into the IS field from finance and economics. Somewhat earlier, Gordon Sick wrote a monograph on capital budgeting with options that was published in a series by the Salomon Brothers Center for Finance Research at New York University. This book began to give us the first look at some of the new analysis methods that were to come. We also saw a book, now recognized as a major work by Avinash Dixit and Robert Pindyck, entitled Investment Under Uncertainty. Its emphasis is on real option pricing, and it laid out how to use theory and mathematical methods from economics and dynamic programming. Unfortunately, the book is not an easy read for most researchers and managers. But for those of us who were interested in developing fluency with ROA theory, it was worthwhile. With the first image, the ideas that developed were motivated by the perceived limitations of NPV. For example, related to our field, the idea that there is an "information structure" around IT and infrastructure investment that involves the opportunity to defer, a lack of certainty about emerging standards, and other managerial uncertainties. The latter can be characterized in terms of the variance of costs and benefits related to an IT investment, and the basic intuition makes sense to most IS managers.

The early literature also offered us the notion of an option-producing asset that the firm can purchase. This is often called the "underlying asset" in most basic discussions of option theory related to stock options. Going back to Judy Lewent's comments, an option develops when a firm secures "the right to enter" some market or product area or some technology-based business which requires some commitment up front that has some real cost. One can think of IT projects as underlying firm-level assets that permit some sort of "entry" to permit the production of future revenue flows. However, such benefits in the future may be contingent on a number of things in the real world (e.g., consistent managerial strategy, predictable development towards some technology standard, availability of a revenue-producing market). Similarly, organizational learning is something that many of us recognize can change our willingness to invest in the future. Option pricing theory tells us that as time goes by, we learn something about our business world and how it will impact the value of follow-on IT investments that we can make.

Another critical recognition in the early to mid-1990s time frame was the importance of the extent of the likely correlation of costs of investing in follow-on IT projects and the benefits that would come from these projects. Also, we came to realize that ROA permitted us to characterize the distributional mechanics of the cost and benefits flows of IT projects. You may be aware of an article by Kambil, Mohsenzadeh and Henderson that uses the binomial or Cox-Rubenstein model for pricing real options. Similarly, Brian Dos Santos showed us for the first time that with a lack of correlation between cost and benefits, we might see the expected value of projects run very high. This also captured our interest because there were lots of situations where IS managers did not quite know how technical standards would work out and what new business opportunities technological or IT innovation would create.

What came out of this first image in ROA research was a key decision rule for IS managers. In lieu of net present value, which advises investing if NPV is greater than zero, the ROA rule – "MAX (acceptable payment, 0)" – tells you to make a decision that maximizes the value of an acceptable payoff from investing in IT, or to do nothing at all.

The second image of ROA research is where I think some of us became very active. Paul was kind enough to refer to some of Michel Benaroch's and my work in MIS Quarterly and ISR. But there is other notable work that has helped us to think about these problems. I would point to, in particular, the work of Alfred Taudes and his co-authors from the Vienna School of Business and Economics. They applied ROA concepts in the context of infrastructure building with ERP and SAP. Their focus was to understand how one could use these methods to identify the right timing for the development and deployment of different SAP modules.

Other ongoing work has tried to emphasize some of the more theoretical issues. The consistent goal has been to make these concepts our own: to bring them into IS research and, to the extent

possible, into IS management practice. People have tried to understand how we go about validating the existence of options in an underlying IS project, and then how to value them. Similarly, people came to recognize in the 1995 to 1998 period that there were difficulties with the baseline ROA models – in particular with Black-Scholes and the binomial model. These models tend to require assumptions that IT managers would not think are reasonable. For example, the idea of the tradability of an IS project in the open market, the risk neutrality of IS senior management decision-makers and so on.

So, during this time, we started to ask questions about how much we could leverage the theory. I am primarily a theorist in this area, not an empiricist. I want to know how far I can push these concepts before the concepts push back and I find that they have become unusable for practitioners.

Now we are gauging the usability of ROA concepts more fully. In Hank Lucas' book on IT and the productivity paradox, he asks these questions too: Is it possible for practitioners to put some of these ideas into play and come up with meaningful assessments in their own context? Qizhi Dai and I have also been motivated to look into how usable ROA is in the corporate context. For example, we found it difficult to implement ROA for the assessment of various e-commerce investments in a large agricultural industry firm. My assessment right now when we think of management practice relative to ROA, in spite of the efforts made by leading consulting firms to try to put these ideas to work, is that we are still trying to make ROA work, and we are not sure that it will work. The reality here is that corporate consulting practices related to ROA have not gotten to the point where the methods are "ready to serve", yet people expect that they can take these ideas and run with them very quickly. There is a lot of work that still needs to be done in the area of interpretation and translation.

This brings us to the third image of ROA research. I would argue that there are new ways to think about going beyond the first and the second image. I am thinking of a third image that has IS investment decision models that embed options but that don't require all of the elements that make the previous methods difficult to use. These include the distributional characteristics of the payoffs, the underlying project asset, the risk neutrality of the decision maker, and other "perfecting" assumptions that make the Black Scholes, the binomial and other option pricing models work for finance professionals in financial market contexts.

There also should be a marked diminution in emphasis on "the numbers" that come out of ROA assessments. Information technology investment is as it always has been: people are trying to make decisions with a "gut feel" for what will work in their organizations. I think a greater interest today should lie with the intuition, the strategic analysis and the insights that can come from real options assessments, as opposed to the details of the numbers. Take a look at the paper by Kogut and Kulatilaka in Organizational Science from November 2001. You will see a similar perspective in their work. Similar efforts are ongoing too. Notable among them is Kevin Zhu's Ph.D. dissertation from Stanford University. He uses option theory coupled with game theory to do a strategic analysis of technology investment and strategic interactions. I also note Qizhi Dai's ongoing dissertation research at the University of Minnesota. She is working to understand the value of real options in the context of technology solution adoption decision-making as it relates to involvement by buyers and suppliers in B2B electronic marketplaces. Both of these people's work involves analytical models that are intended to give stylized insights into how people should be thinking strategically about decision-making problems with embedded options. They are not intended to try to come up with a specific number about what the value is.

Michel Benaroch and I have already tried to do that. That was the nature of our work in the first ISR paper in 1999. Then in the follow up MISQ article in 2000, our greater emphasis was to see if the ROA assumptions work in practice and if the options framework is implementable. As I've already noted, it turns out that it's not so easy. So I would argue that we have challenge and opportunity in equal measure. We need to move now to the next image of ROA research. We

need to do the work that enables IS senior managers and project managers to really trade on these ideas. Thank you.

SPEAKER 2:
Hank Lucas, University of Maryland

I'm going to do a couple of things that are probably surprising. I'm going to be brief and then I'm going to use old technology, and I'm going to tell a couple of stories, which may not sound very scientific.

The first story I have is that one of the things I like to do when I meet a CIO or IS manager, is to ask them how they go about choosing projects. What is your basis for it? In one instance the guy was really kind of angry, almost, when I asked him this. I said, do you do return on investment? Do you cost justify in some way your IT investments? And he sort of pounded the table and said, "Absolutely! We require in this company a positive return on investment for every investment we make – IT, a factory, you name it, we've got an ROI." So I said, "Well, how do you do that? Do you use only tangible savings that you can justify and document?" And he said, "Well, what we do is, we do the ROI, we decide whether we want to do the project or not, and then we put in the appropriate intangibles." So that was number one.

Number two, when I was doing some work in this area I heard about a woman who had a job at a brokerage firm. Her job was to take the IT investment documents and arguments created by the IT group, and I heard it first that she was a traffic cop. She was looking at these things to decide whether or not they should go ahead to the user community, and in some instances to the board of directors, for approval. Most boards of directors require that above a certain level of investment, you have to take the decision to the board. If you're a brokerage firm a lot of your systems exceed that level. So I called her up and asked to have lunch with her because I was really interested in what a "traffic cop" did in this type of situation. I also wondered how long she was going to last in this position. Of course, the first thing she said to me: "I'm not a traffic cop. What I do is I try to help these IT people construct an argument that makes sense to go forward – to help them evaluate an investment because they're not really used to doing this."

And this particular company had one, very significant, well known project, to redo its broker information system – its workstations for its brokers, and the ultimate price tag on that was sort of thrown around at nearly a billion dollars. So that's a significant investment. The first go-around at it was about $750 million, so you figure that's not a bad cost overrun for an IT project. Then I said, "Well, now, tell me. Did you do an NPV? Did you do an ROI? What did you do on an $750 million IT investment?" And she sort of looked a little chagrined and she said, "Well, actually, there was no analysis done on that." I said, "Excuse me... can you explain that to me please. That's not what the textbook says." She said, "Well, it was a sales organization, the brokers worked for the sales organization." The sales organization – this was a few years ago when the brokerage business was extremely good – said, "you know, the last two years we've made more than enough money to pay for this. We want it, and we're going to pay for it." And the board of directors looked at how much money they were making and they said, "You go pay for it". So that was the investment analysis for a $750 million IT investment that turned into a billion dollars.

So, I began to wonder, where do our academic theories of NPV, options pricing, and any other way you want to look at it, apply? I think they do apply – I think these are two extreme kinds of stories. They are not the average company, if there is such a thing. So what I would like to address, in the first of my two points, is where do you apply investment analysis in the IT field because we don't want to be in the situation of having a hammer running around looking for nails. There are probably places, and this may sound heretical, where it just isn't worth the trouble because there are other criteria for making the decision. So, what I'm suggesting here is that I have tried to describe different kinds of systems.

Let's talk for a minute about IT infrastructure. We all know what that is. Nobody likes to invest in IT infrastructure. That's like being told the foundation to your house is crumbling and you have to shore it up. It doesn't get a lot prettier from that. It's kind of an unpleasant, necessary expenditure. There are systems that are required, so when the government says we need a report for OSHA, I don't think you have to do an ROI on that one. I suppose you could if you wanted to, you get fined or sued, but it doesn't seem worth it. You're going to build the system or you're going to buy it from somebody. There are systems where there is no other way to do the job. How would you start – if you were really crazy enough to do this – how would you start an airline today if you didn't have access to a computerized reservation system? You can't do business in today's travel environment without having that kind of access.

Here are the ones that we talk about a lot in the textbooks. We expect to be able to see a direct return from an investment in technology. There are also some places where we see indirect returns. Those are pretty hard to predict in advance. Rob, Kathie Duliba and I spent more time than I want to talk about – a larger section of our lives than we admit – looking at computerized reservation systems [Duliba et al., 1999] and the indirect benefits that one gets from these. If you want to see another article of that type, look at Orlikowski's [1997] paper on emerging change, which doesn't try to put a dollar and cents value on things, but it says "we put in a system and this is how people used it in an unanticipated, but very positive way."

Competitive necessity – can you be a bank today without having an ATM network? There are things where you really don't have much of a choice. Could Barnes and Noble not put up a website after Amazon.com came along? Did they have to sit down and do a big cost justification of that, or did they say "hey wait, don't spend the time on that, let's go figure out how to build a website?"

There are strategic applications where it's really difficult to figure out what the return might be. And then there's what I like to call transformational IT where you might really be trying to change the whole structure and form of your organization. Again, it is going to be difficult to come up with numbers on these. So what I tried to do is to say, "All right, what kinds of analyses are appropriate, and particularly, can you use options pricing analysis for different categories of IT investment?"

One of the things that Weill and Broadbent [1998] found in their study of infrastructure, which to me was an enlightening and rather discouraging number, they looked at a sample of large companies, where you might expect this to be high and found that 40% of the IT expenditures were for infrastructure.

Now maybe that's an area where if a senior manager is pressing you as to why you're spending all this money, you can construct an argument that your IT infrastructure is something that gives you the option to do something in the future. You just aren't exactly sure what that future might be. But for a large part of these kinds of analyses, you're probably going to have to do them, because you've got to keep a network running, and you've got to keep a worldwide email system operating. If you need a new server, if you need a new router, if you need a new network, you're going to have to do that.

So as I look down this list, there are places where options pricing models may help. I agree with Rob – I think that one of their major advantages is getting people to think about the idea that there's something off there in the future that you may want to take advantage of and you can't do it if you aren't prepared for it. If somebody gives you a lot of grief about those things you can point them to UPS who, about five years ago, decided that they did not have the technology to remain competitive with FedEx and they invested $10 billion over a three to five year period to catch up to the point where they could compete with FedEx on technology, and those are kinds of large expenditures if you don't keep up to date. So my first point is to think about the kind of investment you're making in choosing how to evaluate that investment from an economic standpoint.

The second point I have to make, and this is something that I had fun with. I love the garbage can model.[8] If you've never read Cohen, March, and Olsen [1972] and the others, it's a wonderful tongue-in-cheek description of the way organizations work or don't work. The original model pictures a garbage can full of water with decision makers, decisions, opportunities, and people floating around in a pail and every now and then a decision maker and a situation and a problem come together and something happens in the organization. Well, if you apply this to IT projects we need a slightly larger garbage can because there are so many different entities involved in this. But we have staff members, we have consultants, we have sort of dull systems that we've had for a long time floating up there at the top. I show an anchor down here for our project failures that we'd just as soon forget about so we sink those down to the bottom of the garbage can. Eventually what happens is that out of the end, flows some systems that might provide direct or indirect benefits. There's a lot of leakage in this pipeline coming out for some of these systems that really don't have a great deal of opportunity to show a direct return. There's also some leakage in here because of this thing on the anchor called project failures.

One of the things I would like to call for is that most of our financial forecasts, whenever we are looking at NPV or options pricing, suggest that all of the specifications and all of the benefits that we're predicting for this particular application of IT will, in fact, be there in a year or two when we've finished the project. I would be interested in someone doing some empirical work to find out how many times one gets what they predicted is going to happen in terms of the cost, the time, and the benefits coming back from the system.

So what I'm suggesting is that there is a probability that needs to be included here and that somewhat attenuates the benefits. That is the probability that we will get what we say we're going to get when we make the investment in the project. So those two things are ideas that I would like people to consider as we look at options pricing and other ways to evaluate IT investments. Thank you.

SPEAKER 3:
Kevin Zhu, University of California, Irvine

The way I would start is to look at some examples. Managers often have decisions to make regarding certain kinds of IT investment projects, for example: scalable IT infrastructure. Hank just mentioned a number – 40% of technology investment is made in the area of infrastructure. How are these critical decisions being made? Other examples would include extensible software platforms, open standards, modular ERP systems, customer relationship management, supply chain management, and, more recently, some of the investments in networking and Internet technologies to increase the connectivity of the company with its suppliers and customers.

In thinking about these decisions, what are the best ways to analyze or evaluate them so managers can make a more informed decision, especially for those investment decisions that tend to be very large in scale and involve a great deal of money and resources? So that is the motivation for me to think about what are the relevant measures that would be useful for those kinds of decisions.

The next question, then, is what are the characteristics of IT investment, relative to other types of investment decisions? There are a couple of things I see here, particularly around uncertainty. IT investment decisions tend to embed high uncertainties in terms of technical uncertainties and also market uncertainties. The second characteristic is flexibility. Decision options are often embedded in IT investment projects, especially in those examples I just mentioned such as infrastructure, software platform, and other similar types of investment projects. This means that

[8] For a more detailed description of the garbage can model, see Chapter 2 of Lucas [1999].

managers often have something to do during the lifetime of the project such as changing direction, or altering the scope or scale of the project in response to changing environmental or technical uncertainties.

There is another type of project which I call a sequential project, which means that the investment you made today will lead to some other opportunities downstream. This kind of staged investment will either pave the way or give you a better position down the road for other future opportunities – projects involving platform or infrastructure investments would be good examples of this. So those are some of the main characteristics of IT investments, although this is not a complete summary of IT investments.

Having looked at the characteristics of IT investments, we then study what are the currently available methods that would be useful to think about the investment decisions that exhibit those characteristics. Of course, we can always make decisions based on intuition, judgment or gut-feel, which do have some merit, but sometimes you might run into situations that you want to get some more quantitative methods to help you think about those decisions. Here we have the discount cash flow model or net present value model. Again, this method would be a good starting point, but there is something this method is not very capable of capturing. One is the role of active management. As I mentioned earlier, IT managers or business managers can do something to change the direction of the investment project or reduce or increase the scope or scale of the project. NPV models do not capture these kinds of flexibilities or decision options.

There are other methods – such as decision analysis and simulation – in terms of both quantitative and qualitative methods. Looking across the board, the bad news is that none of them is perfect. We don't have a single method that fits our needs perfectly. Then, relatively speaking, which one would better match the characteristics of an IT investment? From this relative sense, it seems that ROA does have some merit that can capture the characteristics of IT investments as I described earlier.

Having said that, there are also pitfalls that we need to avoid if we apply the real options method to IT investment decisions. The first one is that there is a significant difference between real options and financial options; for example, the tradability and liquidity of an IT asset when compared to a financial security. You can easily buy and sell Cisco shares on Wall Street or in a financial market, but if you wanted to buy or sell a semiconductor plant or equipment – so called real assets – it would be much more difficult. This is what I call the liquidity or tradability issue.

Another difference between real options and financial options is that the exercise of real options often tends to impact the underlying asset. When you are a holder of a financial option, if you exercise it, normally the underlying asset, which is typically the stock of the company, will not change much. Yet, in the world of real options, an exercise decision by the option holder could change the underlying value of the project.

Another issue has something to do with the assumptions that underlie financial option valuation models. When financial economists developed the financial option valuation models such as the Black-Scholes, they didn't keep the needs of the IS community in mind, so there were some different assumptions. Methods, like the Black-Scholes model or even more complex models like compound or exchange options, are often based on non-arbitrage assumptions. Again, they assume that you can replicate the return of your portfolio by some combination of financial securities. We have difficulty doing that to an IT asset. So, realizing these differences and assumptions, we need to be careful. Blind application of ROA could be dangerous and could have misleading results.

Given what has already been said, it seems there is some potential for real options, but there is also some significant challenges for real options, which of course means this is good for research. I think there are at least two main research directions to consider. The first involves

theory development while the second involves theory application, because eventually we want to apply these methods to give some kind of help to decision makers when they face decisions like the ones I mentioned at the start of my presentation.

In terms of theoretical research, we probably need to go back to the assumptions of the financial valuation models to see if we can either relax or change some of them in order to develop models that better fit IT decisions.

Another area is related to competitive interactions among option exercise decisions, considering competitive preemption or technology substitution in IT investment, area that tends to be IT-specific when you compare real options to financial options.

In terms of applications, I agree with Rob. We are more interested in insight than numbers. If we judge the application of the method to the project by numbers, we may be wrong – perhaps 90% of the time, we may be ex-post wrong, though some of the qualitative insights derived from the application of ROA might be useful to managers. For applications, we can apply some of this methodology to real cases, real IT investment decisions, develop some case studies, which is relatively easy to do. I believe some of our colleagues here on the panel are already doing this type of case-based research.

Finally, I would like to share with you some of my own work in this area. A chapter in my dissertation from Stanford University, entitled *Strategic Investment in Information Technologies: A Real Options and Game Theoretical Approach* [Zhu, 1999a], explored a theoretical model that incorporated competitive interactions into option exercise decisions, analyzed through the lens of game theory. There is another paper I presented at the Workshop on Information Systems and Economics, two years ago, in which I tried to apply real options theory to sequential IT investment projects [Zhu, 1999b] . Comparing cash flows with growth options, the primary result is that growth options in IT investment tend to be much more significant than traditional cash flows. I am continuing to do more work in this area. Thank you.

SPEAKER 4:
Andy Whinston, University of Texas, Austin

I want to say first that I agree with most of the earlier speakers, so the possibility of what was billed as a debate with lots of blood flowing may disappoint you, at least so far. Just so that I get in one point of controversy, I was desperately trying to figure out something that I could disagree with and I did find something I think I disagree with! We've emphasized here the importance of insight and I think that is important, but we shouldn't stop at that. That is, insight – and I think Kevin made the most controversial of the points – is that 90% of the time if you write down the numbers, you're going to be wrong. Maybe that's true, but we shouldn't push insight to avoid having a situation where people are wrong because in the end, real options and NPV are supposed to give us precise ways of deciding whether to pursue a project or not. I think the direction that we have to go in, besides the insight – and I would totally agree that the real options idea is much more precise – is to push for preciseness and get people to realize that they have the best information at a certain point in time and they make a better decision. Ex-post, they may be wrong, things may happen, but they have to make a decision based on the numbers and the fact that you're ex-post wrong, and of course the degrees of being wrong, shouldn't just leave us at the level of philosophizing, characterizing and interpreting.

So, as academics, where we can, of course, never be wrong, since we don't really, most of the time, put ourselves on the firing line, we on the other hand have to put the people in businesses, at least encourage them, to be on the firing line and to make mistakes ex-post, but to be correct ex-ante, that is when they make the decisions, they use the best information and after lots of things have happened, which have not been anticipated by anyone, then they may be wrong. The idea of wrong and right, I think, have to be better understood.

So, I'm not going to use transparencies because they cover much of what was presented already. I have a doctoral student, Lihui, who has a handout that summarizes what I will be saying. I tend to ramble as a true academic, so I have the more organized presentation that you can get from her [a copy of the handout is included in Appendix III].

Let me first say a few words about real options and then I want to talk about research opportunities. Real options, as we all know, comes from finance theory, and, as has been pointed out, people in finance have a market orientation so options trade in markets. There's the Black-Scholes formula, there are ideas of replicating portfolios, arbitrage free pricing, all of which give a basis for pricing a traded option. So, again, finance people are very much market oriented in their thinking and the way they approach option theory, although there is a direction in finance theory that looks at non-traded financial assets. In particular, this looks at non-standard options so companies can buy or sell options that are not traded to deal with certain risk management issues, and so there are financial institutions, banks in particular, that will handle that. Then there are issues of valuation based on correlations with traded assets. So, finance theory always tries to relate to markets because they feel that that's where you can get a basis for valuation, and as has been pointed out, we don't have this idea of markets as yet for IT or software services, and I want to comment on that in a few minutes.

So the idea of real options or investments, is that we face uncertain returns and, in particular, in the technology field that we're in, there's a great deal of uncertainty, and to deal nicely with real options, it would be preferable to have, as alluded to, a world where this uncertainty has a kind of binomial form, or in a continuous case of Brownian motion, then we can use some of the results in finance theory. Often though, in the technology field, you may have some radical change, so something impacts the technology that you're using and the valuation and return may change because of something new and that is unfortunately, or fortunately, something that is very characteristic of the IS field. So then one gets into more complex stochastic processes and could get into situations where the calculations, even if you decide to get something very precise, may themselves be somewhat challenging. The thing that we should do from an educational point of view, in my opinion, is get together with our finance colleagues who teach, say, the MBA course in investments and present the net present value idea and to encourage them to present real options and to use examples from IT. That is, instead of us getting into the business of teaching investments in technology, at least in my opinion, is to try to get it into the finance areas of MBA programs and to have real options more of a standard part of that and to get into the issues of irreversibility of investments and the value of an option as a cost that has to be recognized when you exercise it in going ahead with an investment.

So, real options are more precise than NPV and we should make efforts to get it in. Now in the research area, let me mention a few things on behalf of one of my doctoral students, Lihui Lin – I'm going to draw upon her research and present some of the ideas that she's exploring in terms of the role of real options in the IS field. We now have more direction of using application service providers (ASPs). That is, taking technology and buying IT as a service, and having to write contracts with service providers. We have the developments of web services in .NET, where in the future it'll be even more orientation, as Microsoft gets into the business of buying software services or web services and having them delivered over the network and writing contracts for those services. The question is, then, can we write contracts which incorporate some recognition of the uncertainty in the technological sphere, uncertainty in changing technology, networks and the environment, we may have improved technology with improvements in process speed and so forth, and how do we write contracts that provide us with these services where at certain times the buyer can in effect exercise an option that's provided in the context of a contract with the seller to obtain these improvements in the services, so that we can write contracts as buyers of service with sellers that have more anticipation of the changes in the technological environment. There again is where we can start to look at the introduction and extension of contracts within the concept of real options. So, my point then is that finance has a well-developed and well-recognized claim to options theory and to the mathematical development of that field. They have

the celebrated Black-Scholes formula and all sorts of extensions of that, and from an educational point of view, we should emphasize in the finance presentation of investments the real option approach versus net present value with lots of examples from the IS field, because I think they make very good examples, and the finance people are effectively agnostic – they just want to have examples to present their theories and the applications to their MBA students.

But, then, if we're going to do something with it, we have to get into research and I think the research direction is in the future development of web services markets for technology services. Even at some point, if we're going to do things internally and not use .NET, although I think when Microsoft gets itself in place with .NET, that will probably be the direction of things. In any case, you'll have the opportunity within the company to create this replicating portfolio, or at least partially correlate with what is available in the marketplace and get the kind of valuations for real options that you would see in the finance field, and thereby get much more precision, ex-ante with the real option approach. I think there's going to be much more interest in this area as we move towards the direction of creating markets for web services in the same way that we have markets for all sorts of other services, electric power services, for example, and other things that have become much more popular in recent years.

QUESTION AND ANSWER SESSION

Question (Leslie Willcocks, Warwick Business School, U.K.):

First of all, thank you for some very good presentations. I wrote a book called "Beyond the IT Productivity Paradox" [Willcocks and Lester, 1999]. I'd just like to give you some challenges. There are three tests I would like to give real options and ask for your comments on these.

The first is the one that you flagged really, but I'd like to get a bit more detail. One is usability to practitioners, and I think that has four dimensions. One, is it easily understood? Two, is it easy to use? Third, is it preferred? Fourth, is it robust and reliable? So that's the first test. Is it usable to practitioners? The second test is, where it is used, how often does it get it "right"? And the third test is: would it get it "right", more often than if you used something else?

The interesting insight, finally, that I've just put in this line of questioning is, we did a book last year called "Building the E-Business Infrastructure" [Sauer and Willcocks, 2000], and the thing that we discovered is that none of these companies that were getting on very well, doing IT infrastructure well, used real options analysis. What they did do was invest a lot of money in infrastructure and they got their real options from doing dynamic, flexible infrastructure. Isn't that a better route to go rather than play around at the evaluation end of the issue?

Response (Rob Kauffman):

I have the option not to answer it! As to the first issue about usability, I've been there and tried to test that and the answer is: "no," "no," "no," and "maybe," to the first four items that you identified. In particular, the answer is "no" in terms of whether ROA is easy to understand and use for IS practitioners. It requires significant effort on the part of practitioners to learn enough to figure this out. We're in the business of translation. I happen to translate financial economics and evaluative methods from capital budgeting and finance so IS mangers will understand. When I go out and I work with companies, there are people there who know capital budgeting well. But there are others that have a difficult time to understand the concepts behind ROA. Though ROA-based estimates may be right in terms of the "information structure" of the IT investment problems that are being analyzed, they still may not be preferred (see Hank Lucas' remarks earlier in this paper.) Managers who adopt ROA methods still will need to go and talk with other people that ultimately will do the analysis work. More importantly, they will need to get their colleagues to buy into the way that ROA analysis is done and what it ultimately has to say. Often ROA methods clash with other standard practices for IT justification that are used. That's a fact.

The second issue you asked about is whether ROA "gets it right"? My own efforts there have been with respect to traditional infrastructure building, network building, and financial services and recently, with respect to medical technology in one industry, crop forecasting technologies in another, and finally e-business investments. My sense is that where option pricing creates problems for people is in the "dreamscape" nature of how you can think about the range of benefits that will accrue in the future. How do you limit that as an analyst? How do you bring people down to earth and bound their thinking about benefit and cost flows contingent on relevant future events? When is an option so far over the horizon that you don't have any business modeling its cost and benefit flows?

In our MIS Quarterly article, Michel Benaroch and I looked at how well IT managers understand how to estimate variance and volatility in project returns. This is not an easy thing, but it is essential for real option pricing. In the first image, we were excited by what we saw in terms of opportunities. In the second image we began to try to translate and make this "our own," but we haven't been fully successful. Many of us tried the new theory, and brought in new ideas. But I've talked with practitioners, as Hank has, and they want to know if this gives them a better tool for analysis.

A lot of times, I think it's the intuition that changes the way that managers think about the efficacy of ROA, not the numbers. Keep in mind that IS projects don't exist in isolation; they typically exist in groups in project portfolios for an organization. Different projects have different investment and different return characteristics. When you start to think about the power of modern finance methods for portfolio management, asset betas, and the way that project value can move with a moving marketplace, it is clear that IT project value should move with changing standards, organizational strategy, and competition. You begin to see that the intuition of ROA for IT projects gets this right.

Retrospectively, in the area of electronic commerce, I don't think that the application of real option methods would have been entirely appropriate. In many instances there were so many unknowns, marketplace, technology, strategy, competition, regulation, demand, etc., so that trying to quantify the impacts of all of those, and make "the intangibles" tangible, would reduce the reliability of any resulting assessment. I think Hank offers the right advice: you look at what you have to do in terms of competitive opportunity and competitive necessity. Then you make some calls related to your core competencies, rather than entirely by the numbers.

Response (Hank Lucas):

I have a colleague who said to me in pacing in the hall a couple of weeks ago that he knew a consultant who was working in the local area who was applying options pricing theory for clients. So, I said, "gee I'm sorry we didn't know about this about a month ago. Can we have him in for a seminar?" So as soon as we finish the interminable recruiting seminars, we will invite this fellow to come in and try to see what the problems are and if he really is applying options pricing models in his consulting practice.

Question (Eph McLean, Georgia State University):

The last point that Hank made about the idea is that we assume that if we undertake a project that it will be completed and, of course, you look at the statistics figures and it says 73% of all projects are not successful by some criteria, and what it says to me is that too often we attempt to incorporate risk, and discount for risk in our financial metrics, and I would strongly argue that we should consider them independently, but that gut feeling, I look at the financial returns and then I look at the probability that, in fact, they will be realized in terms of the projects. If in fact only one in four are successful, one should argue I look at the option price and the NPV and all the economic aspects and I ask, can my team produce? Can, in fact, we create the project that this investment requires, and that we have or attempt to have metrics for risk that, in fact, will parallel

the investments of the metrics we have for the economic aspects of the project. We don't do enough of that and we tend to embed them. I think managers would be far better off to consider the risk and the probability of success of the project in parallel with the options or other metrics in terms of the value of investment.

Response (Hank Lucas):

In the research I did, I suggested that we ought to weight the returns on an expected value basis by the risk of project failure. Of course, the trouble is most managers don't like probabilities and most IT people don't like to say, "well, here's our risk profile on these twelve projects; we blew it, and on these twenty-four we did all right, so I guess our expected value is .5 times the returns." It's going to be a hard sell. So I think, conceptually, it's a great idea but it's tough to go into a company and get them to think about those kinds of numbers.

Response (Rob Kauffman):

Can I follow up on Eph's comments with my finance professor's hat on? Finance people think about option pricing as a good way to deal with an option to kill a project after a while when it's shown to be a loser, or when it's shown not to provide the right future stream of benefits. In fact, implicit in what option pricing offers are metrics for risk. That's what portfolio management offers, in general. Eph's suggestion is a call to some of us now to look beyond option pricing and to look into the risk management concepts that are available in modern finance. For example, some of you may have heard about "Value At Risk,"[9] developed by J.P. Morgan & Co. and others in the early 1990s. The idea is that asset prices in a portfolio may co-vary and exhibit different levels of correlation relative to shocks in a marketplace, and in the same way, IT projects will co-vary in their potential payoffs with respect to strategic shocks that impact a company and its markets.

Question (Leslie Willcocks, Warwick Business School, U.K.):

I'll be very quick. It's just a slight improvement on what Andy and Lihui Lin have concluded. I think it's a very good conclusion because we've done a lot of research on what we call Netsourcing [Kern, Lacity, and Willcocks, 2002]. You said that the name of the game was to write contracts to exercise options with the sellers to obtain improvements in technologies and networks. I think you should add one element to that, which is, service providers, in the sense that we're finding that service providers themselves are very volatile in getting into contracts and finding that service providers don't deliberate or have gone away is a real contractual issue which real options analysis could address.

Response (Andy Whinston):

Well, I totally agree and I guess in my wording I used a specific reference and, of course, as academics we immediately generalize everything we find and certainly we're looking at the whole service provider industry and at service level agreements in the framework of real options as well as contracts verses spot pricing. So, there's also in terms of having access to net services, as you would call it, or .NET. But, in any case, I certainly agree with you, as Lihui would also.

Question (Eph McLean, Georgia State University):

Andy, your last point about our concept of options and markets and the question is can we move that market perspective into organizations. I'm reminded of Bill Ouchi's work that looks at organization decision making, whether it's for investments or other purposes, using three basics for the phenomena. One, markets and applicability of that within organizations; two, bureaucracies; and, three, plans so that in the first case the idea of decision-making is based on

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[9] For an overview of Value at Risk (VaR), see www.gloriamundi.org .

prices and therefore the price of an option, or options pricing, is very applicable, but, of course, it only handles some things. Then we move to bureaucracies where you have rules to govern and we find out how do we make decisions in this company. What do we resort to? And the last one, which you don't have a lot about this at all, but I think it's very applicable to IT decisions, and that's plans. The idea of plans is: we base our decisions on trust and shared values, and obviously, the way I decide is the way you would decide because we're in the same plan.

If we think about those three, it really goes back to some of the things that Hank was saying, namely, if you're in a situation where prices and markets fit, we have some great applicability here. In the other case, we're looking at, sort of, our internal processes as a bureaucracy or rules.

Then lastly, which is, I think, unfortunately in some cases where most of the decisions that are made is "trust me, boss. This is a decision we're about to make." It really is in fact saying, "We're all part of the same clan. We must decide this together." So, I think if we look at those three, it might offer a little richer perspective on real options in our field.

Response (Andy Whinston):

Of course, you've laid out a huge agenda, which is really the subject of at least one conference. But, the idea, I think, is that when we have markets – and I think this is the idea of finance – when we have markets, we can do a lot of things with markets. We need to have liquidity, active trading, and they give a lot of information that can be used. So one of the points I was trying to make is if we have active markets for software services and we can correlate this with some internal project, then we have a basis for at least looking at the market outside and saying this is an indication of the value of this real option as the underlying investment correlates with something that's traded outside. It's not subject to the other influences that you raise, which are often very subjective, rightly or wrongly. So, to the extent we can have objectivity, which these markets need to have, I think we're in better shape. But, certainly we shouldn't be suddenly saying that markets are going to deal with everything, especially within the organization where we don't have this liquidity, or a basis for creating real markets.

Response (Rob Kauffman):

You know, Andy, I think that we already know about American and European options, but in deference to Eph's ideas, we ought to push the theory a little bit further. I have one more comment related to how far we are with respect to being able to link real options and markets. Part of the argument that I made, and I don't know that I persuaded everyone, but I can tell you that in finance there's as much of a debate about whether you need a full blown market or you don't to make a valuation of real options work well. The closest we've come is the idea that IT projects are part of organizations that, in some cases, are publicly traded and, as a result, the people who make decisions about how to mobilize capital in projects don't make the right decisions. For example, they either over estimate the opportunity cost of capital or under estimate the opportunity cost of capital. It creates opportunities for the market to come and evaluate the firm differently than people who manage and operate the firm. So we've seen over the years instances where IS professionals and executives have seen opportunities within their own organizations that other senior managers and chief financial officers did not. They moved to take portions of their companies to the outside market and create separate corporate identities around newly-identified asset values. That's an aspect of real option pricing that becomes very "real." I would agree that Andy's proposal brings us ever closer to the notion of portfolio replication, no arbitrage, and the discipline of the market.

Question (Lloyd Brodsky, Free University of Amsterdam):

The panel seems to be operating at two levels of abstraction. One is the contribution of the insight and philosophy that abandonment options of future price guarantees are valuable, and I think that

would probably be an easy sell to any executive that has an IT project going south. There's a more complex issue about dealing with underlying markets. The replication assumption is central in market theory.

There really are quite a lot of people with big computers betting billions of dollars looking for price discrepancies that force the Black-Scholes model to work. In IT the closest thing we have to derivative securities are ASPs and web services, but those contracts aren't tradable. The closest thing we have to a really tradable market are the great computing projects that are most closely associated with high energy physics where you could put the hardware on your LAN and lend it to somebody else's project where they dynamically assemble and disassemble super computers for crunching big data sets. The interesting question in terms of doing real empirical work is: to get real options, to what extent do you actually need to fashion models and experiments of how to get basic liquidity and transparency into IT research?

Response (Andy Whinston):

Well, let me take a try at it. It's clear that the issues that we face in terms of getting objective valuations for real options, move to the area of having real options on non-traded assets so the concepts we're looking at are options on non-traded assets, or we can move to incomplete markets. So if we go to non-traded assets, we have to look at options from a more decision-theoretic point of view. We're really away from the finance people who, if you would discuss the decision-theoretic view would say, "leave me alone. I don't want to consider the issue of real options in that setting. It's not finance; it's not of interest to me." So we have to take up a different direction in the research. We start with incomplete markets because that's probably as best as we're going to get. We're not going to be talking about an information project that's trading as IBM or Cisco options are trading. We're not going to have these traded in real liquid markets. I alluded to the fact that we will have, in my belief, .NET, or its competitors. At some point, these will be the closest thing we have to some kind of market based approach to software services, but that remains to be seen.

We need to focus our research on aspects of incomplete markets, which is a very difficult area and is an area of some limited research in finance, all the way to what would be a decision-theoretic approach to real options, which comes from decision theory, which really doesn't require the types of things you get in finance. It's not based on arbitrage, replication, and synthetic portfolio ideas. So, I think we're moving to a new research area and that, of course, is good for IS, because, again, we shouldn't just be taking finance and trying to parade it around here in IS. At the textbook level we have to be our own masters, so to speak. In that sense, we have to work in that area and that's where I think the research challenge lies. So, I think I'm somewhat agreeing with you that real options has its intuition, but when we want to get down to getting numbers and I tried to argue earlier that that's ultimately where we have to go, we're going to have to look more into research and topics that have not been that well developed in finance.

Response (Rob Kauffman):

Can I follow up quickly and comment that this further helps us all to recognize the importance of Leslie's initial set of questions: How usable will these ROA ideas be? What you've just heard Andy describe takes no small effort to try to figure out if you read the finance literature. It also takes considerable effort if you want to encourage the finance faculty to teach that material in MBA classes. And, even if that happens, it's not clear that everyone who conducts applied real options assessments will be able to express the core ideas in a meaningful way to a broad audience of decision-makers and senior IS managers.

Burt Swanson is in the audience today. I'm reminded of Burt's emphasis in years gone by of the importance of argumentation relative to IT valuation. While you can probably tell by looking at the published work that I've done that I have worked through what it takes to incorporate "precision"

in the use of ROA methods. However, I'm also a realist and a pragmatist, so I would like to try to help managers to use these methods.

I was jotting down some notes as I heard Hank speaking, so I have some ideas about research directions. For example, when we get to the point where we have markets for software modules and tradability of the .NET software components that Andy describes, will people still agree on the variance of implementation costs and returns of these tradable assets? What will it take to get convergence with respect to market assessments of value? In addition, if the models are complex, will financial analysts and planners be able to come up with similar models for similar decision-making settings? My experience in a recent project at Cargill and another at Yankee 24 electronic banking network earlier in 1990s was that it is very difficult to agree upon "the model," much less all of the details that belie it. Think of the work that Chris Kemerer and his colleagues did on function point analysis and the estimation of software project size – at least they could get convergence on measurement.

So Andy, with all due respect, I think we have a lot of work to do to try to get to the place that you're suggesting that we can go.

Response (Kevin Zhu):

Since I raised the question of replication and tradability, I think Andy just offered a few solutions; one is the incomplete market approach, while another is decision theory. Decision theory is really looking at the value to the decision maker inside the company, which is where you really get rid of the need for the market. That's kind of a different approach from finance theory, which could be considered a contribution to the IS field. Another thing I want to point out is the recent emergence of electronic markets, especially in B2C and B2B exchanges. That could influence the tradability and liquidity of IT assets. That's something we need to watch for.

Question (Rob Fichman, Boston College):

I just wanted to follow up, Rob, on the comment you were making about usability and options. It seems now we're getting more into the managerial domain viewing real options as an innovation in managerial practice. We can see the option pricing models as being the kind of the technology of real options and then we may have process issues and cultural issues and I wanted to just touch on that last one. If we think about organizations as truly adopting this, I think we'll have some profound changes to their culture. They'll be more interested in taking on risky ventures up front. They also should be more prone to terminating those when the uncertainty ball bounces the wrong way. They should be continuously seeking information about payoffs, especially disconfirming information, which I think all these are a little bit of a divergence from the way many organizations operate, and then looking at failure or termination of a project through a different kind of lens, not necessarily a failure, but just a risk that didn't pay off. So, I'm up to my question now, which is: Do you think that in the absence of these more profound cultural changes that the use of option pricing models is going to add a net benefit or a net loss, actually, to payoffs over the long term? It could be the throwing out of the frying pan of under-valuation into the fire of over-valuation, if you haven't had these complementary changes, and do you have a sense for the feasibility of bringing these cultural changes to organizations, especially Rob, in your consulting practice – you might have a sense for that?

Response (Rob Kauffman):

I think it's hard. We're in this uncomfortable middle ground right now where the organizational cultures that we see have people who are risk-averse decision-makers with respect to very large investments in technology. Hank's example of $750 million at Merrill Lynch is not just a matter of a "career-limiting decision" in one organization. It could impact a lifetime of work, if something goes dramatically wrong. But, underlying the formal models of option pricing is the assumption

that decision-makers are risk-neutral. They look at the payoffs of a project in terms of its expected value, its expected return, and gauge the returns relative to some other projects that have a known and equivalent return.

But that's not the world that we live in. The world that we live in has technological change that is so rapid that if we think in any way like I just described, we know that we're not doing the right thing for our organizations. We have to be modest risk takers and some of these models then begin to disintegrate – the finance models, in particular. Andy has offered the decision-theoretic models as an alternative way to go. I think that we have a unique opportunity on our side of the academic fence as IS researchers. We can look at the way that some of these decision-making approaches are interpreted, are infused into organizations, and ultimately are understood by people. Again, it's a process of argumentation. How well we develop these will be based on how carefully we think through how the organization works as a garbage can relative to investment decision-making, and not an efficient market. It's not going to be easy. It's going to take a while.

Response (Hank Lucas):

One of the points that you make, which I think is very good, is killing off projects because we hear a lot about that. The standard figures would imply that a huge number of projects are killed off. I think they may just be mauled, I'm not sure they're really killed off. What happens is that you do something partially because so many reputations are at stake. A lot of the examples I've seen of projects actually being terminated have been when there's been some kind of a merger or a take-over of a company, and a project that's similar in one company wins over the guy that was taken over. I can think of very few projects that have really, actually been terminated, maybe that's because nobody's going to stand up and have a press conference about that. There were a couple of them in the Clinton administration, there was a new commissioner of the Internal Revenue Service and he stood up and said that we have just spent $3 billion on projects that do not work in the real world. I use that as a classic example, except its kind of sad when you think about whose $3 billion that was. It's very hard to find those kinds of examples, and that's one of the limitations, I think of OPMs. There really is no market for a half-completed SAP installation that I'm aware of. Even if you have a custom system it's just as bad, so there really are significant issues there in trying to do something with a project. So people tend to try to pull them out and put more money into them.

Comment (Paul Tallon):

Unfortunately, we don't have an option on extending the 90-minute time that we are restricted to for the debate. I hope that you've been able to take away from the debate an appreciation of what real options are all about, but also to see the direction that the research is beginning to move in.

Response (Kevin Zhu):

Can I make a brief announcement, or a proposal really? I think given the research issues, there looks like there are a lot of issues, and messy issues that could lead to good research questions and papers. I'm thinking and I'm talking to some of my colleagues here that we could have a special issue of real options in one of the IS journals. The point I want to make here is we should try to do some research and then come back next year or in two years time and have an even more lively discussion.

Concluding Comment (Paul Tallon):

With that I'd like to thank each of our four speakers for their insights and perspectives and to thank you, the audience, for sharing your time with us.

APPENDIX II. HANDOUT ON REAL OPTIONS: BASIC CONCEPTS AND LEARNING SOURCES FOR INFORMATION SYSTEMS RESEARCHERS

Paul P. Tallon
Boston College

The purpose of this handout is to provide ICIS audience members with some background information on real options. Additional sources of information on real options are indicated on the second page of the handout. [These sources have now been included in the reference section of this paper].

WHAT IS A REAL OPTION?

In a financial sense, options refer to the right (but not the obligation) to buy or sell shares of a security such as Dell Corp., at a predetermined price on or before a given date. While real options are similar to financial options, a key distinction is the non-financial nature of the underlying asset being acquired.

WHAT DO REAL OPTIONS HAVE TO DO WITH IT INVESTMENTS?

Investment appraisal techniques such as net present value (NPV) have been widely criticized because of their inability to model uncertainty, a factor that is particularly relevant in the context of IT investment decisions. Even where an IT investment appraisal yields a negative NPV (usually taken as a signal that the investment should not take place), an investment could still generate potentially valuable options, which in favorable circumstances (meaning technical risk or other sources of uncertainty become less critical) could make the initial IT investment worthwhile (see example in Kambil, Henderson and Mohsenzadeh, [1993]). The logic of real options also recognizes that corporations may be able to defer an investment decision into the future until the uncertainty has been resolved, as opposed to making an immediate and perhaps irreversible investment that may flounder if conditions prove unfavorable.

HOW DO I VALUE A REAL OPTION?

The Black-Scholes model is most often associated with valuing options on traded financial securities. This model can be used to value IT options (specifically a call option on an IT investment), though as indicated in the literature, there are some caveats as to the assumptions that underlie the model.

The following variables are involved in estimating the Black-Scholes option value (analogous real option descriptions of these variables are given in parentheses):

Stock price (present value of cash flows from investment)	V
Exercise price (extent of investment in IT)	X
Time to expiration (length of time that decision can be deferred)	T
Risk free rate of return (yield on government bond)	r_f
Volatility (variance/standard deviation of cash flows)	σ

The appropriate Black-Scholes formula is then applied as follows:

$$C = V\,N(d_1) - X\,e^{-rfT}\,N(d_2)$$

where:

$$d_1 = [\ln(V/X) + (r_f + \sigma^2/2)T] / [\sigma\,T^{1/2}]$$

$$d_2 = d_1 - \sigma\,T^{1/2}$$

N(.) = probabilities from the cumulative normal distribution

$V_T - X$ indicates the call option's terminal value

$V_T - e^{-rfT}\,X$ indicates the call option's current value

HOW DO I APPLY REAL OPTIONS TO AN ACTUAL IT INVESTMENT DECISION?

In practice, the application of real options has proven difficult, though not impossible. Several case studies have been published, describing how to evaluate and interpret the options value of an IT investment. For example, Benaroch and Kauffman [1999, 2000] examine an electronic banking, point-of-sale deployment while Taudes, Feurstein and Mild [2000] review a decision by an auto-parts manufacturer to upgrade from SAP R/2 to R/3. In each case, there are a number of parameters, which must be carefully considered: future cash flows, volatility, etc. Benaroch and Kauffman [2000] offer some suggestions for how to address these issues. Finally, the identification of options that flow from a particular investment decision is a constant challenge facing business and is executives. Furthermore, the introduction of "options thinking" into the strategic management of IT is an evolving area of research that tries to identify policies and practices to manage and monitor the value of continuing options over time, including the ability to abandon an option that is unlikely to yield a positive future outcome.

APPENDIX III. REAL OPTIONS FOR IT INVESTMENTS: APPLICABILITY, LIMITATIONS AND SOLUTIONS

Lihui Lin
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INTRODUCTION

Researchers in Information Systems (IS) have begun to realize that real options theory provides useful insights into investments in information technology (IT) [Clemons, 1991; Dos Santos, 1991; Kumar, 1996]. Option pricing models have been used to evaluate real world IT projects [Benaroch and Kauffman, 1999; Panayi and Trigerogis, 1998; Taudes et al., 2000, Schwartz and Zozaya-Gorostiza, 2000]. For example, Benaroch and Kauffman [1999] use a Black-Scholes approximation for an American call option on a dividend-paying stock to evaluate the project of point-of-sale debit service in an e-banking network.

Real options theory recognizes that the ability to delay, suspend and abandon a project is valuable when the value of the project is uncertain. In evaluating IT investments that exhibit high growth potential and high uncertainty, while traditional decision rules such as internal rate of return (IRR) or net present value (NPV) are often inadequate [McGrath, 1997], real options analysis seems to be a better tool [Lucas, 1999]. In practice, IT managers realize that the value of appropriate timing is significant considering rapid technology development and an uncertain business environment.

In this note, we provide a real options perspective on investment and how it relates to IT investments, in terms of its applicability and limitations. We also present some implications of the real option view for IS research and education.

REAL OPTIONS AND IT INVESTMENT: APPLICABILITY

The traditional economic theory of investment is based on the NPV rule, in which it is assumed that either the investment is reversible, or, if the investment is irreversible, the firm can only invest now, otherwise it will never be able to do so in the future [Dixit and Pindyck, 1994]. The real option critique of the NPV rule and the neoclassical investment models that are based on this rule is that a firm with an investment opportunity has an *option* to invest now or later. Once the firm exercises its option to invest, the lost option value is part of the opportunity cost of the investment.

Given that the value of the project is uncertain, when the option value of the investment opportunity is considered, the critical asset value (or the "hurdle" rate) is much higher than that considered by the NPV rule, i.e. the project should be "deep in the money" to justify committing resources. Studies show that when there is high uncertainty, the option value of an investment is significant and as a result, an investment rule that ignores this option value (in effect, assigning zero value to the option) could give rise to a misleading decision. Therefore, because of the innovative nature of IT, it is preferable to use the real options approach to evaluate uncertain IT projects.

REAL OPTIONS AND IT INVESTMENTS: LIMITATIONS

One must also realize that real option analysis has certain assumptions that limit its applicability to IT investments. For example, ROA assumes that the total value of a project – broken into a stream of future cash flows – follows a certain stochastic process. If the project involves the production of a commodity – the price of which can be reasonably regarded as following a stochastic process – then ROA is appropriate. An example of this would be a copper mining project involving a tangible end product [Brennan and Schwartz, 1985]. However, in the context of IT, the output is usually a non-traded IT service. Although IT services are of value to the corporation, attributing marginal cash flows to these services is a complex undertaking, and while this problem may be common to all decision models, the challenge specific to ROA is to justify the assumptions around the stochastic processes for the marginal revenue and costs attributed to the project.

Another challenge of evaluating IT projects using ROA is the difficulty of determining an appropriate discount factor. If investors are risk-neutral, then the discount factor is simply the risk-free interest rate, though it seems unreasonable to expect that IT investors would seek the same rate of return from an IT project as a risk-free treasury bond. Thus risk neutrality cannot be convincingly justified.

If investors are risk-averse, they will demand a risk premium on a project. The risk premium can be calculated according to the rate of return on a financial asset that has the same systematic risk as the project. Under the assumption of complete markets, a financial asset with this level of systematic risk exists and so a portfolio or bundle of these financial assets can be created to replicate the risk in the project. In this way, if the project or cash flows were traded, a replicating portfolio can be constructed from the traded project and a risk-free bond.

In summary, while we can argue that ROA is appropriate for evaluating IT investment, particularly in recognizing the value of timing, we must still accept that ROA is limited by the fact that IT projects are not traded.

IMPLICATIONS OF REAL OPTIONS FOR IS RESEARCH AND EDUCATION

The real options view on investment has important implications for both IS research and education.

From our earlier discussion, we find that while it is appropriate to use ROA to evaluate IT projects, ROA is limited by the fact that IT projects and services are not traded. However, by using industry indices and markets for IT services, it may be possible to make better and more informed decisions on IT investments. Such indices and markets could provide a solid base for estimating the stochastic processes followed by revenue flows generated by IT investments, while trading in these markets would also reveal investors' risk attitudes, offering an objective measurement for the correct discount factor for IT investments. It is worth noting that industry has already begun to develop markets for IT services. For example, the introduction of .Net services by Microsoft Corporation is an example of smart marketplaces for web services.

Real options can be used not only in evaluating IT investments, but also in IT outsourcing and contracting [Lin and Whinston, 2001]. In these situations, the introduction of new markets and industry indices is even more crucial. When one firm is making IT investment decisions, errors in estimating cash flows and the discount factor may lead to incorrect conclusions and cause the firm's value to decline. However, when two parties are trying to contract on an IT project, they may fail to reach a mutually beneficial agreement because of the lack of objective measurement for the value of the project, creating a social cost. The information provided by these service markets can also reduce negotiation costs, which can be a considerable contractual cost in today's IT-intensive firms.

While real options theory has been taught in financial investment courses, its relevance to IT investments has not been reflected. Greater cooperation and interaction between IS and finance faculties could help to change this situation.

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EDITOR'S NOTE: The following reference list contains the address of World Wide Web pages. Readers who have the ability to access the Web directly from their computer or are reading the paper on the Web, can gain direct access to these references. Readers are warned, however, that

1. these links existed as of the date of publication but are not guaranteed to be working thereafter.

2. the contents of Web pages may change over time. Where version information is provided in the References, different versions may not contain the information or the conclusions referenced.

3. the authors of the Web pages, not CAIS, are responsible for the accuracy of their content.

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