Real Options Methodology Applied to the ICT Sector: A Survey (*)

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Abstract: This survey focuses on the application of real options methodology to the information and communications technology (ICT) industries. It examines the development of the methodology to areas as diverse as wireless cell site investments to dynamic pricing issues. In addition to aiding the reader in understanding the breadth of the applications, it demonstrates the importance of the topic. It provides a guide to the reader who is interested in exploring the topic in greater depth.

Key words: Discounted cash flow, economic methodology, information and communications technology (ICT), investment, investment under uncertainty, options, present discounted value, real options, valuations.

The real options approach uses the tools of financial options to value real (physical) assets instead of the traditional present value or discounted cash flow approach. Because the tool is better able to capture the dynamics of investments, its supporters claim it is a better tool to evaluate investments. On the other hand, critics contend that the theory has not yet been critically assessed, empirically verified, nor have its benefits been demonstrated [1]. We cannot settle this debate, but we feel that the research and evidence are beginning to mute this criticism.

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[1] An anonymous referee provided this insight.

The real options approach has been applied to several industries, such as mining (BRENNAN & SCHWARTZ, 1985; KEMMA, 1993; SLADE, 2001), oil (PADDOCK *et al*., 1988; PICKLES & SMITH, 1993; DIAS & ROCHA, 1999), pharmaceutical (MICALIZZI, 1999; HARTMANN & HASSAN, 2006), airline industry (STONIER, 1999), and electricity (DENG, 2001; JOHNSON & SOGOMONIAN, 2001) [2]. Although the application of the methodology has been made to a variety of industries, we focus on the application of real options to the ICT sector. Recently, along with the wide acceptance of real options, many academics and practitioners are actively working to apply real options in the information and communications technology (ICT) sector [3].

Research studies in the ICT sector (e.g., CLEMONS, 1991; DOS SANTOS, 1991; KAMBIL *et al*., 1993; KUMAR, 1996; CHALASANI, JHA & SULLIVAN, 1997; ALLEMAN & NOAM, 1998; BENAROCH, 2002; ALLEMAN & RAPPOPORT, 2006; PINDYCK, 2004, 2005a, 2005b) have recognized the importance of utilizing the theory of real options to justify the option-like characteristics of ICT investments. Although the theory of real options provides a theoretically rigorous framework to analyze the optimal exercise of options, people have expressed a number of concerns related to the efficacy of applying option pricing theory to ICT sector.

We hope this review will give the reader a good foundation to begin understanding and appreciating the significance of this approach, particularly in the policy setting.

The paper is organized as follows: The first section provides a guide to the literature for the reader who would like to explore the topic in greater depth. The second section examines real options applications to the ICT sector. This section is sub-divided into a general overview of real options in the ICT sector; capacity planning and network optimization; standards and patents; regulations and policy; and other ITC applications. We close with a brief summary.

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2 Due to space limitations, we do not describe the nature of real options approach and methodology in detail. Many illustrations of the technique and applications of real options are available for the interested reader, including those in this volume – KRYCHOWSKI (2008), SUTO, ALLEMAN & RAPPOPORT (2008), and SADOWSKI, VERHEIJEN & NUCCIARELLI (2008) – provide a review of the methodology. We will not repeat these here, but refer the reader to the next section in this paper – “Guide to the Literature”.

3 We use ICT for the internet, telecommunications and information technologies. For the narrower portion of the ICT sector – computer networks and software, etcetera, we use the phrase information systems and technologies (IST).

■ Guide to the literature

For a novice to the field, we recommend MAUBOUSSIN (1999). He gives a brief introduction to the concept and application of real options. The books and article below direct the reader to more in-depth analyses on the topic.

For a broad review of the literature on real-options research, the reader is directed to TRIGEORGIS (1996), who survey the relevant work from the financial perspective and to DIXIT & PINDYCK (1994, 1995), who reviewed and developed it from the economists' perspective. For a briefer account, see DIXIT & PINDYCK (1996). DIXIT & PINDYCK and other economists usually look at the delay option. For a comprehensive, but not detailed treatment of real options AMRAM & KULATILAKA (1999) is useful. The second part of their book has case studies of most of the real options applications – growth, abandonment, switching, and start-up – unfortunately, it is not easy to duplicate their results in many of these studies.

The finance literature is fuller in its coverage of the various aspects of all of the options available to a firm. HULL (2009) has an extensive coverage of theory and application of financial options (and a chapter on real options), which are necessary to understand real options. BODIE & MERTON (2000) cover options theory and value as well as a section on real options in their financial text. Similarly, BREALEY *et al*. (2006) have three chapters in their corporate finance text which addresses options, valuing options and real options, respectively. BENNINGA (1997) has examples of how to calculate real options with step-by-step instructions for spreadsheets.

Several books explicitly devoted to the real options methodology and applications have been published in this century. BRANCH (2003), COPELAND & ANTIKAROV (2001), and MUM (2002) are useful general introductions. While the COPELAND & ANTIKAROV (2001) book is sub-titled *A Practitioners Guide*, it concentrates on setting up and solving a variety of real options problems. They do not address the application of the techniques except the one chapter on case studies. BRANCH (2003), *Real Options in Practice*, and MUN (2002), *Real Options: Tools and Techniques for Valuing Strategic Investments and Decisions* live up to their titles. Both are more narrative in style, but MUN (2002) supplements its material with several appendices and a CD-Rom which develop the calculations routines.

DIXIT & PINDYCK (1994) is a comprehensive book on modern 'real options' theory in the 1990s. This book covers the topic, based on real options valuation on how companies can manage to succeed when they must function in a world where strategies must be determined in the face of large risks, with large potential payoffs and losses at stake. The three aspects that authors deal with in their theory are the 'irreversibility' of costly fixed plant and equipment, the 'uncertainty' of the information base upon which the probabilities will be estimated, and the 'timing' of the investment project over a series of future time periods.

HULL (2009) is a comprehensive book on the subject of options. It provides the basis for understanding the underlying principles for valuing derivative instruments, such as futures and options. The study of the option pricing model begins in Chapter 8. Chapter 10 on one-step binomial tree model leads to an intuitive description of risk-neutral valuation. Chapter 11 introduces continuous time stochastic processes in an intuitive setting. Chapter 12 is devoted to the Black-Scholes-Merton theory of option pricing. Chapter 32 is dedicated to real options.

■ Applications to the ICT sector [4]

Overview

Real options are applicable to a variety of situations: The resource sector (petroleum and mining industries), real estate, electric utilities, and pharmaceutical industry. Real options have been used to evaluate the price of commodities, patents, standards, and merger and acquisition decisions. In general, real options applications have an element of risk involved in the decisions such as the strategic behavior of competition, uncertainty of demand, the outcome of research and development (R&D) projects, etcetera. The development option is the classical application of the real option methodology. DIXIT & PINDYCK (1994) and TRIGEORGIS (1996) are the established volumes on these options. Other options are enumerated in TRIGEORGIS (1996) including learning, growth, abandonment (shut-down), switching, and start-up. Resources development and R&D are some of the early applications. When to develop the resource or continue the research and when to abandon it are applications of the methodology.

[4] In this survey we do not evaluation the specific methodology used to solve the real options problem nor do we address explicitly the calculations methods used. These are the significant issues, but are covered adequately in the literature previously cited.

These early applications were made a decade before the methodology was to be applied to ICT industries. However, since the late 1990's a growing literature exists in the applications of real options to the ICT sector.

HAUSMAN (1997, 1999) was among the first to suggest that real options had relevance to the ICT sector. Clearly, the "option" to lease unbundled network elements (UNE) is a simple application of options theory, although unrecognized as such by policymakers. Unfortunately, many of his insights were lost in the internecine squabbling among the antagonists in the policy debates at the time. Most commentators agreed that sunk costs were an important component of the industry and this is where real options could offer insights in the application of access charges (ALLEMAN & RAPPOPORT, 2006; PINDYCK, 2004, 2005a).

ALLEMAN & NOAM (1999) edited articles was among the first books exploring real options applications to the telecommunications sector (see below). But despite its title, it offers little practical advice on the application of real options to the ICT sector, although, taken as a whole, the volume demonstrates the need for real options applications. The first two chapters (TRIGEORGIS 1999; BHAGAT 1999) have an introduction to real options.

SMALL (1998) also was an early exponent of real options. He studied investment under uncertain future demand and costs with the real options method; while his analysis offered insights, it was neither detailed nor sophisticated in his approach. Similarly, ERGAS & SMALL (2000) applied the real options methodology to examine the sunk cost of assets and the regulator's impact on the distribution of returns. They attempted to establish linkages between regulation, the value of the delay option and economic depreciation. More recently, ALLEMAN & RAPPOPORT (2006), in a different context, develop the linkage to depreciation and also showed how the methodology could be applied to optimal pricing. As the approach has become better understood, more applications have developed. For example, D'HALLUIN *et al.* (2004a) have applied real options methodology to an ex post analysis of capacity in long distance data service. They show that the over-capacity of the network could possibly have been avoided with the application of real options. The same authors also applied the methodology to the determination of cell site replacement in wireless service (D'HALLUIN, *et al.*, 2004b). Similarly, PAK & KEPPO (2004) have applied the approach to network optimization; and KULATILAKA & LIN (2004) apply the methodology to strategic investment in technology standards.

Pricing

The principal use of the application in the ICT sector has been in pricing issues. It is to this area we now turn. Several papers have addressed interconnection and access pricing issues. HAUSMAN (1999, 2002) has applied the real options methodology to examine the sunk cost of assets and the delay option in the context of unbundled network elements (UNEs). PINDYCK (2004, 2005a) has refined this analysis. PINDYCK (2004) shows that failure to account for sunk costs leads to distortions in investment incentives and distortions in unbundled network elements, a variant of access pricing. Similarly, PINDYCK (2005a) shows that sharing of infrastructure at rates determined by regulators subsidizes entrants and discourages investment when sunk costs are not properly considered in the determination of the prices. He suggests how these prices can be adjusted to account for sunk costs. Similarly, HAUSMAN & MEYERS (2002) estimate the magnitude of mistakes by the failure of regulators to account for sunk costs, while applied to the railroad industry; it has ready applications to the ICT sector. HORI & MIZUNO (2004) have applied real options to access charges in the telecommunications industry. LOZANO & RODRIGEZ (2005) use a lattice approach (for its intuitive appeal) to show that access prices are higher than the traditional net present value approach.

CLARK & EASAW (2003) address access pricing in a competitive market. They show, as have others, that when uncertainty is considered, the price should be higher than under certainty. Entrants should pay a premium to enter the market in order to reward the incumbent for bearing the risk of uncertain revenues. ALLEMAN & RAPPOPORT (2006) consider the sunk costs as an opportunity cost. Their paper determines the efficient access price in the regulatory context by combining the results of real options methodology and a variant of the efficient component pricing rule.

In a different context, PINDYCK (2005b) demonstrates how sunk costs serve as an entry barrier and demonstrates its effect on market structure. This is significant from the policy perspective, since one of the instruments used by regulators and relied on by legislatures is competition. This paper demonstrates that competition is not viable in the context of large sunk costs and, by implication; the promotion of competition via a variety of "handicapping" devices is inefficient and wasteful. One could say that this has been demonstrated with the FCC's failed competitive local exchange carrier (CLEC) policy initiatives, or at least this was a major element in this failed policy (ALLEMAN & RAPPOPORT, 2005).

HORI & MIZUNO (2004) analyze the open access policy in public utility industries, industries characterized by large sunk costs, that is allowing competition to enter the market with the alleged effect of increasing efficiency and innovation. The authors justify the use of real options approach to analyze this competitive environment based on the irreversibility of investment under uncertainty. They address the delay option as well as sequential opportunities for investment timing. The model uses an equilibrium approach to analyze the effects of competition and access charges, as well as bypass of the charges. Competitors' strategy can be access, bypass or access to bypass.

The social benefit of the access charge is analyzed. It found that only the regulatory pricing policy that can be used to achieve the social optimum is usage access charges. In addition, lump-sum subsidies and taxes are needed to achieve socially optimal timing.

All of these papers have in common the assumption of large sunk, irreversible costs. They show that the access prices are not only incorrect, as expected, but uniformly show that the current regulatory approach calculates access prices that are below those that would be suggested by using the real options methodology.

Capacity planning/Network optimization

Capacity planning is the set of long term decisions enabling firms to expand or reduce capacity in response to stochastic demand fluctuations or other economic changes. Capacity establishes the firm's overall level of production output capability and costs. Hence it determines the firm's future performance. It is a strategic decision

Four papers address the issue of capacity planning or network optimization with real options methodology. D'HALLUIN *et al.* (2004a) have applied real options methodology to an ex post analysis of capacity in long distance data service. The same authors also applied the methodology to the determination of cell site replacement in wireless service (D'HALLUIN *et al.*, 2004b). Similarly, PAK & KEPPO (2004) have applied the approach to network optimization at a given capacity.

The PAK & KEPPO (2004) paper assumes a fixed capacity and then determines how to minimize network blocking or delay in case of traditional calling or buffered (internet) networks, respectively. Their model does not optimize the capacity.

The flexibility to change the network routing is modelled as an option. A change in routing is considered exercising the option. The number of nodes (or routers) along with the uncertainty of network demand for different routes determines the value of this option and routing. This model's routing selection is based on the future network blocking possibilities – a stochastic process – and the correlation among the demands for different routes. The optimization is based on maximising profits, i.e. revenues minus costs. Not surprisingly, the authors find that the lower the correlations among demand and the higher the demand uncertainties, the more the alternative routing are used. Thus, the network routing options are more valuable.

All of the authors find the methodology useful to the capacity and network optimizations problems.

Standards/Patents

KULATILAKA & LIN (2004) examine a first entrant into a market with a new technology. In contrast to the decision to invest or not in the technology, the authors ask "Should the firm license the technology to a competitor or keep it proprietary and if licensing, what is the optional royalty rate?" They also point out that, in general, the "first-mover" firm has the incentive to establish this technology as a standard, particularly if the technology exhibits "network effects", because this may dissuade the competitors from pursuing other technologies which may be superior to its own. The authors cite Google as implementing this strategy successfully. Their model calculates the optimal royalty based on real options methodology. The investment in technology generally represents a sunk or irreversible investment; thus the company can defer, or become the "first-mover" and encourage competitors to accept the standard and license it to them. The stronger the network effects, the greater the royalty that can be demanded; and the stronger the network effects, the lower is the value of the option to defer.

In a 1999 court case, Grain Processing, in the United States, provided a potential patent infringer with the opportunity to test the validity of the patent, and, if found valid, the infringer only has to pay a reasonable royalty, on a "but-for" argument. That is, the infringer could have use of a technology which would be indifferent to its consumers, but inefficiencies i.e. more costly to produce, than the infringed technology. According to HAUSMAN, LEONARD & SIDAK (2007):

> "By providing potential infringers with increased option value if they use the patented technology, Grain Processing [the court's decision] reduces the deterrent effect of litigation and therefore encourages infringement. Consequently, it reduces the returns to research and development, and so also the incentives to innovate."

Regulation and policy

Regulatory constraints can affect the valuations of the firm's investment which, in turn, has an adverse impact on consumers' welfare. In particular, the inability to exercise any or all of the delay, abandon, start/stop, and time-to-build options has an economic and social cost. ALLEMAN & RAPPOPORT (2002) point out, inter alia, as they do in their other papers on the topic (ALLEMAN & RAPPORT, 2005, 2006, 2008) that the introduction of uncertainty can make a significant difference in the valuation of a project or company.

The Alleman/Rappoport paper attempts to quantify regulatory issues with real options methodology. It uses the impact of the regulatory constraint on the volatility of the cash flow to show that regulatory constraints on this cash flow will have an impact on investment valuations. A model is developed to estimate the cost of regulation for broadband service, which shows that the cash flow constraints and the inability to delay and abandon have a significant cost.

The Telecommunications Act of 1996 mandates network sharing, as do regulatory authorities elsewhere. PINDYCK (2005a) addresses the impact on investment incentives of these arrangements. He focuses on the implications of irreversible investment. He notes that "[…] the goal is to promote competition; the sharing rules now in place reduce incentives to build new networks or upgrade existing ones." These network investments are irreversible – a sunk cost [5]. The basic framework adopted by regulators allows entrants to utilize such facilities at prices reflecting what it would cost a new, efficient, large-scale network to be built. Such sharing opportunities are extensive, covering virtually the entire suite of network services provided, and are extremely flexible, as the entrant can rent facilities in small

[5] Note the goal is for competition, not efficient investment, a mistake in our view.

increments for short duration, with no long-term contracts required. Because the new entrant does not bear the sunk costs, this leads to an asymmetric allocation of risk and return that is not properly accounted for in the pricing of network services, which creates a significant investment disincentive.

In a related work, PINDYCK (2005b) explains the importance of real options in network share and antitrust economics. He explains the difference between sunk costs and fixed costs, and the definition of the option to invest. The author defines sunk cost as "an expenditure that has been made and can not be recovered, even if the firm should go out of business," and fixed costs as "an ongoing expenditure… [that]… can be eliminated if the firm shuts down". The author also explains that under uncertainties, sunk costs (lump sum upfront payments) are risky, thus representing an entry barrier. Besides economies of scale, inherent to fixed costs, sunk cost also represents a significant entry barrier. Additionally, sunk costs include the option value while fixed costs do not include it. This means that when a company decides to make an investment it foregoes the possibility to invest this money in another project or business that might generate a higher value. Therefore, it is important to account for the option value as a sunk cost when evaluating potential investments.

Pindyck introduces real options as part of the analysis of sunk costs. He concludes that the net present value analysis is incorrect because it considers the possibility "to invest" or "not to invest", ignoring the possibility of waiting to invest later.

Pindyck also addresses how firms learn from others (examples are R&D projects and oil explorations). However, learning from others might also be an incentive to wait. If all the firms are waiting for the other to invest, this could lead to inactivity. If one firm invests, it is likely that the others will also do the same thing. The externality is that the firm that decided to invest first might not benefit from this decision at the same level as the other firms did. Under antitrust considerations, this situation might lead to inefficient underinvestment.

All of the above papers show that real options cannot and should not be ignored by the policy community.

Other ICT applications

Several other applications of real options are possible. Below we address application in cellular development, and then we turn to the information systems and technology (IST) sector.

HARNO (2004) examines UMTS technology rollout in Western Europe; he analyses the value of the 3G services for France, Germany, Italy and United Kingdom. Since the project can be phased according to the density of the market (urban, suburban, and rural), the author uses a real options methodology to determine whether to delay or abandon the project at each phase after the initial one. These results are compared to traditional DCF methods. The author finds that the loss of potential revenues makes the defer decision unwise no matter which technique is used.

For evaluating investment of information systems and technologies, the theory of real options has been applied to assess the potential business value of investments (PANAYI & TRIGEORGIS, 1998; TAUDES, 1998; BENAROCH & KAUFFMAN, 1999; BENAROCH, 2002; CLEMONS & GU, 2003; FICHMAN, 2004). Similarly, SCHWARTZ & ZOZAYA-GOROSTIZA (2003) develop options models which take into consideration the effect of uncertainty in costs and benefits associated with IST investment opportunities, using data on the deployment of point-of-sale debit services by the Yankee 24 network as reported in BENAROCH & KAUFFMAN (2000). CLEMONS (1991) has shown that IST related benefits include flexibility and increased responsiveness, both of which can be evaluated with real options. KUMAR (2002) develops a framework that is intended to aid in understanding decision support system value.

SAHA (2006) evaluates information systems as an enterprise architecture decision-making process. Because investments involve multiple risks, there are several potential ways for a firm to configure investment paths using series of compound options. Real options must be deliberately planned and intentionally embedded in a target investment in order to incorporate managerial flexibility and risk control mechanism. SAMBAMURTHY *et al.* (2003) conceptualize IST-enabled capabilities as options which impact organizational agility in exploiting future business opportunities.

Given the high uncertainties underlying investment and its indirect effects, the application of real options to the information systems and technology field has mostly been used to justify strategic investments in information technologies that provide a long-term view of business value, using illustrative examples; Integrated Services Digital Network (ISDN) services (DOS SANTOS, 1991), Credit Card Services (CLEMONS & GU, 2003), electronic banking (BENAROCH & KAUFFMAN, 2000), SAP R/3 software (TAUDES *et al.*, 2002).

Software platforms may not generate value directly, but they enable value-added applications to be implemented (TAUDES, 1998; FICHMAN, 2004). Their value lies in the options they create around building applications or serving as platform investments (TAUDES *et al.*, 2000; DAI *et al.*, 2000). Software design (SULLIVAN *et al.*, 1999) is analyzed as an investment activity and introduces options thinking to improve design decision-making. For instance, TAUDES (1998) evaluates sequential exchange options in order to obtain estimates for the value of software growth options. TAUDES *et al*. (2000) used an options model to quantify the benefits of switching from an earlier-generation software, SAP R/2 to the next version, SAP R/3, for a real-world manufacturing company.

BENAROCH & KAUFFMAN (1999) provides a formal theoretical grounding for the validity of the Black-Scholes option pricing model in the context of the spectrum of capital budgeting methods that might be employed to assess IST investments. Their paper shows why the assumptions of both the Black-Scholes and the binomial option pricing models place constraints on the range of IST investment situations that one can evaluate that are similar to those implied by traditional capital budgeting methods such as discounted cash flow analysis. Finally, the paper presents the first application of the Black-Scholes model that uses a real world business situation, which is the deployment of point-of-sale (POS) debit services by the Yankee 24 shared electronic banking network of New England. In another article, BENAROCH (2002) found that the embedded option within investments is a crucial task that allows organizations to configure investment in order to effectively address business risks.

BALDWIN & CLARK (2001)'s book has been the first to observe that the value of modularity in computer system design could be modelled by the real options approach. Assuming that a product was designed in a modular fashion, authors analyzed the effect of modular design on product development performance by quantifying the value of modularity in terms of increased design flexibility. They applied the theory of real options to show that the mix-and-match feature of modular design could dramatically speed the rate of performance improvement.

As can be seen from the above review, we have only begun to scratch the surface of possible applications using the real options methodology.

■ Summary

All of the authors in this survey, starting with DIXIT & PINDYCK (1994), NICHOLS (1994) and TRIGEORGIS (1996) demonstrated that decisive benefits are provided by real options and play a critical role in analyzing generic investments. All projects embed real options, when management has the ability to make future decisions about the project in response to changing market conditions and business environment.

Although investments can deliver substantial value to firms, managers are confronted with the measurement of their value. So, a framework for providing a disciplined analysis of the value-creating capabilities of investments (PANAYI & TRIGEORGIS, 1998) is needed. In view of the inability of traditional discounted cash flow (DCF) methods to gauge the value of flexibility under uncertainty, the real options approach has emerged.

Lack of consideration of real options methodology has distorted investment timing and magnitude. Investment decisions become more critical as competition enters the field and ever larger investments are required in the ICT infrastructure. Ignoring real options implications may underestimate entry barriers, thus overestimating the ability of a competitive market structure to function.

These papers offer powerful arguments to consider sunk costs in pricing, capacity and network issues, as well as antitrust economics and regulatory and public policy concerns. They also offer a good explanation on how the magnitude of the option value is directly related to the level of uncertainty of future market conditions. We hope you not only enjoy reading this review, but that it opens your eyes to a new and innovative technique in investment evaluation.

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