

# Real options in infrastructure projects: theory, practice and prospects

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Developed from financial options theory and pricing models, real options have evolved to become a mainstream area of academic inquiry. This account traces the field generally from its origins to present day. Research has demonstrated the potential for real options to enhance project value by managing uncertainty through investment, structuring and design decisions. Despite this, real options theory is not widely used as a whole or within the discipline of infrastructure development and construction project management. The creation of infrastructure occurs almost exclusively in a project-based environment. Not surprisingly, project managers play a pivotal role in the success of such projects and make frequent decisions that shape and reshape implementation strategies. Perhaps, the path towards disseminating real options into infrastructure project practice is to improve the understanding of the managerial environment and behaviour. Hence, the characteristics of infrastructure projects and project management underpin six propositions, which need further investigation to aid bridging the chasm between the notion of real options and its application in actual project settings. Each proposition is linked to the literature and project management practice.

*Keywords:* Infrastructure, research dissemination, project management, real options.

## Introduction

Development projects often include many types of uncertainties that can determine project success. Project uncertainty can thwart efforts to meet performance targets, increase project value or otherwise drive project behaviours and results. For example, uncertain project durations can impact financial performance targets negatively if the project is late and liquidated damages must be paid. In contrast, uncertain material prices can increase profits for a lump sum contractor if those prices drop after bidding and before material purchases. Whether handling uncertainty is considered risk management or benefit enhancement is based largely on targets and perspective (Ford and Lander, 2011). In spite of this, successfully managing uncertainties is critical for project success.

Uncertainty management can take many forms, including avoidance of uncertainty, shifting of impacts to others, creating buffers to absorb impacts or

providing flexibility to respond in different ways contingent on how uncertainty resolves. Flexibility can be particularly effective for managing uncertainty in projects (Miller and Lessard, 2000). Organizations that build proactive flexibility in the form of options into project decisions and plans create opportunities to influence project performance.

Generally, an option—in the context of this discussion—is a right without the obligation to change action in the future depending on how uncertainty resolves. As an example, a project that develops two technologies to fulfil a need may, but does not have to, switch from the default or reference technology to the alternative if that alternative becomes more attractive. The added cost of the second technology is the option's cost. Switching to the alternative technology is 'exercising' the option, a decision that often must occur by an 'exercise date' and incurs an exercise price to implement. Hence, the value of an option is the difference between the values of the underlying asset (e.g. the project) with and without the option.

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Options were developed in the financial markets to provide investors the opportunity to take alternative positions relative to a financial asset, so both the buyer and seller usually expect future asset price uncertainty to resolve in their favour. As financial options became commonplace, researchers in the fields of finance and decision science saw similarities between financial options and firm investment decisions as well as project planning choices. Consequently, the field of real options—where the underlying asset represents a real or tangible product or project—developed to account for the uncertainty inherent in areas such as natural resource production and infrastructure development. We trace the origins and evolution of real options over roughly the last half century, emphasizing developments in theory and practice. This account leads us to the well-known issue of transferring the theoretical and conceptual appeal of real options into professional practice. Within the domain of infrastructure development and construction projects, the dissemination challenge is prevalent; however, the issues are somewhat complicated by the complexity of these projects. Our exposition posits several propositions that warrant further investigation to convert real options from largely a theoretical construct to routine practice.

## Origins

The roots of the notion of financial options may be traced back to 1900 and the French mathematician Louis Bachelier. Bachelier's dissertation *The Theory of Speculation*, although effectively ignored for 60 years, characterized security price behaviour as a random walk and discussed evaluation of stock options (Fama, 1970). In the 1970s, Merton, Black and Scholes solidified the theory of pricing financial options with their seminal works (Black and Scholes, 1973; Merton, 1973).<sup>1</sup> Their work, later recognized with the Nobel Prizes, became the foundation for future study of both financial and real options.

Subsequently, Myers (1977) introduced 'real options' when describing the discretionary future investments of a firm as call options. Real options differ from financial options in that the underlying assets are real assets that are often not traded and represent, for example, contingent decisions to delay, abandon, expand, contract or switch project components or methods. While Myers is typically credited with coining this term, others had long recognized that conventional firm investment and capital budgeting approaches did not properly account for strategic considerations or managerial flexibility. Dean (1951) was one of the first financial economists to contemplate the discrepancy of capital budgeting methods to

address managerial behaviour. Magee (1964) suggested the use of decision-tree analysis to overcome the problem. In fact, Magee's underlying premise was that the wrong framework was being applied. Interestingly, the debate between finance and decision theorists about the treatment of managerial flexibility has continued into this century, but more on this is given later.

By the 1980s, the subject of options was receiving substantial attention. Modelling research was focused on alternative valuation approaches, such as the discrete-time, binomial method developed by Cox *et al.* (1979), as well as various option types such as an exchange option (Margrabe, 1978), a compound option (Geske, 1979) and sequential compound options (Carr, 1988). Schwartz and Trigeorgis (2001) noted that these lines of inquiry 'opened up the potential, in principle, to value investments with a series of investment outlays that can be switched to alternative states of operation, and particularly to eventually help value strategic inter-project dependencies'. In other words, the quantitative underpinnings necessary to determine the objective value or price<sup>2</sup> of a variety of real options had been formed. Real option theorists were not idle during this period; Schwartz and Trigeorgis (2001) also traced efforts that began as early as 1979 to value various real options, quantify the value of strategic decisions such as phased investments, utilize numerical methods to handle real asset behaviour that is not analytically treatable and apply real options concepts and methods to various sectors ranging from manufacturing to large-scale projects.

## Evolution

As the theory and field of real options developed, the research—and debates—have coalesced generally around four major themes: (1) the interaction of strategy and finance theory, (2) valuation methods, (3) theoretical frameworks and (4) applications.

## Strategy and finance

Hayes and Garvin (1982) continued the discussion started by Dean when they questioned the utility and capacity of conventional capital planning and budgeting practices; they argued that the standard discounted cash flow approach decreased the willingness of managers to make capital investments since it relied too heavily on correct perceptions of past and present economic conditions and was often applied incorrectly. Later, Myers (1987) discussed the apparent disconnect between finance theory and strategic planning; this work was, in part, a response to prior criticisms. In

doing so, he described several discretionary investment opportunities confronting a firm as real options. He concluded that ‘strategic planning needs finance. Present value calculations are needed as a check on strategic analysis and *vice versa*. However, the standard discounted cash flow techniques will tend to understate the option value of growing, profitable lines of business’. So, Myers recommended extending the theory of capital budgeting to incorporate option pricing models. Barwise *et al.* (1989) followed suit with a similar argument. With a ‘call to arms’ so to speak, a litany of works began to do just that. By the start of the twenty-first century, several notable books on real options, devoting significant attention to strategic considerations during investment decision-making, had been published (e.g. Dixit and Pindyck, 1994; Amram and Kulatilaka, 1999; Trigeorgis, 1999; Copeland and Antikarov, 2001).

### Valuation methods

Merton, Black and Scholes provided the foundation for the continuous-time models used in real options, while Cox, Ross and Rubinstein did the same for discrete-time models. Since then, many researchers have extended the basic building blocks. Trigeorgis (2001) provided a comprehensive but succinct review that, among other things,

- explained the significance of the replicating portfolio concept—first recognized by Cox and Ross (1976)—that enables risk-neutral valuation; this presumption is often employed in real options models,
- described works, such as those of Mason and Merton (1985) and Kananen and Trigeorgis (1994), which emphasized that like conventional capital budgeting, the point of real options valuation is to determine the worth of an option as if it were traded in the market; hence, the presence of a reasonable replicating portfolio or ‘twin security’ in the market is enough for real options models and
- discussed the use of numerical methods for more complex real option situations where analytical solutions are impossible or impractical such as backward induction in Monte Carlo simulation (Barraquand and Martineau, 1995; Broadie and Glasserman, 1997) and finite difference schemes (Brennan and Schwartz, 1978; Hull and White, 1990).

Risk neutrality is worth special attention since it is rather pervasive in real options work. Since flexibility and asymmetry characterize option payoffs, this indicates a fluctuating discount rate over time, which is

problematic for traditional discounted cash flow methods. Assumption of risk neutrality overcomes this problem by transforming the actual setting into a risk-neutral world. Here, risk preferences and the expected return of the underlying asset are eliminated, so all assets appreciate at the risk-free rate; furthermore, the volatility of the underlying asset in the options model remains, consequently project uncertainty is still captured. The main assumption behind risk neutrality is that the market is complete, so that a tracking portfolio can be found among traded assets, which allows replication of the cash flow from the option (a form of the ‘no arbitrage’ principle). Thus, when movement of the underlying asset is spanned by a complete market, options can be valued as if investors are risk neutral, since assets are available for them to hedge the uncertain cash flows. When the initial value for a project and market prices of the underlying assets are unknown or difficult to estimate, a risk-neutral analogy is often difficult to imagine since investors in this case do not have complete market securities and information to track or hedge the cash flows. Indeed, projects with these characteristics are relatively rare in today’s world. Cash flows from infrastructure projects, however, can still be reasonably tracked by traded proxies in the market, albeit with some difficulty and error, despite the specificity of projects and the infrequency of real asset trading.

### Theoretical frameworks

As has been mentioned earlier, Magee’s early work proposed decision-tree analysis to support investment decisions as a way to explicitly account for different types of risks and changes in conditions with time. Since then, finance and decision theorists have pondered various frameworks for coping with this issue. As the debate evolved, the core of the argument became the treatment of private (non-systematic) and public (systematic) risks. This delineation distinctly recognizes that there are limits to the applicability of the risk-neutral or no arbitrage principle. Dixit and Pindyck (1994) proposed assessing the characteristics of a project before committing to a theoretical framework. Specifically, their approach looked more carefully at the elements contributing to project uncertainty. If a project is dominated by public risks, then the approach assumes that changes in the value of the project will be spanned by existing assets in the economy. Therefore, an analyst should use a constructed tracking portfolio to value options. Alternatively, if the project is dominated by private risks, then the spanning assumption does not hold. Hence, an analyst should use decision analysis techniques to value options. Smith and Nau (1995) also recognized that real asset

investments typically possess both public and private risks, but countered that one should not be forced to determine which type of risk is dominant. Their hybrid framework combined techniques from decision-tree analysis and risk-neutral option valuation. Like that of Dixit and Pindyck, the basic assumption underlying this method is that the market is only complete enough to allow hedging of public risks. In other words, any public risk can be hedged by a traded asset, but a private risk cannot. So, a decision tree is built where subjective probabilities are assigned to events characterized by private risks, while risk-neutral probabilities are determined for events typified by public risks. Borison (2005) provided an efficient synopsis of the alternative theoretical frameworks generally used in real options analysis, spanning from what he called the classic approach—no arbitrage principle applies and market data available for twin security—to the hybrid approach—Smith and Nau’s framework.

In the domain of infrastructure projects, de Neufville *et al.* (2008) made an important distinction between the types of real options with their notion of options ‘on’ projects versus options ‘in’ projects. Options ‘on’ projects are concerned with flexibility such as the ability to defer, phase, abandon or accelerate projects; the literature is ripe with examples of these options. Options ‘in’ projects are concerned with optimizing technical systems by providing deliberately the flexibility to alter systems such as to expand capacity or to switch sources of fuel. This distinction is significant since the latter option involves engineering and design decisions more so than investment decisions. In many instances, these types of options are embedded in engineered or technical systems or processes. As de Neufville *et al.* pointed out that ‘Options enable system operators to reconfigure their system when appropriate to do so. They give system managers the flexibility to defer choices until later on, when they have seen how the future actually develops’.

### Applications

As the theory, models and frameworks associated with real options developed, so too did the applications. Brennan and Schwartz (1985) provided an early, well-known application to natural resources (copper and gold). The work has applied real options in nearly all industry sectors ranging from manufacturing to land development to infrastructure projects and more generally in settings such as research and development. Many have examined options in the context of infrastructure and construction (e.g. Moel and Tufano, 1999; Ford *et al.*, 2002; Ho and Liu, 2003; Zhao and Tseng, 2003; Chareonpornpattana *et al.*, 2004; Cui *et al.*,

2004; Garvin and Cheah, 2004; Ng and Björnsson, 2004; Ng *et al.*, 2004; Zhao *et al.*, 2004).

## Current state

### General

Today, the field of real options is well established within the academic environment and in some professional settings. Research in the field continues. An annual international conference is now in its 16th year. Generally, consensus exists about real options concepts and the value of real options ‘thinking’, but this consensus has not necessarily translated into mainstream practice (Lander and Pinches, 1998; Graham and Harvey, 2001; Triantis and Borison, 2001; Triantis, 2005; Coleman *et al.*, 2010). For example, Ryan and Ryan (2002) surveyed 205 Fortune 1000 Chief Finance Officers and found that only 11.4% use real options, while 96% use net present value. Block (2007) found only slight improvement (to 14.3%) in the following five years. Baker *et al.* (2011) surveyed Canadian firms, finding that only 16.8% reported using real options. Several explanations for the slow adoption have been offered. Amram, a leading real options researcher, stated that ‘We’ve missed something important. To communicate, [real options analysis] has to be transparent and clear’ (Teach, 2003).

Triantis (2005) directly addressed this issue in his five challenges that must be met to take real options from an appealing theoretical concept to a useful practitioner’s tool: (1) improve real options models to better reflect reality, (2) understand ‘split’ real options that are owned by multiple agents, (3) model managerial behaviour, (4) develop heuristics and (5) link real options values to the value of the whole firm. Each of Triantis’ challenges suggests an explanation for the slow adoption of real options by practitioners. Others (Lander and Pinches, 1998; Schmidt, 2003; Teach, 2003) believe that the cause of slow adoption is a lack of knowledge and understanding of real options by managers and some believe that the education of current and future managers about real options (e.g. in MBA programmes) will successfully address this barrier, resulting in widespread adoption and use. Another explanation is that quantitative real options models rely on too many assumptions that may be reasonable for pricing financial options but are not accurate for many real options and, therefore, cannot price or value real options accurately. If practising project managers suspect that this is true, they are likely to avoid these quantitative models. Yet another rationale concerns the mathematical complexity of some of the models. Many have suggested that the use of sophisticated mathematics such as stochastic calculus limits

the accessibility of such models to average decision-makers.

### Engineering and infrastructure project domain

Similarly, research in academic settings within the engineering and infrastructure disciplines continues (e.g. Mattar and Cheah, 2006; Chiara *et al.*, 2007; Brandao and Saraiva, 2008; Tseng *et al.*, 2009; Menassa *et al.*, 2010; Shan *et al.*, 2010; Ford and Lander, 2011). Evidence also exists that improved management of uncertainty would bolster infrastructure project performance. For example, Miller and Lessard's (2000) study of 60 large (\$985 million average cost and 10.7 years average duration) engineering projects concluded that project success depended largely on the amount of uncertainty and how these uncertainties were managed. However, the general explanations offered for the low adoption of real options techniques do not necessarily include or address the unique characteristics of infrastructure projects and managerial behaviour. Foremost, the managers of infrastructure projects work in a 'risk-rich' environment where many risks must be managed for project success; many of these risks can cause large decreases in project performance and risks are interdependent. This situation promotes practices that focus project management on limiting negative exposure to uncertainty rather than on capturing upside potential and thereby limits the potential benefits of real options use to risk reduction. Additionally, the management of large-scale infrastructure projects is quite complex when compared with many real options contexts, including

- the management of multiple production activities that routinely employ a wide variety of resources, methods and technologies,
- the coordination of labour, materials and equipment within an environment that is temporary and time constrained,
- the management of business, environmental and safety risks before, during and after projects and
- the leadership of a diverse set of stakeholders who often have uncommon interests towards a common goal.

Indeed, many projects are multi-million dollar, multi-year enterprises where the opportunity to 'get it right' is limited, and little or big mistakes may not necessarily be absorbable for either the project manager or organization. These features and characteristics of the construction industry make it fertile ground for the use of real options. They also contrast sharply with the financial options and many real options that have been the basis for most real options models. Moreover,

researchers in the infrastructure domain (and elsewhere) have argued that the assumptions in many real options models do not fully reflect actual project conditions (e.g. Lander and Pinches, 1998; Alessandri *et al.*, 2004; Garvin and Cheah, 2004; Ford and Sobek, 2005). Many of these criticisms are familiar: well-behaved future asset values, complete markets for assets, arbitrage opportunities, few and independent options and the independence of option holders from the future performance of the underlying asset.

### Outlook for real options in infrastructure projects

#### Probing the dissemination challenge

From a scholarly perspective, the capacity of real options to add project value has been adequately demonstrated, and the failure to disseminate real options widely in practice has been documented. Spanning the gap between real options theory and the derived pricing models and real options use in professional settings is a central, if not the foremost, challenge of real options research. Many of the issues regarding real options dissemination into infrastructure development and management practice reflect the challenges put forward by Triantis roughly five years ago. Only the magnitude of the problems is likely greater due to the nature of this industry and its projects. One might conclude that the gap between real options theory and infrastructure project practice is too wide. If this is the case, then research in this domain will remain a hobby of academics, where no harm is done but no benefits are accrued.

Closing this gap requires re-examining critical aspects of the construction industry and infrastructure projects. Specifically, infrastructure development is well known for its project-based organization. As such, project managers play a dominant role; they make most, if not all, of the key decisions throughout a project's lifecycle. In other words, once the decision to initiate a project is made, an array of project managers are constantly making choices among alternatives ranging from organizational structures to task sequencing to material procurement. These types of decisions are likely to have real options akin to the 'in' project options previously described since such decisions involve proactive measures that managers may take to alter project outcomes in the face of uncertainty. Consequently, realization of the much-talked-about potential of real options—at least within the realm of infrastructure projects—may result through a better understanding of the managerial environment and behaviour of these critical individuals.

### Propositions to bridge the dissemination gap

Six propositions may explain the real options theory–application gap in infrastructure projects. Each proposition integrates real options and project features into a partial hypothesis for the failure to fully exploit real options in infrastructure project management. Each proposition is described, linked to infrastructure management practice, supported as critical to spanning the dissemination gap by linking it to one of Triantis' (2005) five challenges and reinforced with the literature.

**Proposition 1** *Real options models assume many repeated bets but project managers make one-shot choices.*

An important characteristic of projects is that the typical project manager oversees one or a few projects at any given time. Therefore, most opportunities to use a specific option occur infrequently and often only once per project. This creates a relatively short-term and local perspective of managing uncertainty in many project managers. One result is the perception of risk as exposure to isolated events, as opposed to average outcomes across a diverse risk portfolio. An exposure perspective assumes that the worst-case scenario will occur and makes decisions to improve these worst-case outcomes. In contrast, a probabilistic perspective presumes that decisions are made based on the average of many possible outcomes and managers seek to improve the average. Research using controlled experiments supports the existence and common use of an exposure-based perspective of risk (Li, 2003). In these experiments, subjects preferred a chance with a lower expected payoff and a higher minimum payoff (i.e. less exposure) to a chance with a higher expected payoff and a larger chance of no payoff. The subjects took an exposure-based perspective by preferring to improve their worst-case scenario instead of maximizing their expected value, even though they were provided and understood the reward structure.

An exposure perspective can be (locally) rational because a modest to significant failure in any one project may have very substantial consequences for the project manager's career or professional status (e.g. demotion, dismissal or loss of professional licence). A bias towards an exposure perspective is exacerbated in situations where the project manager works in an organization that does not have a diversified project/risk portfolio, and the isolated failure can cause cascading consequences throughout the organization. In such a case, the local perspective is rather appropriate since a significant mistake by a project manager could actually put the organization in severe financial distress.

The distinction between an exposure and probabilistic perspective of risk is important because not all options increase project value, even when priced

accurately and the price indicates that the option should be purchased. Whether an option *actually* adds value or not depends on uncertainty resolution and managerial decisions (the proper application of an effective exercise decision rule). If the uncertainty resolves such that the option should not be exercised and the correct managerial decisions are made, then the option purchase and maintenance costs are paid without capturing benefits. These options *decrease* project value. They are recommended because they are valued based on the average payoff of the many possible outcomes, as if the manager was making many repeated bets on how the uncertainty will resolve, for example, as if the same or similar circumstances and option will occur many times and the option holder will capture the average of all the benefits and losses. Infrastructure project management practice often differs markedly from this assumption. Project managers face many one-shot choices where they will likely only experience the circumstances and options once. This encourages an exposure-based perspective of risk and can create problems for managers of options with only a single opportunity for the option to add value.

Consider the simplified example of a construction project that is expected to fall behind schedule. The expected completion date is 100 days after the original deadline, with a range of possible delays ranging from 50 days to 150 days. Overtime can be used to change the expected completion date to an average of 85 days late with a range of 50–100 days. Alternatively, the project manager can purchase an option to improve productivity that will change the expected completion date to an average of 75 days late with a range of 40–125 days. A project manager with an exposure-based perspective of risk (e.g. who fears being dismissed if the project is over 100 days late) may apply a one-shot perspective and use the single worst possible conditions to select a strategy instead of a probabilistic perspective that uses average values. In this example, this would result in the manager using overtime instead of purchasing the productivity option because overtime reduces project exposure (the maximum completion delay) from 150 to 100 days, more than the improved productivity option, from 150 to 125 days, even though improved productivity would better the average project schedule performance 10 days more, by 25 days (from 100 to 75 days) instead of the 15 days with overtime (from 100 to 85 days). With all the other things being held equal and if averages prevail, the productivity option adds more project value than the overtime strategy. But the manager rationally chooses overtime based on his or her one-shot, exposure-based perspective that precludes waiting for the average payoff.

What might cause a project manager to take either an exposure-based or probabilistic perspective and make the very different decisions that each suggests? One or both the following factors might explain this. First, project managers may foresee circumstances in which they must explain an expense to obtain or maintain an option that, in hindsight, did not add project value because the option was not needed. Using expected values allows valuation with uncertain futures but also makes the value added by any one option uncertain. Project managers may avoid such strategies that are difficult to defend, even if they can add more value. Second, the choice of an exposure or probabilistic perspective may depend upon whether the project manager can survive the potential losses in value that may occur if either the option is not exercised or wrongly exercised or if losses exceed benefits before the law of averages evens out and the long-term net value of the real options is realized. This choice depends on the manager's time horizon and risk tolerance and the incentive structures used by an organization for its project managers. If the project manager adopts an exposure perspective, he or she is likely to act conservatively and only execute low-risk, low-payoff options. In contrast, if a probabilistic perspective is adopted, the project manager can rely more on the law of averages in decision-making and use more high-risk, high-payoff options.

One argument against an exposure perspective being a rational barrier to real options adoption is that the option should be considered similar to insurance, in that the option cost (insurance premium) is justified for the increased protection from loss (insurance coverage) whether the option is exercised (claim made) or not. This is essentially an argument for a probabilistic perspective. The competitive nature of the construction industry can explain why practitioners do not implement this policy. To remain competitive in many bidding circumstances, firms cannot afford to include the cost of loss-limiting (i.e. put) options and remain competitive because a competitor will assume that the uncertainty will resolve in the desired way such that the high expenses will not occur or that they can be recovered, such as through a deadline extension. Laryea and Hughes (2011) found construction bidding behaviour that supports this explanation. Such a 'hope-for-the-best' practice of not including protection for uncertain conditions is fatal to over-optimistic firms in the long run (over many projects). But the potential to shift costs to others (e.g. through change orders due to unexpected conditions or a deadline extension that reduces liquidated damages) and low barriers to entry in some parts of the construction industry maintain a population of such competitors, preventing more cautious firms from including reasonably put options.

Proposition 1 specifies Triantis' third challenge to model managerial behaviour for engineering and infrastructure projects and identifies a critical aspect of managerial decision-making that should be included in real options models. Real options models that more accurately reflect managerial decision-making that is based on the exposure (versus probabilistic) perspectives of risk will broaden the use of real options in practice.

**Proposition 2** *Project managers are risk averse in valuing real options.*

Like most managers, infrastructure project managers tend to be risk averse, meaning that they are willing to forego some benefits to reduce uncertainty.<sup>3</sup> Given two otherwise-equal strategies, they prefer the one that depends less on the resolution of an uncertainty to determine whether, or how much, it adds value to their project. Many managerial actions in which uncertainty is perceived to make little or no difference in whether value is added or not (e.g. budget increases, scope decreases) can and do increase project value. In sharp contrast, all real options are, and if perceived accurately are understood to be, very dependent on how uncertain conditions resolve. For example, a risk-averse manager would extend a project's deadline to reduce a project's forecasted completion delay and resulting financial penalties instead of adopting a new, untested technology to accelerate production, even if the resultant expected delay with the deadline strategy is larger. This could be because the duration reductions of the new technology are considered more uncertain and more likely to fail to lessen the completion delay than the deadline change.

Managers may tacitly implement risk aversion by adding a cost to real options that reflects their level of risk aversion. This would decrease the value of real options to the manager relative to more certain alternatives and thereby decrease the use of real options. The lower value that a manager is willing to accept to get certainty is the certain equivalent value of the uncertain strategy. Differences between the risk-neutral and risk-averse option values effectively add risk aversion costs to real options that can be as large as the difference between the net risk-neutral value of the option and the manager's certain equivalent of that value. Risk aversion and the resulting reduced use of real options, though, may be very rational from the manager's perspective. Why would a manager take the risk of being wrong (e.g. not needing to exercise the option to add value and thereby reducing project value) when less risk can be taken with a more certain alternative? However, the size of those changes in option value may be larger than needed to reflect the value of reduced uncertainty and may decrease real option values more than they should and thereby diminish

real options use more than a project manager's risk aversion justifies.

Proposition 2 also specifies Triantis' third challenge to model managerial behaviour for engineering and infrastructure projects by identifying risk aversion (and risk seeking) as an important aspect of managerial decision-making that should be included in real options models. Work related to this proposition could develop heuristics (Triantis' fourth challenge) for the effective use of real options to manage risk.

**Proposition 3** *Project managers manipulate the value of underlying assets that are the basis of option value, thereby decreasing option values.*

Most option pricing models assume that the option holder does not influence the value of the underlying asset. This assumption is usually unstated in the literature. Its foundation originates from option pricing models for financial assets (e.g. stocks in a market that can reasonably be assumed to be perfect) in which the option holder is independent of the asset except through the market. For some real options this assumption is reasonable. For example, the holder of an option to accelerate exploitation of a fossil fuel reservoir by drilling additional wells cannot influence the characteristics of the reservoir (e.g. size and porosity) or the market price of the refined products. In sharp contrast, when development project managers use real options to control their projects, they also purposefully and strongly contradict the assumption of the option holder—uncertainty independence by working to manipulate the value of, and uncertainties in, their projects. These are the 'in' options discussed previously. Examples of these uncertainty manipulations in project management are numerous, including taking subcontracted work in-house and using construction-manager-at-risk contracts that include options to change builders. Miller and Lessard (2000) described these dependencies in major project decisions, and Alessandri *et al.* (2004) described this type of linkage in a specific set of project management decisions. In these cases, real option decisions and other project management decisions are tightly linked. Therefore, real options models that assume independence of option holders and underlying assets and uncertainties may not value strategies accurately enough to guide project managers. Since project managers manipulate project uncertainties to increase project values, this reduces the potential benefits of options. Therefore, violating this valuation assumption causes real options to be over-valued using traditional models. If managers intuitively value options and include these two features of project management practice—many possible actions and asset manipulation—this reduces the value of options compared with valuation with traditional models,

requiring that the options increase project value more to be justified and reducing the use of real options by project managers.

Proposition 3 addresses Triantis' first challenge to improve real options models to better reflect reality by identifying two important features of project management reality (many possible actions and asset manipulation) that are missing from current real options models.

**Proposition 4** *Project managers have inadequate resources to fully exploit real options.*

Real options theory says that when an option adds value, the potential holder of the option should purchase, maintain and use the option. But practising managers often require that options add lots of value before they are purchased. We have heard managers describe the circumstances which justified the purchase of an option as 'no brainers', that is, the option added so much value that the manager considered the choice to purchase the option to be obvious. Why do practising managers require very large expected payoffs and (presumably) regularly forego obtaining and using options with smaller values that potentially add value? Resource limitations play a part. As described earlier, development project managers often have a plethora of alternatives for adding project value. Most of them require resources to identify, design, analyse and implement. Limitations on several types of resources restrict the use of real options, including (1) funds for purchasing and retaining flexibility, (2) labour, equipment and materials to implement management decisions, (3) combinations of cognitive ability, tools and methods to understand, design, evaluate and implement options and other value-adding alternatives and (4) time and attention to recognize and use options and other value-adding alternatives.

The bounded rationality of project management teams may create the largest impact of limited resources on real options use. Infrastructure projects are inherently unique and complex. Therefore, the challenges of managing complex projects may make simplifying the management effort a priority or at least of equal importance to adding project value. A structured practice of recognizing, designing and implementing real options adds significant complexity to project management, so the additional intricacy of real options analysis is not necessarily welcome. Infrastructure project managers are forced to choose from among their many alternatives for increasing project value when faced with these constraints. Choices are often based on a benefit/cost ratio analysis to maximize total project value derived from any given set of limited resources. Alternatives with the largest perceived ratio are typically chosen first. If conditions such as holding many project improvement alternatives (Proposition 3), attitudes

such as risk aversion (Proposition 2) and managerial perceptions such as not understanding and, therefore, avoiding options drive manager's evaluations, then real options will have relatively low benefit/cost ratios and will, therefore, be selected rarely.

Proposition 4 also addresses Triantis' first challenge to improve real options models to better reflect reality. The ubiquitous constraint of limited resources and bounded rationality of project management teams should be incorporated into real options models to increase their fidelity with actual projects.

**Proposition 5** *As option holders, project managers do not necessarily seek to maximize project value.*

Infrastructure projects usually involve three principal parties: an owner, a designer and a builder. These participants typically have diverse objectives that strongly impact decision-making. For example, a project's owner may value early completion to maximize project value, but the builder may prolong construction duration unnecessarily to keep crews busy while awaiting the start of subsequent projects. Options about project deadlines include non-monetary measures of value and are potentially held by multiple project participants or shared. Differences in objectives can cause project managers to make project management decisions, including those about real options, that maximize their own objectives, but not the project value (Henisz and Levitt, 2012).

The fact that option holders do not seek to increase asset values contrasts directly with real options theory and is related to the classic agency problem discussed by organizational behaviour theorists. As used in practice, real options are often valued and assessed in dimensions that cannot be measured with money or at least with project money. Managers may assess an option differently than the project owner (or its investors) would. For example, Ford and Ceylan (2002) found that a manager at the US Department of Energy's National Ignition Facility linked an unfortunate resolution of uncertainty without a specific option (unsuccessful technology development) with project failure. The high profile nature of the project and failures of previous managers made the potential of project failure and its impacts on his career unacceptable to the manager. Therefore, the manager might have valued the option more highly than the project owner (Congress in this case), who might have been willing to accept project failure.<sup>4</sup> This pushes real options adoption and use away from traditional 'optimal' and 'project-maximizing' choices.

The presence of objectives or factors other than monetary project value changes environment for real options analysis substantially. As in domains other than engineering and infrastructure projects (e.g. see Hovmand

and Ford, 2009), practitioners value real options with non-monetary performance measures. This can lead to an increase in the perceived value of certain options to a project manager over their value derived only from monetary project valuations. This also suggests that project managers have various motivations, as well as a variety of means to manipulate or influence asset values. This variety of project manager objectives and choices tends to decrease the perceived value of project-money-centric options.

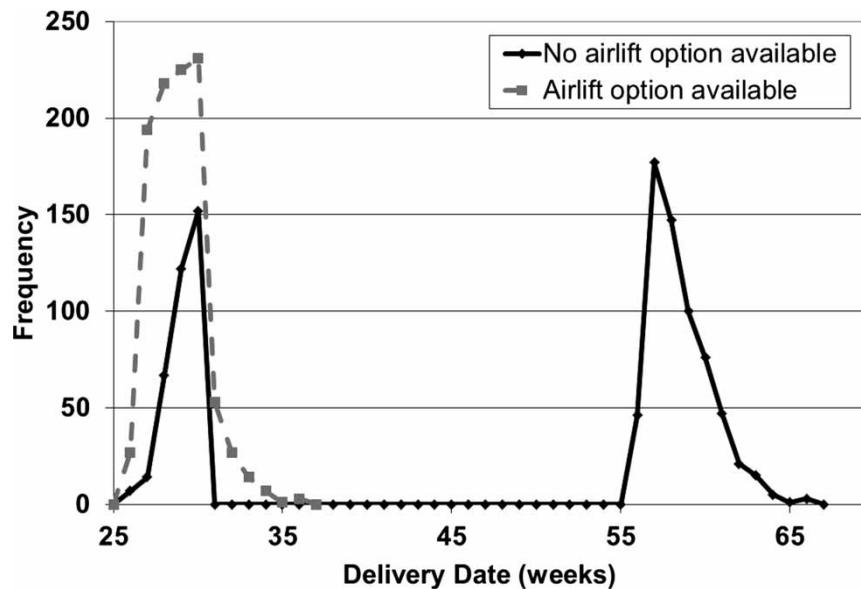
Proposition 5 addresses Triantis' first challenge to improve models to reflect reality and his second challenge to understand 'split' real options that are owned by multiple agents. Construction and infrastructure projects contain many real options that are held or shared by several stakeholders.

**Proposition 6** *Exercising options can have dramatic secondary impacts on project management that increase the difficulty of project management.*

A special but particularly widespread case of limited resources that all project managers and project management teams experience is bounded rationality (Simon, 1996), their maximum cognitive capacity. Project management tools can expand the capacity, but an upper limit remains. Project complexity often approaches or exceeds the bounded rationality of project managers and project management teams. Therefore, all else being equal, project managers prefer simpler alternatives to more complex ones. This can decrease the attractiveness of options that add management complexity from the perspective of the project manager.

Consider the example of an actual situation disguised as the Project Isolated case described by Johnson *et al.* (2006). Project Isolated is a new fossil fuel development project in a remote location requiring a specialized piece of equipment that was only available from one manufacturer. Once the manufacture of equipment is complete, it will be transported over a long distance by sealift from the manufacturer to the project location. The site is only accessible by sea during a short window of time due to weather. The manufacturing completion date, sealift travel duration and closing date of the weather window are uncertain. If the weather window is missed, the next available window is several months later. This would significantly delay the development of Project Isolated and delivery of the product and, therefore, severely degrade project performance. The project team is considering purchasing an option to transport the equipment by a faster but more expensive airlift to avoid missing the weather window.

Johnson *et al.* (2006) developed a relatively simple project simulation model of the Project Isolated case that included the airlift option. In addition to reflecting



**Figure 1** Project Isolated: distribution of delivery dates with and without the airlift option

the airlift option value, the model simulates delivery dates with and without the airlift option (Figure 1).

The airlift option has at least two significant impacts on project management. First, without the airlift option, the project manager must only design and prepare for one mode of delivery (sealift). But with the airlift option, the project manager must design and prepare for two possible delivery modes (sealift and airlift). Preparing for both sealift and airlift deliveries is a more difficult project management task than planning for either one. Second, the option transforms the delivery date distribution from a bimodal distribution (solid line in Figure 1) into a single modal distribution (dashed line in Figure 1). Using the airlift option requires the project management team to prepare for delivery in one, not in two, discrete time periods. The combined impacts of the option may increase project management complexity (e.g. if two delivery modes are difficult to accommodate and two arrival periods are easy to accommodate), decrease complexity (e.g. if two delivery modes are easy and one delivery period is easy) or the net impact may be difficult to determine. Faced with potentially exceeding the project manager's bounded rationality, if an option is used, some managers will find options less attractive and tacitly discount options to account for the anticipated additional managerial complexity.

Proposition 6 addresses Triantis' first and third challenges (improve real options models to reflect reality and model managerial behaviour) by specifying project management impacts as an important feature of applying real options to project practice. The proposal also

suggests a domain for the development of heuristics for real options use (Triantis' fourth challenge).

## Conclusions

Fundamental features and characteristics of infrastructure projects, their managers and existing real options models have created large barriers to the widespread adoption and use of real options by practising managers. The current work contributes to the advancement of infrastructure project development by briefly tracing real options theory development and identifying and describing six barriers to the adoption and use of real options. These barriers prevent or severely limit project managers from capturing the potential benefits of real options and thereby improving infrastructure management and project performance.

We suspect that the multiplicity and interdependence of the causes of the barriers prevent any single approach from succeeding. Advancements in multiple areas that borrow from and link different perspectives are needed. The barriers can only be overcome by broadening the development of real options tools and methods to include, and therefore balance, valuation, project characteristics and managerial practice. Future work on real options for infrastructure projects can test the six propositions described here with project data, improve real options pricing models and, most valuably, develop and test tools, models and methods to improve the options thinking of practising infrastructure project managers. Doing so may be difficult, but can transform

real options into a standard part of every project manager's toolkit.

## Notes

1. Cox and Ross (1976) also made important original contributions to the theory of pricing financial options.
2. Consistent with the real options literature, we use 'price' to mean an objective, market-based monetary worth of an option and 'value' to mean an individual's potentially subjective assessment of an option's worth.
3. This meaning follows from the economic definition that given two opportunities with the same return (benefits), a risk-averse person prefers the one with less risk (defined as variance due to uncertainty). The person, therefore, requires more return to accept more risk/uncertainty or will forego return to get less risk/uncertainty. This definition is consistent with risk aversion reflecting the valuation of a risky alternative less than objective ('risk-neutral') probabilities indicating that the alternative is worth.
4. There is no direct evidence that this assessment took place.

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