Options and flexibility in PPP toll road projects

Author:
Nguyen, Tuan Anh

Publication Date:
2019

DOI:
https://doi.org/10.26190/unsworks/2108

Options and flexibility in PPP toll road projects

Tuan Anh Nguyen

A thesis in fulfilment of the requirements for the degree of
Doctor of Philosophy

Supervisor: Professor David G. Carmichael
Co-supervisor: Dr. Steven Davis

School of Civil and Environmental Engineering
University of New South Wales
Sydney, Australia

September 2019

Thesis/Dissertation Sheet

Surname/Family Name	:	**Nguyen**
Given Name/s	:	**Tuan Anh**
Abbreviation for degree as give in the University calendar	:	**PhD**
Faculty	:	**Engineering**
School	:	**Civil and Environmental Engineering**
Thesis Title	:	**Options and flexibility in PPP toll road projects**

Abstract 350 words maximum: (PLEASE TYPE)

Concessional deliveries, encompassing public-private partnerships (PPP, P3), privately-financed initiatives (PFI), and build-operate-transfer (BOT), are promoted widely in the development of public infrastructure. The main feature in these deliveries is that the public sector authority uses finances and skills of the private sector concessionaire in providing infrastructure, particularly where the public sector has budget constraints. Each party – the authority and the concessionaire – carries different levels of risks, arising from project uncertainties and attempts to reduce these risks by adjusting the agreement between the parties. In the extreme case, a party may withdraw from the negotiations if the risks carried might be unacceptable, or one party may request a guarantee from the other party.

The literature presents the role of options, embedded with revenue-related guarantees, in addressing the uncertainty, risk, and fairness in PPP agreements in toll road projects, but falls short in providing flexibility to deal with the long-short conflict of the upfront fixed concession period and physical variation orders during the post-construction stage. The literature on real options analysis also criticises that such options in PPPs may be valued using financial market options techniques, applies these by analogy and relies on a high level of mathematical skills.

The thesis suggests fair ways forward to provide flexibility in (i) dealing with uncertainties in all kinds of revenue-related guarantees in PPPs; (ii) establishing a fair concession period over which the concessionaire collects revenue based on actual project performance instead of the existing upfront fixed period; (iii) presenting a proactive approach to anticipate changes and allow for physical variations and identifying a method by which variations are to be priced, leaving only their extent and timing unknown.

The thesis improves the understanding of incorporating flexibility in, but not limited to, PPP toll roads and presents an original single unifying approach for analysing all options scenarios, an approach based on discounted probabilistic cash flows. This thesis approach is straightforward, offers a ready way to evaluate the flexibility, requires minimal financial and mathematical knowledge, and can be readily implemented by practitioners. This thesis is thus of interest to anyone involved in PPP toll road projects.

ORIGINALITY STATEMENT

'I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.'

Signed ……………………………………………..............

Date ……………………………………………..............

INCLUSION OF PUBLICATIONS STATEMENT

UNSW is supportive of candidates publishing their research results during their candidature as detailed in the UNSW Thesis Examination Procedure.

Publications can be used in their thesis in lieu of a Chapter if:

- The candidate contributed greater than 50% of the content in the publication and is the "primary author", ie. the candidate was responsible primarily for the planning, execution and preparation of the work for publication
- The candidate has approval to include the publication in their thesis in lieu of a Chapter from their supervisor and Postgraduate Coordinator.
- The publication is not subject to any obligations or contractual agreements with a third party that would constrain its inclusion in the thesis

Please indicate whether this thesis contains published material or not:

☐ This thesis contains no publications, either published or submitted for publication
(if this box is checked, you may delete all the material on page 2)

☒ Some of the work described in this thesis has been published and it has been documented in the relevant Chapters with acknowledgement
(if this box is checked, you may delete all the material on page 2)

☐ This thesis has publications (either published or submitted for publication) incorporated into it in lieu of a chapter and the details are presented below

CANDIDATE'S DECLARATION

I declare that:

- I have complied with the UNSW Thesis Examination Procedure
- where I have used a publication in lieu of a Chapter, the listed publication(s) below meet(s) the requirements to be included in the thesis.

Candidate's Name	Signature	Date (dd/mm/yy)
Tuan Anh Nguyen		

AUTHENTICITY STATEMENT

‘I certify that the Library deposit digital copy is a direct equivalent of the final officially approved version of my thesis.’

Signed ……………………………………………...........................

Date ……………………………………………...........................

COPYRIGHT STATEMENT

Acknowledgements

I would like to express my sincere gratitude to my supervisor, Professor David Carmichael, who gave me motivation, confidence and academic direction to help me complete this thesis. His untiring support and intellectual advice encouraged me through my difficult moments and significantly influenced my research and future career. I would also like to express my appreciation to my co-supervisor Dr Steven Davis for his advice and support during my study.

I would also like to thank my review panel members, Professor Ian Turner, Associate Professor Arnaud Castel, Associate Professor Lucy Marshall, Dr Ali Akbar Nezhad and Dr Johnson Shen for their constructive comments and suggestions on my research progress reviews.

I would also like to thank Mr Van Hien Nguyen in Transport Engineering Design Inc. (TEDI) and Mr Minh Tam Vu in National University of Civil Engineering, Vietnam for their support in collecting financial and technical data of Vietnamese highway projects.

I gratefully acknowledge the Australia Award Scholarship (AAS) for the generous financial and academic support to make my PhD journey possible. My sincere thanks also go to Matthew, Tatjana and Semra in the AAS office at UNSW for their very useful advice and support.

I would also like to thank staff members and fellow officemates in the School of Civil and Environmental Engineering and my friends in Australia and overseas for their words of encouragement and for all the fun we had during my four-year study period.

Last but not least, a special thanks to my family. Words cannot express how grateful I am to my mother and father for all their sacrifices to raise me. I would like to express my deep appreciation to my beloved wife Chung and my son Khanh for their smiles, understanding and spiritual encouragement throughout my study which made completion of this study possible.

Table of Contents

List of Figures

List of Tables

List of Acronyms

BOT	build-operate-transfer
DCF	discounted cash flow
IRR	internal rate of return
MGR	minimum revenue guarantee
NPV	net present value
OV	option value
PBP	payback period
PERT	project evaluation and review techniques
PFI	privately-financed initiatives
PPP	public-private partnership
PW	present worth
TAM	toll adjustment mechanism
TFC	traffic floor and ceiling

List of Symbols

X_i	actual net cash flow in year i, $Y_{i1} - Y_{i2}$
Y_{i1}	actual cash inflow in year i, from the viewpoint of the option holder
Y_{i2}	actual cash outflow in year i, from the viewpoint of the option holder
$X\|_T$	net equivalent cash flow in year T, $X\|_T = Y\|_{T1} - Y\|_{T2}$
$Y\|_{T1}$	equivalent cash inflow in year T for option calculation purposes, from the viewpoint of the option holder
$Y\|_{T2}$	equivalent cash outflow in year T for option calculation purposes, from the viewpoint of the option holder
T	year of exercising the option
PW_i	present worth due to X_i
$PW\|_t$	collective present worth over years 0, 1, 2, …, t
E[ ]	expected value
Var[ ]	variance
c, a	superscripts denoting the concessionaire and authority respectively
C_i	maximum revenue guarantee (threshold) in year i (pre-agreed); a revenue cap; related to TC_i where a traffic ceiling is defined
F_i	minimum revenue guarantee (threshold) in year i (pre-agreed); a revenue floor; related to TF_i where a traffic floor is defined

R_i	revenue in year i
$Toll_i$	toll per vehicle in year i (possibly pre-agreed)
$Tollcap_i$	toll cap per vehicle in year i (pre-agreed)
TC_i	traffic ceiling guarantee in year i, $TC_i = Tcr \times E[\nu_i]$
Tcr	traffic ceiling ratio, used in establishing the traffic ceiling guarantee, TC_i
TF_i	traffic floor guarantee in year i, $TF_i = Tfr \times E[\nu_i]$
Tfr	traffic floor ratio, used in establishing the traffic floor guarantee TF_i
f	revenue cap growth rate (constant cap growth per year)
f_c	minimum threshold growth rate (percent/year, compounding yearly)
g	revenue growth rate (constant revenue increase per year)
g_c	revenue growth rate (percent/year, compounding yearly)
α, β	percentages, or fractions $0 \le \alpha, \beta \le 1$
ν_i	traffic (vehicles/year) in year i
γ	traffic growth rate (constant number of vehicles per year)
γ_c	traffic growth rate (percent/year, compounding yearly)
ϕ_c	toll growth rate (percent/year, compounding yearly)
wi, wo	superscripts denoting with invoking and without invoking toll adjustment mechanism (Chapter 4), respectively

Where the subscript i is omitted, then the variable takes a constant value for all i.

Currencies. USD US dollar, $; HKD Hong Kong dollar (HKD1.00 ≈ USD0.13); CNY Chinese yuan (CNY1.00 ≈ USD0.16); INR Indian rupee (INR1.00 ≈ USD0.016); VND Vietnamese dong (VND1.00 ≈ USD0.000043); converted date 14 December 2018.

Abstract

Concessional deliveries, encompassing public-private partnerships (PPP, P3), privately-financed initiatives (PFI) and build-operate-transfer (BOT), are promoted widely in the development of public infrastructure. The main feature in these deliveries is that the public sector authority uses the finance and skills of the private sector concessionaire in providing infrastructure, particularly where the public sector has budget constraints. Each party – the authority and the concessionaire – carries different levels of risks, arising from project uncertainties and attempts to reduce these risks by adjusting the agreement between the parties. In the extreme case, a party may withdraw from the negotiations if the risks carried might be unacceptable, or one party may request a guarantee from the other party.

The literature presents the role of options, embedded with revenue-related guarantees, in addressing the uncertainty, risk, and fairness in public-private partnership agreements in toll road projects, but falls short in providing flexibility to deal with the long–short conflict of the upfront fixed concession period and physical variation orders during the post-construction stage. The literature on real options analysis also criticises that such options in public-private partnership may be valued using financial market options techniques, applies these by analogy and relies on a high level of mathematical skills.

The thesis suggests fair ways forward to provide flexibility in (i) dealing with uncertainties in all kinds of revenue-related guarantees in PPPs; (ii) establishing a fair concession period over which the concessionaire collects revenue based on actual project performance instead of the existing upfront fixed period; and (iii) presenting a proactive approach to anticipate changes and allow for physical variations and identifying a method by which variations can be priced, leaving only their extent and timing unknown.

The thesis improves the understanding of incorporating flexibility in, but not limited to, PPP toll road projects and presents an original single unifying approach for analysing all options scenarios, based on discounted probabilistic cash flows. This thesis approach is straightforward, offers a ready way to evaluate flexibility, requires minimal financial and mathematical knowledge, and can be readily implemented by practitioners. This thesis is thus of interest to all stakeholders involved in PPP toll road projects.

Chapter 1: Introduction

1.1 Overview

1.1.1 Public-private partnerships and revenue-related risk

The increasing demand for infrastructure investment worldwide is significant (McKinsey Global Institute, 2013; Pratap and Chakrabarti, 2017; Rozenberg and Fay, 2019). In developed countries, the substantial replacement of aging infrastructure is becoming urgent, while in developing markets, population growth, increased urbanisation and increased income per capita are driving the demand for new infrastructure investment. This trend is leading to the widening gap between the need for investment and the funding ability and resources of governments. Governments worldwide, both in developed and developing countries, face budget constraints in meeting the ongoing significant demand for infrastructure.

Concessional project delivery methods, such as public-private partnerships (PPP) or privately-financed initiatives (PFI), were introduced as an effective solution to fill this budget gap in providing infrastructure (Grimsey and Lewis, 2004; Yescombe, 2007), especially for toll road projects. In these project deliveries, the private sector concessionaire, referred to as the concessionaire, is responsible for designing, financing, constructing and operating the toll road subject to the authority's regulations, during the pre-agreed concession period. For PPP toll road projects, the concessionaire pays the initial costs of construction and operation, and recoups this initial investment by collecting tolls during the concession period. At the end of this period, the operation of the toll road is transferred with the ownership at no cost back to the public sector authority, referred to as the authority. Apart from solving the budget constraints, the authority uses the experience and skills of the concessionaire, and this helps to improve the discipline of management, enhance the coordination and the quality of service, and speed up project delivery (European Commission, 2003; OECD, 2008). This project delivery method, if properly structured, also provides an effective mechanism for transferring risk between the two parties. A PPP project can be considered viable if both financial and social cost-benefit analysis show positive results. In the thesis, only the financial aspects of investment analysis are addressed; analysis involving some broader economic/social perspectives in PPP toll roads is a separate matter and is not discussed.

The major rationale is that a PPP toll road project may generally involve a wide variety of risks, derived from the project uncertainties, due to the huge initial investment costs, uniqueness, complexity and the lengthy concession period (Czerwinski and Geddes, 2010; Grimsey and Lewis, 2005; Yuan and Li, 2018; Yescombe, 2007). Depending on how a PPP agreement is structured, the concessionaire carries a differing level of financial risk, primarily arising from road usage, patronage or demand uncertainties. While investment costs and ongoing maintenance and operation costs are reasonably predictable, demand is not (Bain, 2009; Cruz and Sarmento, 2019; Flyvbjerg et al., 2005), and is influenced by the magnitude of the tolls being charged, travel times, vehicle operating costs, and the availability of alternative roads and transport. The viability analysis of the project from the concessionaire's viewpoint, among other things, looks at the financial risk carried, and attempts to reduce this risk by adjusting the agreement between the parties. The concessionaire may request subsidies or guarantees from the authority (Blank et al., 2009; Brandao and Saraiva, 2008). The authority may, in turn, request reciprocal guarantees. An agreement involving guarantees, if properly structured, allows the risk to each party to be managed, and makes the project more viable. If the calculated risk carried is considered unacceptable, either party might withdraw from the project.

Recent studies have shown the role of options in addressing the uncertainty, risk, and fairness in public-private partnership agreements in toll road projects, specifically the financial aspects of such agreements (Alonso-Conde et al., 2007; Ashuri et al., 2012; Carbonara et al., 2014; Chiara et al., 2007; Huang and Chou, 2006; Mirzadeh and Birgisson, 2016; Wibowo et al., 2012). An option gives the holder the right, but not the obligation, to accommodate changes and respond to the uncertainties about the nature of change in the future. An option is only exercised if it is worthwhile for the holder to do so. For example, within the context of financial agreements and toll roads, the option may translate to adjusting future revenue in response to uncertain and changing future road demand. However, establishing an option has a cost as the holder needs to pay extra for some direct or indirect premium.

Options, associated with financial agreements, introduce flexibility into the project financial outcome by adjusting future revenue, but require significant cost and effort. Both option holders, the authority and the concessionaire, face a dilemma on whether to incorporate upfront flexibilities or options. Some flexibility features and options can be incorporated at the beginning of the concession negotiation process with the view that the pre-agreed level of flexibility in project revenue may (but not necessarily) take place in the future, depending on future circumstances. Flexibility and options are thus key issues to deal with revenue-related risk in PPP toll road projects.

The existing literature focuses on revenue-related guarantees introduced to deal with uncertainties in demand during the operational phase. These guarantees can take different forms (Alonso-Conde et al., 2007; Ashuri et al., 2012; Blank et al., 2009; Carbonara et al., 2014; Carmichael et al., 2018; Chiara et al., 2007; Liu et al., 2019; Martins et al., 2015; Mirzadeh and Birgisson, 2016; Shan et al., 2010). Each option or case of flexibility is presented and analysed in standalone papers. There is thus still a gap in presenting a comprehensive outline of such guarantees. A literature summary of the state-of-the-art on options in PPP toll road projects is not currently available.

Options, embedded with financial guarantees, introduce flexibility for the project's revenue, from the viewpoint of whoever owns options, and having flexibility (by claiming guarantees) has value. Such guarantees may be valued using an options analysis. In general, the revenue is uncertain, being based on road usage, patronage or demand. This uncertainty needs to be captured in any analysis. Typically, the literature uses financial market options techniques, applies these by analogy, and customises them according to the authors' preferences. Each option scenario is presented and analysed in separate studies. This creates the need for a single unifying approach for analysing all PPP toll road options.

1.1.2 Long–short conflict of the concession period

Public-private partnerships may be classified as belonging to concessional delivery methods, which also incorporate privately-financed initiatives or projects (PFI), and different types of build-operate-transfer (BOT) (Carmichael, 2014). Public-private partnership delivery is popular with the public sector because it enables infrastructure to be designed, constructed and operated using private funding. It can also be used by the private sector, though the majority of applications appear to be with the public sector. The relevant public sector authority uses the finance and skills of a private sector consortium in this delivery. In return, the concessionaire is given a length of time – called a concession period – over which its investment can be recovered.

A defining characteristic of public-private partnership is a concession period, agreed between the two main parties – an authority and a concessionaire. The concession period is the time given to the concessionaire to design and construct the infrastructure and collect revenue, before handing the infrastructure back to the authority (Shen et al., 2002). This period may be, for example, 20, 30, 40 or 50 years, and is different for each project, but is usually *long enough at least to fully amortize major initial investments* (World Bank, n.d.). A concession period that is too long financially benefits the concessionaire in the later years, at the expense of the public, while a concession period that is too short does not allow the concessionaire to fully recoup its initial investment or provide a suitable return for the investment.

The issue becomes what is an appropriate concession period to include in any PPP agreement. For toll roads, an appropriate concession period should allow the concessionaire to receive an appropriate return for its investment, but not be so long that the motoring public suffers by paying tolls over an excessive period. Determining an appropriate concession period would appear to be crucial in setting up the PPP delivery of a project. Fixed concession periods, as are currently used in some contexts or countries, lack the flexibility to deal with this 'long–short' conflict, or to accommodate future uncertainties.

There is rational argument which suggests that concession periods granted on PPP toll road projects are too long in many instances (Niu and Zhang, 2013; Tan et al., 2010). In effect, the concessionaire receives payback for its investment well within the concession period, while the public continues to pay tolls for longer times than it should. This position excludes those projects where demand estimates, prior to the project, fall short of actual demand once the road is in operation; such estimates may be wrong because of errors in interpreting survey demand data and/or the public's price elasticity of demand behaviour.

Existing publications have performed a range of analyses for concession periods (Bao et al., 2015; Khanzadi et al., 2012; Ngee et al., 1997 ; Shen et al., 2002; Shen and Wu, 2005; Yu and Lam, 2013; Zhang, 2011; Zhang and AbouRizk, 2006; Zhang et al., 2016). Because of future uncertainties, any concession period established pre-PPP agreement may turn out to be inappropriate based on actual project performance. No publications look at defining a concession period based on actual project performance, and concession periods which appropriately treat both parties – the authority (equivalent to the public) and the concessionaire – based on actual project performance. This creates the need to establish flexible concession period based on actual project performance, instead of determining the pre-agreed length of time based solely on the accuracy of the project cost and revenue estimations.

1.1.3 Variations in the post-construction concession period

The initial PPP agreement is for a defined scope. In many cases, the authority may wish to make a physical change during the post-construction concession period in PPP toll road projects. Physical changes, for example, could include adding an extra lane, extending the existing road, providing another entrance ramp or exit ramp or similar – and not changes generally, such as changing the toll pricing formula. However, as there is no provision in the PPP agreement to do this, this has to be negotiated with the concessionaire, who is then in an opportunistic position of bargaining strength. Conversely, the authority is in a position of bargaining weakness and may have to agree to excessive concessionaire demands. The concessionaire would only agree to a change if it is worthwhile to the concessionaire to do so, and may bargain, for example, for an extension of the concession period or a readjustment of the toll pricing formula. These bargains may then shift the financial burden to the authority and the public as they have to pay the extra cost to claim their variation order (Almarri and Blackwell, 2014; Cruz and Marques, 2013b; Fernandes et al., 2019; Guasch et al., 2007; Marques and Cruz, 2012).

This has created the need for PPP agreements to anticipate change and allow for variations and their method of pricing, and in particular major physical changes to the infrastructure. This is a proactive approach to change, which appears inevitable, rather than passively proceeding and dealing with changes as they are required.

1.2 Research objectives

The aim of the research is to establish flexibility in PPP toll road projects, from the perspective of financial agreements, a flexible concession period and physical variations.

From an extensive literature review, a number of gaps are identified:

- There is incoherence in the literature on options and flexibilities associated with revenue-related risk in PPP toll road projects.
- There is inconsistency in using financial market options techniques to value ‘real’ infrastructure-based options.
- Fixed concession periods are currently used which lack the flexibility to deal with the ‘long–short’ conflict of the concession period, or to accommodate future uncertainties.
- There is a need for PPP agreements to introduce the ability to anticipate major changes and allow for physical variations to the infrastructure and the method of pricing.

The thesis addresses the research problem and fills these gaps in the literature. The five objectives of this thesis are to:

- Clarify the literature and improve the understanding of revenue-related guarantees, embedded with options, in the context of PPP toll roads.
- Compare the results of option values, dealing with revenue-related guarantees, calculated by the probabilistic cash flow approach presented by Carmichael et al. (2011) and Carmichael (2016a), with the existing approaches in selected publications.
- Reinforce the consistencies of the probabilistic cash flow approach in valuing real infrastructure-based options.

- Present a fair way of establishing a flexible concession period, based on actual project performance in PPP toll roads.
- Introduce an approach to incorporate variation orders into PPP agreements and their methods of pricing to deal with major physical changes during post-construction stage of the concession period.

1.3 Research contributions

By addressing the five research objectives, the main contributions of the thesis include:

- The thesis is a comprehensive resource on revenue guarantee options in PPP toll road projects. This state-of-the-art literature summary encompasses all existing PPP revenue-related guarantee options, both one-sided and two-sided revenue protection.

- The research represents the probabilistic cash flow approach, developed by Carmichael et al. (2011) and Carmichael (2016a), in valuing infrastructure-based options. Compared to the existing literature related to financial market techniques, the thesis demonstrates consistency in applying the proposed approach for valuing all PPP toll road options. The approach does not rely on the financial market options literature, and is a straightforward extension of conventional engineering viability analysis of projects. It offers a convenient way to evaluate multiple options, requires minimal financial and mathematical knowledge, and hence can be readily implemented by practitioners. The approach presented in the thesis can be applied to a wide variety of situations and locations. People involved in the infrastructure sector, including investors, decision makers, and engineers, can benefit from this approach.

- The thesis introduces the term ‘bound options’ which is developed as an advanced and superior version of traffic floor and ceiling (Iyer and Sagheer, 2011) and collar (Shan et al., 2010) to mitigate financial risk in PPP toll roads. For the associated bound options, there is no need for any upfront premium; the premium of the lower bound option can be used to cancel the premium of the upper bound option. The presence of the two yearly guarantees provides flexibility, with the levels (option exercise prices) set as constants or time-varying based on projected future cash flows.

- The research suggests a way forward to provide flexibility in establishing the period over which the concessionaire collects revenue based on actual project performance, while beyond a calculated point in time, an option becomes available to the authority to take over the operation of the road. The thesis approach eliminates the controversial aspects existing in current public-private partnerships associated with the length of the concession period. As a by-product, the approach also eliminates another controversial matter of the setting of tolls – toll formulae and toll adjustments over time.

- The thesis suggests that the PPP agreements proactively identify an approach by which variations are to be valued, identifying major potential physical changes, leaving only their extent and timing unknown.

Overall, this thesis benefits academics, practitioners and those in the infrastructure sector through the introduction of options and flexibilities, and an approach of analysing and valuing that helps establish the viability of flexible infrastructure, especially for PPP toll road projects.

1.4 Thesis structure

Figure 1.1 outlines the structure of the eight chapters of this thesis.

Chapter 2 presents a survey of the literature on the definitions and classifications of real options and the link between options and flexibilities in infrastructure. The chapter then provides an overview of financial market techniques in analysing options values, highlighting inconsistencies in applying these techniques for valuing infrastructure-based real options. The chapter then focuses on financial agreements (one-sided and two-sided revenue guarantees), the establishment of the concession period, and variations and negotiation issues in non-PPP and PPP contracts. The chapter concludes by identifying gaps in the literature.

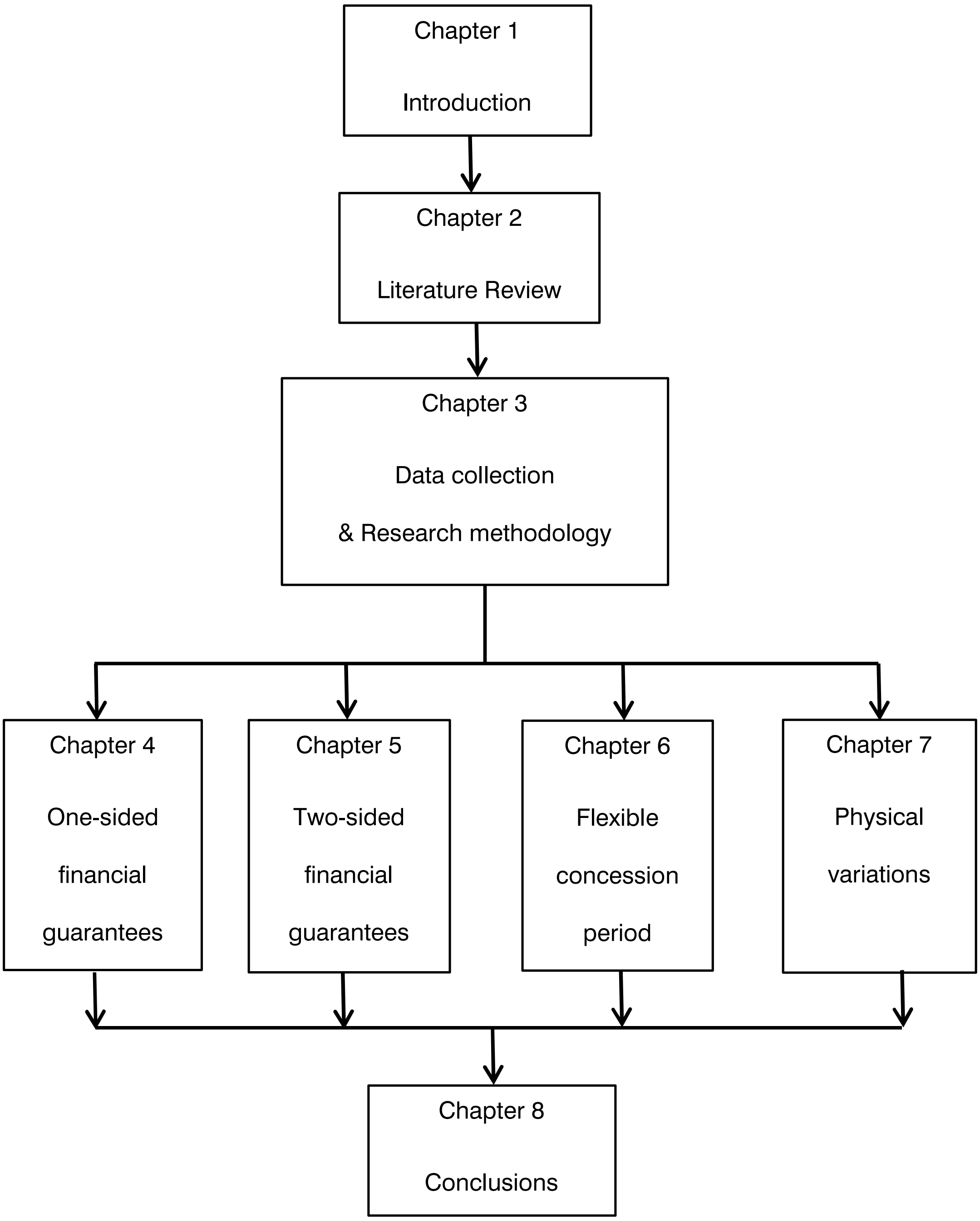

Figure 1.1 Structure of the thesis.

Chapter 3 outlines the research methodology and provides the financial and technical data for two Vietnamese toll road projects that have been used as case studies and examples for option valuing in Chapters 5 and 6. The chapter then presents the probabilistic cash flow approach as the main tool used throughout the thesis for options analysis.

Chapters 4 and 5 provide an overview of revenue-related guarantee options (both one-sided and two-sided protection) in PPP toll roads, and apply an original unified approach, based on probabilistic cash flow approach, to analyse these guarantees. Compared to the existing literature, the two chapters demonstrate consistency in applying the proposed approach for valuing all PPP toll road options. Chapter 5 then introduces the term 'bound options' which is developed as an advanced and superior version of the traffic floor and ceiling (Iyer and Sagheer, 2011) and the collar (Shan et al., 2010) to mitigate revenue-related risk in PPP toll roads.

Chapter 6 proposes a flexible approach to deal with the 'long–short' conflict in the establishment of the concession period, and to accommodate future uncertainties. The chapter suggests a way forward, providing flexibility in establishing the period over which the concessionaire collects revenue based on actual project performance, while beyond a calculated point in time, an option becomes available to the authority to take over the operation of the road. The implications of variability and uncertainty leading to establishing payback periods at pre-investment time, as well as probabilistic payback periods, are examined. A case study example is used in this chapter.

Chapter 7 demonstrates the need for PPP agreements to have the ability to anticipate major changes and allow for variations to the infrastructure and their method of pricing. The chapter introduces the adoption of an option to order variations, from the viewpoint of the authority, to deal with major physical changes of PPP toll road projects after construction.

Chapter 8 summarises the research findings and draws conclusions on the viability of options and flexibility for PPP toll roads, with respect to revenue guarantees, the concession period, and variation orders. The thesis emphasises valuation based on the approaches presented. The methods used, but not necessarily the assumptions and associated data, are applicable to other situations and locations.

1.5 Publications

Some content of this thesis is contained in three papers which have been published and submitted for publication (Figure 1.2). These papers present the analysis and discussion in Chapters 4, 5 and 6 of the thesis.

Chapter 4:

Carmichael, D. G., Nguyen, T. A. and Shen, X. (2018), Single treatment of PPP road project options, *ASCE Journal of Construction Engineering and Management,* Vol. 145, No. 2, p. 04018122, 11 pages.

Chapter 5:

Carmichael, D. G., Nguyen, T. A. and Shen, X. (2018), Single treatment of PPP road project options, *ASCE Journal of Construction Engineering and Management,* Vol. 145, No. 2, p. 04018122, 11 pages.

Nguyen, T. A. and Carmichael, D. G. (2018), Bound options in road infrastructure concession delivery, *The 22nd Annual International Real Options Conference, ROC 2018*, WHU Otto Beisheim School of Management, Dusseldorf, Germany, June 21–23.

Chapter 6:

Carmichael, D. G., Nguyen, T. A. and Shen, X. (2019), Determining a fair concession period in PPP toll road projects, *ASCE Journal of Construction Engineering and Management*, (Submitted).

Figure 1.2 List of publications.

Chapter 2: Literature review

2.1 Introduction

The literature has recognised the problem of providing flexibility in PPP toll road projects and the need to establish options dealing with future uncertainties. This chapter surveys the literature on real options and flexibilities in PPP projects. The literature review focuses on the applications of real options in infrastructure and the analytical methods for valuing such options. The main topics and order of this literature review are presented in five sections:

- Section 2.2 discusses flexibility and real options in infrastructure.
- Section 2.3 outlines the existing financial options evaluation methods.
- Section 2.4 provides an overview on financial agreements in public-private partnerships.
- Section 2.5 discusses the 'long–short' conflict in determining the concession period.
- Section 2.6 focuses on variations and renegotiations issues in general construction contracts and public-private partnerships.

The chapter then concludes by identifying gaps in the literature.

2.2 Flexibility and real options in infrastructure

2.2.1 General concepts

Infrastructure projects, in particular, have high uncertainty because they are unique and long-lasting (Cruz and Marques, 2013a; Martinez-Cesena et al., 2013; Martins et al., 2015). The projects, involving huge initial investment costs and maintenance and operation expenses, are designed and built in the present, yet they face considerable uncertainties far into the future, which is normally 30–50 years or even longer. The uncertainties, stemming from technical, financial, political, social and environmental issues, may negatively affect project cash flows and result in the failure of projects. Construction management improvements are making much progress in incorporating flexibility into the decision-making process, aiming to adapt projects to dynamic future circumstances (Ashuri et al., 2011; Carmichael and Taheriattar, 2018; de Neufville and Scholtes, 2011; Dobes, 2010; Fricke and Schulz, 2005; Pollack, 2017; Slaughter, 2001; Till and Schneider, 2005; Zhao and Tseng, 2003). Accordingly, incorporating flexibility seeks to significantly reduce project life cycle costs by offering a more timely and reasonable response to changing market conditions (Ford et al., 2002; Garvin and Ford, 2012; Trigeorgis, 1996).

Flexibility provides options for decision makers to respond to future uncertainty (Guthrie, 2009; Mun, 2002; Nembhard and Aktan, 2010). The following examples present the case. Managers of growing projects need to decide the time and extent of their business expansion. The concessionaire in a public-private partnership project must choose whether to claim the revenue shortages under a minimum revenue guarantee agreement offered by the authority. The authority has to decide when is the appropriate time to take over the operation of the project before the end of the flexible concession period. While these issues seem diverse, they share key features. In each case, the decision makers have to select when and to what extent to take a particular action, either reversible or irreversible, in their projects. The outcomes of taking (or not taking) this action are uncertain because the action is only taken if it is worthwhile to do so. Furthermore, the timing and extent of the action taken by the decision makers may significantly alter the onward cash flows generated by the project.

For valuing the above examples, the conventional discounted cash flow (DCF) technique, based on deterministic analysis of cash inflows and outflows, is not applicable for analysing such complicated issues because of the existence of uncertainty. The main limitation of this method is that expected future cash flows inadequately reflect the flexibility within the investment project (Myers, 1984; Trigeorgis and Mason, 1987). This approach also ignores the fact that the above expansion plan may be postponed until the decision makers feel more confident by receiving all needed information about future market conditions. Similarly, for the revenue guarantee case, the traditional approach assumes that the concessionaire will follow a predetermined schedule, even if the revenue shortage may never occur. In the case of the flexible concession period, the conventional approach assumes that all future cash flow scenarios are committed by the concessionaire, and this does not allow change at the time of exercising the option in line with actual project performance.

The appropriate approach should recognise that a decision in infrastructure projects is rational. That is, any time when decision makers make decisions, they base their choices on all available information related to the current circumstances of the project. As presented in these examples, decision makers only take an action on their projects if this action is beneficial to them, depending on the updated project context. This feature is standardised as the term 'real options', coined by Myers (1977), to describe its similarity to the theory and practice of analysing and pricing the financial options that are traded in financial markets. Decision makers in these markets are confronted with similar problems as they have to choose whether or not to buy, called 'call option', or to sell, called 'put option', their financial assets, such as stocks and bonds. Alternatively stated, real options are an extension of financial options analysis to non-financial (real) investment projects to provide managerial flexibility in responding to dynamic market uncertainty (Amram and Kulatilaka, 1999; Dixit and Pindyck, 1994). Naturally, the body of literature on real options adopted many similarities and assumptions from those established for financial options (Triantis, 2005; Trigeorgis, 1996).

Options present flexibility in decision making, and options analysis values the flexibility in the investment. An option provides the option holder a right without obligation to do an action in the project. That option is present, and it may or may not be exercised, depending on future conditions, due to the existence of uncertainty. In general, it would only be exercised if it is worthwhile to do so. Thus, options enable the option holder to take advantages of any involved upside or advantage, but limit any downside or disadvantage. The upside obtained gives a value of the option. It can be shown that the option value increases with the level of uncertainty (Carmichael, 2016a; Carmichael et al., 2018; Nguyen and Carmichael, 2018). Compared to the conventional analysis, options analysis may transform an investment either from initially unworthy into worthy or from worthy into even more worthy.

2.2.2 Taxonomy of real options

Real options can be recognised as plain options and compound options (Kodukula and Papudesu, 2006; Rhee et al., 2008; Yeo and Qiu, 2003). The plain option is designed to take a single action in a project, whereas a compound option incorporates a chain of options or combinations of multiple options. Some common types of real options include the following.

Defer and abandon options

A defer or wait option gives management an opportunity to delay the implementation of projects while clarifying the unknown information until the entire project environment becomes overwhelmingly favourable. This option exists because the current project's situation seems uncertain, and the option holder may exercise this to avoid a premature decision. This leaves it open for decision makers to delay their decision (for example, the start of the project) and wait for a profitable signal in the future (Ingersoll and Ross, 1992; McDonald and Siegel, 1985; Paddock et al., 1988). However, if the project outcomes present poor financial performance, decision makers can adopt the abandon option and shut down the project permanently (Blank et al., 2009; Dixit, 1992; Huang and Chou, 2006; Myers and Majd, 1990; Rambaud and Perez, 2016). In that case, the abandon option stops the given project's losses while providing salvage value from selling the abandoned project assets and equipment.

Expand options

Expand options have the capacity to expand infrastructure projects with a predetermined level of flexibility. This option exists because of uncertainty surrounding the need for future expansion of infrastructure (de Neufville et al., 2006; Kester, 1984; Kogut, 1991; Pellegrino et al., 2013; Rambaud and Perez, 2017; Slaughter, 2001). In the first stage of planning, an adaptable design should be considered by creating extra construction works that aim to achieve flexibility (Ashuri et al., 2011; Sun et al., 2019; Zhao and Tseng, 2003). These additional constructions, supporting the expanded structure, involve an extra cost with an upfront premium. In return, the infrastructure increases its flexibility to expand whenever it is needed (Krüger, 2012; Sun et al., 2019). At the year of exercising the option, the expansion cost is required, termed the 'exercise price'. This option is only exercised if the potential benefits resulting from the expansion exceed the expansion cost. For example, in the case of road expansion, the designers can design for and build on reserved land, located in either the median strip or on both sides of the initial road, so the road has the ability to add extra lanes for future expansion. These extra construction works involve a significant cost at the beginning of the project. However, the increased flexibility gives the option holder an opportunity to build additional lanes quickly and effortlessly and transform the existing road to meet the increasing future travel demand (Ashuri et al., 2011; Fawcett et al., 2015; Krüger, 2012).

Contract options

The contract option can be considered as a stop-loss strategy that seeks to save a project from tremendous losses due to poor market conditions (Copeland and Antikarov, 2001; Kodukula and Papudesu, 2006). This option is applicable for projects where there is a need to reduce the project's operational scale or sell part of the project's facility (de Neufville and Scholtes, 2011; Geltner, 2007). The exercising decision takes place once the benefits, resulting from the contracting project, prevail over those from maintaining the current status. This option might be combined with an expand option as renewal strategies to either recover the former project production or upgrade to an even larger operation scale whenever the market conditions improve (Amram and Kulatilaka, 1999; de Neufville and Scholtes, 2011; Trigeorgis, 1996).

Other options

Switching options offer the possibility of switching among models of systems at an associated cost (Copeland and Antikarov, 2001; Ford and Sobek, 2005; Kozlova, 2017; Trigeorgis, 1993). This option provides its holder the right to change or switch from the current specific operation approach to an alternative (Brandao et al., 2013; Hahn and Dyer, 2008; Savolainen, 2016; Trigeorgis and Tsekrekos, 2018). For instance, in the case of a toll road, an option to switch enables the project operator to switch from conventional human-operated tollbooths to an electronic tolling system to upgrade the toll collection network in future, if it is worthwhile to do so.

A sequential option is a chain of options. In each link of this chain, an option might be any of the single options, in different sequences, and thus there is no one form of sequential options (Carmichael, 2016a; Herath and Park, 2002). This option is incorporated into multi-staged projects where options are available at each stage, and this determines what happens subsequently with the project (Dockendorf and Paxson, 2015; Leiblein and Ziedonis, 2007). In the sequence of options, a dependent (succeeding) option is exercised after an independent (preceding) option. For example, consider the case with a chain of contract and expand options. The contract option might be combined with an expand option as renewal strategies to either recover the former project production or upgrade to an even larger operational scale whenever the market conditions improve. In this case, the contract (independent) option is exercised before the later expand (dependent) option.

Rainbow options are compound options that deal with multiple sources of uncertainty (Johnson, 1987; Kodukula and Papudesu, 2006; Nembhard and Aktan, 2010; Stulz, 1982). For instance, the movements in toll rate, interest rate, and traffic demand are examples of uncertainty sources in highway projects. Their fluctuations significantly affect project revenue, and each of them may follow a specific probability distribution with separate volatility. These underlying parameters could be correlated with one another, or not. Compound rainbow options can be considered the most realistic and the most complex real options (Copeland and Antikarov, 2001; Hucki and Kolokoltsov, 2007; Meng and Ding, 2013; Rubinstein, 1991; Wang et al., 2018).

2.2.3 Applications of real options in infrastructure

The literature on real options is very extensive (Ipsmiller et al., 2019; Kozlova, 2017; Martinez-Cesena et al., 2013; Martins et al., 2015; Savolainen, 2016; Triantis and Borison, 2001; Trigeorgis, 2005; Trigeorgis and Tsekrekos, 2018). The references cited below emphasise the diverse range of the applications of real options.

Water and electricity

Deng et al. (2013) study the value of flexibility to extend standard drainage canals of urban water management systems in Singapore and to use a novel water catchment technology based on real options analysis. This research illustrates that integrating flexibility into the decision-making process can reduce initial cost and improve the value of an investment, and enable decision makers to change the project, in response to the dynamic environment.

Manocha and Babovic (2018) present two sequencing approaches, named 'Build to Target' and 'Build up', to improve the sub-selecting process of adaption pathways of flood management systems. The research outcome demonstrates the advantages of these two sequencing approaches and the capacity of real options analysis to quantify and capture the value of flexibility.

Zhang and Babovic (2012) discuss real options to use alternative water resources through two innovative water technologies in the water supply system of Singapore. Based on real options analysis, innovative water solutions introduce flexibility to the water supply system and can improve the system from multiple perspectives.

Marques et al. (2015) develop an innovative real options analysis for a decision-making process under uncertainty in the field of water supply network design. The authors propose an option to defer a decision, associated with a simulated annealing algorithm as the optimisation tool, to minimise the overall cost during the whole project horizon of the water distribution network. This delay comes at a cost; however, this related expense seems lower than that of the upgrading project in a predetermined time horizon. This conclusion consolidates the benefit of using options to adapt the solution to accommodate different future possible decisions and capture the value of flexibility. This also agrees with the conclusion of research by Erfani et al. (2018) and Suttinon and Nasu (2010).

In the context of electricity power projects, Kozlova (2017) shows that the application of real options in renewable energy power generation projects mainly focuses on options to defer and to invest, which are only available in the planning stage of projects, and disregards the setting of flexibility in the operation stage with integrating real options in the technological design of the project.

Martinez-Cesena et al. (2013) point out that options analysis enhances the viability of electricity generation projects, including renewable energy; however, the main barriers to adopting options theory are deficiencies of understanding and knowledge by practitioners. It can be shown that project managers are not familiar with options analysis and they might also underrate the rationale of the theory.

Mining

Decision makers in mining projects normally face a dilemma regarding whether to keep investing in mining projects when the commodity market price is lower than the expected level, or simply forgo the invested capital and discard the project. The dilemma is caused by uncertainty derived from the price of exploited ore and mineral reserves in the mining pit (Ajak and Topal, 2015). There are a large number of papers on operating flexibility in the design and planning stage of mining projects.

Cortazar and Casassus (1998) present the implementing of a real options model for valuing an investment project that expands production capacity and/or modifies the unit costs of a copper mine. This model incorporates managerial flexibilities which allow opening or closing of project production and delaying the investment. Dias (2004) discusses the application of a comprehensive set of sequential real options for investment valuation of petroleum exploration and production. The presented cases include the option to select alternatives to develop an oilfield, the option to drill a wildcat in an unexplored basin, the option to invest and the option to expand the production of the optional wells.

Inthavongsa et al. (2016) develop a dynamics decision framework, based on real option analysis, which includes four strategic operating options for open pit mine planning projects: option to defer, to expand, to maintain and to shut down. Dimitrakopoulos and Sabour (2007) propose a simulation-based real options method to value practical mining problems, including expand and abandon flexibility, while analysing the non-uniformity of project parameters and the existence of multiple uncertainties such as metal price, foreign exchange rate and geological uncertainty.

Sabour et al. (2008) develop a multi-criteria framework with multiple value indicators for ranking alternative mine designs. Samis (2000) develops a portfolio framework for valuing a mine with multiple ore zones of different quality where the selection of mining depends on the current market prices. Hahn and Dyer (2008) study the recombining binomial lattice approach for valuing the switching option, which provides a right to switch output from oil to gas production, in petroleum projects. Ajak and Topal (2015) use flexible design, incorporated with real options, which demonstrates the ability to switch among different pits. Once flexibility is in place, it improves project resilience to withstand unfavourable futures incorporated in the exploitation design, leading to significant increase of the project's value.

Transport infrastructure

Numerous studies have concentrated on illustrating the opportunity to enhance an infrastructure project's value and performance by using various types of real options. Zhao and Tseng (2003) propose the option pricing model to assess the flexibility value of the expand option in a public parking garage. In their research, the parking demand uncertainty is captured by using a trinomial tree, and stochastic dynamic programming is applied to clarify the optimal expansion decision. Garvin and Cheah (2004) adopt an option pricing model which is embedded with a deferral option to enhance traditional project evaluation and capture the managerial flexibility in infrastructure projects. During an infrastructure project's planning and design, uncertainties, stemming from poor traffic demand and operational cost overrun, have been incorporated in key decisions about the right of way width and number of road lanes. Considering the main sources of uncertainty, including land price, traffic demand, highway deterioration and their interdependencies, Zhao et al. (2004) present a multi-stage calculus model for decision making in developing, operating and rehabilitating highway projects. Huang and Chou (2006) develop two single option pricing models for valuing the option to claim a minimum revenue guarantee and option to abandon in the pre-construction phase of the Taiwan High Speed Rail project, and examine the combination of these two options. The results indicated that both options could create substantial value, and they have a negative correlation, as the value of the minimum revenue guarantee increases when the option to abandon decreases.

The option to expand demonstrates an ability for a highway to widen and upgrade in both the horizontal and vertical directions. Horizontal expansion aims to expand the highway by increasing the number of road lanes whereas vertical expansion makes an effort to reinforce the thickness of the road course by adding additional courses in the road base and surface. Both approaches reinforce road course tolerance and increase vehicle capacity. Ashuri et al. (2011) apply real options theory to financially evaluate toll road investments that involve the fixed (one-stage) design and the adaptable (two-stage) design. In this model, traffic uncertainty is simulated by Monte Carlo simulation on a risk-neutral binomial lattice that aims to maximise the project value at the optimal time for the project expansion. Fawcett et al. (2015) study six option strategies for highway course structures that try to upgrade the pavement once traffic volume exceeds a predetermined tolerance. This research illustrates the relationship between environmental impact and cost for some alternative strategies in the same graph with cost-priority and eco-priority contours. The findings, however, are unique to the case study, so it is impossible to take a broad view of other projects which have distinctive characteristics.

Mirzadeh and Birgisson (2016) emphasise the option pricing framework is a proper valuation tool, especially when the projects include government support mechanisms and are formed in public-private partnership. The authors develop a binomial pyramid option pricing approach for two risk variables (revenue and cost) to assess project value and bankruptcy situation for the government support mechanism of Price Adjustment Clauses (PACs). The authors also argue that risks in public-private partnership road projects should be allocated between the private sector concessionaire and the public sector authority by adjusting the concession contract and the level of government support.

Using Least Squares Monte Carlo and the Longstaff–Schwartz algorithm, Power et al. (2015) propose a risk-based framework, allowing both financial and physical variables, to analyse the decision of timing and magnitude for major repairing investment of infrastructure projects. Pellegrino et al. (2013) identify a variety of key risks and summarise associated risk alleviation approaches, based on real option strategies, in public-private partnership projects. The authors present an option-based risk management framework (OBRiM) to explore the possibilities and rationale for implementing real options dealing with potential risks, such as technical, commercial, economic, financial and political risk.

Sun et al. (2019) develop a trading mechanism for an expansion option to solve expansion issues in build-operate-transfer (BOT) projects, rather than using renegotiations. Based on data collected from highway case studies in China, the authors emphasise this trading expansion option model reduces the renegotiation transaction costs for the public and increases the respective payoffs for both the authority and the concessionaire.

2.3 Financial options evaluation methods

2.3.1 Existing evaluation methods

This section provides an overview of the methods commonly used to calculate the option value. These existing methods are developed for financial options valuation and have then been extended to real options applications. This section does not present the theoretical basis and the derivation of the methods as there are many resources that explain the mathematics and concepts behind the theory (Carmichael, 2014; Copeland and Antikarov, 2001; Guthrie, 2009; Kodukula and Papudesu, 2006; Mun, 2002; Nembhard and Aktan, 2010). This section discusses the concepts, pros and cons, and deficiencies of the existing methods, and critically assesses the applications of these methods to real options.

Partial differential equations

The partial differential equation (PDE) method involves solving a partial differential equation with specified boundary assumptions and conditions, such as option type, volatility, and expiry date. In this method, the value of an option is given by an equation. The well-known model in this group is the Black-Scholes method (Black and Scholes, 1973; Merton, 1973). The Black-Scholes equation is a simple way to estimate option value, however it may be more appropriate for financial options than for real options (Carmichael, 2016a; Carmichael et al., 2011; Kodukula and Papudesu, 2006).

The reason for the inconsistency is this method relies heavily on the following assumptions of a perfectly financial market (Hull, 2002):

- The volatility of an underlying asset remains constant over time.
- The underlying asset price movements follow the Wiener process, called geometric Brownian motion.
- The underlying asset price presents a lognormal distribution.
- The interest rate is risk-free and constant.

- The exercised date of the option is set at the expiry.

These assumptions may not reflect adequately what is observed in the financial market and this leads to the limited application of this model for many reasons noted by Carmichael et al. (2011) and Carmichael (2016a):

- The Black-Scholes model is developed for European financial options that can only be exercised on a fixed date and no dividends are included. Real options, by contrast, can be exercised anytime during their life.
- The assumption related to the lognormal distribution of the underlying asset price is a deficiency, because this may not be suitable for the involved cash flows of real options.
- The Black-Scholes model assumes the risk-free rate, exercise price and volatility remain constant over time, and does not allow measurable changes of these variables in the market.

Adjustments of this model have been proposed to overcome such issues, including constant volatility, early exercising and incorporating dividends, however Black-Scholes is still widely used to estimate option value due to its simplicity (Copeland and Antikarov, 2001; Guthrie, 2009; Hull, 2002; Martinez-Cesena et al., 2013; Martins et al., 2015; Mun, 2002; Savolainen, 2016).

Trees (lattice approach)

Lattices share the same characteristic as the conventional decision tree that is in the form of a branching tree and set out the evolution of the possible value of the underlying asset over the option lifetime. There are major differences between a lattice and a conventional decision tree method. A lattice will recombine with another lattice at an appropriate node, whereas this does not happen in a decision tree. Moreover, a lattice represents a chance node, while a decision tree provides a choice and its effects (Kodukula and Papudesu, 2006; Zhao and Tseng, 2003).

In trees or lattices, the movement of the underlying asset price and volatility are simulated in discrete scenarios (Copeland and Antikarov, 2001; Guthrie, 2009). This method offers more flexibility compared to the Black-Scholes equation because it allows the key input parameters, such as exercise price and volatility, to be changed over the valuing process. In this method group, the binomial tree approach is used widely to deal with a single risk variable (Kodukula and Papudesu, 2006).

The price evolution of an underlying asset in a tree model can be handled by following the probability of the asset future price moving upward and downward (Hull, 2002). Starting at the initial price, all possible values of the underlying asset are observed graphically in the form of a branching tree. The last nodes at the end of the binomial tree provide the range of possible underlying asset values at the option expiry. Because of this visual feature, the lattice can be applied easily to forecast the movements of underlying asset prices that vary with respect to an asset's volatility (Culik, 2016; Kodukula and Papudesu, 2006). Thus, transparency in the possible underlying asset values is a key advantage of the binomial method. This feature helps estimators and practitioners to use less effort to explain the obtained value to upper management for trading decisions and approval (Kodukula and Papudesu, 2006).

The total length of time in the tree method is the option timeline, and it can be divided by as many time steps as estimators wish. An increase in the number of time steps leads to the exponential increase of the number of possible outcome values, although the range of these outcomes (minimum and maximum) may not change significantly at the final step of the lattice. This increase also leads to the smoother frequency distribution curve of these values. Generally, the higher the number of time steps, the finer the distribution curve of underlying asset value, and therefore the higher the level of accuracy of option calculation (Copeland and Antikarov, 2001; Guthrie, 2009; Kodukula and Papudesu, 2006).

Simulations

Simulations are applied to model the evolution of underlying asset value and uncertainty. The most widely used simulation method is Monte Carlo simulation (Berk and Podhraski, 2018; Glasserman, 2003; Hawas and Cifuentes, 2017; Herath and Park, 2002). In this method, widely diverse scenarios are generated by changing sets of input parameters in the same calculation. The calculation is then repeated thousands of times to observe the probability distribution of option values. This stochastic method is able to deal with many kinds of real options and multiple uncertainties. It, however, takes enormous time and requires a high level of mathematics knowledge and specialised software and computational techniques (Martinez-Cesena et al., 2013; Martins et al., 2015; Mun, 2002; Savolainen, 2016; Sun et al., 2019).

2.3.2 Comments on existing methods

The previous section highlights several methods are available to calculate option values and, within each method, there are many alternative computational techniques to deal with the mathematical complexity. Some methods include complex mathematics, while others are more intuitive and can be illustrated easily. The choice depends on the desired simplicity, available input data, and the validity of the method for a specific application. Many practitioners are comfortable using these financial options methods to analyse real options problems (Barton and Lawryshyn, 2011; Borison, 2005; Carmichael, 2016a; Carmichael et al., 2011).

The option is defined as 'real' because it deals with physical properties, compared to 'financial' options, which deal with underlying assets in financial market, such as stocks or bonds. Real options and financial options are significantly different (Eschenbach et al., 2007; Kodukula and Papudesu, 2006; Mun, 2002) despite sharing some characteristics. A financial option is based on an underlying asset, for example stock or bond, which is tradeable in the financial market and its value is not influenced by its holders, whereas a real option represents real property (no underlying asset), is not traded and is dependent on the management of the asset. While the exercising of financial options may offer immediate benefit, exercising real options can bring long-lasting continuation of returns. Parameters of financial options, such as underlying asset, exercise price, expiry date and exercise conditions, are clearly defined in the embedded contracts, whereas these parameters, related to managerial decisions, of real options are discretionary or flexible.

Due to these differences, the existing approaches adopted to analyse financial options have been criticised as unsuitable for real options. Some researchers have highlighted the unsuitability of using financial option valuing approaches for real options (Barton and Lawryshyn, 2011; Borison, 2005; Carmichael, 2016a; Carmichael et al., 2011). These methods, mentioned in the above section, include partial differential equations (PDE), tree or lattice, and simulations. The main unsuitability is derived from the treatment of volatility of the underlying asset, as there is no equivalent remedy for real options. Other assumptions acknowledged for financial options, such as constant volatility, tradeable asset, geometric Brownian motion, lognormal distribution, and deterministic exercise price, also do not translate well to real options.

In summary, given this context, there is a need to develop a more appropriate method to value real options in infrastructure projects. This thesis thus presents a single unifying approach, based on the probabilistic cash flow approach, to calculate values of all options in public-private partnership toll road projects. This approach, developed specifically for real options, avoids all of the criticisms of the use of financial option analogies for real options.

2.4 Financial agreements in public-private partnerships

The recent literature provides a great deal of study on introducing managerial flexibilities, embedded with real options, in financial agreements in public-private partnership infrastructure projects. Those financial agreements mentioned in the literature reflect how risk-sharing mechanisms between the two parties, the authority and the concessionaire, are structured. Ho and Liu (2002) present the theoretical and quantitative framework of option pricing to value the government guarantee and its effect on project financial viability. Cheah and Liu (2006) value the government guarantee option, applied to the case of the Malaysia Singapore Second Crossing bridge, based on a Monte Carlo simulation. Chiara et al. (2007) discuss the valuation approach for the so-called Australian option, multiple-exercise options, in a toll road project. Based on the Taiwan High Speed Rail project, Huang and Chou (2006) present the case with the combination of a minimum revenue guarantee and an option to abandon. Almassi et al. (2013) study a computational valuation tool to help the public sector in public-private partnership projects to determine contractual configurations and guarantees by minimising cost and risk involved. Brandao et al. (2012) discuss the application of a real options approach to analyse the effect of a minimum demand guarantee on mitigating the risk of the metropolitan subway system in Brazil. Wibowo et al. (2012) present the operational methodologies of quantifying payments of guarantees for the concessionaire, involving costs of acquiring land, toll adjustment delays and compensation payments, given to PPP toll road projects. Ashuri et al. (2012) develop a risk-neutral valuation method to value the minimum revenue guarantee. Chiara and Kokkaew (2013) introduce the dynamic revenue insurance contract, as an alternative to the conventional government guarantees, modelled as multiple-exercise options. Caselli et al. (2009) propose the application of real options analysis to establish the indemnification price, to be paid by a public administration, in financing a public-private partnership toll road project. Carbonara et al. (2014) develop a real option based model for determining the revenue guarantee level from the government, which creates fairness by balancing the concessionaire demand for profitability and public sector financial interests. Buyukyoran and Gundes (2017) identify optimum upper and lower boundaries of compound minimum revenue guarantee and maximum revenue cap, based on real options theory, which establish a fair risk allocation structure. Shan et al. (2010) introduce a collar option as a combination of put and call options where the concessionaire holds a floor (a put option), protecting against revenue below the floor, and simultaneously offers a cap (a call option), sharing the revenue above the ceiling.

Generally, public-private partnership financial agreements between the authority and the concessionaire can involve a range of guarantees or adjustments under differing names or descriptors:

- Minimum revenue guarantee (MRG). The guarantee involves the authority paying the concessionaire if the actual toll revenue falls below a pre-agreed threshold. This puts a limit on the revenue downside for the concessionaire. Most studies on toll road options are of this type (Brandao and Saraiva, 2008; Carbonara et al., 2014; Cheah and Liu, 2006; Chiara et al., 2007; Galera and Soliño, 2010; Kokkaew and Chiara, 2013; Wibowo, 2004).

- Buyout. The authority holds the right to buy the concession back before the end of the concession period, at a predetermined exercise price, subject to certain conditions (Power et al., 2016; Rose, 1998).

- Revenue-sharing. The authority holds the right to claim a percentage share of excess revenue when the revenue exceeds an agreed upper limit or threshold (Power et al., 2016; Song et al., 2016).

- Restrictive competition guarantee. This guarantee secures a road's revenue against loss caused by competing roads (Liu et al., 2014).

- Toll adjustment mechanism (TAM). This is similar in intent to a guaranteed minimum revenue to the concessionaire, however the toll adjusted mechanism gives the concessionaire the right to adjust tolls to achieve a desired revenue (Chen et al., 2017).

- Collar: A collar combines both lower and upper revenue thresholds to create a band. The concessionaire holds an option on low revenue, while the authority holds an option on high revenue (Attarzadeh et al., 2017; Jun, 2010; Shan et al., 2010).

- Traffic floor and ceiling (TFC): Traffic floor and ceiling is based on pre-agreed lower (floor) and upper (ceiling) traffic levels. The concessionaire holds the traffic floor option, while the authority holds the traffic ceiling option. It is the same as a collar (Shan et al., 2010), but with two differences: an upfront cost or premium, and a guarantee covering only part of any traffic shortfall or traffic exceedance (referred to as a partial coverage guarantee) (Blank et al., 2009; Iyer and Sagheer, 2011; Kokkaew and Chiara, 2013).

The existing literature focusing on revenue-related agreements can be classified into two groups: one-sided protection and two-sided protection.

One-sided revenue protection includes minimum revenue guarantee, buyout, revenue sharing, restrictive competition guarantee, and toll adjustment mechanism. These provide revenue protections to either party, the concessionaire or the authority, to cope with fluctuating revenue. Minimum revenue guarantee, restrictive competition guarantee, and toll adjustment mechanism are similar in intent as providing a mechanism to limit the concessionaire's losses by compensating the concessionaire should the project's revenue fall below a defined level, threshold or floor (Chiara et al., 2007) in any year. By contrast, revenue sharing enables the authority to require the concessionaire to share either partially or fully the excess revenue where the project's revenue exceeds a defined level (Power et al., 2016; Song et al., 2016). Buyout allows the authority to take project control back from the concessionaire before the end of the concession period, subject to certain conditions (Power et al., 2016; Rose, 1998).

A two-sided revenue protection combines both minimum revenue guarantee and revenue cap to create a band of revenue that benefits both parties, the authority and the concessionaire (Attarzadeh et al., 2017; Blank et al., 2009; Iyer and Sagheer, 2011; Jun, 2010; Kokkaew and Chiara, 2013; Shan et al., 2010). The guarantees may be viewed as the concessionaire and the authority holding options (rights but not obligations) to claim revenue from the other party when the revenue goes outside the pre-agreed levels. In any year, the concessionaire holds a lower bound option (based on a revenue floor), while simultaneously the authority holds an upper bound option (based on a revenue cap). Depending on how the levels are structured, project viability is improved for both parties.

Each of the above options and scenarios are discussed and analysed in separate studies. The literature lacks a comprehensive review covering all revenue guarantee options available in public-private partnership toll road projects. This creates the need for a state-of-the-art literature summary to encompass all existing revenue-related guarantee options, including one-sided and two-sided protection.

2.5 Determining the concession period

The concession period is a key variable to be determined in a public-private partnership contract. The concession period is the agreed length of time during which the concessionaire has the right to invest and operate the infrastructure facility before it is transferred back to the authority (Shen et al., 2002). Generally, a long concession period financially benefits the concessionaire and results in a loss to the authority and the public as they have to pay tolls for a longer time (Shen and Wu, 2005). Conversely, a short concession period poses financial risks for the concessionaire as it cannot recover its initial investment or generate a suitable return (Yu and Lam, 2013). Therefore, this long–short conflict creates the need to identify an appropriate concession period, which can protect both the authority's and the concessionaire's benefits.

Numerous studies focus on how to determine the appropriate length of the concession period. A concession period can be considered appropriate if the length of time can lead to a win-win situation while satisfying both the authority's and the concessionaire's desirable requirements (Bao et al., 2015; Carbonara et al., 2014). Ngee et al. (1997) propose a multiple linear regression model to identify the concession period. Using project net present worth, Shen et al. (2002) discuss a bounded interval for the concession period, considering the trade-off between the public sector's and the private sector's interests. Shen and Wu (2005) take into account the surrounding risks and uncertainties to determine an interval for the concession period length using the combination of net present worth analysis and Monte Carlo simulation. Zhang and AbouRizk (2006) discuss the trade-off between the authority's and concessionaire's benefits in determining an interval length of the concession period, based on Monte Carlo simulation and the critical path method. Ng et al. (2007) develop the fuzzy set theory and Monte Carlo simulation to deal with the concession period issue. Commenting on determining the concession period, Shen et al. (2007) propose this period is agreed based not only on the preferred economic benchmarks but also the bargaining power of the authority and concessionaire. Zhang (2011) presents a web-based concession period model considering existing risks and trade-off between the authority and concessionaire benefits. Hanaoka and Palapus (2012) apply Monte Carlo simulation and bargaining game theory dealing with the concession period issue considering the trade-off between the interests of the two parties (the authority and the concessionaire). Khanzadi et al. (2012) use system dynamics and fuzzy set theory to obtain an interval for the concession period considering the various influencing factors. Yu and Lam (2013) assess the impact of influential factors on the determination of the concession period based on Monte Carlo simulation. Bao et al. (2015) develop an incomplete information bargaining model to determine the length of the concession period.

In summary, studies have performed a range of analyses for concession periods. Because of future uncertainties, any concession period established before public-private partnership agreement may turn out to be inappropriate based on actual project performance. No studies examine defining a concession period based on actual project performance, and concession periods which appropriately treat both parties – the authority (equivalent to the public) and the concessionaire – based on actual project performance. This is examined in Chapter 6.

2.6 Variations and renegotiations

2.6.1 Variations in a construction contract

Variations or change orders refer to physical changes to the scope of works in the original contract, including additions, substitutions or omissions to the scope of work (Akinsola et al., 1994; Murdoch and Hughes, 2000). A physical change in a road project, for example, is the addition of an extra lane, the provision of another entrance ramp or exit ramp or similar. The work and the conditions in a variation order are generally determined by negotiation between owner and contractor (Bajari and Tadelis, 2001; Syal and Bora, 2016).

The issuing and valuing of variations have long been acknowledged as a major contributor to conflict and disputes (McGowan et al., 1992; Potts and Patchell, 1995). These conflicts and disputes may have negative financial impacts on projects (Atkinson, 1992; Seeley, 1993), including a reduction in labour productivity (Hanna et al., 1999; Hanna and Gunduz, 2004; O'Brien, 1998; Thomas and Napolitan, 1995), delay in completion (Arain and Pheng, 2007; Fisk, 1997) and the additional cost incurred from variations claims (Arain, 2005; Arain and Pheng, 2005).

Variations exist because of the dynamic and complex nature of construction projects. For most projects, it is not possible to anticipate and incorporate every potential or challenge into the contract from the outset (Grossman and Hart, 1986; Hart and Moore, 1988). Dealing with this, contracts, in general, may include clauses enabling the owner or principal to alter the specification of the original contract and to price these variations. Such provisions are usually called variations clauses. These give the contract administrator the power to change the nature of the required work of the contractor (Murdoch and Hughes, 2000). Without these, the contract would, in principle, have to either reject any variation instruction or be renegotiated against these changes.

Regarding variation order negotiation, the process for agreeing to a variation order begins when one of the parties to a contract requests a variation to that agreement. The instigation of a variation could come from the owner or the contractor, but with the final approval of the owner (Syal and Bora, 2016). During the negotiation, the contractor prepares a variation order proposal, quoting a price and scope for the extra work. Once the owner and contractor have agreed on scope, price and schedule, a formal written variation order is finalised and signed by all parties. Then, the contractor proceeds to perform the changed work.

Naturally, the contractors may be the most advantaged party during variation negotiation because they earn their income and benefit from an increase of works including unit rates, time extension and variation in quantities without competition from other contractors (Alnuaimi et al., 2010). The contractors can also be less cost conscious in doing the variation works and they may deliberately delay the final settlement of all alterations until the final negotiated agreement with the owner is issued (Levin, 2016). For these reasons, the contractor is then in an opportunistic position of bargaining power. Conversely, the owner is in a position of bargaining weakness and may have to agree to excessive contractor demands. In the extreme case, declining the excessive demand of the contractor is tantamount to breaking off the negotiation and the withdrawing of the contractor. If resuming negotiation, on the other hand, the contractor has an advantageous negotiation position, and this places a financial burden on the owner who has to pay an unreasonable extra cost for claiming the variation. This negotiated extra cost often creates unfair outcomes for the owner as the amount may be much more significant than the variation should actually cost. Notes on this issue are presented in research works by Alnuaimi et al. (2010), Bajari et al. (2006), Chang and Ive (2007), Charoenngam and Mahavarakorn (2011), Levin (2016), Lu et al. (2014), Okada et al. (2017), and Saunders (1996).

Construction-only contracts, historically and naturally, adopt two different approaches to the pricing of variations (Levin, 2016; Murdoch and Hughes, 2000):

- Using rates derived from express terms laid down in the contract: The variation clause will anticipate allowing changes that are valued using pricing information that directly relates to the build-up of the contract sum. This schedules of rates and prices in the original contract will facilitate the valuation of variations. Once a variation is needed, the contract will typically adopt this approach so that the rates in the priced original contract will be used to value the variation.
- Using a separate schedule of rates or prices by re-negotiating: Alternatively, the approach to valuing variations is to use rates and prices that have no relationship to the contract sum (Murdoch and Hughes, 2000). A contract may contain a value of the original scope but stipulate that variations should be valued by reference to an entirely separate schedule of rates. This separate schedule of rates and variation extent will be decided and approved via the renegotiation process.

These conventional methods are not applicable in valuing variation because of the existence of uncertainty, and the variation may or may not take place at the discretion of the party (owner or contractor) who initiates the variation.

Commenting on physical variations or changes, some researchers have adopted a built-in flexible contract using real options theory. Flexibility in the contract refers to a capability to change in line with future circumstances. For toll roads, the needs and wants of users and operators change mainly in line with traffic demand. de Neufville and Scholtes (2011) adopt the needed flexibility in design, and subsequently in the contract, in order to deliver significantly increased value of projects. Ashuri et al. (2011) present a financial valuation framework based on real options analysis to evaluate investments in toll road projects under a two-phased development plan. Fawcett et al. (2015) study options strategies of highway course structures that try to upgrade pavement once traffic volume exceeds a predetermined tolerance. Demirel et al. (2017) discuss the relation between flexibility and the ability to proactively anticipate and address possible contingencies and their solutions. Martins et al. (2015) review the application of real options in infrastructure and conclude that the flexibility allows these projects a more progressive adaptation to changing circumstances and decreases the downside risks. In summary, the literature acknowledges that the added flexibility embedded with real options allows the possibility of change to projects to cope with future uncertainty. However, the literature mainly focuses on some specific flexibilities through real options analysis and it has not presented the above variations issues to the owner.

2.6.2 Variations in PPPs

Changes or variations are inevitable in public-private partnership projects because the projects are long term and have complex characteristics with a high level of uncertainty (Cruz and Marques, 2013a; Gifford et al., 2014; Guasch, 2004; Hwang and Low, 2012). However, there is no provision in public-private partnership agreements to deal with these changes. PPP stakeholders (the authority and the concessionaire) are more prone to conduct renegotiation of concession contracts (Baeza and Vassallo, 2010; Guasch, 2004; Guasch et al., 2014). Renegotiation can be seen as resulting from adopting incomplete contracts (Xiong and Zhang, 2016) because it seems impossible to incorporate all possible anticipated changes (variations) in the terms of a written PPP contract at the beginning of the concession period (Akinsola et al., 1994). Moreover, the cost of writing complete contracts that can deal with all possible contingencies, even with a low probability of occurrence, is prohibitively expensive (Tirole, 1999). Therefore, the issue of incomplete contracts is unavoidable as no contract can include every possible contingency (Hart, 2003). Furthermore, a more complex contract may reduce transparency in the use of public budgets in PPP agreements (Sarmento and Renneboog, 2016).

Any change requiring amendments or revision of the original concession contract is defined as a renegotiation (Fatokun, 2018; Guasch et al., 2007; Xiong and Zhang, 2016). Most of the growing body of literature on the renegotiation of PPP projects is focused primarily on identifying the causes and effects of renegotiations and how to cope with them when they occur. For the negotiation of physical changes, the variations are caused by both design and technical factors (Fatokun, 2018). Regarding design factors, changes in concession design scope (Cruz and Marques, 2013b; Sarmento, 2014), and traffic demand overestimation and risk (Baeza and Vassallo, 2010; Cruz et al., 2015; de Brux, 2010; Domingues and Zlatkovic, 2015; Guasch et al., 2014) are treated as primary causes of variations. Related to technical factors, the variations involve unilateral changes of design concept during project execution (Cruz et al., 2015; Cruz and Marques, 2013b), variations or additional works (Sarmento, 2014), and specification changes during technical development of projects (Bitran et al., 2013; Cruz and Marques, 2013b; Guasch et al., 2014; Sarmento, 2014). In general, the previous research centres on the changes and renegotiations during design, pre-construction and construction phases, and it stops short of dealing with the post-construction variations in PPP agreements.

The literature reports a high percentage of renegotiations in PPP agreements worldwide, such as in Latin America and the Caribbean (Bitran et al, 2013; Guasch, 2004), the United States (Gifford et al., 2014), Australia (Czerwinski and Geddes, 2010), Asia (de Brux, 2010; Zhang and Xiong, 2015), United Kingdom (Fatokun, 2018), France (Athias and Saussier, 2018), Portugal (Sarmento, 2014), Spain (Baeza and Vassallo, 2010) and Greece (Nikolaidis and Roumboutsos, 2013). Commonly, the concessionaire submits a low price for the concession contract, which does not cover all necessary carried risks, in order to win the concession bidding and then relies on variation orders during construction and post-construction to recover lost profit damages, leading to cost and schedule overruns (Sarmento and Renneboog, 2016). Due to the inevitable incompleteness of concession contracts, the authority and concessionaire primarily rely on renegotiation as the main tool to provide the necessary flexibility to deal with changes and variations in PPP agreements. This means the high incidence of renegotiations continues with a higher frequency, even occurring shortly after the PPP contract is signed (Guasch, 2004; Guasch et al., 2014). As a result, it may have negative impacts on both the PPP's performance and efficiency and undermine the credibility of PPP projects.

While renegotiation may be necessary to improve the performance of the partnership, there is evidence that renegotiation may create an unbalanced position of bargaining strength between the authority and concessionaire (Cruz et al., 2015; Sarmento and Renneboog, 2016; Yescombe, 2007; Zhu et al., 2016). If the authority needs to claim any variations of concession, the authority is in a position of bargaining weakness and may have to agree to excessive concessionaire demands. The concessionaire would only agree to a change if it is worthwhile to the concessionaire to do so, and may bargain, for example, for an extension of the concession period or a readjustment of the toll pricing formula. These bargains may then shift the financial burden to the authority and the public as they have to pay the extra cost to claim their variation order (Almarri and Blackwell, 2014; Baeza and Vassallo, 2010; Cruz and Marques, 2013a; de Brux, 2010; Fernandes et al., 2019; Guasch et al., 2007; Marques and Cruz, 2012).

In summary, the literature acknowledges that renegotiation is a primary tool to address changes and variations of PPP and non-PPP contracts, and the main disadvantage of variation negotiation is the authority or owner is in a position of bargaining weakness and, as a result, has to pay an extra cost or suffer a loss to claim its variations. However, the literature fails to develop any systematic approach to deal with these variations issues. There is, thus, a need for PPP agreements to introduce the ability to allow for physical variations to the infrastructure and their method of pricing. The PPP agreement should proactively identify a method by which variations are to be priced, identifying major potential changes, leaving only their extent and timing unknown. Such variation can be analysed as an option, held by the authority. Having an option introduces flexibility for the authority to order variation, dealing with changes of future circumstances. This idea is developed in Chapter 7.

2.7 Gaps in literature

From the literature review, four main research gaps are identified and summarised as follows.

- *There is no comprehensive review on financial guarantees dealing with revenue-related risk*

  All options and scenarios, dealing with revenue-related risks in PPP toll road projects, are discussed and analysed in separate studies. The literature lacks an integrated review covering all revenue guarantee options available in PPP toll roads. This creates the need for a state-of-the-art literature summary to encompass all existing PPP revenue-related guarantee options.

- *Financial options analysis approaches are not appropriate for real options*

The literature uses financial market options techniques, such as the Black-Scholes equation, lattice approach and Monte Carlo simulation, and applies these by analogy, to calculate options values (Copeland and Antikarov, 2001; Guthrie, 2009; Ipsmiller et al., 2019; Kodukula and Papudesu, 2006; Martinez-Cesena et al., 2013; Martins et al., 2015; Savolainen, 2016). Many assumptions applying to such financial options techniques do not fit well to real options (Barton and Lawryshyn, 2011, Borison, 2005; Carmichael, 2016a; Carmichael et al., 2011; Lewis et al., 2008; Smith, 2005). Each option is presented and analysed in standalone studies and relies on the high level of mathematical skills of their authors. Thus, there is a need for a single unifying approach which does not rely on the financial market options literature for analysing all options. This is particularly for, but not limited to, PPP toll road projects.

- *The concession period is fixed upfront and does not reflect actual project performance*

The literature on the 'long–short' conflict of the concession period has performed a range of analyses for appropriate concession periods (Bao et al., 2015; Hanaoka and Palapus, 2012; Khanzadi et al., 2012; Ngee et al., 1997; Shen et al., 2002; Yu and Lam, 2013; Zhang and AbouRizk, 2006). However, because of future uncertainties, any concession period established before the PPP agreement may turn out to be inappropriate based on actual project performance. No publications comment on defining a concession period based on actual project performance, and concession periods which appropriately treat both the authority and the concessionaire based on actual project performance. A holistic approach that can provide flexibility in establishing the concession period based on the actual project performance for the concessionaire is lacking.

- *There is a need for public-private partnership contracts with built-in variations clauses*

The literature demonstrates that renegotiation is used as the main solution to deal with changes and variations in PPP agreements (Cruz et al., 2015; Guasch and Straub, 2006; Sarmento and Renneboog, 2016; Zhu et al., 2016) because there is no clause in the concession contract to instruct these variations. The renegotiation, dominated by the concessionaire, places the authority in a weaker position of bargaining power, and there are considerable disadvantages to the authority and the public (Almarri and Blackwell, 2014; Cruz and Marques, 2013; Fernandes et al., 2019; Guasch et al., 2007; Marques and Cruz, 2012). This creates the need for a concession contract that has built-in physical variations clauses that anticipate major possible variations and changes adopted and provide a method of valuing during the post-construction stage of the concession period. This is likely an effective measure to tackle the renegotiation problems, and to minimise the potential for disputes in the valuation process. This aims to facilitate the smooth functioning of the work without the need for additional contracts covering the changes. Since physical variations clauses are included in PPP agreements, options should be available to deal with these kinds of variations, leaving only their extent and timing unknown. This is unavailable in the literature.

The following chapter presents the research methodology to address these research gaps.

Chapter 3: Research methodology

3.1 Research methodology

This chapter describes how the research is carried out to achieve the research objectives introduced in the previous chapters.

- *Literature review*

  Through the comprehensive literature review, the research provides an overview of the options adopted to establish flexibility in offering revenue-related guarantees and dealing with a fixed concession period and variation issues. Based on this, the research approach is then developed as an extension of the original work from Carmichael et al. (2011) and Carmichael (2014, 2016a) on valuing options in infrastructure. The formulation behind this work is summarised in Section 3.3.

- *Comparative cash flow analysis*

  The research approach considers all cash flows, including cash inflows and cash outflows related to exercising an option, from the viewpoint of whoever (the authority or the concessionaire) is exercising the option, in the context of PPP toll road projects. Where exercising an option changes existing cash flow, the difference in cash flows (with and without exercising) is taken into consideration.

- *Estimation of benefits and costs*

The benefit and cost estimation, associated with the case studies described below, uses the standards and guidance in the context of the Vietnamese construction industry. The estimation is also based on quantity take-offs from drawings, together with quotations from various engineers, builders, skilled trades people, and industry representatives.

- *Analysis*

In order to examine the consistency of the thesis approach in valuing real options, the thesis analyses examples and case studies of options from selected publications in the literature. This is based on using assumptions as compatible as possible with these papers.

Supplementary sensitivity analyses, conducted by changing the values of the case variables, are also used to show the difference of option value trends calculated from the thesis approach and the existing literature.

3.2 Case studies in Vietnam

The research provides the financial and technical data for two Vietnamese toll road projects that are used as case studies and examples for option valuing in Chapters 5 and 6.

3.2.1 Hanoi–Haiphong toll highway

The six-lane highway completed in December 2015 is 105.5 km in length, and involves an investment of approximately 45,500 billion Vietnamese Dong (VND) (equivalent to USD 2 billion). The highway was built to improve traffic flow between Hanoi, the capital of Vietnam, and Haiphong, the largest port city in the north of Vietnam. Its design complied with international standards, and it was the first toll road built using a PPP in Vietnam's northern region. The three-year design and construction period is followed by a 28-year operating period.

The revenue from toll collection alone was considered to be not enough to recoup the initial investment and operating costs. In order to improve the project viability, the authority, the Vietnam Ministry of Transportation, offered the concessionaire privileges including reimbursement of land clearance costs, toll collection from an existing adjacent road, and the right to invest and operate service stations along the highway.

The revenue from these sources is additional to the main toll revenue of the highway. Collectively, the revenue from these additional sources is equivalent to a minimum guaranteed revenue.

The concessionaire's costs include operation and maintenance costs, finance and investment costs and corporate tax.

The case study is used for option valuation as an example in Chapter 6.

3.2.2 *Lo Te–Rach Soi toll highway*

The Lo Te–Rach Soi toll highway project is located in the south of Vietnam. This road started construction in 2017 and is planned to open in 2020. The highway will play a pivotal role in the Mekong Delta region's traffic network as it will link Ho Chi Minh City and provinces in Long Xuyen Quadrangle, ease traffic density on the existing National Highway 1A, and form a complete road network in the area. The Lo Te–Rach Soi four-lane highway is 53 km in length, and involves approximately USD 800 million in total investment.

This four-lane toll highway is designed for travel at speeds of 100 km/h, reducing the travel time from Lo Te to Rach Soi from the current 1.5 hours to about 40 minutes. This road is built as a parallel route to the adjacent existing congested two-lane national road QL80.

The case study is used for option valuation as an example in Chapter 5.

3.3 The probabilistic cash flow approach

3.3.1 Outline

Financial market options tools, as used in existing studies on PPP toll roads, require knowledge of the volatility of an underlying. In financial market options, underlyings refer to, for example, stock prices, carbon prices, and energy prices, which are modelled as time series with associated volatilities. In most cases, this volatility is not known directly, may not be available, or may not be agreed upon by different researchers (Lewis et al., 2008). However, the cash flow approach to real options (Carmichael, 2016a; Carmichael et al., 2011) avoids financial market option pricing tool analogies, is directly applicable to real options, and is consistent with conventional engineering feasibility study practice. This thesis shows how all types of options, both in existing published cases and the proposed novel options in PPP toll roads, can be treated in a single way through this cash flow approach.

Only cash flows directly connected with the option calculation are considered. The cash flows are considered from the viewpoint of the option holder, eliminating the need to distinguish between different option types mentioned in the financial market options literature, such as puts and calls. With a second order moment approach (Ang and Tang, 1975; Benjamin and Cornell, 1970), as adopted in this thesis, only estimates of means or expected values, E[ ], and variances, Var[ ], of cash flows are required. Issues involved in estimating analogous volatilities are avoided in favour of using cash flow variances. Estimates for expected values and variances can be obtained through usual engineering estimating practices (Carmichael, 2014). Should Monte Carlo simulation be preferred as the analysis tool over a second order moment approach, probability distributions of the cash flows would be required (Carmichael, 2016a; Carmichael et al., 2011).

Typically, for road PPPs, the cash flows involving an option can be thought of in terms of a cash outflow and a cash inflow at time T, the time of exercising the option (Figure 3.1). In Figure 3.1, for option calculation purposes, and from the viewpoint of the option holder, $Y|_{T1}$ is the equivalent cash inflow in year T, and $Y|_{T2}$ is the equivalent cash outflow in year T. The net equivalent cash flow in year T is $X|_{T} = Y|_{T1} - Y|_{T2}$. The origins of these cash flows differ in each application, and are explained subsequently. In some applications a cash flow may be revenue forgone, while in other applications, the two cash flows may represent the cash flows associated with exercising and not exercising an option. Where cash flows connected to the option extend beyond year T, then these are reduced to their present worths (equivalent cash flow) at year T, to also give a figure such as Figure 3.1. Both deterministic and probabilistic cash flows can be accommodated.

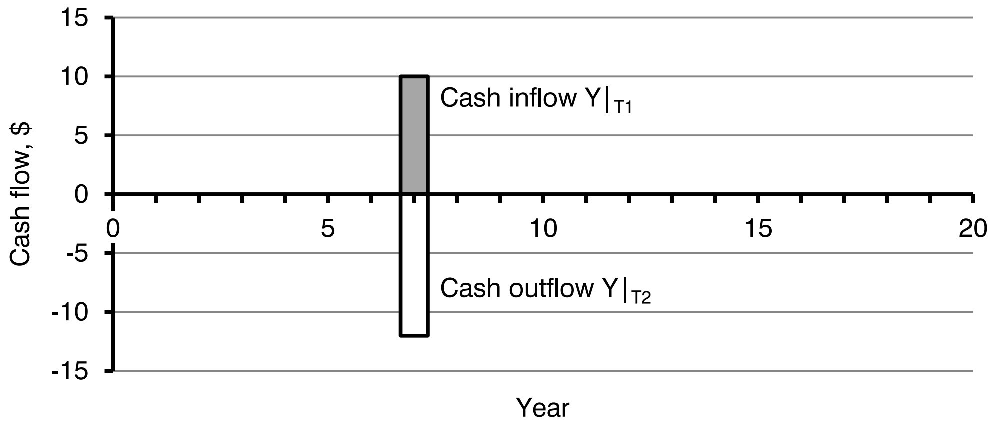

Figure 3.1 Example of cash flows involved in an option at time T.

In the following, E[ ] is expected value; Var[ ] is variance; i is a year counter, i = 1, 2, …, n; n is the concession period; PW is present worth; r is interest rate (per annum); and T is the time of exercising an option, $1 \le T \le n$.

(i) For option calculation purposes, where the cash flows at T are the only cash flows of interest, actual cash flow notation could be used, $E[Y|_{T1}] = E[Y_{i1}]$ and $Var[Y|_{T1}] = Var[Y_{i1}]$, and similarly for $Y|_{T2}$.

(ii) For option calculation purposes, where cash flows Y_{i1} over time periods i = T+1, T+2, …, n, are of interest, these are collectively discounted to T.

$$E[Y|_{T1}] = \sum_{i=T+1}^{n} \frac{E[Y_{i1}]}{(1+r)^{i-T}} \tag{3.1}$$

$$Var[Y|_{T1}] = \sum_{i=T+1}^{n} \frac{Var[Y_{i1}]}{(1+r)^{2(i-T)}} + 2\sum_{i=T+1}^{n-1} \sum_{j=i+1}^{n} \frac{Cov[Y_{i1}, Y_{j1}]}{(1+r)^{i+j-2T}} \tag{3.2}$$

The above points (i) and (ii) explain the difference between actual cash flows and equivalent cash flows; they are the same for all cases in Chapters 4 and 5, except for the buyout and toll adjustment mechanism cases. Equivalent cash flows have been introduced in order to simplify the presentation across all cases, and for no other reason.

Similar expressions apply for $Y\big|_{T2}$.

Then,

$$E[X\big|_{T}] = E[Y\big|_{T1}] - E[Y\big|_{T2}] \tag{3.3}$$

$$Var[X\big|_{T}] = Var[Y\big|_{T1}] + Var[Y\big|_{T2}] - 2Cov[Y\big|_{T1}, Y\big|_{T2}] \tag{3.4}$$

The expressions containing covariance terms can be replaced with expressions involving correlation coefficient, ρ_{12}, between $Y|_{T1}$ and $Y\big|_{T2}$, as follows:

$$Var[X\big|_{T}] = Var[Y\big|_{T1}] + Var[Y|_{T2}] - 2\rho_{12}\sqrt{Var[Y|_{T1}]}\sqrt{Var[Y|_{T2}]}$$

For a relationship between any general variables, Z and X_s, and general constants, a_s, of the form, $Z = \sum_{s=1}^{m} a_s X_s$, then:

$$E[Z] = \sum_{s=1}^{m} a_s E[X_s]$$

$$Var[Z] = \sum_{s=1}^{m} a_s^2 Var[X_s] + 2\sum_{s=1}^{m-1} \sum_{t=s+1}^{m} a_s a_t Cov[X_s, X_t]$$

The present worth is obtained by discounting the net equivalent cash flow $X\big|_T$ to i = 0:

$$E[PW] = \frac{E[X\big|_T]}{(1+r)^T} \tag{3.5}$$

$$Var[PW] = \frac{Var[X\big|_T]}{(1+r)^{2T}} \tag{3.6}$$

Similar expressions can be developed for the case where both cash flows and the interest rate are random variables (Carmichael and Bustamante, 2014; Carmichael and Handford, 2015). Continuous time discounting could be used, but discrete time discounting, typically with a period of a year, would be favoured by most engineers (Carmichael, 2014). The interest rate and variances can be selected as being different for different cash flows and at different points in time if desired.

In the previous expressions, where r and the variances change over time, they take on a subscript i.

The option value, OV, is then calculated from:

$$OV = \Phi M \tag{3.7}$$

Where Φ is the investment feasibility, defined as the probability of positive present worth being positive, $P[PW > 0]$, and M is the mean of the present worth upside, and is measured relative to PW = 0 (Carmichael, 2014). Any suitable probability distribution can be used for PW; in the following, a normal distribution is used for convenience in the calculations. For overall investment viability, OV should exceed any upfront cost or premium paid by the option holder; in some cases, there is no premium paid and hence only the magnitude of OV needs to be examined. With no premium, and for the particular case where the present worth expected value is positive, viability exists based on present worth alone, irrespective of any OV calculation (Carmichael, 2016a).

3.3.2 Evaluation steps

This section outlines practical steps for valuing options based on conventional investment thinking using cash flow. It shows that options can be valued by using a single Equation (3.7).

Step 1: Identify cash flows and assumptions

- Identify actual cash inflow, Y_{i1}, and outflow, Y_{i2}, from the viewpoint of the option holders. These cash flows, which not related to the option, are not included in the calculations.
- Define the cash inflows and outflows of interest, either only cash flows in year i or the cash flows over time periods i = T, T + 1, T + 2, …, n.
- Identify the correlation between cash flows and cash flow components.
- Determine the concession period (n) and option expiry period.
- Assume value of discount rate, r.

Step 2: Draw a cash flow diagram

- Draw a cash flow diagram presenting the principle of options.
- Identity the equivalent cash inflow ($Y|_{T1}$) and outflow ($Y|_{T2}$) in year T for option calculation purposes from the viewpoint of the option holders.
- Define a condition where the option can be exercised. An option is only generally exercised if the net equivalent cash flow in year T, $X|_T > 0$, that means the equivalent cash inflows ($Y|_{T1}$) exceed the equivalent cash outflows ($Y|_{T2}$).

Step 3: Conduct probabilistic analysis

- Estimate expected value, E[ ], and variances, Var[ ] of all cash inflow and outflow components. Cash flow components can be revenue, traffic volume, cost or their growth numbers and rates. Estimates may be handled in a number of ways. Here, optimistic (a), most likely (b), and pessimistic (c) values are estimated as is done in the planning technique PERT (Carmichael, 2006).
- Estimate the mean or expected value = $(a+4b+c)/6$, and variance = $[(c-a)/6]^2$ (see for example, Carmichael, 2006; Carmichael and Balatbat, 2008).

Step 4: Calculate mean or expected value and variance of net equivalent cash flow in year T, $X|_T$, following Equations (3.3) and (3.4).

Step 5: Discount the net equivalent cash flow $X|_T$ to i = 0, to obtain the present worth, PW, following Equations (3.5) and (3.6). An assumption to obtain the distribution of the present worth is needed. Any distribution considered as an appropriate presentation of present worth can be used, but the normal distribution might be used commonly (Hillier, 1963; Tung, 1992).

Step 6: Calculate feasibility (Φ) and mean of upside (M)

- The feasibility, Φ, is the probability that the present worth is positive. This is the area under the positive part of the present worth distribution curve (see Figure 3.2).
- The mean of the present worth upside, M, can be calculated by either using equations for a normal distribution or dividing the upside part of the present worth distribution into vertical strips and calculating its area and centroid (Carmichael et al., 2011).

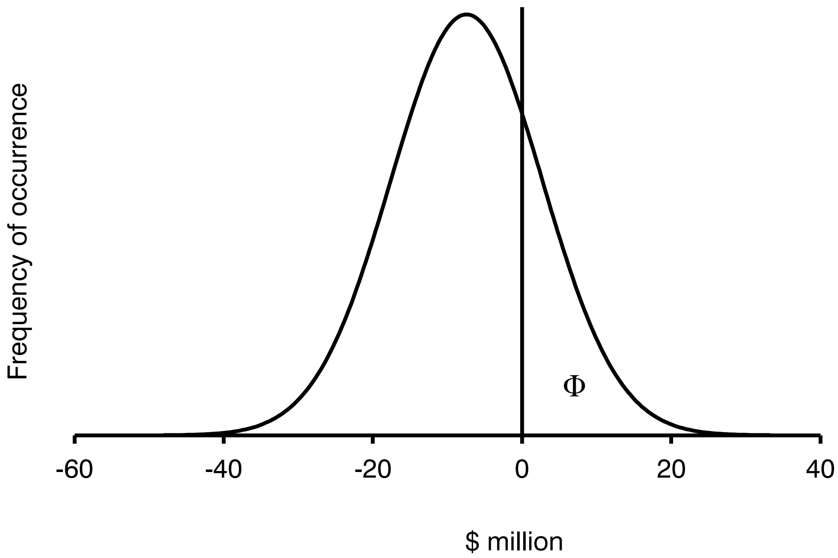

Figure 3.2 Example of a normal distribution of PW (time 0) of total cash flows.

Step 7: Calculate option value (yearly) using Equation (3.7).

Step 8: Plot the (yearly) option value versus year of exercising (if applicable).

Step 9: Calculate the total option value (sum of yearly option values) over n years (if applicable).

Depending on the established option features and how the option cash flows, based on the option holder viewpoint, are structured, the thesis adopts either partly or fully the above nine-step procedure to calculate the option values. It is shown that all option scenarios in this thesis, regardless of whether exercised yearly or discretely throughout a project's concession period, can be treated in this common way.

The following chapters examine examples and scenarios of all options in PPP toll roads and, accordingly, reinforce the consistencies of the probabilistic cash flow approach in valuing infrastructure-based real options.

Chapter 4: One-sided financial guarantee options of PPP toll roads

4.1 Introduction

The uncertainty, risk, and fairness in PPP agreements in toll road projects, especially the financial aspects of such agreements, may be partly addressed by having options (Alonso-Conde et al., 2007; Ashuri et al., 2012; Carbonara et al., 2014; Chiara et al., 2007; Huang and Chou, 2006; Mirzadeh and Birgisson, 2016; Wibowo et al., 2012). As presented in Chapter 2, an option gives the holder the right, but not the obligation, to do something on the project in the future. An option is only exercised if it is worthwhile for the holder to do so. Within the context of financial agreements and toll roads, which is the focus of this chapter, the option, for example, may translate to adjusting future revenue in response to uncertain and changing future road demand. This right may come about, in return, for some direct or indirect cost (premium) to the holder.

Depending on how a PPP agreement is structured, the concessionaire carries differing degrees of financial risk, primarily arising from road usage, patronage or demand uncertainties. While capital costs and ongoing operational costs are reasonably predictable, demand is not, and is influenced by the magnitude of the tolls being charged, travel times, vehicle operating costs, and the availability of alternative roads and transport. The viability analysis of the project from the concessionaire's viewpoint, among other things, looks at the financial risk carried, and attempts to reduce this risk by adjusting the agreement between the parties.

The concessionaire may request subsidies or guarantees from the authority (Blank et al., 2009; Brandao and Saraiva, 2008). The authority may, in turn, request reciprocal guarantees. An agreement involving guarantees, if properly structured, allows the risk to each party to be managed, and makes the project more viable. If the calculated risk carried is considered unacceptable, either party might withdraw from the project.

The existing literature focuses on revenue-related guarantees introduced to deal with uncertainties in demand during the operational phase. These guarantees can take different forms (Alonso-Conde et al., 2007; Ashuri et al., 2012; Carbonara et al., 2014; Chiara et al., 2007; Huang and Chou, 2006; Mirzadeh and Birgisson, 2016; Wibowo et al., 2012). Third parties, such as insurance companies, may be involved, but the intent is the same whether third parties are involved or not, namely to assist the authority and the concessionaire with viability and risk management. Such guarantees may be valued using an options analysis. In general, the revenue is uncertain, being based on road usage, patronage or demand. This uncertainty needs to be captured in any analysis. Typically, the literature uses financial market options techniques, applies these by analogy, and customises them according to the analysts' preferences. Each option is presented and analysed in standalone studies. In contrast, this chapter (and part of the next chapter) presents a single unifying approach for analysing all PPP toll road options, an approach based on discounted probabilistic cash flows (Carmichael, 2014, 2016a; Carmichael et al., 2011). The approach is a straightforward extension of conventional engineering viability analysis of projects, and does not rely on the financial market options literature. It offers a ready way to evaluate multiple options, requires minimal financial and mathematical knowledge, and hence can be readily implemented by practitioners.

PPP financial agreements between the authority and concessionaire can involve a range of guarantees or adjustments under differing names or descriptors. As discussed in Section 2.4, the existing literature focuses on revenue-related agreements which can be classified into two groups: one-sided protection and two-sided protection. One-sided revenue protection provides revenue guarantees or adjustments, a minimum guarantee or maximum cap, to one party (either the concessionaire or the authority), while two-sided protection combines the guarantees to benefit both parties. This chapter focuses on one-sided revenue protection.

This chapter is structured as follows. The literature on PPP toll road options is first reviewed in Section 4.2. In the next sections, each existing publication on PPP toll road options is presented and interpreted in terms of this thesis's approach. All options are analysed and evaluated using the proposed unifying approach of this thesis. Discussion and conclusions follow. The chapter is written in terms of the two parties to the PPP agreement, namely, the authority and the concessionaire.

4.2 Background

As discussed in Section 2.4, this section summarises all scenarios of one-sided revenue protections options in literature which are covered in this chapter.

- Minimum revenue guarantee (MRG). The guarantee involves the authority paying the concessionaire if the actual toll revenue falls below a pre-agreed threshold (Brandao and Saraiva, 2008; Carbonara et al., 2014; Cheah and Liu, 2006; Chiara et al., 2007; Galera and Soliño, 2010; Kokkaew and Chiara, 2013; Wibowo, 2004).

- Buyout. The authority holds the right to buy the concession back before the end of the concession period, at a predetermined exercise price, subject to certain conditions (Power et al., 2016; Rose, 1998).

- Revenue-sharing. The authority holds the right to claim a percentage share of excess revenue when the revenue exceeds an agreed upper limit or threshold (Power et al., 2016; Song et al., 2016).

- Restrictive competition guarantee. This guarantee secures a road's revenue against loss caused by competing roads (Liu et al., 2014).

- Toll adjustment mechanism (TAM). This is similar in intent to MRG (a guaranteed minimum revenue to the concessionaire), however TAM gives the concessionaire the right to adjust tolls to achieve a desired revenue (Chen et al., 2017).

Within these existing publications, traffic or revenue is commonly assumed to follow a time series such as geometric Brownian motion with associated volatility measure (Brandao and Saraiva, 2008; Carbonara et al., 2014; Cheah and Liu, 2006). Monte Carlo simulation may be used to generate realisations (Ashuri et al., 2012; Chiara et al., 2007; Kokkaew and Chiara, 2013), or the Black-Scholes equation might be used if applicable. By contrast, this chapter's approach does not have restrictive assumptions on time series or volatility, and does not require exercise prices to be deterministic or at a single point in time; uncertainty is incorporated through variance estimates. There is also no need to distinguish between option types, for example a call option or put option, as each case considers the cash flows from the viewpoint of whoever holds the option.

This chapter shows how existing published cases, dealing with one-sided financial guarantees, can be treated in a single way through the probabilistic cash flow approach. Existing PPP toll road option cases are grouped as one-sided financial guarantees, including MRG, buyout, revenue sharing, restrictive competition guarantee, and TAM. In each case, this chapter's analysis is compared to the existing literature. To make this comparison, this chapter makes assumptions as compatible as possible with the existing literature, but not necessarily exactly the same, primarily because this thesis uses variance instead of volatility, and there is no universal agreement on what volatility should be used or the conversion between volatility and variance (Lewis et al., 2008).

The result given in Hull (2002) is adopted in this chapter to guide the conversion between variance and volatility, while acknowledging that a single formula for converting between variance and volatility has not been agreed upon by researchers (Lewis et al., 2008).

$$\sigma = \sqrt{\frac{\ln\left(\frac{\mathrm{var}[\Theta_{T'}]}{E[\Theta_{T'}]^2} + 1\right)}{T'}}$$

where σ = volatility; Θ = variable being considered; and T' = time at which the conversion is being done.

In the general case, the daily traffic, toll, and any thresholds or equivalents could be anticipated to change yearly. The form of the analysis presented in this chapter does not change, should any of these vary from year to year or be constant from year to year. Notation directly applying to the option cases is given in the specific section of this chapter.

4.3 Minimum revenue guarantee

Outline

A minimum revenue guarantee (MRG) refers to a mechanism for capping the revenue (traffic demand) downside risk to the concessionaire, resulting from revenue uncertainty. The authority provides a guarantee of a minimum annual revenue (equivalent to a threshold value), F_i, to the concessionaire. This can be viewed in terms of the concessionaire holding n independent options over the concession period. The concessionaire exercises each option, and claims the revenue shortfall, when the actual annual revenue is lower than this defined minimum threshold (Brandao and Saraiva, 2008; Carbonara et al., 2014; Cheah and Liu, 2006; Chiara et al., 2007; Galera and Soliño, 2010; Kokkaew and Chiara, 2013; Wibowo, 2004). The total value of having the yearly options is the sum of the yearly option values.

In any year i = T (Figure 3.1), the option is only exercised if the revenue shortfall, $X|_T > 0$, where $Y|_{T1}$ is the minimum guarantee (threshold) value (F_i at i = T), and $Y|_{T2}$ is the revenue (R_i at i = T).

Example

Adapting Brandao and Saraiva (2008), and using a comparable traffic volume standard deviation equal to 30% of its expected value, together with additional compatible estimates, a concession period n = 25 years, interest rate r = 15% per annum.

Ordinarily, the daily traffic volume, toll and minimum revenue threshold could be anticipated to change yearly, but here are kept constant. The analysis does not change, should any of these vary from year to year.

The revenue, R_i, in any year i, i = 1, 2, …, n, is the product of the annual traffic volume, ν, and the toll per vehicle, Toll.

$$R_i = \nu_i \times Toll_i$$

Then,

$$E[R_i] = Toll_i \times E[\nu_i]$$

$$Var[R_i] = Toll_i^2 \times Var[\nu_i]$$

In any year i, if the option is exercised,

$Y|_{T1} = F_i$, the minimum guarantee threshold value

$Y|_{T2} = R_i$, the revenue

This is shown in Figure 3.1 for one year.

The net cash flow is the revenue shortfall, $X|_T = Y|_{T1} - Y|_{T2} = F_i - R_i$.

The concessionaire will exercise the option and claim any revenue shortfall from the authority when $X|_T$ is positive. The option is not exercised if X_i is negative.

Minimum guarantee level (constant) $E[F_i]$ = USD 1.5 billion, $Var[F_i] = 0$, and revenue (constant) $E[R_i]$ = USD 1.9 billion, $Var[R_i]$ = (USD 0.57 billion)^2.

Here, F_i is 80% of $E[R_i]$, and F_i and R_i are assumed to repeat for all i = 1, 2, …, n.

For i = T, $E\left[X|_T\right]$ = USD –0.4 billion, and $Var\left[X|_T\right]$ = (USD 0.57 billion)^2. From this, E[PW] and Var[PW] resulting from $X|_T$ can be obtained, and the option value for any year calculated as the solid curve in Figure 4.1.

Comparison with the literature

The sum of the yearly option values for 25 years is approximately USD 0.52 billion. This is higher by approximately 0.4% as a proportion of the threshold value, when compared to Brandao and Saraiva (2008). This is based on using assumptions, as compatible as possible, with Brandao and Saraiva (2008).

The yearly option values change with the level of guarantees as shown in Figure 4.1. The level of guarantee, that constitutes the minimum threshold in year i, is defined as a percentage of the expected annual revenue in year i, namely, $E[R_i]$. The yearly option values increase as the level of guarantee increases, and this trend agrees with the observations of Brandao and Saraiva (2008).

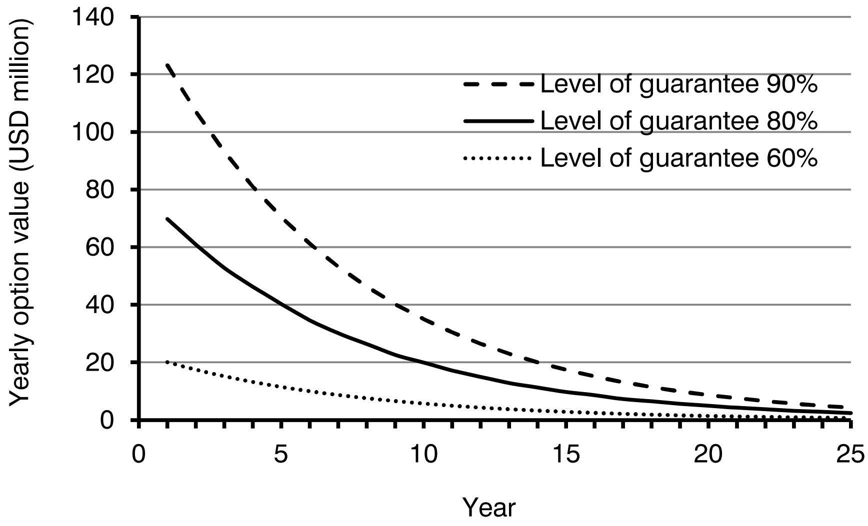

Figure 4.1 Minimum revenue guarantee example; change in yearly option value with level of guarantee.

4.4 Buyout

Outline

The ability to price and collect revenue from a toll road may be leased to a concessionaire for a finite duration, under what might be called a Comprehensive Development Agreement (CDA). Combined with this, a buyout option gives the authority the right to buy the concession back before the end of the concession period, at a predetermined buyout cost (exercise price) (Power et al., 2016). After buying back, the authority can then either collect the revenue itself, or lease out the revenue collection to another entity.

The buyout option may be exercised, at time T, only if the update value (to the concessionaire) of the revenue remaining till the end of the concession period (that is, over the period from i = T to i = n) exceeds a pre-agreed level (equivalent to a buyout cost) (Rose, 1998). The update value is the (updated) present worth (discounted to T) of the remaining revenue cash flows (Power et al., 2016). Expressed differently, this means taking all the cash flows from i = T to i = n and discounting them to time T to give a collective discounted value – the updated value. The exercising may be defined as two forms:

- The buyout option can be exercised at a pre-specified year within the concession period.
- The buyout option can be exercised in any year of the concession period.

Example

Consider the buyout option example of Power et al. (2016), using a comparable traffic volume standard deviation equal to 25% of its expected value, instead of traffic volume volatility, and the following assumptions:

Traffic volume (million vehicles) in year 1, $E[\nu_1] = 36.085$; $Var[\nu_1] = 9.021^2$

Toll per vehicle (constant), Toll = USD 10

Traffic growth (million vehicles per year), $E[\gamma] = 5$; $Var[\gamma] = 1^2$

Buyout cost at year 6, F_6 = USD 8,600 million

Interest rate per annum, r = 11.6%

Concession period, n = 25 years

The buyout cost (here a constant) equals the product of a buyout multiplier (here 1.5) and the present worth (at year 0) of revenue over the 25-year concession period (here USD 5,700 million).

The project will generate revenue in year i, i = 1, 2, …, 25 as follows,

$$E\left[R_i\right] = E\left[R_1\right] + \left(i-1\right).\text{Toll}.E[\gamma]$$

$$\text{Var}\left[R_i\right] = \text{Var}\left[R_1\right] + \left[\left(i-1\right).\text{Toll}\right]^2 \text{Var}[\gamma]$$

with $E[R_1]$ = USD 360 million and $Var[R_1]$ = (USD 90 million)^2.

Consider exercising the buyout option in year 6, interpreted from the viewpoint of the option holder (the authority). The buyout cost, a known amount, $E[Y|_{62}] = F_6$ = USD 8,600 million, and $\text{Var}[Y|_{62}] = 0$ based on Power et al. (2016).

$Y|_{61}$ according to Equations (3.1) and (3.2) where the value of R_i, for i = 6, 7, …, 25, could be assumed to be well correlated.

Discounting these cash flows, E[PW] = USD –399 million; Var[PW] = (USD 541 million)^2. From Equation (3.7), OV = USD 72.56 million.

Where the buyout cost remains the same or constant (here, USD 8,600 million), irrespective of the year of buyout, the same calculation can be repeated for exercising at any year i = 1, 2, …, 25. The solid curve in Figure 4.2 shows how the option value changes with the year of exercising.

The current set of values might be considered favourable to the authority over the concessionaire in terms of early buyout, and would need negotiation, and in particular negotiation perhaps on a variable buyout cost.

Figure 4.2 shows the influence of changing the value of the buyout multiplier through using example buyout multipliers of 1.5 (as in the previous numerical example) and a slightly larger 1.6. The buyout cost equals the product of the buyout multiplier and the present worth (at year 0) of revenue over the 25-year concession period.

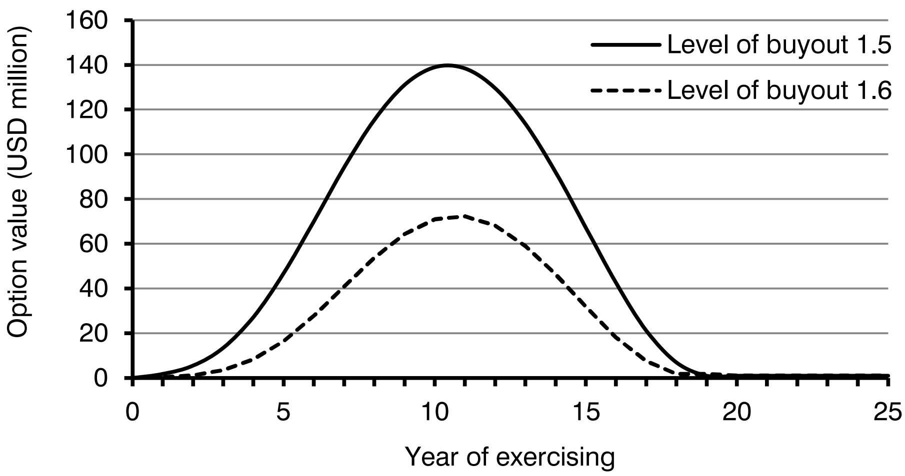

Figure 4.2 Buyout example (constant buyout cost); change in option value with level of buyout.

Where the buyout cost, F_i, is defined as a multiplier of the present worth of the revenue remaining till the end of the concession period (buyout cost reducing with time), the calculation of the option value for exercising at any year i = 1, 2, …, 25 is repeated. Figure 4.3 shows how the option value changes with year of exercising and buyout multiplier magnitude. This result is similar to revenue sharing (discuss in Section 4.5). While revenue sharing allows the authority to collect excess revenue if revenue is higher than an upper threshold, buyout gives the authority the right to buy back the project and collect the full revenue for the remainder of the concession period.

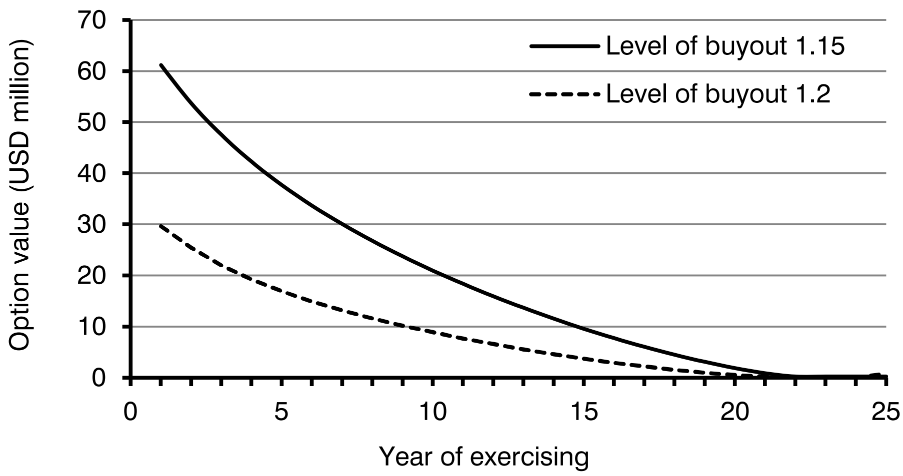

Figure 4.3 Buyout example (reducing buyout cost); change in option value with level of buyout.

Comparison with the literature

The chapter's analysis gives an option value (based on exercising in year 6, with a fixed buyout cost) higher by approximately 0.5% as a proportion of the buyout cost, compared to Power et al. (2016).

Figure 4.2 shows that the optimal time for the authority to exercise the buyout option, and buy back the Comprehensive Development Agreement (CDA), occurs near the middle of the concession period, where the plot peaks. This reflects the increasing yearly revenue with time, countered by the decreasing present worth of future revenue with time. This optimality finding agrees with the conclusion of Power et al. (2016). As shown in Figure 4.2 and Figure 4.3, the option value changes with year of exercising and decreases with increasing level of buyout cost for both constant and varied buyout cost. These trends agree with the observations of Power et al. (2016).

4.5 Revenue sharing

Outline

A revenue sharing option gives the authority (as option holder) the right to claim a percentage share, β, of the revenue that exceeds an upper limit (maximum revenue cap) in any year. The cap is adjusted upward by a constant amount each year. The concessionaire retains a (1 - β) share of this excess revenue (Power et al., 2016). The option is exercised in any year when the revenue exceeds the pre-agreed limit. The total value of having the yearly options is the sum of the yearly option values.

In any year i = T (Figure 3.1), the option is exercised if the excess revenue above the cap, $X|_T > 0$, where $Y|_{T1}$ is the revenue (R_i at i = T), and $Y|_{T2}$ is the maximum revenue cap (C_i at i = T). The authority receives β percent of the revenue excess, that is, $\beta X|_T$. The option value is calculated based on the present worth derived from an expected value $\beta E[X|_T]$, and a variance $\beta^2 \mathrm{Var}[X|_T]$.

Example

Consider the example of Song et al. (2016) with the following assumptions: *(Currency here is in Chinese yuan (CNY))*

Revenue in year 1: $E[R_1]$ = CNY 138 million; $Var[R_1]$ = (CNY 48 million)^2

Revenue growth per year: E[g] = CNY 20 million; Var[g] = (CNY 8 million)^2

Revenue cap in year 1: $E[C_1]$ = CNY 180 million; $Var[C_1]$ = (CNY 42 million)^2

Revenue cap growth per year: E[f] = CNY 27 million; Var[f] = (CNY 9 million)^2

Interest rate r = 15% per annum; and concession period n = 25 years.

In Song et al. (2016), a single volatility was assumed. Here, with revenue, revenue growth, revenue cap, and revenue cap growth all random variables, comparable standard deviations of 30%, 40%, 25%, and 30%, respectively, of their expected values have been assumed.

For R_i and g assumed independent, i = 1, 2, …, 25:

$$E[R_i] = E[R_1] + (i-1)E[g]$$

$$Var[R_i] = Var[R_1] + (i-1)^2 Var[g]$$

For C_i and f assumed independent, i = 1, 2, …, 25:

$$E[C_i] = E[C_1] + (i-1)E[f]$$

$$Var[C_i] = Var[C_1] + (i-1)^2 Var[f]$$

The revenue, R_i, and the revenue cap, C_i, i = 1, 2, …, 25, could be anticipated to be independent, and this is the case assumed in the calculations here, but the calculations change little should that not be the case.

The solid curve in Figure 4.4 shows the option value in any year, calculated for β = 80%. The change in the decline rate of the option value, most noticeably around year 10, occurs because E[PW] and Var[PW] decline at different rates over time. The trend, however, remains downward.

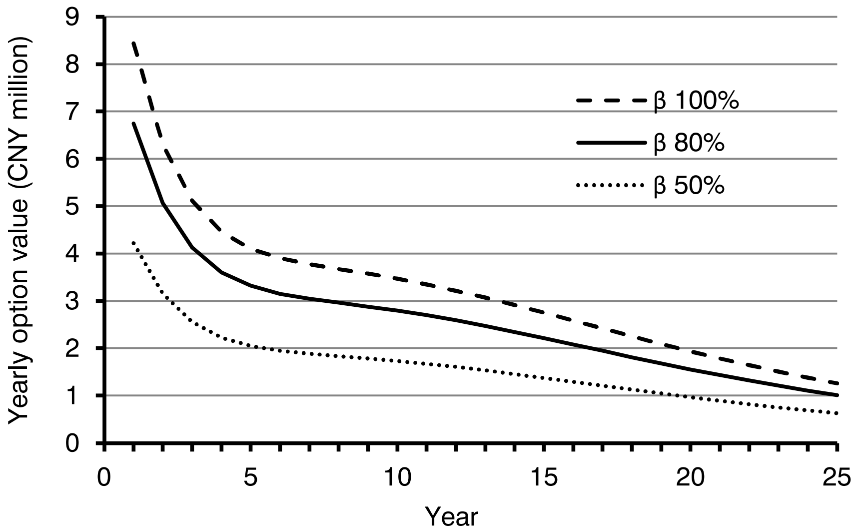

Figure 4.4 Revenue sharing example; change in yearly option value with β.

Comparison with the literature

While exact numerical comparison is not possible because of the method used in Song et al. (2016), the trend in Figure 4.4, showing how the yearly option value changes with percentage sharing β, is consistent with the trend given in Song et al. (2016). The yearly option value changes with the level of the revenue cap, $E[C_1]$ as shown in Figure 4.5. This trend is also consistent with that given in Song et al. (2016).

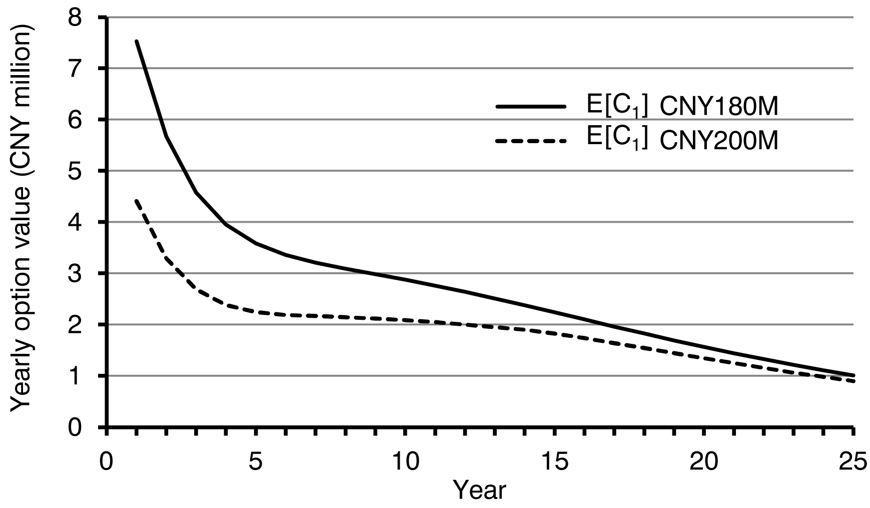

Figure 4.5 Revenue sharing example; change in yearly option value with change in revenue cap; β = 80%.

4.6 Restrictive competition guarantee

Outline

Traffic volume on a road can be influenced by the existence of alternative roads. Alternative roads, where are either untolled or tolled, compete with each other for vehicles and lead to lower revenue of the toll road. In order to address revenue loss caused by competing roads, a restrictive competition guarantee (non-compete clause) has been proposed. Here, the authority promises either to not approve any competing roads during the concession period, or to provide reimbursement to the concessionaire. This guarantee secures the original road's revenue against loss caused by competing roads (Liu et al., 2014).

Interpreted in an options sense, if the authority approves and/or builds a competing road in year i, the concessionaire (option holder) can exercise the option to claim reimbursement from the authority. The authority then compensates the concessionaire a percentage, α, of the revenue shortfall when the net revenue is lower than a pre-agreed amount (revenue threshold) in any year. The revenue threshold is adjusted each year. The value of a restrictive competition guarantee is the sum of the option values in each year of the concession period.

In any year i = T (Figure 3.1), the option is exercised if the revenue shortfall, $X\big|_T > 0$, where $Y\big|_{T1}$ is the minimum revenue threshold (F_i at i = T), and $Y\big|_{T2}$ is the revenue (R_i at i = T). The concessionaire receives α percent of the revenue shortfall, that is, $\alpha X\big|_T$. The option value is calculated based on the present worth derived from an expected value $\alpha E[X\big|_T]$, and a variance $\alpha^2 \, Var[X\big|_T]$.

Example

Consider an example adapted from Liu et al. (2014), using a comparable traffic volume standard deviation equal to 40% of its expected value, and the following assumptions:

Revenue in year 1, $E[R_1]$ = CNY 207 million, $Var[R_1]$ = (CNY 76 million)^2

Revenue growth rate per year, g_c = 7.5%

Minimum threshold at year 1, $E[F_1]$ = CNY 140 million, $Var[F_1]$ = (CNY 20 million)^2

Threshold growth rate per year, f_c = 8%

Interest rate, r = 5% per annum

Concession period, n = 20 years

Reimbursement (percentage of revenue shortfall), α = 70%.

Cash inflow growth:

$$R_i = (1+g_c)^{i-1} R_1$$

$$E[R_i] = (1+g_c)^{i-1} E[R_1]$$

$$Var[R_i] = (1+g_c)^{2i-2} Var[R_1]$$

Cash outflow growth:

$$F_i = (1+f_c)^{i-1} F_1$$

$$E[F_i] = (1+f_c)^{i-1} E[F_1]$$

$$Var[F_i] = (1+f_c)^{2i-2} Var[F_1]$$

The values of F_i and R_i, i = 1, 2, …, 20, are assumed to be independent, but need not be.

The solid curve in Figure 4.6 shows the change in option value with time. The upward trend shown is because, in the example calculations, the project revenue increases at a lower rate than the minimum threshold. Accordingly, the option has a higher likelihood of being exercised later in the concession period. Changing the interest rate leads to different option value trends (Figure 4.6). Higher interest rate values lead to lower present worth and, in turn, to lower option values.

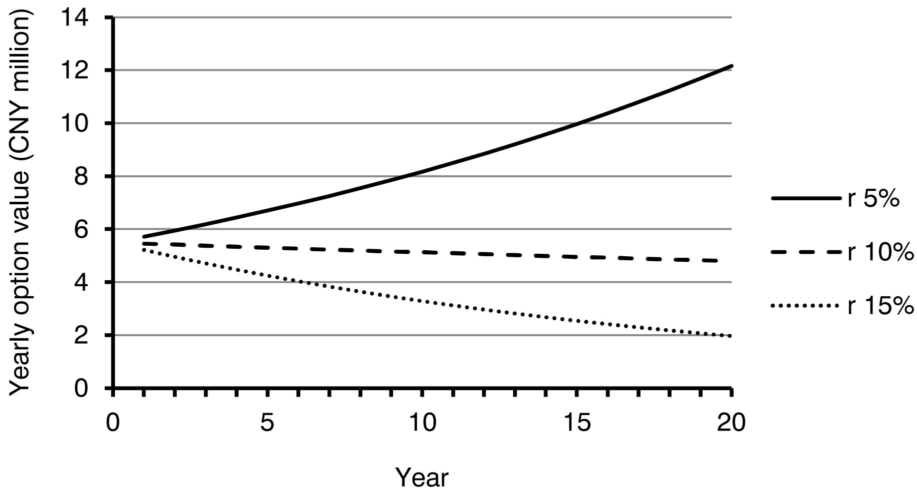

Figure 4.6 Restrictive competition guarantee example: yearly option value trends with changing interest rate.

Figure 4.7 shows how the option value changes with α, the reimbursement percentage of revenue shortfall. Lower α values lead to lower option values, as anticipated. The influence of changing minimum threshold values is shown in Figure 4.8. The yearly option values increase as the level of the revenue threshold increases.

Comparison with the literature

This chapter's analysis gives a summed yearly option value higher by approximately 0.2% as a proportion of the revenue threshold value when compared with Liu et al. (2014). The summed yearly option value is obtained by using Equation (3.7) for each year and then adding these values over all years of the concession period. The trend shown in Figure 4.8 agrees with the observations of Liu et al. (2014).

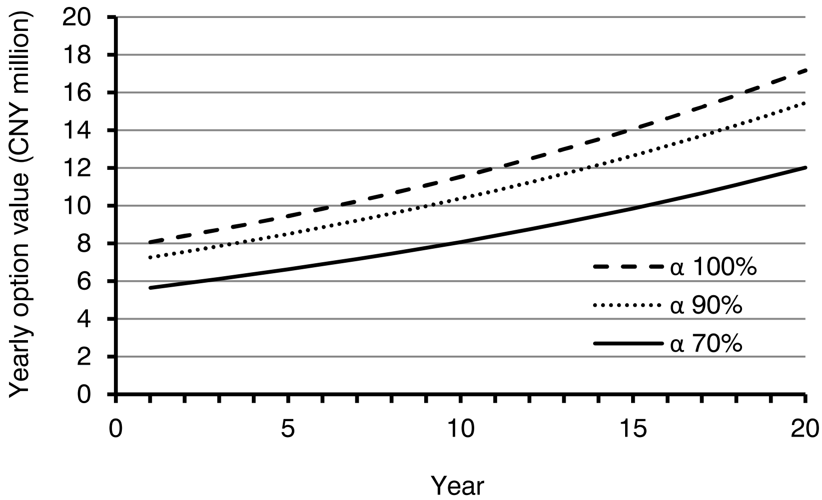

Figure 4.7 Restrictive competition guarantee example: influence of α.

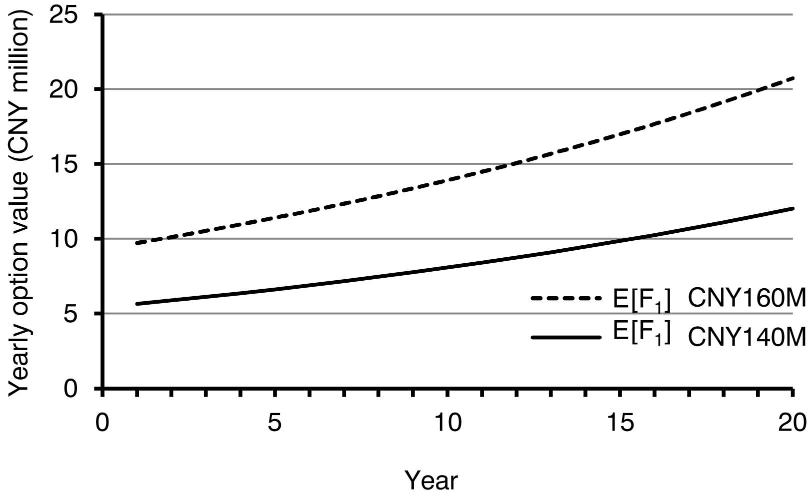

Figure 4.8 Restrictive competition guarantee example: influence of changing the revenue threshold.

4.7 Toll adjustment mechanism

Outline

A toll adjustment mechanism (TAM) is similar in intent to a minimum revenue guarantee (MRG), in that it provides protection for the concessionaire from revenue downside loss, resulting from revenue uncertainty. Whereas a MRG gives the concessionaire a guaranteed minimum revenue (the threshold), a TAM gives the concessionaire the right to adjust tolls to achieve a revenue level negotiated between the concessionaire and the authority (Chen et al., 2017).

Tolls increase annually at a fixed growth rate. However, tolls can be raised further (up to a pre-agreed toll cap) by the concessionaire if the TAM is invoked, that is the option is exercised. The TAM, if invoked at time i = T, gives the concessionaire the right to adjust (raise) the toll for the remaining period T + 1, T + 2, …, n, if the actual revenue (to the concessionaire) in year T is lower than a pre-agreed level (Chen et al., 2017). The toll cap in any year represents the maximum toll that the concessionaire may charge, whereas the pre-agreed minimum revenue level in any year defines the TAM exercise trigger. Both the toll cap and the pre-agreed minimum revenue level are included in the PPP agreement, and are established by negotiation between the concessionaire and the authority. The exercising can only be done once within the concession period depending on the PPP agreement – either at a predefined year or in any year.

It could be assumed that the traffic would decrease as the toll increases. Accordingly, the traffic with a toll adjustment mechanism (TAM) which increases the toll might be estimated to be lower than the traffic without a TAM.

In any year i = T (Figure 3.1), the option is exercised, and the tolls increased for the remainder of the concession period, if the actual revenue in year T, R_T, is less than the agreed minimum revenue threshold. Then $Y|_{T1}$ is the revenue (R_i^{wi}) for years i = T + 1, T + 2, …, n discounted to year T; $Y|_{T2}$ is the revenue (R_i^{wo}) for years i = T + 1, T + 2, …, n discounted to year T; and $X|_T = Y|_{T1} - Y|_{T2}$ is the revenue difference (with and without).

Example

Consider the TAM example of Chen et al. (2017) in Hong Kong, Scenario 5, using a comparable traffic volume standard deviation equal to 20% of its expected value and the following assumptions.

Without adjusted tolls:

Traffic in year 1 (million vehicles), $E[\nu_1^{wo}] = 73$; $Var[\nu_1^{wo}] = 14.6^2$

Traffic growth rate per year, $\gamma_c^{wo} = 2\%$ of ν_1^{wo}

Toll per vehicle in year 1, $Toll_1^{wo} = HKD\ 18$

Toll growth rate per year, $\phi_c = 6\%$ of $Toll_1^{wo}$.

With adjusted tolls (up to toll cap – an upper limit):

Traffic in year 1 (million vehicles), $E[\nu_1^{wi}] = 36.5$; $Var[\nu_1^{wi}] = 7.3^2$

Traffic growth rate per year, $\gamma_c^{wi} = 2\%$ of ν_1^{wi}

Toll cap per vehicle in year i, $Tollcap_i^{wi}$ = HKD 20 for years 2 and 3; HKD 25 for years 4 and 5, HKD 30 for years 6 and 7, HKD 35 for years 8–11, HKD 45 for year 12, HKD 55 for year 13, HKD 65 for year 14, HKD 75 for year 15, HKD 85 for years 16–21, and HKD 100 for years 22–30;

Interest rate r = 12% per annum

Concession period n = 30 years.

The superscripts wi and wo denote with invoking and without invoking TAM, respectively.

Without TAM adjustment, the road will generate revenue, $R_i^{wo} = \mathrm{Toll}_i \nu_i^{wo}$, in year i, i + 1, …, n.

Then

$$E[R_i^{wo}] = \mathrm{Toll}_i^{wo} E[\nu_i^{wo}] = (1+\phi_c)^{i-1}(1+\gamma_c^{wo})^{i-1}\,\mathrm{Toll}_1^{wo} E[\nu_1^{wo}]$$

$$\mathrm{Var}[R_i^{wo}] = (\mathrm{Toll}_i^{wo})^2\,\mathrm{Var}[\nu_i^{wo}] = [(1+\phi_c)^{i-1}(1+\gamma_c^{wo})^{i-1}\,\mathrm{Toll}_1^{wo}]^2\,\mathrm{Var}[\nu_1^{wo}]$$

With TAM adjustment, the toll is raised to the toll cap leading to revenue, $R_i^{wi} = \mathrm{Tollcap}_i \nu_i^{wi}$, in year i, i+1, …, n.

Then

$$E[R_i^{wi}] = \mathrm{Toll}_i^{wi} E[\nu_i^{wi}] = (1+\gamma_c^{wi})^{i-1}\,\mathrm{Tollcap}_1^{wi} E[\nu_1^{wi}]$$

$$\mathrm{Var}[R_i^{wi}] = (\mathrm{Toll}_i^{wi})^2\,\mathrm{Var}[\nu_i^{wi}] = [(1+\gamma_c^{wi})^{i-1}\,\mathrm{Tollcap}_1^{wi}]^2\,\mathrm{Var}[\nu_1^{wi}]$$

Assume that the TAM is exercised in year 10, and the toll cap applies in the following years. Then E[PW] = HKD –3.011 billion, and Var[PW] = (HKD 3.022 billion)^2. From Equation (3.7), OV = HKD 253.4 million. For other years of exercising, Figure 4.9 shows the corresponding option values. The curve's shape is influenced by the toll cap changing over time.

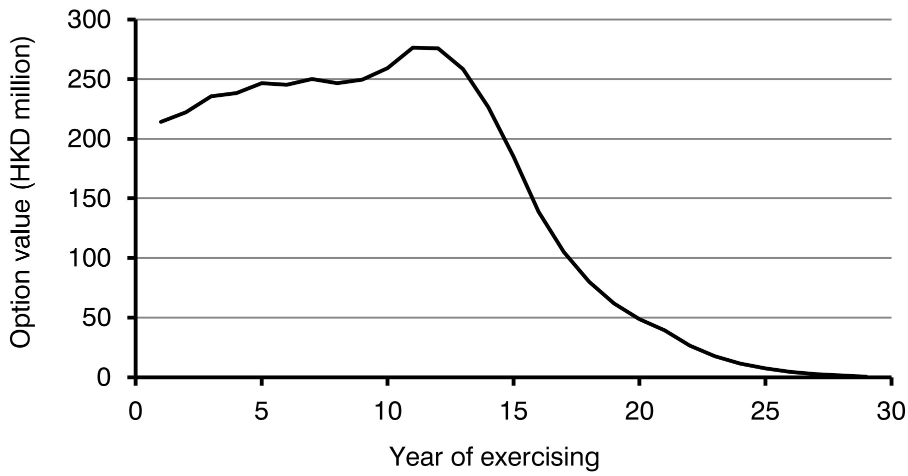

Figure 4.9 Toll adjustment mechanism example: option value versus year of exercising.

Comparison with the literature

The maximum yearly option value (year 11) is approximately 2% higher than that given in Chen et al. (2017), as a proportion of the corresponding and equivalent minimum revenue threshold.

Adapting two more assumed scenarios (scenarios 6 and 8) of Chen et al. (2017), the yearly option values increase as the level of traffic volume and toll caps increase, and this trend agrees with the observations in Chen et al. (2017).

4.8 Conclusion

For all the different option cases analysed previously in this chapter, which deal with one-sided financial guarantees, when compared to the existing literature relevant to each case, this chapter's analysis gives option values that are essentially the same. Supplementary sensitivity style analyses, conducted by changing the values of the case variables, showed option value trends to be the same as the existing literature. The differences between this chapter's option values and those of existing publications, as a proportion of similar exercise costs, is less than a few percentage points. Exact agreement would not be anticipated because of different assumptions applied between those in this chapter's approach (using variance) and those of existing publications (using volatility). Nevertheless, in this chapter's analysis, assumptions as compatible as possible with the existing literature were used.

A main difference between this chapter's approach and that of the existing literature is that this chapter's approach was developed especially for real options and uses conventional discounted cash flow thinking familiar to engineers. This is compared with the existing literature, which uses methods from the financial markets literature and draws analogies between underlying market variables and infrastructure variables. This chapter's approach accommodates uncertainty through the use of variances rather than volatility as in the existing literature. Volatility choice is based on analogies with the financial markets methods, and the term may not have direct transference to infrastructure. The probability distribution for present worth can be assumed to be any appropriate distribution, though a normal distribution was used for convenience in the preceding calculations. Users are free to use an asymmetric probability distribution if they believe it reflects present worth more appropriately. This chapter's approach can deal with cash inflows and outflows with different levels of correlation, and which change over time over the concession period, deterministic cash flows, and interest rate variability and uncertainty.

The approach in this chapter is the same regardless of the PPP guarantee or agreement, for example, whether a minimum guarantee or a maximum guarantee. The approach also makes no difference in analysing option types, as occurs in the financial markets literature.

The next chapter (Chapter 5) addresses the two-sided financial guarantees which require the participation of two parties (the authority and the concessionaire). The chapter refers to a situation where the concessionaire holds its option based on a revenue floor in any year, while simultaneously the authority holds an option based on a revenue cap. Depending on how the levels of thresholds are structured, project viability is improved for both parties.

Chapter 5: Two-sided financial guarantee options of PPP toll roads

5.1 Introduction

The existing literature focuses on financial agreements which are discussed in Chapter 4, including minimum revenue (MRG), buyout, revenue sharing, restrictive competition guarantee, and toll adjustment mechanism (TAM), are classified as one-sided protection to either the concessionaire or the authority, to cope with fluctuating revenue. Minimum revenue guarantee (MRG), restrictive competition guarantee, and toll adjustment mechanism (TAM) are similar in intent in providing a mechanism to limit the concessionaire's losses by compensating the concessionaire should the project's revenue fall below a defined level, threshold or floor (Chiara et al., 2007) in any year. By contrast, buyout and revenue sharing provide the authority a right to take project control back from the concessionaire before the end of the concession period (Power et al., 2016; Rose, 1998), and to require the concessionaire to partially share the excess revenue where the project's revenue exceeds a defined level (Power et al., 2016; Song et al., 2016).

The guarantees, such as minimum revenue (MRG), restrictive competition guarantee, and toll adjustment mechanism (TAM), provide one-sided revenue protection to the concessionaire against downside revenue-related risks. In return, the authority may require an upfront premium payment from the concessionaire. Alternatively, the public sector authority could request a simultaneous upper level guarantee on revenue received (a revenue cap) by the concessionaire (Almassi et al., 2013; Alonso-Conde et al., 2007; Ashuri et al., 2012; Carbonara et al., 2014; Galera and Soliño, 2010; Huang and Chou, 2006; Iyer and Sagheer, 2011; Jun, 2010; Kokkaew and Chiara, 2013; Mirzadeh and Birgisson, 2016; Power et al., 2016; Shan et al., 2010; Song et al., 2016). Together, the lower and upper levels (floor and cap) define a finite bandwidth of revenue. The guarantees may be viewed as the concessionaire and the authority holding options (rights but not obligations) to claim revenue from the other party when the revenue goes outside the pre-agreed levels. For yearly revenue occurring between the guarantee levels, the concessionaire collects and keeps all revenue.

This chapter refers to the above situation as a two-sided financial guarantee, with the options capable of being exercised yearly over the concession period. In any year, the concessionaire holds a lower bound option (based on a revenue floor), while simultaneously the authority holds an upper bound option (based on a revenue cap). Depending on how the levels are structured, the project viability is improved for both parties.

Related work includes Iyer and Sagheer (2011) and Shan et al. (2010). Iyer and Sagheer (2011) propose a traffic band that combines a traffic floor with a traffic cap leading to put and call options. This ensures more certainty in revenue flow to the concessionaire by restricting any downside income loss, while sharing any windfall gains. However, that treatment does not allow for an asymmetric or time-varying traffic floor-cap band, as developed in this chapter. Shan et al. (2010) develop collar put and call options. However, each collar has a different set of exercise prices and is valid for only one year. The exercise prices in a collar provide flexibility because their value can be adjusted in order to suit the parties' financial needs. For the zero cost collar, in each year, the premium of the concessionaire's option is designed to equal the premium of the authority's option, such that the collar scenario represents no upfront cost to either party. The two option values are used as proxies for the two premiums. The concessionaire's option value is calculated based on the minimum revenue guarantee (revenue floor, F_i), and then the authority's maximum revenue guarantee (revenue cap, C_i) is adjusted so the two yearly option values are equal (Nguyen and Carmichael, 2018).

This chapter first discusses two-sided financial guarantees, including the collar (Shan et al., 2010) in Section 5.3 and the traffic floor and ceiling (Iyer and Sagheer, 2011) in Section 5.4. The chapter then introduces the term 'bound options' in Section 5.5 as a superior version of the collar and the traffic floor and ceiling, and explores the benefits, drawbacks, and applicability of bound options in PPP road infrastructure projects.

Options valuation is done through a probabilistic cash flow approach, which provides a ready way to evaluate any option, and is accessible to a large number of engineers because it does not require any sophisticated financial market option knowledge. The chapter is of interest to those contemplating concessional delivery of infrastructure projects, such that both parties' interests are fairly addressed.

5.2 Concept of two-sided revenue guarantee

This section presents how a two-sided guarantee works in securing project revenue for the concessionaire and the authority. A two-sided revenue guarantee combines both a minimum revenue guarantee and revenue cap to create a band of revenue (Nguyen and Carmichael, 2018). In any year i, the concessionaire holds a lower revenue option (based on a revenue floor), while simultaneously the authority holds an upper revenue option (based on a revenue ceiling). For option analysis purposes, the floor and ceiling guarantees generate two revenue thresholds (or exercise prices) at year i – one for the minimum revenue guarantee and one for the revenue sharing, denoted F_i and C_i respectively.

Figure 5.1 shows the cash flow diagram relative to a lower threshold where the actual revenue at year i, denoted R_i, is lower than the revenue floor, F, here constant. In these cases, the concessionaire exercises its option to claim the revenue shortfall from the authority. The revenue shortfall in year i, denoted s_i, is calculated as the difference between F and the R_i. The revenue shortfalls are shown as upwardly pointing arrows, because they are treated as cash inflows from the point of view of the concessionaire (the option holder). The concessionaire's option is not exercised if s_i is negative.

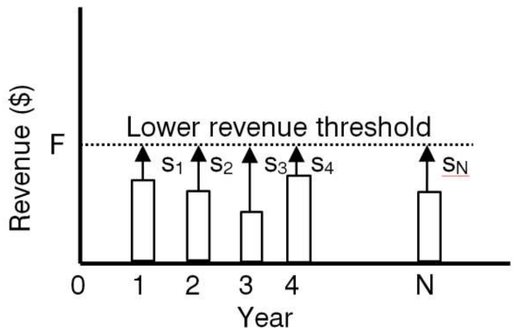

Figure 5.1 Cash flow of lower revenue guarantee.

By comparison, Figure 5.2 shows the cases where the R_i are higher than the upper threshold or revenue ceiling, C, here constant. The authority exercises its option and requests the excess revenue at year i, denoted e_i, from the concessionaire where e_i is the difference between R_i and C. Revenue excesses are regarded as cash inflows from the point of view of the authority (the option holder), and are shown as upwardly pointing arrows. The concessionaire only receives the ceiling, C, instead of the full R_i. The authority's option is not exercised if e_i is negative.

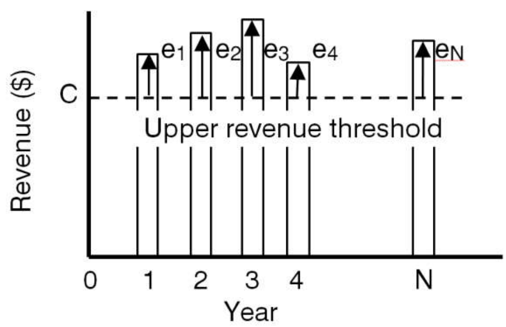

Figure 5.2 Cash flow of upper revenue guarantee.

If R_i occurs within the band defined by the floor and the ceiling, no option is exercised and the revenue is collected entirely by the concessionaire.

Revenue fluctuates over time. One example of a revenue scenario (during a 10-year period) is shown in Figure 5.3. The dashed and dotted lines illustrate the fixed upper (ceiling) and lower (floor) revenue thresholds. If the actual revenue goes below the minimum guarantee (floor, dotted line), the concessionaire's option is exercised. Hence, the shaded area A between the actual revenue and the minimum guarantee is a positive benefit from the concessionaire's point of view in exercising its option. If the actual revenue goes above the maximum guarantee (ceiling, dashed line), the authority's option is exercised. Hence, the shaded area B between the actual revenue and the ceiling is a positive benefit from the authority's point of view in exercising its option. In other years, the revenue lies within the bandwidth and no options are exercised. The revenue to the concessionaire in any year is secured to lie within the band.

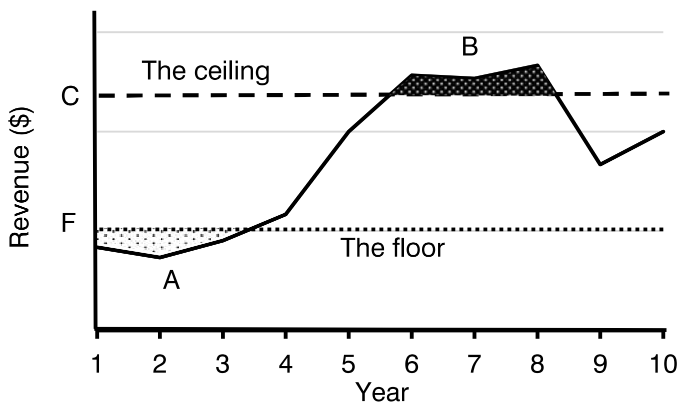

Figure 5.3 Example of revenue movement over time.

5.3 Collar

Outline

A collar combines both lower and upper revenue thresholds to create a band. This might be interpreted in the literature (Shan et al., 2010) as put and call options respectively, but such distinction is not necessary. In any year i, there are two possible options, and depending on the actual revenue, one or neither of these is exercised. The concessionaire holds an option on low revenue. If the revenue falls beneath a minimum revenue guarantee or revenue floor, F_i, the concessionaire has a right to claim the revenue shortfall from the authority. The authority holds an option on high revenue (cap). If the actual revenue is higher than a maximum revenue guarantee or revenue cap, C_i, the authority has a right to collect the excess revenue. Revenue occurring within the thresholds' envelope or band is unaffected. As an alternative to floors and caps in revenue, the situation may be expressed in terms of floors and caps in traffic volume.

The floor, F_i, and cap, C_i, can be determined in either of two ways, in terms of zero cost to both parties, or partial cost to one party, but not to the other party.

No cost to each party can be obtained by setting, in each year, the premium of the concessionaire's option designed to equal the premium of the authority's option. This is referred to as a zero cost collar, such that the collar scenario has no upfront cost to either party. The two option values are used as proxies for the two premiums. The values of F_i and C_i are adjusted so that the two option values applying to the concessionaire and the authority are the same value (Shan et al., 2010). This might be done by first choosing F_i, calculating the associated option value, and then using this option value in a reverse calculation to give C_i.

For the partial cost collar, referred to as an income-producing collar (Shan et al., 2010), F_i and C_i are negotiated between the two parties. The values of F_i and C_i can be adjusted to produce a narrower or wider band, with a consequent change in their respective premiums and option values. Higher F_i and lower C_i separately lead to increased option values. The difference in the premiums represents an income to one party and a cost to the other party. However, the parties may agree that there is no upfront premium cost to either party. In such cases, F_i and C_i might be adjusted according to what might be perceived as a 'fair' allocation of uncertainty to each party.

Using this thesis's cash flow approach, lower and upper revenue threshold values can be set asymmetrically in each year, and different for all years, without requiring any additional work, assumptions, or considerations.

Introduce the superscript notation of c and a for concessionaire and authority, respectively. In any year i = T (Figure 3.1), the concessionaire's option is exercised if the revenue shortfall, $X\big|_{T}^{c} > 0$, where $Y\big|_{T1}^{c}$ is the minimum guarantee (threshold) value (F_i at i = T), and $Y\big|_{T2}^{c}$ is the revenue (R_i at i = T). This is the same as the previous minimum revenue guarantee, discussed in Chapter 4. In any year i = T (Figure 3.2), the authority's option is exercised if the revenue excess, $X\big|_T^a > 0$, where $Y\big|_{T1}^a$ is the revenue (R_i at i = T), and $Y\big|_{T2}^a$ is the maximum revenue cap (C_i at i = T). This is the same as the previous revenue sharing where β equals 100%, discussed in Chapter 4.

Example

Consider the collar example of Shan et al. (2010), using a comparable traffic volume standard deviation equal to 25% of its expected value and the following assumptions:

Traffic in year 1 (vehicles/day × 365 days), $E[\nu_1] = 25{,}000$; $Var[\nu_1] = (6{,}250)^2$

Traffic growth rate per year, γ_c = 6% for years 2–5, 3.5% for years 6–10, and 2% for years 11–35

Toll per vehicle in year 1, $Toll_1$ = USD 1.30

Toll growth rate per year, ϕ_c = 5% for years 2–5, 3% for years 6–10, and 2% for years 11–35

Minimum revenue guarantee, year i, F_i = 78.6% of $E[R_i]$

Interest rate, r = 7.5% per annum

Concession period, n = 35 years.

F_i, here, is deterministic and set as a percentage of the expected revenue, adapted from Shan et al. (2010), Iyer and Sagheer (2011), and Kokkaew and Chiara (2013). For the previous minimum revenue guarantee and revenue cap example in Chapter 4, F_i is taken as constant for all i.

The concessionaire's option

In year 1, for example, $E[Y|_{12}^{c}]$ = USD 11.86 million, $Var[Y|_{12}^{c}]$ = (USD 2.97 million)^2, and $E[Y|_{11}^{c}]$ = USD 9.32 million. Then, $E[X|_{1}^{c}]$ = USD –2.54 million, and $Var[X|_{1}^{c}]$ = (USD 2.97 million)^2. Discounting, E[PW] = USD –2.36 million, Var[PW] = (USD 2.76 million)^2. From Equation (3.7), the concessionaire's option value (year 1), $OV|_{1}^{c}$ = USD 0.296 million.

The calculation is repeated for other years. The solid curve in Figure 5.4 shows the concessionaire's option value in any year.

The authority's option

The authority's option value, in any year, would ordinarily be calculated based on the expected value, E[PW], and variance, Var [PW], of the present worth of the cash flows associated with the authority's option. However, here the authority's option value is set equal to the concessionaire's option value (just calculated). See Figure 5.4 for how these option values change over time.

If R_i is assumed to follow a symmetrical probability distribution, then setting F_i and C_i equidistant from $E[R_i]$ will lead to option values for the authority and the concessionaire being the same. Where R_i does not follow a symmetrical probability distribution, this C_i value will need adjusting.

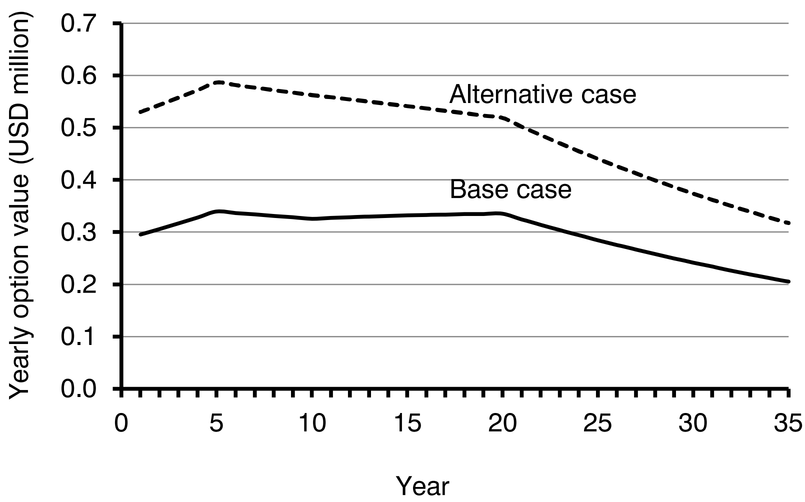

Figure 5.4 Collar example; yearly option values – concessionaire's (or authority's) options – with changed input data.

Note: Alternative case (mention below) has reduced traffic, reduced traffic growth rate, and increased minimum revenue guarantee percentage.

Comparison with the literature

Comparing available results at years 1, 2, 5, and 10, the chapter's analysis gives option values higher by approximately 1% as a proportion of the concessionaire's minimum revenue guarantee in the corresponding years, when compared with Shan et al. (2010).

The yearly option values (same for the concessionaire and the authority) change with the level of guarantee as shown in Figure 5.4. The base case referred to in Figure 5.4 corresponds with the preceding example values. The alternative case referred to in Figure 5.4 has the following changed values: the expected daily traffic in year 1 is reduced to 23,000 vehicles; the traffic growth rate (years 1–5) is reduced to 5%; and the minimum revenue guarantee is increased to 88.3% of the revenue, with the maximum revenue guarantee set equidistant at 111.7%. Moving the guarantee levels closer to $E[R_i]$ increases the option values; while a direct numerical comparison is not possible, this trend is consistent with intuition and the trend given in Shan et al. (2010).

5.4 Traffic floor and ceiling

Outline

The traffic floor and ceiling (TFC) is based on pre-agreed lower (floor) and upper (ceiling) traffic levels. These two traffic thresholds (floor and ceiling) can be converted to revenue thresholds by multiplying each traffic level by the corresponding toll.

As noted in Section 4.3, the revenue, R_i, in any year i, i = 1, 2, …, n, is the product of the annual traffic volume, ν_i, and the toll per vehicle, $Toll_i$.

$$R_i = \nu_i.Toll_i$$

Then, the minimum and maximum guaranteed levels of revenue, F_i and C_i, are determined based on the traffic floor and traffic ceiling guarantees, respectively.

$$F_i = TF_i \times Toll_i$$

$$C_i = TC_i \times Toll_i$$

The concessionaire holds the traffic floor option, while the authority holds the traffic ceiling option, as with the collar. Percentages α and β are nominated $0 \le \alpha; \beta \le 1$, such that if the traffic in any year is lower than the pre-agreed floor level, the floor option is exercised and the concessionaire (holder) claims a percentage α of the revenue shortfall, while if the traffic is higher than the maximum pre-agreed ceiling level, the ceiling option is exercised and the authority (holder) receives a percentage β of the revenue excess.

In each year, the traffic floor and ceiling (TFC) involves two options based on lower and upper traffic levels (equivalent to revenue levels or thresholds). It is the same as a collar (Shan et al., 2010), but with two differences: an upfront premium, and a guarantee covering only part of any traffic shortfall or traffic exceedance (a partial coverage guarantee):

- The zero cost collar has no premium requirement from either party, while the traffic floor and ceiling (TFC) requires premium payments from both the concessionaire and the authority. Premiums, while affecting project viability, do not enter the option value calculations, and hence do not change the previous statements on collar options.

- The collar provides a full coverage guarantee (equivalent to coverage ratios α, $\beta = 1$) above the upper threshold, and below the lower threshold respectively, whereas traffic floor and ceiling (TFC) only offers partial revenue protection (coverage ratios $0 \leq \alpha, \beta \leq 1$).

Negotiation between the parties is needed on the traffic floor and ceiling values, and the lower and upper coverage ratios α and β (Kokkaew and Chiara, 2013; Mirzadeh and Birgisson, 2016).

Using the thesis's cash flow approach, traffic floor and ceiling values can be set asymmetrically in each year, and be different for all years, without requiring any additional work, assumptions, or considerations.

In any year i = T (Figure 3.1), the concessionaire's option is exercised if the revenue shortfalls, $X\big|_T^c > 0$, where $Y\big|_{T1}^c$ is the minimum guarantee (threshold) value (F_i at i = T), and $Y\big|_{T2}^c$ is the revenue (R_i at i = T). The concessionaire receives α percent of the revenue shortfall, that is, $\alpha X\big|_T^c$. The option value is calculated based on the present worth derived from an expected value $\alpha E[X\big|_T^c]$ and a variance $\alpha^2 Var[X\big|_T^c]$. This is the same as the previous collar, but with α introduced.

In any year i = T (Figure 3.1), the authority's option is exercised if the excess revenue is above the cap, $X\big|_T^a > 0$, where $Y\big|_{T1}^a$ is the revenue (R_i at i = T), and $Y\big|_{T2}^a$ is the maximum revenue cap (C_i at i = T). The authority receives β percent of the revenue excess, that is, $\beta X\big|_T^a$. The option value is calculated based on the present worth derived from an expected value $\beta E[X\big|_T^a]$ and a variance $\beta^2 Var[X\big|_T^a]$. This is the same as the previous collar, but with β introduced.

Example

Consider the example of Iyer and Sagheer (2011), using a traffic volume standard deviation equal to 25% of its expected value and the following assumptions: *(Currency here is in Indian Rupee (INR)).*

Traffic in year 1 (vehicles/day × 365 days), $E[\nu_1]$ = 20,654; $Var[\nu_1]$ = $(4,957)^2$

Traffic growth rate per year (compounding yearly), γ_c = 6%

Toll per vehicle (constant), Toll = INR 28.50

Traffic floor ratio, Tfr = 80%

Traffic ceiling ratio, Tcr = 130%

Traffic floor at year i, $TF_i = Tfr \times E[\nu_i]$

Traffic ceiling at year i, $TC_i = Tcr \times E[\nu_i]$

Lower and upper coverage ratios, α = 50% of $X\big|_i^c$, and β = 50% of $X\big|_i^a$

Interest rate, r = 12% per annum

Concession period, n = 20 years.

The concessionaire's option

The revenue at year i (R_i) is regarded as a cash outflow (Y_{i2}^c), while the revenue minimum level (F_i) is regarded as a cash inflow (Y_{i1}^c). The shortfall in revenue, $X\big|_i^c = Y\big|_{i1}^c - Y\big|_{i2}^c = Y_{i1}^c - Y_{i2}^c = F_i - R_i$, for i = 1, 2, …, 20.

Growth in revenue is calculated as:

$$Y^c_{i2} = (1+\gamma_c)^{i-1} Y^c_{12}$$

$$E[Y^c_{i2}] = (1+\gamma_c)^{i-1} E[Y^c_{12}]$$

$$Var[Y^c_{i2}] = (1+\gamma_c)^{2i-2} Var[Y^c_{12}]$$

The authority's option

The revenue at year i (R_i) is regarded as a cash inflow (Y^a_{i1}), while the revenue maximum level is regarded as a cash outflow (Y^a_{i2}). The excess revenue, $X\big|^a_i = Y\big|^a_{i1} - Y\big|^a_{i2} = Y^a_{i1} - Y^a_{i2} = R_i - C_i$, for i = 1, 2, …, 20.

Growth in revenue is calculated as:

$$Y^a_{i1} = (1+\gamma_c)^{i-1} Y^a_{11}$$

$$E[Y^a_{i1}] = (1+\gamma_c)^{i-1} E[Y^a_{11}]$$

$$Var[Y^a_{i1}] = (1+\gamma_c)^{2i-2} Var[Y^a_{11}]$$

For example, in year 8:

- Concessionaire's option: $E[Y\big|^c_{82}]$ = INR 323.1 million, $Var[Y\big|^c_{82}]$ = (INR 78.2 million)^2, $E[Y\big|^c_{81}]$ = 80% of $E[Y\big|^c_{82}]$ = INR 258 million.

- Authority's option: $E[Y|_{81}^{a}]$ = INR 323.1 million, $Var[Y|_{81}^{a}]$ = (INR 78.2 million)^2, $E[Y|_{82}^{a}]$ = 130% of $E[Y|_{81}^{a}]$ = INR 420 million.

The option values in each year are shown in Figure 5.5.

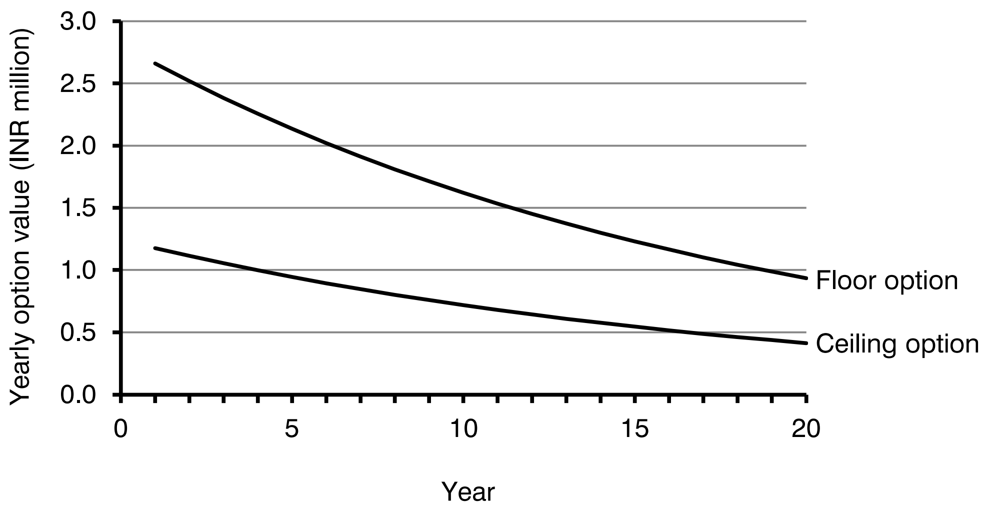

Figure 5.5 Traffic floor and ceiling example: yearly floor and ceiling option values, Tfr = 80%, Tcr = 130%.

Comparison with the literature

This chapter's analysis calculates the concessionaire's and authority's summed yearly option values lower by approximately 1% and 0.7%, respectively, as a proportion of the sum of revenue threshold values for 20 years, when compared with Iyer and Sagheer (2011).

Figure 5.6 and Figure 5.7 show how the concessionaire's and authority's option values change with Tfr and Tcr, respectively. The yearly option values increase as a result of a higher minimum floor guarantee and a lower maximum ceiling guarantee, and this trend is consistent with the results of Iyer and Sagheer (2011).

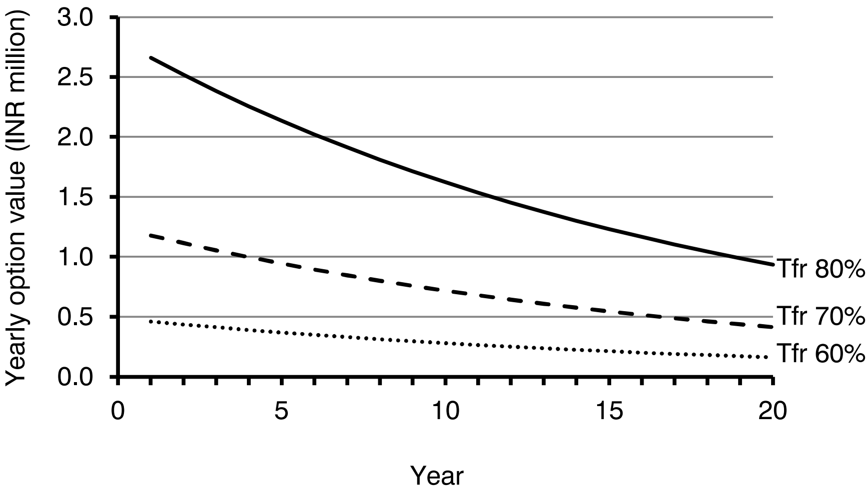

Figure 5.6 Traffic floor and ceiling example: yearly floor option value; influence of Tfr.

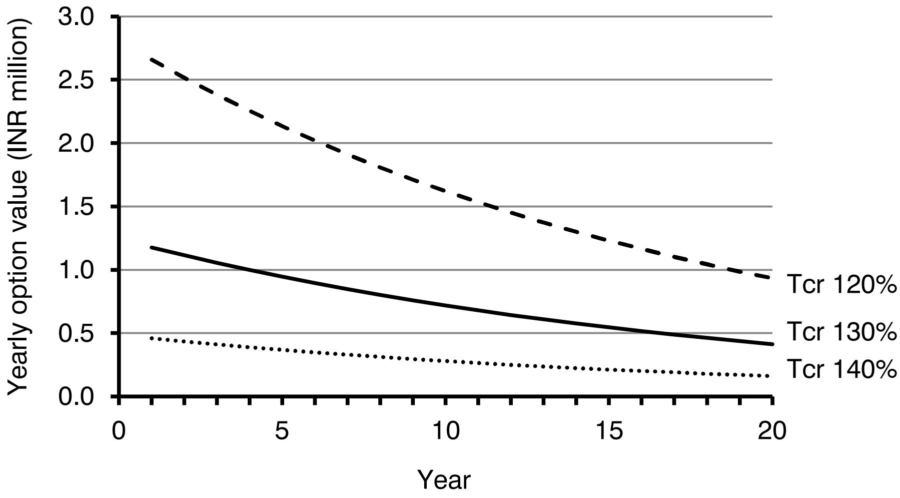

Figure 5.7 Traffic floor and ceiling example: yearly ceiling option value; influence of Tcr.

5.5 Bound options

Outline

As discussed above, related work includes Shan et al. (2010) in Section 5.3 and Iyer and Sagheer (2011) in Section 5.4. Iyer and Sagheer (2011) develop a traffic band that combines a traffic floor with a traffic cap leading to put and call options. This ensures more certainty in revenue flow to the concessionaire by restricting any downside income loss, while sharing any windfall gains. However, that treatment does not allow for an asymmetric or time-varying traffic floor-cap band, as developed in this bound option section. Shan et al. (2010) propose collar put and call options. However, each collar has a different set of exercise prices and is valid for only one year. The exercise prices in a collar provide flexibility because their value can be adjusted in order to suit the parties' financial needs.

Similar to collar and traffic floor and ceiling (TFC), in any year, the concessionaire holds a lower bound option (based on a revenue floor), while simultaneously the authority holds an upper bound option (based on a revenue cap). However, the term 'bound options' is used to distinguish outstanding features related to threshold levels:

- The threshold levels can be adjusted such that neither party pays any upfront premium, and project viability is improved for both parties.
- The presence of the two yearly guarantees provides flexibility, with the levels (option exercise prices) set as constants or time-varying based on projected future cash flows.
- The two thresholds can be established both as symmetrical and asymmetrical from revenue at year i.

In any year, there are two options: one based on the lower bound and held by the concessionaire, and one based on the upper bound and held by the authority. The option which is exercised in year i will depend on the actual revenue in year i. The other option is not exercised in year i. Because of the uncertainty in the revenue, both options in year i have a value. The two options are evaluated for each year i separately.

The concessionaire's option

From the concessionaire's point of view, the cash flow associated with the lower bound option at year i, denoted as $X|_i^c$, is the difference between the lower bound at year i, F_i, and the revenue at year i, R_i. $X|_i^c = Y|_{i1}^c - Y|_{i2}^c = F_i - R_i$, for i = 1, 2, …, n.

The authority's option

From the authority's point of view, the cash flow of the upper bound option at year i, denoted as $X|_i^a$, is the difference between the revenue at year i, R_i and the upper bound at year i, C_i. $X|_i^a = Y|_{i1}^a - Y|_{i2}^a = R_i - C_i$, for i = 1, 2, …, n.

The expected values and variances of the revenue in year i, R_i, i = 1, 2, …, n, are estimated by first estimating optimistic (a_i), most likely (b_i), and pessimistic (c_i) values in each year. This leads to a yearly expected value, $E[R_i] = (a_i + 4b_i + c_i)/6$, and variance, $Var[R_i] = [(c_i - a_i)/6]^2$ (Carmichael, 2006).

Example

This section looks at examples based on the Lo Te–Rach Soi toll highway project in Vietnam (see project information in Chapter 3). Here, it is assumed that there are bound guarantees in place during the first 10 years of the 53-km highway. The interest rate is 10% per annum. The valuation of the bound options is done here based on the revenue resulting from tolls collected (and not from traffic volume, income cash flow or cash flow to equity). Other cash flows are excluded from the valuation.

The probabilistic cash flow approach accepts any type of upper and lower bound or threshold values, and can be fixed or varied. In the following examples, the bounds are assumed firstly fixed and then varied (as a percentage of the expected value of project revenue, $E[R_i]$). The positive benefits of exercising the options are the differences between the lower or upper revenue bounds and the actual revenue.

Optimistic and pessimistic values for revenue are assumed ±50% either side of the most likely values. Revenue expected value and variance in year i are presented in Table 5.1.

Example 1: Fixed bound

The lower threshold, F, is USD 80 million and the upper threshold, C, is USD 110 million. The yearly revenues and associated present worths are given in Table 5.1.

	Year									
	1	2	3	4	5	6	7	8	9	10
$E[R_i]$ (USD million)	84	86	90	95	98	100	104	106	105	103
$Var[R_i]$ (USD million)^2	196	205	225	251	267	278	300	312	306	295
$E[PW^c]$ (USD million)	–3.6	–5.0	–7.5	–10	–11	–11	–12	–12	–10	–8.9
$Var[PW^c]$ (USD million)^2	162	140	127	117	103	88.5	79.1	67.9	55.1	43.8
$E[PW^a]$ (USD million)	–23	–20	–15	–10	–7.5	–5.6	–3.1	–1.9	–2.1	–2.7
$Var[PW^a]$ (USD million)^2	162	140	127	117	103	88.5	79.1	67.9	55.1	43.8

Table 5.1 Values relevant to lower and upper bound option calculations.

Figure 5.8 shows the tails of the present worth probability density functions corresponding to the lower and upper bound options in year 5. A normal distribution is adopted, but any appropriate distribution could have been used. Present worth to the right of the vertical axis (positive present worth) is referred to as the upside. The area beneath each curve is the feasibility, Φ.

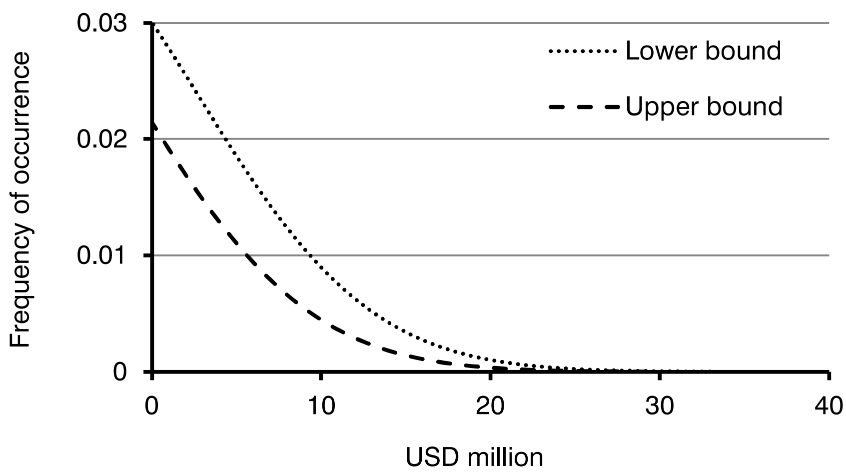

Figure 5.8 Bound options example; present worth upside for lower and upper option calculation purposes in year 5.

The concessionaire's option (year 5)

F = USD 80 million, $E[R_5]$ = USD 98 million, $Var[R_5]$ = (USD 16.34 million)^2.

Then, $E[X|_5^c]$ = USD –18 million and $Var[X|_5^c]$ = (USD 16.34 million)^2.

Discounting, $E[PW^c]$ = USD –11.2 million, $Var[PW^c]$ = (USD 10.14 million)^2.

From Equation (3.7), the lower bound option value is USD 0.693 million.

The authority's option (year 5)

$E[R_5]$ = USD 98 million, $Var[R_5]$ = (USD 16.34 million)^2, C = USD 110 million. Then, $E[X|_5^a]$ = USD –12 million and $Var[X|_5^a]$ = (USD 16.34 million)^2.

Discounting, $E[PW^a]$ = USD –7.5 million, $Var[PW^a]$ = (USD 10.14 million)^2.

From Equation (3.7), the upper bound option value is USD 1.37 million.

The calculation of the option values for other years is done similarly.

Figure 5.9 plots option values over time. During the ramp-up period, the project revenue is low, and so the lower bound option held by the concessionaire has a high chance of being exercised. Accordingly, the lower bound option value is higher than the upper bound option value. This situation is reversed at the end of the 10-year period, where the project revenue has increased.

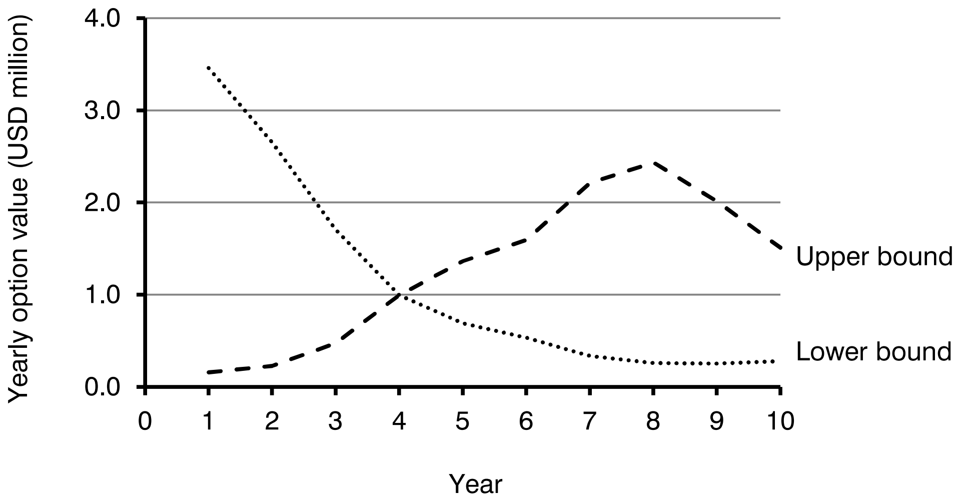

Figure 5.9 Bound options example; yearly lower and upper option values.

Total option values, for both option types, over 10 years are the sums of the respective yearly option values, and are shown in Table 5.2, for different bandwidths. Wider bandwidths lead to lower total values, as anticipated. Choice of bandwidth will reflect concessionaire and authority risk attitudes.

	Bandwidth, [F:C] (USD million:USD million)		
	[70:120]	[80:110]	[90:100]
Total value of lower bound (USD million)	3.08	11.13	30.25
Total value of upper bound (USD million)	4.50	13.04	32.20

Table 5.2 Total option values of fixed lower and upper bounds, over 10 years.

Example 2: Varied bound

In the varied bound case, the lower and upper bounds or thresholds at year i, F_i and C_i, are assumed as proportions of the expected value of revenue at year i, $E[R_i]$ (Attarzadeh et al., 2017; Iyer and Sagheer, 2011; Kokkaew and Chiara, 2013). Let $F_i = \alpha E[R_i]$ and $C_i = \beta E[R_i]$, where α, β are percentages, or fractions ($0 \leq \alpha, \beta \leq 1$), for the lower and upper bounds or threshold levels, respectively. The other assumptions remain the same as *Example 1*.

The lower and upper bound option values over time are given in Figure 5.10, for α = 80% and β = 110%.

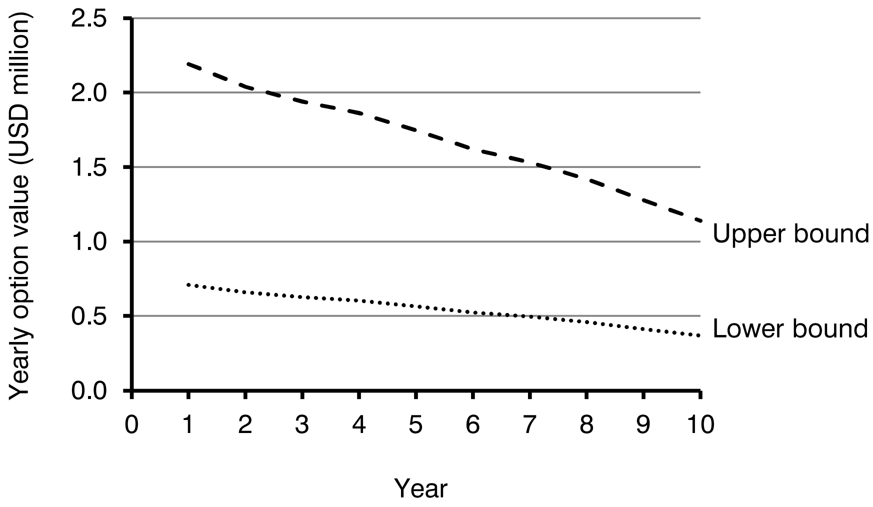

Figure 5.10 Bound options example; yearly lower and upper bound option values with $\alpha = 80\%$, $\beta = 110\%$.

Total option values, for both option types, over 10 years are shown in Table 5.3, for different α and β combinations. As in the fixed bound case, moving the threshold levels closer to $E[R_i]$ increases the option values, as anticipated.

	Bandwidth, [α:β] (%;%)		
	[70:120]	[80:110]	[90:130]
Total value of lower bound (USD million)	1.35	5.43	16.78
Total value of upper bound (USD million)	5.43	16.78	1.35

Table 5.3 Total option values for varied lower and upper bounds, over 10 years.

If R_i is assumed to follow a symmetrical probability distribution, then setting F_i and C_i equidistant from $E[R_i]$ will lead to option values for the authority and the concessionaire being the same. The total values decrease in line with the lower α and larger β; lower α and larger β lead to smaller lower bound and upper bound option values. This trend is consistent with the results from the traffic floor and ceiling of Iyer and Sagheer (2011).

Bandwidth selection

Bound options are potentially able to address both parties' interests fairly, with appropriate bound or threshold selection. The concessionaire holds the lower bound option, and the authority holds the upper bound option. The selection of bandwidth affects the option values. As such, the selection of the lower and upper bounds would involve negotiation between the two parties. Two possibilities are to set the bounds or bandwidth such that the two option values are equal in any year, or that the total values are equal over the total concession period.

Consider the case where the yearly lower and upper bound option values are equal for each i. This occurs, for example, when R_i is assumed to follow a symmetrical probability distribution, and the lower and upper bounds are set equidistant from the expected revenue, $E[R_i]$. The concessionaire's option value is first calculated for a given lower bound, and then the authority's upper bound is adjusted to give the authority's option value the same as the concessionaire's option value.

For the fixed bound case, and summing the respective option values over 10 years, Figure 5.11 plots the total option value for the concessionaire (this is the same for the authority) versus bound or threshold level.

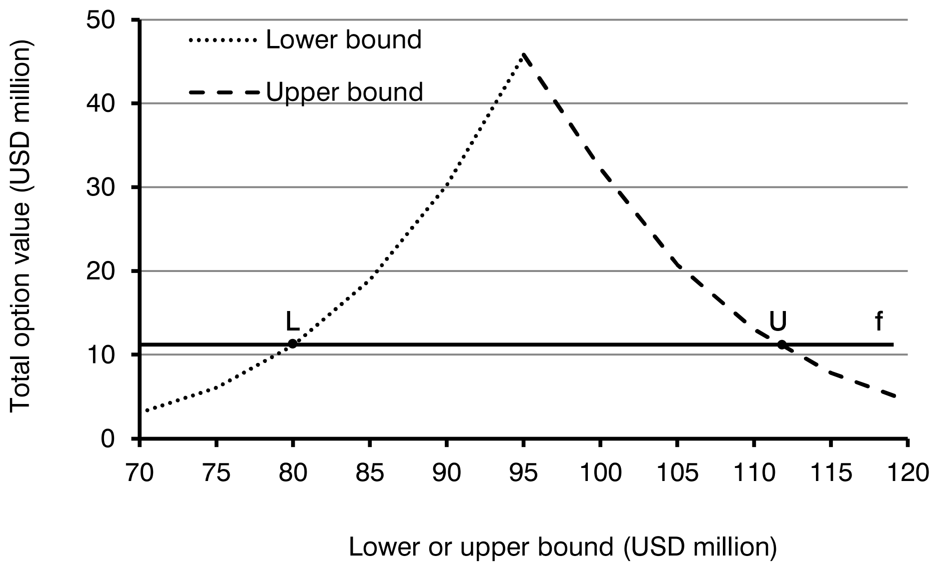

Figure 5.11 Bound options example; the total value of n options versus lower or upper bound levels.

The selection of bandwidth can be done graphically based on the equilibration of the concessionaire's total option value and the authority's total option value. For example, the horizontal line, f, goes through point L at a given lower bound of USD 80 million and a total lower option value of USD 11.13 million. Line f intersects the upper bound total option value curve at point U giving an upper bound or threshold level of USD 111.6 million. These two bounds, namely a lower bound of USD 80 million and an upper bound of USD 111.6 million, lead to the total values of the concessionaire's options and the authority's options being the same at USD 11.13 million.

5.6 Conclusion

In concessional delivery of infrastructure projects such as toll roads, revenue shortfall (below a lower bound or threshold level) for the concessionaire, resulting from uncertain patronage, can be alleviated by a guarantee from the authority. In return, the concessionaire could be made responsible for sharing any excess revenue (above an upper bound or threshold level) with the authority. The combination of the lower and upper revenue thresholds can be treated as a two-sided revenue-based guarantee. The upper and lower level bounds create a bandwidth of revenue. The yearly value of these guarantees can be established through option analyses. The threshold levels can be selected to avoid either the concessionaire or the authority paying any premium, or through fairness to both parties. This is compared to a less fair one-sided guarantee, such as a minimum revenue guarantee or maximum cap, addressed in Chapter 4.

This chapter used the probabilistic cash flow approach to evaluate the yearly options. It provides a straightforward approach to estimate the value of an option, requires minimal mathematical background, and is aligned with traditional engineering investment appraisals. It also avoids the terminology, assumptions, and constraints required in financial market options analysis.

For the two different option cases analysed for a two-sided financial guarantee, when compared with the existing literature relevant to each case, namely the collar of Shan et al. (2010) and the traffic floor and ceiling of Iyer and Sagheer (2011), this chapter's analysis gives option values that are essentially the same. Supplementary sensitivity style analyses, conducted by changing the values of the case variables, showed option value trends to be the same as the existing literature. Similar to the conclusions drawn in the previous chapter on one-sided protections, the differences between this chapter's option values and studies on the collar of Shan et al. (2010) and the traffic floor and ceiling of Iyer and Sagheer (2011), as a proportion of similar exercise costs, are less than a few percent. This chapter's analysis made assumptions as compatible as possible with the existing literature. Exact agreement would not be anticipated because of different assumptions applied between this chapter's approach of using variance and the existing publications using volatility.

In general, wider bandwidths lead to lower values of bound options. This trend is consistent with intuition and the trend given in the collar of Shan et al. (2010) and the traffic floor and ceiling of Iyer and Sagheer (2011). The chapter suggests selecting the bandwidth by equalising either the yearly or the sum of yearly values of the lower and upper bound options. The bandwidth selection can be negotiated, ensuring fairness for both the concessionaire and the authority.

The chapter offers a way forward to the fair implementation of concessionally-delivered projects.

The following chapter proposes a flexible way to deal with the ‘long–short’ conflict in the establishment of the concession period, and to accommodate future uncertainties.

Chapter 6: Flexible concession period of PPP toll roads

6.1 Introduction

Public-private partnerships (PPP) and related concessional delivery methods are popular for the delivery of infrastructure across the world, and have been used in different forms for several centuries (Auriol and Picard, 2013; Medda, 2007; Mody, 1996; Monod, 1982; Tang et al., 2010). A defining characteristic of PPPs is a concession period agreed between the two main parties – an authority and a concessionaire. The concession period is the time given to the concessionaire to design and construct the infrastructure and collect revenue, before handing the infrastructure back to the authority (Shen et al., 2002). This period may be, for example, 20, 30, 40 or 50 years, and is different for each project, but is usually *long enough at least to fully amortize major initial investments* (World Bank, n.d.). A concession period that is too long financially benefits the concessionaire in the later years at the expense of the public while a concession period that is too short does not allow the concessionaire to fully recoup its initial investment or provide a suitable return for the investment.

The issue is what an appropriate concession period to include in any PPP agreement should be. For toll roads, an appropriate concession period should allow the concessionaire to receive an appropriate return for its investment, but not be so long that the motoring public suffers by paying tolls over an excessive period. Determining an appropriate concession period would appear to be crucial in setting up PPP delivery of a project. Fixed concession periods, as are currently used, lack the flexibility to deal with this 'long–short' conflict, or to accommodate future uncertainties.

There is rational argument which suggests that concession periods granted on PPP toll road projects are too long in many instances (Niu and Zhang, 2013; Tan et al., 2010). In effect, the concessionaire receives payback for its investment well within the concession period, while the public continues to pay tolls for longer than it should. This position excludes those projects where the demand estimates, prior to the project, fall short of actual demand once the road is in operation; such estimates may be wrong because of errors in interpreting survey demand data and/or the public's price elasticity of demand behaviour.

There is also the puzzling situation surrounding the use of discounted cash flow (DCF) techniques such as present worth (PW, or net present value – NPV) and internal rate of return (IRR), which are used to establish the viability of a project. In performing a discounted cash flow analysis, at commercial levels of discount rates, cash flows far into the future have very little present worth. For example, the present worths of $1 occurring at different times into the future and at different rates are shown in Table 6.1.

Years into the future	Present worth of $1 at interest rate (p.a.)					
	0%	1%	2.5%	5%	10%	25%
5	1.00	0.95	0.88	0.78	0.62	0.33
10	1.00	0.91	0.78	0.61	0.39	0.11
25	1.00	0.78	0.54	0.30	0.09	-
50	1.00	0.61	0.29	0.09	0.01	-
100	1.00	0.37	0.09	0.01	-	-

Table 6.1 Present worths of $1 occurring in the future (Carmichael, 2014).

The question that arises is: why are concession periods longer than say 20 to 25 years used? Cash flows beyond approximately 20 to 50 years, especially at high interest rates, have small present worth, and contribute little to present day decisions based on any discounted cash flow analysis. For example, the present worth factor at 10% per annum for 50 year is just almost 0.01. Typical toll roads have net cash outflow initially followed by many years of net cash inflow, and so it is the future years of net cash inflow which have small present value, but it is tolls, in these same future years, which are considered unnecessary by and antagonise motorists.

The chapter suggests a way forward, providing flexibility in establishing the period over which the concessionaire collects revenue. The value analysis to the authority of taking over control of the road is done through an options treatment, and incorporates estimates of uncertainty. Only the financial aspects of PPP agreements are addressed; options involving some physical aspect of roads are a separate matter (Carmichael, 2018).

This option analysis is based on option holder – the authority – point of view, and an option only is exercised if it is worthwhile for option holder to do so. This is financial analysis. Social/economic analysis, for the society as a whole, is excluded and is not treated in this chapter.

The chapter proposes that in a PPP agreement: (i) no explicit fixed concession period should be stated, but rather it is flexible and established based on actual project performance; and (ii) beyond a calculated point in time, an option becomes available to the authority to take over the operation of the road. The chapter's approach eliminates the controversial aspects existing in current PPPs associated with the lengths of concession periods. As a by-product, the approach additionally eliminates another controversial matter of the setting of tolls, including the determining appropriate levels of tolls associated with congestion, suitable periodic toll adjustments, and the toll-demand-concession period trade-off.

The chapter's structure is as follows. Section 6.2 provides a literature review on how concession periods are established and optimised. The chapter's suggested methodology involving a flexible concession period follows in Sections 6.3 and 6.4. In Section 6.5, the implications of variability and uncertainty leading to establishing payback periods at pre-investment time, as well as probabilistic payback periods are examined. A discussion and conclusion follow in Sections 6.6 and 6.7. A case study example is carried throughout this chapter.

The chapter is original in addressing variable concession periods, options associated with concession periods and probabilistic concession periods. The chapter is of interest to stakeholders dealing with public-private partnerships.

6.2 Background

6.2.1 Public-Private partnerships

Public-private partnerships are said to have a number of potential benefits (European Commission, 2003), most notably the absence of the requirement for public money. But there are disadvantages: the need for management and performance measurements to be put into place to monitor the project; loss of public control and flexibility in making the necessary policy adjustments for future demand and contingencies (Cruz and Marques, 2013; Rall et al., 2010); the potential for non-compete clauses obstructing future infrastructure projects (Makovsek et al., 2014); and excessive discretion possibly being granted to the concessionaire in regard to setting and increasing the operational user-charges (Kashani, 2012). Flexible PPP agreements, as proposed here, could partly address these downsides.

In establishing any PPP agreement, uncertainties need to be addressed. These include construction delays and cost overruns, operating and maintenance costs, demand, interest rates, inflation, taxation, competition, sources of financing, insurance costs, and unforeseen events (European Commission, 2003; Grimsey and Lewis, 2002; McCowan, 2004; Ng and Loosemore, 2007; Shen et al., 2006). Many of these uncertainties are the responsibility of the concessionaire.

6.2.2 Alternative structure

Over the past decade, attempts have been made to address risk to the authority and risk to the concessionaire, primarily looking at revenue allocation resulting from uncertain road usage or demand (Alonso-Conde et al., 2007; Attarzadeh et al., 2017; Carbonara et al., 2014). However, little attention has been paid to addressing the concession period's influence on the fairer outcome of a PPP to both parties.

In an attempt to get a PPP agreement that is fair to both parties, alternatives to focusing on concession periods have proposed introducing mechanisms such as minimum revenue guarantees and revenue sharing into the PPP agreement (Almassi et al., 2013; Ashuri et al., 2012; Blank et al., 2009; Brandao and Saraiva, 2008; Shan et al., 2010). Such mechanisms target patronage or demand, and lower and upper thresholds on revenue and traffic. However, these mechanisms can create contingent issues for the authority (Carpintero et al., 2015; Chiara and Kokkaew, 2013); the concessionaire may focus instead on minimising costs and jeopardise the quality of the infrastructure, rather than attracting patronage. Mechanisms such as minimum revenue guarantees and revenue sharing can also incentivise tenderers to alter their proposed financial models. The tenderer may propose overly optimistic traffic forecasts, or higher discount rates in order to change thresholds in the PPP agreement, even if the assumptions are inaccurate. As well, the mechanisms do not address the view expressed here about the public needlessly paying tolls towards the end of a concession period.

Buyout options have been discussed by Rose (1998) and Power et al. (2016). Rose (1998) outlines an authority-owned option, with a zero exercise price, to take over the road before the end of the concession period if the concessionaire's after tax internal rate of return (IRR) exceeds a defined percentage; the gain to the authority at time of exercising is the present worth of the remaining cash flows (from the time of exercising till the end of the concession period). This is referred to as a conditional buyout option by Power et al. (2016), who argue that this option value is low. Power et al. (2016) also describe an option to buyout for a predetermined exercise price where exercising only occurs if the present worth of the remaining cash flows exceeds the exercise price. However, it is anticipated that this exceedance would only turn out to be small because it would not be in the concessionaire's interest to negotiate an exercise price that would lead to otherwise.

6.2.3 Concession period

The concession period is one of the most important parameters in establishing the financial feasibility of a PPP project. It is to the advantage of the concessionaire, under current practice, to negotiate for a long concession period and have discretion over setting user charges in order to secure loans and service interest costs, while achieving a desirable return (Chung, 2009; Ngee et al., 1997; Zhang and Chen, 2013). However, if the concession period is too long, the concessionaire is able to gain long-term revenue at little cost, while the authority or the public pay unnecessary long-term user charges (Niu and Zhang, 2013). User charges that regularly increase are disliked by users (Yu and Lam, 2013). Accordingly, under current practice, the authority should negotiate the shortest concession period possible and give little discretion to the concessionaire in setting user charges (Ngee et al., 1997).

Commonly, deterministic present worth (PW) (or net present value – NPV), internal rate of return (IRR) and payback period (PBP) thinking is used by the concessionaire to establish minimum concession periods. To acknowledge uncertainty, sensitivity analysis and Monte Carlo simulation might be used (Carbonara et al., 2014; Hanaoka and Palapus, 2012; Liou and Huang, 2008). The literature also suggests fuzzy-logic (Khanzadi, 2012; Nasirzadeh et al., 2014), system dynamics (Ullah et al., 2018; Xu et al., 2012), and game theory (Bao et al., 2015; Javed et al., 2014; Shen et al., 2007) as potential additional tools.

A sensitivity analysis demonstrates how a change in an input parameter affects the output of a financial model. However, it says nothing of the likelihood attached to this change. Ngee et al. (1997) examine changes in user charges and concession period on internal rate of return through a sensitivity analysis.

Shen et al. (2002) discuss NPV and concession period selection. The NPV required for the concessionaire is taken to be greater than the initial capital investment multiplied by an expected rate of return. A positive NPV during the post-concession period is sought by the authority (Wu et al., 2012).

Unlike a sensitivity analysis, Monte Carlo simulation attempts to capture uncertainty in arriving at a distribution for NPV. Shen et al. (2005) extend Shen et al. (2002) through Monte Carlo simulation and use different underlying probability distributions in calculating NPV. In the hypothetical scenario in Shen et al. (2005), a large range (15–24 years) was obtained for the concession period satisfying the requirements of both a risk-neutral authority and concessionaire. Such a large range may not help the parties in their negotiations. Zhang and AbouRizk (2006), also using Monte Carlo simulation, consider the variables of project development cost, duration of activities, demand, service fees, and operational and maintenance costs. The authors then take the 75th percentile for NPV values, the 95th percentile for the duration of construction, and investment rate of return to determine a concession period range. By combining Monte Carlo simulation and game theory, Hanaoka and Palapus (2012) generate a concession period interval that is negotiable between the authority and the concessionaire.

The use of fuzzy sets has been suggested by Ng et al. (2007). The intent is to produce a concession period for any specified internal rate of return (IRR). Ng et al. (2007) show the trade-off between investment return, usage charges and the concession period, for certain assumptions. Nasirzadeh et al. (2014) use fuzzy logic to determine the concession period via NPV. Khanzadi et al. (2012) combine fuzzy sets with system dynamics. Validation of the system dynamics model, based on historical data and expert judgment, was not undertaken. The use of game theory and bargaining has also been suggested (Bao et al., 2015; Hanaoka and Palapus, 2012; Shen et al., 2007).

Yu and Lam (2013), based on questionnaires on the concession period for a PPP tunnel project in Hong Kong, suggest that the most influential factors in establishing the concession period are: interest rate, inflation, traffic flow, tolls, expected rate of return, capital investment and cost during operation. The authors propose using an agreement that allows for adjustment of the terms from time-to-time. Ye and Tiong (2003) focus on the construction phase impact on the length of the concession period and conclude that because toll roads have low construction complexity and market-led revenue, a fixed period may be the best choice. Carbonara et al. (2014) suggest that the concession period end should be calculated as the time at which the difference between the NPV of the project pre-transfer and NPV post-transfer is minimised.

In summary, publications have performed a range of analyses for concession periods. Because of future uncertainties, any concession period established pre-PPP agreement may turn out to be inappropriate based on actual project performance. No studies look at defining a concession period based on actual project performance, and concession periods which fairly treat both parties – the authority (equivalent to the public) and the concessionaire – based on actual project performance. This is treated in this chapter.

6.3 Deterministic analysis

6.3.1 Case study outline

A case study involving the Hanoi–Haiphong toll highway in Vietnam is developed in the chapter to illustrate issues associated with the chapter's proposal. The case study is used in two different ways below: the deterministic calculations are in Sections 6.3 and 6.4; and the calculations incorporating uncertainty are in Section 6.5.

As presented in Section 3.2.1, the six-lane highway is 105.5 km in length, and involves an investment of approximately 45,500 billion Vietnam Dong (VND) (equivalent to USD 2 billion). The highway was built to improve traffic flow between Hanoi, the capital of Vietnam, and Haiphong, the largest port city in the north of Vietnam. Its design was compliant with international standards, and it was the first toll road built using a PPP in Vietnam's northern region. The three-year design and construction period (completed in December 2015) is followed by a 28-year operating period.

The revenue from toll collection alone was considered insufficient to recoup the initial investment and operating costs. In order to improve the project viability, the authority, the Vietnam Ministry of Transportation, offered the concessionaire privileges, including:

- Reimbursement of land clearance costs;
- Toll collection from an existing adjacent road; and
- The right to invest and operate service stations along the highway.

The revenue from these sources is additional to the main toll revenue of the highway. Collectively, the revenue from these additional sources is equivalent to a minimum guaranteed revenue.

The concessionaire's costs include operation and maintenance costs, finance and investment costs and corporate tax.

6.3.2 Deterministic calculation

Data in the following calculations are based on Vietnam Ministry of Transportation information and forecast traffic volumes. The concessionaire's deterministic net cash flows over time, based on a medium traffic growth scenario, are shown in Figure 6.1. The net cash flows include allowances for taxation.

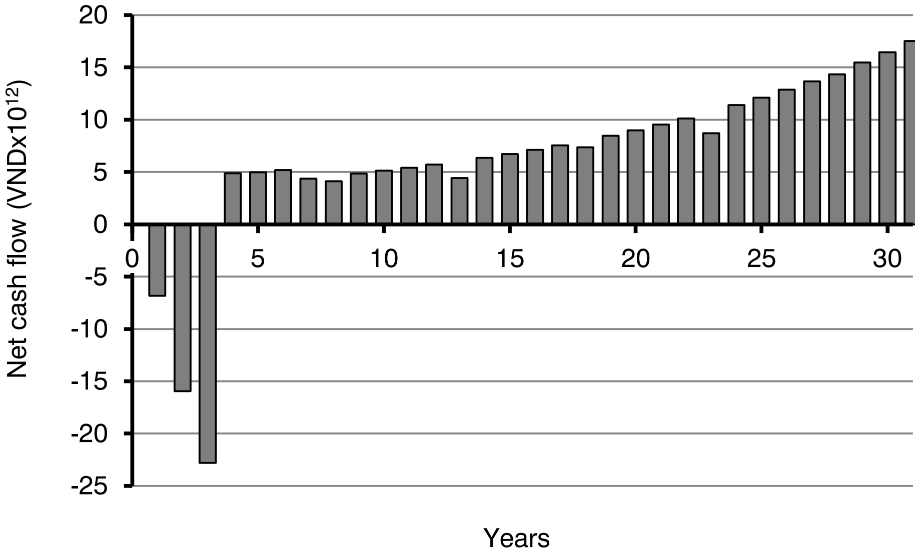

Figure 6.1 Concessionaire's net cash flow (deterministic).

Discounting at 8.4% per annum (p.a.), based on a weighted average value of the interest rates from all funding sources, Figure 6.2 gives the cumulative discounted cash flow.

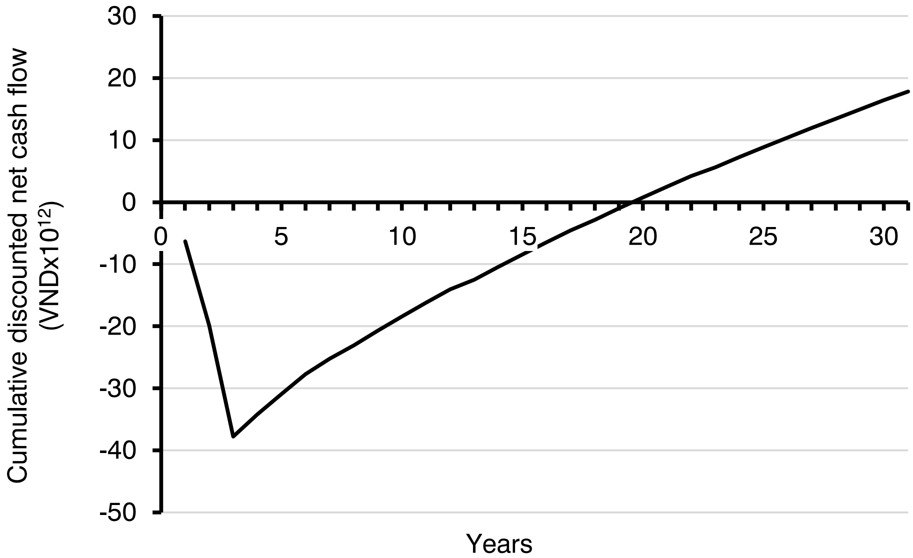

Figure 6.2 Concessionaire's cumulative discounted cash flow values (deterministic, discounted at 8.4% p.a.).

Figure 6.2 shows a discounted payback period of approximately 19.5 years. Other interest rates will lead to other payback periods in line with Table 6.2.

Interest rate (% p.a.)	Payback period (years)
0	12
5	15.5
8.4	19.5
10	23
12	32

Table 6.2 Change in payback period by interest rate.

6.3.3 Incorporating uncertainty

Variability in highway toll revenue is established through Vietnam Ministry of Transportation traffic volume growth scenarios of low, medium and high. To estimate toll revenue variances (and expected values), the three scenarios are regarded as pessimistic, most likely and optimistic values respectively, as is done in PERT, but other estimating methods could be used (Carmichael, 2016a). Variances in the revenue from the additional sources (outlined in Section 6.3.1) are obtained by assuming similar estimate ranges as that assumed for highway traffic variability, namely ±50% either side of the most likely values. The traffic revenue and additional revenue are assumed perfectly correlated in order to establish the variance of the total revenue to the concessionaire. Variability in costs was estimated from available information.

Figure 6.3 shows how the payback period changes with variability in the net cash flow. In Figure 6.3, plots are given for expected value (Figure 6.2) and plus and minus one standard deviation in the net cash flow. Plus and minus two and three standard deviations trend similarly in terms of distance from the expected value plot.

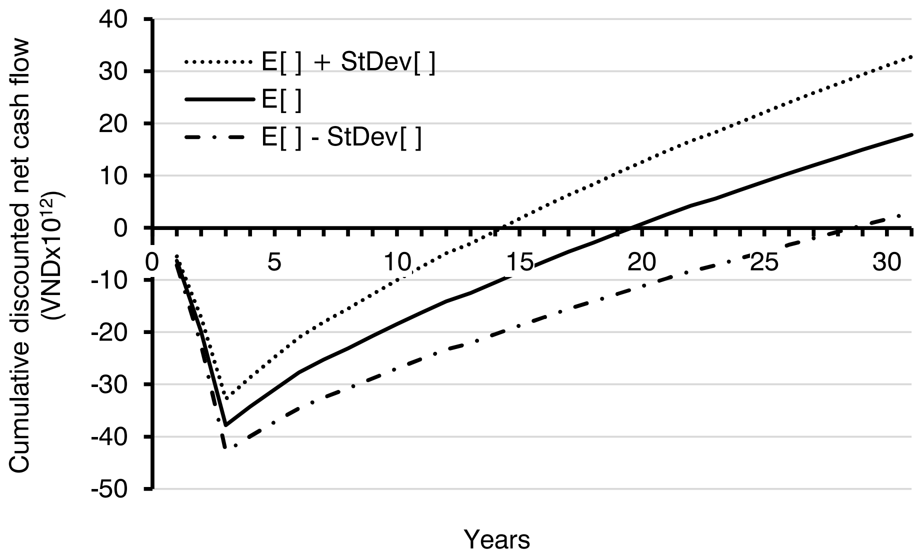

Figure 6.3 Concessionaire's cumulative discounted net cash flow – expected value (E) and plus and minus one standard deviation (StDev).

6.4 Flexible concession period

6.4.1 Outline

In existing practice, concession periods could be anticipated to be negotiated as part of risk management for both the authority and the concessionaire. If generous contingencies are included to take care of uncertainties, it is anticipated that concession periods could be adopted greater than what would be desired by the road user.

This chapter proposes that the concession period should be flexible, that is, it is not fixed upfront (pre-investment), but rather is determined with time based on actual project costs and revenues. In particular, the concession period is determined such that the concessionaire has a guaranteed and fair way of getting a return for its investment, yet does not burden the road user long into the future.

There is an analogy here with a lump sum contract (analogous to a fixed concession period) and a cost reimbursable contract (analogous to a flexible concession period). A lump sum price includes a contingency but the price is fixed; cost reimbursement does not include a contingency, but the price is only determined after the work is done. Similar issues involving lump sum payment versus cost reimbursable payment will transfer across this analogy to fixed concession periods versus flexible concession periods, and disclosure and verification of costs in the cost reimbursable case.

This chapter suggests that the concession period should be calculated relative to an actual payback period. The payback period represents a recovering of costs only and does not give a concessionaire a return above its investment. This is so unless the interest rate used incorporates a margin for this return to give a discount rate (Department of Infrastructure and Regional Development (Australia), 2013).

Carmichael (2017), among others, notes the irrationality of using discount rates in cases involving uncertainty, and so this approach is not adopted here. Rather, this chapter suggests using a basic interest rate, equivalent to what some publications might call a 'risk-free' rate.

No prospective concessionaire will invest where the concession period is less than the payback period, but rather a concessionaire wants something extra – a positive 'return', R. Note that R is not the same as the usual ROI, return on investment.

Let $PW\big|_t$ be the discounted cumulative sum (present worth) of the actual yearly net cash flows (revenue minus costs) up to and including year t.

$$PW\big|_t = \sum_{i=0}^{t} \frac{X_i}{(1+r_i)^i} \tag{6.1}$$

where X_i is the actual net cash flow in any year i. Then, the chapter's proposal is:

No concession period is stated upfront (pre-investment). The concessionaire operates the road provided $PW\big|_t < R$*, where* R *is a negotiated and nominated concessionaire's return for the investment. For* $PW\big|_t \geq R$*, the authority can (but* *does not have to) exercise an option to take over ownership. The option cannot be exercised for* $\left.\mathrm{PW}\right|_t < \mathrm{R}$.

The concessionaire operates the road for as long as it takes to get the nominated return, R. The length of time it takes for the concessionaire to get this nominated return becomes equivalent to conventional thinking on what a concession period is. An estimate of this period of time is possible pre-investment (Section 6.5 below), and this estimate becomes more refined over time when the road is in operation and actual cash flows become known.

6.4.2 Comments

The above proposal requires the following operational matters.

1. The formula for calculating the return, R, is selected by agreement of the concessionaire and the authority upfront (pre-investment). Some possibilities are:

- as a percentage of initial investment cost;
- as a fixed amount, possibly allowing for some escalation based on inflation and some consumer rise/fall index; or
- as variable with time.

Clearly, the greater the value of R selected, the longer the concession period.

Shen et al. (2002, 2006, 2007) suggest that the additional return to the concessionaire (calculated pre-investment) should be the product of the concessionaire's capital investment and the concessionaire's desired rate of return. Desired rates of return may be, for example, 15% or 20%, and depend on the concessionaire's opportunity costs, risks and risk attitude, among other factors.

2. The interest rate, r_i, used in each year i for discounting purposes is selected by agreement of the concessionaire and the authority for each year, and selected in that year. This interest rate contains no adjustment for the concessionaire's business 'risks' or adjustment for the road project 'risks'.

3. Open book accounting is necessary for both revenue and costs, such that the actual net cash flow (revenue minus costs) in any year i, X_i, can be agreed each year between the concessionaire and the authority. The X_i are only privy to the concessionaire and the authority, and are not publicly available. This requires no new thinking over what is currently required for PPP guarantees such as minimum revenue or revenue sharing (Carmichael et al., 2018).

4. With X_i and r_i agreed as each year i passes, it is possible to calculate $PW\big|_t$ each year, and hence establish, on an ongoing basis, whether $PW\big|_t$ is less than,

equal to or greater than R. With each year of operation, an updated estimate of the approximate concession period becomes possible.

5. The concessionaire and the authority need to agree on the accounting principles used. The chapter's suggested approach raises issues that are similar to those that occur in cost reimbursable contracts. For such contracts there is a need for agreement between the parties on what is reimbursable and what is not reimbursable, how overheads are handled and so on (Carmichael, 2000). Here there is a need for agreement on what are costs and what are revenues. There is also a need to consider the concessionaire's business profits and business overheads and how they might be incorporated into R, such that only project overheads get included in the project costs.

6. Having a concession period undetermined at the project start may raise issues about the level of quality that the concessionaire builds into the road. Typically, the road will have to satisfy certain performance standards on handover at the expiration of the concession period to the authority. The road design, construction and maintenance will therefore be based on this time period, which is now variable. However, the approximate concession period can be established upfront (pre-investment) provided sensible estimates are used for future costs and revenue (Section 6.5 below).

7. Used by itself, the approach suggested is more suitable for high-demand roads. For low- or uncertain-demand roads, the approach can be used in conjunction with any guarantee that the parties may wish to use, for example, a minimum revenue guarantee (Carmichael et al., 2018). Such guarantees could be structured to give a reasonable payback period, and not have the concessionaire operate the road indefinitely.

8. Care will need to be exercised by the authority over the road design and construction, and the period allowed for these activities. There will need to be an agreed scope and quality statement, and an agreed time period for design and construction. Without these agreed upfront (pre-investment), there is the potential for the concessionaire to manipulate the outcome.

9. There is also potential for manipulating the operating and maintenance levels, which in turn influences cash flows. There will need to be agreed operation and maintenance parameters. For example, closing lanes reduces user comfort, and possibly increases user preference to travel on alternative roads.

10. It is anticipated that for usual road cash flows, the present worth of all cash flows is negative in the initial years, and becomes positive in later years. Should the cash flows be such that $\mathrm{PW}\big|_t < \mathrm{R}$ always, then the ownership and operation of the road remains with the concessionaire. Should this be unacceptable to the authority, then a fallback concession period could be stated in the PPP agreement,

in which case, the concessionaire would cease operating the road at the end of this fallback period.

11. The concessionaire could have an option to abandon the road and transfer its operation to the authority (Carmichael et al., 2018). However, this might only be contemplated if the road was losing money. This situation is not considered here.

6.4.3 Example analysis

As mentioned, R might be established as: an agreed percentage of the total investment; an agreed fixed amount; or an agreed amount variable with time. Consider the situation where R is established as a percentage for the case study highway. A similar commentary applies where R is a fixed amount. A deterministic analysis is used.

Figure 6.4 shows the situation for R defined as a fixed percentage of 20% of the total investment. The concession period corresponds to the intersection (point A) of the dashed line (the value of R) and the cumulative cash flow plot – here approximately 25 years. Greater (lesser) values of R lead to longer (shorter) concession periods, as anticipated. In a pre-investment analysis, the time corresponding to A could be used as a guide to the approximate concession period that could be anticipated.

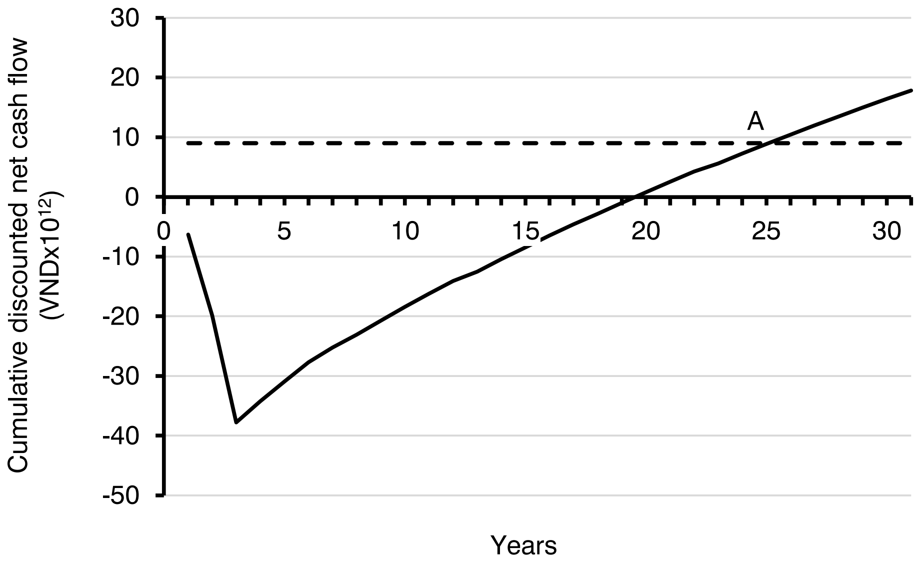

Figure 6.4 Concessionaire's cumulative discounted net cash flow (solid curve) with constant R value (dashed line) superimposed.

A variable percentage could be defined in a number of ways. For example, let R increase by p% per year, a pre-defined and agreed amount. Then $R_{t+1} = R_t(1+p\%)$. A similar situation to Figure 6.4 occurs but now the dashed line rises over time instead of being horizontal. Larger (lesser) values of p lead to longer (shorter) concession periods, as anticipated.

6.5 Option evaluation

6.5.1 Outline

The previous section refers to using actual X_i and r_i to determine the period over which the concessionaire operates the road. A deterministic analysis is repeatedly done yearly into the future. Separate to this, it is also possible to do an upfront (pre-investment) analysis in order to:

- establish project viability;
- establish an approximate concession period; and
- calculate the value to the authority (or road user) of holding an option to take over ownership of the road.

For the upfront analysis, in order to capture the future uncertainty, a probabilistic analysis is used, allowing for the revenue and costs in each year to contain uncertainty. That is, revenue and costs are probabilistic. A second order moment analysis (Ang and Tang, 1975; Benjamin and Cornell, 1970) is used here, but Monte Carlo simulation could also be used if probability distributions are available for the variables, though it is purely numerical and gives less insight. A second order moment analysis uses expected values, E[ ], and variances, Var[ ], to characterise the variables. Uncertainty is embodied in the variance terms. A deterministic sensitivity analysis is considered unsuitable because it says nothing about the frequency of occurrence of the sensitivity ranges of independent variables; it also requires a discount rate that performs two roles – to account for the time value of money and to account for uncertainties (Carmichael, 2017). Rather, a method acknowledging uncertainty directly is required.

In an upfront analysis, $PW\big|_t$ is no longer a deterministic variable, but rather it is now a random variable with moments, $E[PW\big|_t]$ and $Var[PW\big|_t]$. $PW\big|_t$ could be anticipated to follow a normal distribution for larger t, because of the additive cash flow components.

The net cash flow, X_i, at any time period, i = 0, 1, 2,…, n, is the result of two cash flow components: the total revenue Y_{i1} and the total cost Y_{i2}. For uncertainty in the net cash flow:

$$X_i = Y_{i1} - Y_{i2}$$

$$E[X_i] = E[Y_{i1}] - E[Y_{i2}]$$

$$Var[X_i] = Var[Y_{i1}] + Var[Y_{i2}] - 2\rho_{12}\sqrt{Var[Y_{i1}]}\sqrt{Var[Y_{i2}]}$$

where ρ_{12} is the correlation coefficient between Y_{i1} and Y_{i2}.

And from Equation (6.1):

$$E[PW\big|_t] = \sum_{i=0}^{t} \frac{X_i}{(1+r_i)^i}$$

$$Var[PW\big|_t] = \sum_{i=0}^{t} \frac{Var[X_i]}{(1+r_i)^{2i}} + 2\sum_{i=0}^{t-1}\sum_{j=i+1}^{t} \frac{\rho_{ij}^{x}\sqrt{Var[X_i]}\sqrt{Var[X_j]}}{(1+r_i)^{i+j}}$$

where ρ_{ij}^{x} is the correlation coefficient between X_i and X_j. In the following, perfect correlation is assumed (ρ_{12}, ρ_{ij}^{x} = 1), but other assumptions are possible.

6.5.2 Project viability

$PW\big|_t$ can be calculated for t = 1, 2, … years. For cash flows such as shown in Figure 6.1, as t gets bigger the mean of the probability distribution for $PW\big|_t$ will become more positive, negative $PW\big|_t$ values will become smaller, and the area under the $PW\big|_t$ distribution to the left of the origin will become less. Figure 6.2 and Figure 6.3 show how the mean value of $PW\big|_t$ changes with increasing t.

That is, project viability increases with t. For any time t, there will always be negative values of $PW\big|_t$, and there will always be an area under the $PW\big|_t$ distribution to the left of the origin. A commercial decision is required as to what proportion of the $PW\big|_t$ distribution corresponding to negative $PW\big|_t$ is considered acceptable. This might be, for example, 25%; that is 75% of the $PW\big|_t$ distribution corresponds to positive $PW\big|_t$. Figure 6.5 shows how $PW\big|_t$, and the probability that $PW\big|_t$ is positive, change as t changes; the expected value of and the probability distribution for $PW\big|_t$ move to the right with increasing t, while the variance of $PW\big|_t$ increases with t (as more cash flows are incorporated into the calculation of $PW\big|_t$), giving flatter probability distributions. Superimposing on Figure 6.5 a dashed line corresponding to the value at which $E[PW\big|_t] = R$ shows the associated probability that $PW\big|_t > R$ for each value of t.

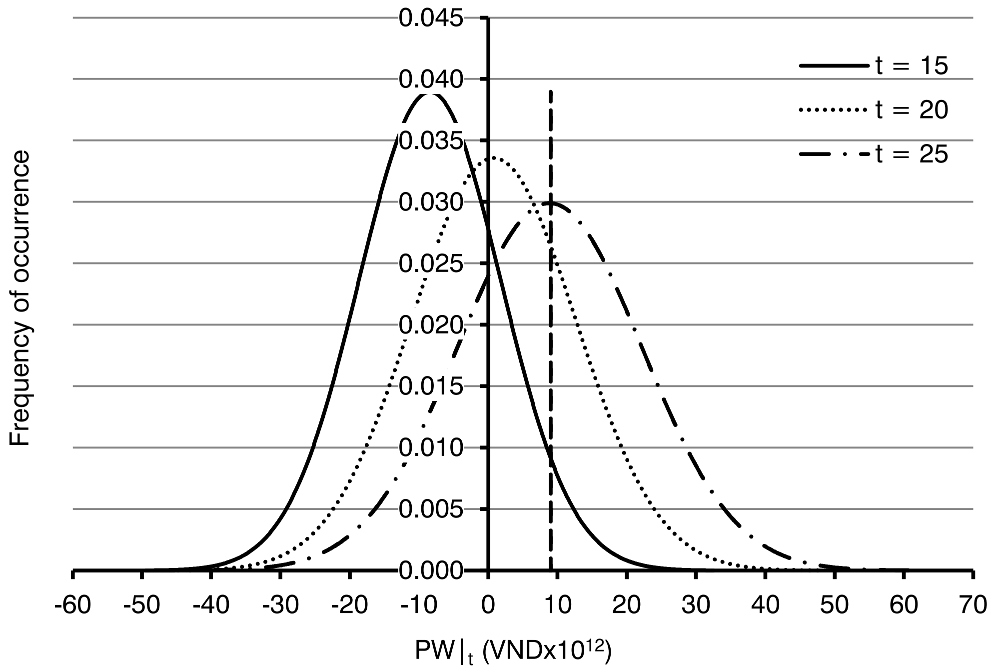

Figure 6.5 Probability distribution of $PW\big|_t$ for different t, with R at 20% of total investment shown with dashed line.

6.5.3 Approximate concession period

An approximate upfront value for the concession period can be established through looking at the payback period. The payback period may be taken as the time for the total actual cash inflows to become equal to the total actual cash outflows, discounted to time 0, or discounted to some other agreed suitable time reference. It represents a breakeven point in time for the concessionaire. Typically in feasibility studies, the more quickly an investor recovers invested money, the more attractive the investment is.

In an upfront analysis, the payback period is a probabilistic variable because of the uncertainties in the cash flows and interest rate. Let the payback period (PBP) be defined as the time t where $PW\big|_t = 0$. PBP = t when $PW\big|_t = 0$. Thus, the probability that PBP is less than an assumed t is the same as the probability that $PW\big|_t$ is negative (Carmichael, 2014; Carmichael and Balatbat, 2008).

$$P[PBP > \text{nominated } t] = P[\,PW\big|_t < 0 \mid \text{nominated } t] \tag{6.2}$$

Then the cumulative distribution function for PBP is obtained from 1 – P[PBP > t].

For practical computation, this approach would appear satisfactory. In terms of related calculations of internal rate of return, *it is good enough for most practical purposes* (Hodges and Moore, 1968, p. 359); some special circumstances are noted by Hillier (1965).

The distribution for PBP may be found numerically. For each of a series of values of t, E[$PW\big|_t$] and Var[$PW\big|_t$] are obtained leading to a probability distribution for $PW\big|_t$; from each distribution, a value for the cumulative distribution for PBP is obtained according to Equation (6.2), and subsequently the probability density function for PBP is obtained either by differentiation of the cumulative distribution function, or by assuming PBP follows a normal distribution. It is argued by Hillier (1965) that if the probability distribution for $PW\big|_t$ is normal, then the probability distribution for the internal rate of return will approximate that of a normal distribution. This argument should extend to the payback period.

Figure 6.6 shows the cumulative distribution function for the payback period corresponding to the probabilistic version of the cash flows in Figure 6.1.

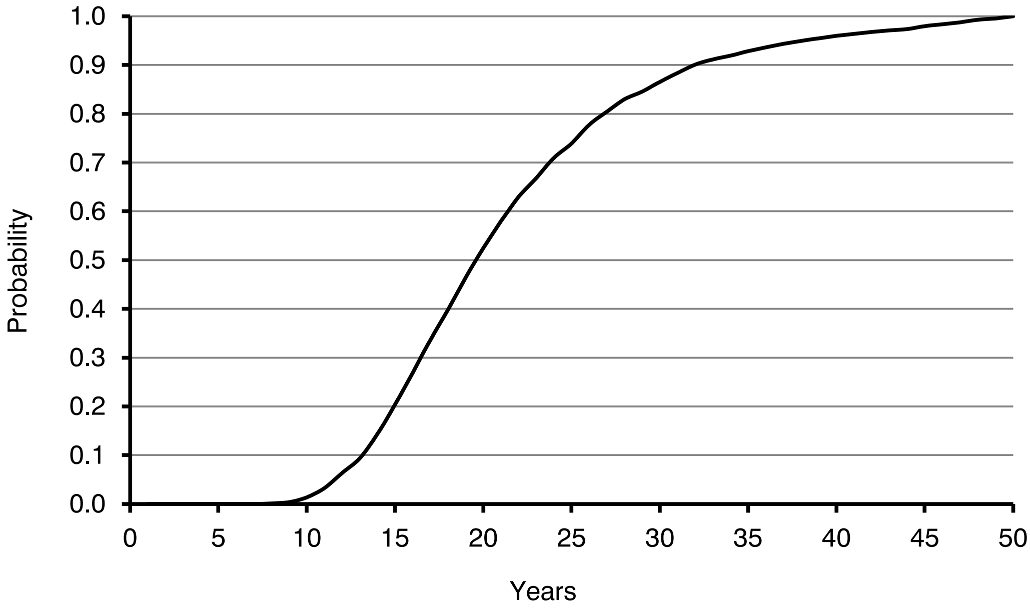

Figure 6.6 Cumulative distribution function for payback period.

6.5.4 Option value

The authority holds the option to take over the toll road at some time in the future, but may not exercise that option. If the authority's option is exercised, then the concessionaire only operates and receives revenue from the road from i = 0 to the time at which $\left.PW\right|_t = R$. After this time, the authority is able to own and operate the road. Should the option not be exercised by the authority, the concessionaire continues ownership and operation.

In Figure 6.5, probability distributions of $\left.PW\right|_t$ for different t are shown, while the vertical dashed line is located at the value where $E[\left.PW\right|_t] = R$. Calculating the loss to the road user by the authority not exercising its option is equivalent to calculating the option value based on the tails of the above distributions to the right of the dashed line. Based on Carmichael et al. (2011) and Carmichael (2014, 2016a), this option value is calculated from Equation (3.7).

where Φ is P[$PW\big|_t$ > R], P is probability, and M is the mean of the $PW\big|_t$ distribution to the right of R measured from $PW\big|_t$ = R.

The expected value and variance of, and distribution for $PW\big|_t$, change with t (Figure 6.5). The vertical dashed line (value of R) in Figure 6.5 may also vary with t depending on the PPP agreement. The loss to the road user increases with time if the authority's option is not exercised, because this option value increases with time. The longer it takes for the authority to exercise the option, then the greater the cost to the road users. This is also intuitive, but this chapter's method establishes the quantitative value of the cost to the road users. The loss to the road users changes over time as in Figure 6.7.

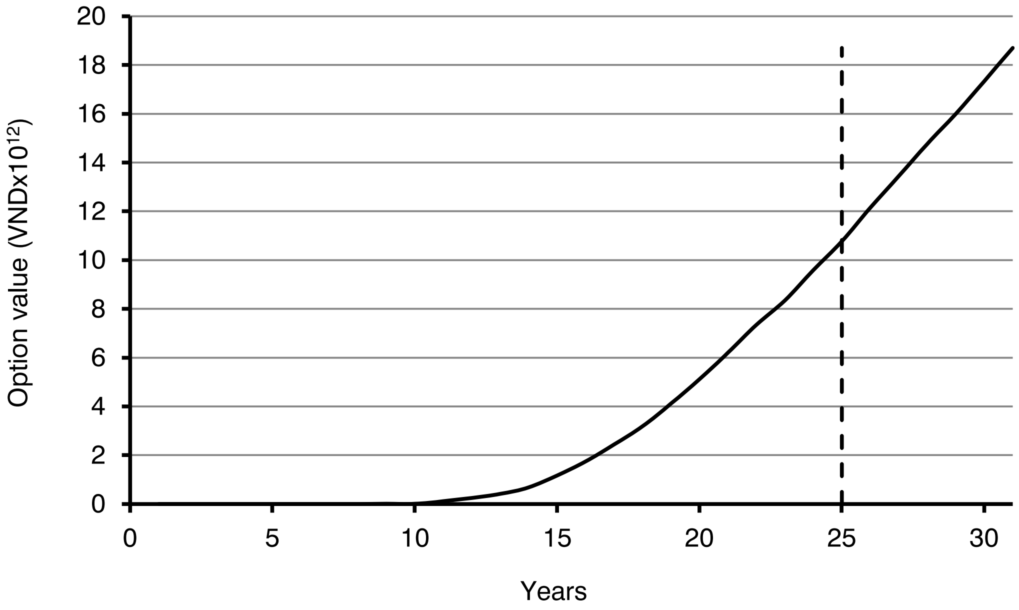

Figure 6.7 Loss to the road user over time with non-exercising of the authority's option, with R shown with dashed line.

Road user losses to the right of the dashed line in Figure 6.7 are avoidable through the authority exercising its option. Later exercising (equivalent to longer concession periods) leads to higher road user losses, and higher gains to the concessionaire.

6.6 Discussion

The chapter's approach of not stating the concession period upfront (pre-investment) avoids the controversial aspects of concession periods. The approach avoids concession periods which are too short (disadvantageous to the concessionaire) and periods which are too long (disadvantageous to the authority and the road users). The concessionaire's involvement lasts only as long as it takes to reach a fair return for its investment.

The approach also eliminates the controversial matters surrounding the setting of tolls of what are suitable tolls and what are suitable periodic toll adjustments within the PPP agreement. With the chapter's approach, larger tolls translate to earlier payback, earlier ownership of the road by the authority and the public paying over fewer years.

The user loss, as presented in Figure 6.7, is value of unnecessarily additional cost to the road users for longer concession periods, and this loss is avoidable through the authority exercising its option. Later exercising option (equivalently, longer concession periods) leads to higher gains to the concessionaire, and higher losses to road users. This financial calculation of road user losses accepts an assumption that the level of congestion is the same (and optimal) at all levels of the user-charge beyond year of exercising the option. A broader social/economic analysis of total user losses after exercising option, involving the effects of toll-demand-congestion trade-off, is not discussed in the thesis.

Forecast traffic demand possibly contains the highest level of uncertainty in a PPP road project and leads to the highest risk (Hensher, 2018). Accordingly, under existing practice, any prescribed upfront concession period will necessarily reflect this high risk. As well, traffic forecasts may be manipulated to suit whichever party is paying for them – low for the concessionaire, high for the authority. The chapter's approach, on the other hand, establishes the equivalent of the concession period but based on actual, not uncertain or biased, traffic and demand; the chapter's approach removes the risk and bias from the concession period determination.

Black (2014), analysing eight Australian toll roads and tunnels, shows the average traffic to be 48% of what was originally forecast. This contributes to a general opinion that traffic forecasts are also characterised by optimism bias (Bain, 2009; Cruz and Sarmento, 2019; Flyvbjerg et al., 2005). Patronage models may be flawed (Abigroup, 2012; Evans and Peck, 2012). There is also the suggestion that the preferred concessionaire tenderer will be the one that has the highest or most aggressive forecasted revenue or traffic, giving potential concessionaires an incentive to manipulate their models (Abigroup, 2012; Johnston, 2012). The chapter's approach avoids optimism bias and any other bias.

In many cases in the past, risk associated with uncertain traffic demand was carried by the concessionaire (Johnston, 2012). This risk might be reduced by the inclusion in the PPP agreement of non-compete clauses for juxtaposed arterial roads, as well as decreasing the capacity of alternative routes in the corridor that the PPP road is serving (NSW Audit Office, 2000). The chapter's approach avoids such risk deliberations.

The chapter's approach requires open book accounting, trust, cooperation and goodwill between the two parties – the concessionaire and the authority. Open book accounting is not new in infrastructure delivery. Trust, cooperation and goodwill concepts exist in partnering, relationship contracting, integrated project delivery or alliance ideas.

It is anticipated that negotiation between the parties will be required before actual cash flows and appropriate interest rates can be agreed upon. In any investment analysis, there can be different viewpoints on what is the appropriate interest rate to use (Carmichael, 2016b, 2017). The chapter's analysis allows the interest rate to vary yearly, and it can also be extended, for pre-investment analysis, to allow for uncertainty in the interest rate (Carmichael and Bustamante, 2014; Carmichael and Handford, 2015).

6.7 Conclusion

The chapter provided a means to establish the time over which the concessionaire controls a PPP toll road that is fair to both parties. It avoids stating a definite concession period upfront, but rather the equivalent of a concession period is established based on actual cash flows as the project progresses. It avoids the need for the concessionaire to include conservatism and contingencies in its feasibility studies because of future uncertainties. This is the same argument used in contract payment types – fixed price contracts are costed higher than schedule of rates or unit price or cost reimbursable contracts because of the need to include contingencies.

The chapter's approach eliminates the controversial aspects existing in current PPPs associated with the lengths of concession periods, toll setting and toll adjustments.

The chapter demonstrated how the option value to the authority of taking over control of the road could be calculated. The approach, based on a second order moment analysis, and acknowledging uncertainty, requires minimal mathematical knowledge and is an extension of conventional engineering feasibility analysis.

A case study on a Vietnamese public-private partnership toll road demonstrated the approach and typical values.

The following chapter discusses variations and renegotiation issues in both general construction contracts and PPPs and, accordingly, proposes an effective mechanism to deal with major physical changes of PPP toll roads, from the authority's viewpoint, during post-construction stage of the concession period.

Chapter 7: Variation option in PPPs

7.1 Introduction

This chapter focuses on physical changes in public-private partnership toll roads itself during the post-construction phase of the concession period – for example, the addition of an extra lane, the provision of another entrance ramp or exit ramp or similar – and not changes generally such as changing the toll pricing formula or extending the concession period. The initial PPP agreement is for a defined scope. Should the authority wish to change something during the post-construction concession period, and there is no provision in the PPP agreement to do this, then this would have to be negotiated with the concessionaire, which is then in an opportunistic position of bargaining strength. Conversely, the authority is in a position of bargaining weakness and may have to agree to excessive concessionaire demands. The concessionaire would only agree to a change if it is worthwhile to the concessionaire to do so and may bargain, for example, for an extension of the concession period or a readjustment of the toll pricing formula. There are also legal costs in dealing with changes this way. Change may be required for a variety of reasons such as technology (Love et al., 2002; Wu et al., 2004), statutory and regulatory (Hsieh et al., 2004; Sun and Meng, 2009), social and economic (Henckel and McKibbin, 2010; HM Treasury, 2012), and demographic and patronage shifts (Ashuri et al., 2011). In many cases, pre-project forecasts of demand and economic variables are not realised (Bain, 2009; Cruz and Marques, 2013b; Domingues et al., 2014).

Construction-only contracts anticipate changes and so include variation clauses that specify what changes are allowed and how changes are to be dealt with. They allow for addition, substitution or omission from the original scope, may range from being of a minor nature upwards, and may include matters such as alterations to design, quantities and quality; both additions and deductions are possible. Express terms included in construction-only contracts give the power for the owner or principal to instruct a variation; without such express terms, the contractor may reject any variation instruction (Carmichael, 2000, 2002). The express terms facilitate the smooth functioning of the work without the need for additional contracts covering the changes. Variations are best valued by agreement between the owner or principal and the contractor. Rates and prices submitted in the contractor's tender may facilitate this; alternatively some fair valuation of direct and indirect costs, including any impact on connected work, is needed.

The chapter argues that PPP agreements should anticipate changes and allow for variations and their method of pricing and, in particular, major physical changes to the infrastructure. This is a proactive approach to change, which appears inevitable, rather than passively proceeding and dealing with changes as they come. The instigation of variations could come from the authority or the concessionaire, but with the final approval of the authority. To minimise the potential for disputes in this valuation, this chapter suggests that the PPP agreement proactively identifies a method by which variations are to be priced, identifying major potential changes, leaving only their extent and timing unknown.

The chapter firstly summarises background on variations and negotiation issues in non-PPP and PPP agreements in Section 7.2, and discusses the position of bargaining strength and disadvantages presented to the owner or the authority during renegotiation. Uncertainty associated with variation costs is examined in Section 7.3. The chapter then discusses how a variation option works in Section 7.4 and comments on its operational matters in Section 7.5. Finally, the probabilistic cash flow approach, given in Chapter 3, is demonstrated on valuing variation option as a case example in Section 7.6, discussing on the application of options and the valuation approach. Discussion and conclusion are followed in Sections 7.7 and 7.8.

7.2 Background

As discussed in Section 2.6.1, for a general construction contract, the literature emphasises that a contractor may be the most advantaged party during variation order negotiation because it is in an opportunistic position of bargaining power (Alnuaimi et al., 2010; Levin, 2016). The advantageous negotiation position for the contractor exists, and this places a financial burden on the owner who has to pay an unreasonable extra cost for claiming its variation. This extra cost often results in unfair outcomes to the owner as that amount may be much more significant than it should actually cost. Notes on that issue are presented in research by Alnuaimi et al. (2010), Bajari et al. (2006), Chang and Ive (2007), Charoenngam and Mahavarakorn (2011), Levin (2016), Lu et al. (2014), Okada et al. (2017), and Saunders (1996).

Construction-only contracts, historically and naturally, adopt two different approaches to the pricing of variations: (1) using rates derived from express terms laid down in the contract, or (2) using a separate schedule of rates or prices by re-negotiating (Bajari et al., 2014; Murdoch and Hughes, 2000). These above conventional methods are not applicable in valuing such variations because of the existence of uncertainty, and the variation may or may not take place at the discretion of the party (owner or contractor) which initiates the variation.

Commenting on physical variations or changes, some researchers adopt a built-in flexible contract using real options theory where flexibility in a contract refers to a capability to change in line with future circumstances. For toll roads, the needs and wants of users and operators change mainly in line with traffic demand. The flexibilities and options allow these projects a more progressive adaptation to changing circumstances and decrease the downside risks (Ashuri et al., 2011; de Neufville and Scholtes, 2011; Demirel et al., 2017; Fawcett et al., 2015; Martins et al., 2015). The literature acknowledges that the incorporated flexibility, embedded with real options, allows the possibility of change to projects to cope with future uncertainty. However, the literature mainly focuses on some specific flexibilities through real options analysis and it has not generally presented the above variation issues to the owner that are developed in this chapter.

For public-private partnerships, as discussed in Section 2.6.2, changes or variations are inevitable because PPPs have long-term, complex characteristics with a high level of uncertainty (Cruz and Marques, 2013a; Gifford et al., 2014; Guasch, 2004; Hwang and Low, 2012). However, there is no provision in PPP agreements to deal with these changes, and PPP stakeholders (the authority and the concessionaire) are more prone to renegotiate concession contracts (Baeza and Vassallo, 2010; Guasch, 2004; Guasch et al., 2014).

The literature on PPP acknowledges renegotiation may be necessary to improve the performance of the partnership, but it also argues that renegotiation may create an unbalanced position of bargaining strength between the authority and the concessionaire (Cruz et al., 2015; Sarmento and Renneboog, 2016; Yescombe, 2014; Zhu et al., 2016). Current research comments on the renegotiation issue and its disadvantages to the authority and/or the public as follows.

Marques and Cruz (2012) argue that the concessionaire holds an advantage of having more information about the project, without other competitors who were eliminated at the awarding stage, so the concessionaire will be in a position to dictate conditions to its advantage. The authors point out that renegotiation and related disputes may lead to a deadlock prompting an early termination of the concession contract, and terminations are very harmful to the authority and the public, since they have to pay a disproportionate compensation to the concessionaire. Almarri and Blackwell (2014) emphasise renegotiation leads to extra costs to the authority and the public and propose the improvement of risk-sharing mechanisms in the design of the contract to avoid the disadvantages of renegotiation. Quiggin (2005) states that most contract variations arise from the authority, and the bargaining always seems to be in favour of the concessionaire. Options can help to resolve the issues associated with the need for variations in the scope and renegotiations, in light of changing needs and circumstances over time. However, these above studies do not provide any estimates on the extra cost paid by the authority or the public via renegotiation.

Bajari et al. (2006, 2014) show that opting for renegotiations to deal with variations leads to extra costs to consumers. These extra costs can be in the form of increased toll charges on road users, or as government compensation to the operator, and such variations to the original contract undermine the legitimacy of the awarding process. Based on project data from the California Department of Transportation, the study estimates imply that adaptation costs, referred to as the extra cost paid for claiming change orders, are significant – on average they range from 7% to 15% of the winning bid.

Sarmento (2014) concludes that the bargaining power in PPP renegotiation seems to be mostly held by the concessionaire and, accordingly, the authority is asked to incur the additional cost to compensate the concessionaire for ordering a variation. Based on a sample of 243 projects from 1999 to 2012 in Portugal, the research calculates the average of the extra cost ranges from 10% to 30% of the original value.

Based on data from 61 concession contracts in Chile, Colombia and Peru from 1993 to 2010, Bitran et al. (2013) note that the extra costs of renegotiations lead to increases in the concession period of around 20%, and these costs account for up to 30% of the corresponding initial cost. As a result, the road users, not the concessionaires, often incur most of the costs of renegotiations by paying higher toll prices.

Baeza and Vassallo (2010) argue that renegotiations in concession toll road projects in Spain occur with a high frequency. These renegotiations often result in toll increases and extensions in the length of the concession period, and the users or the taxpayers suffer the consequences of the renegotiation. Based on data from 17 concession contracts, the extra cost paid after renegotiation is up to 15% of initial estimates.

Guasch et al. (2007, 2014) discuss renegotiation leads to an increase in costs to governments, and finally to road users, and therefore erodes the potential benefits and the main economic driver for higher efficiency under the PPP model. Based on lessons from renegotiations in Latin America over 25 years, the research estimates these additional costs, on average, are up to 15% of the initial investment.

Agreeing with Guasch et al. (2007), Fernandes et al. (2019) point out that any renegotiation occurs in a bilateral, noncompetitive environment, thus weakening the negotiating position of the authority. Using the real data from the renegotiation case of a Portuguese road concession, Fernandes et al. (2019) demonstrate the overall costs increased 40% compared to the initial cost, and accordingly there was an increase in the travel cost for road end users of approximately 40%.

In summary, the literature acknowledges that renegotiation is a primary tool to solve change and variation issues in both PPP and non-PPP contracts. The main disadvantage of variation negotiation is the authority or owner is in a position of bargaining weakness and, as a result, has to pay an extra cost or suffer a loss to claim its variations. This extra cost is significant, and often results in an extension of the concession period or an increase of the toll price for end users (Almarri and Blackwell, 2014; Cruz and Marques, 2013b; Fernandes et al., 2019; Guasch et al., 2007; Marques and Cruz, 2012; Sarmento, 2014). However, the literature fails to develop any systematic approach to deal with such variations issues. This chapter proposes that PPP contracts should ideally contain a mechanism that enables an effective response, dealing with physical variations, to changing circumstances in the post-construction phase throughout the concession period of toll roads. An option should be available for the authority to order variation to the project. Having the variation option, the authority sets a threshold on the concessionaire's bargaining power via variation negotiation as the authority can order its variation at its favourably controlled price. This position may exclude those projects where trust, cooperation and goodwill concepts exist in partnering and relationship contracting between the two parties—concessionaire and authority. In such cases, variation negotiation itself can lead to a win-win situation while satisfying both the authority's and the concessionaire's desirable requirements. Given that at the time of drafting the concession contract, the nature of these changes is uncertain, such clauses need to establish a high level of flexibility, and can only be formulated from an extensive knowledge of what kind of changing circumstances might be expected.

7.3 Uncertainty of variation costs

In order to clarify the extra cost, mentioned above, paid by the authority and the public to claim its variation, this chapter examines two variation costs and their uncertainty, related to variation issue, the variation cost via negotiation and the variation cost calculated using rates and methods within the contract.

At year $i = T$, when a variation order is needed, the two variation costs, both via negotiation and via rates and methods within contracts, carry a different level of uncertainty. This uncertainty needs to be captured in any analysis.

Variation cost via negotiation

The variation cost via negotiation has some degree of uncertainty that may come from a variety of sources (Bajari et al., 2014). The first source is derived from uncertainty related to the accomplishment of changed works, adapting to future market circumstances, new site conditions, and unknown scope of works. The second source of uncertainty is unknown resources devoted to contract renegotiation and dispute resolution. The parties, both the authority and the concessionaire, might disagree about the compensation the concessionaire should receive from the variation order. The concessionaire might prefer an alteration that maximises its benefits from the variation order, while the authority may desire an alternative alteration that minimises the total variation cost (Bajari et al., 2006; Levin, 2016). These two sources lead to a high level of uncertainty of the variation cost via negotiation. Commenting on such uncertainty, the literature makes efforts to estimate how large the variation cost is after negotiation compared to its initial value. This range varies widely depending on the project scale and type (Ahadzi and Bowles, 2004). Based on estimates from the United States construction industry, Ibbs et al. (1998) point out that the variation cost estimated initially around USD 13–26 billion could reach USD 50 billion after negotiation dealing with claims and legal disputes. Empirical research conducted in the UK by Ahadzi and Bowles (2004) indicates that the variation cost after negotiation may be from 25% to 200% higher than the initial value. Findings from Alnuaimi et al. (2010), Bajari et al. (2006), Fernandes et al. (2019), Guasch et al. (2014), Hanna and Gunduz (2004), Oladapo (2007), Oyewobi et al. (2015) and Sunday (2010) agree that the additional costs via negotiation may vary widely from 10% to 80% of initial estimates. Generally, it can be inferred that the variation cost via negotiation has a high level of uncertainty, influenced by the project scale, type, claims, and disputes.

Variation cost calculated using rates and methods within a contract

At year i = T, this variation cost will be calculated based on the rates and methods provided in the original contract (Levin, 2016; Murdoch and Hughes, 2000). While the rate and pricing method of this variation cost are reasonably predictable, the extent and timing of a variation are not, and they are influenced by future circumstances at the time the variation is required; as a result, this variation cost is uncertain. However, it is anticipated that the variation cost via rates and methods within the contract has a lower level of uncertainty compared to the variation cost via negotiation. This is because it only includes uncertainty associated with the extent and timing of the variation work itself, without considering renegotiation effects (Akinsola et al., 1994; Athias and Saussier, 2010; Bajari and Tadelis, 2001; de Brux, 2010; Levin, 2016). Estimates of that value by Hsieh et al. (2004), based on case examples in Taiwan, can be used to infer that the standard deviation of the variation cost over the expected value may range from 7% to 17%. This agrees with the findings of Aziz (2013), Desai et al. (2015), Finke (1998), Serag et al. (2010), Sun and Meng (2009), and Shrestha and Maharjan (2018).

The difference between the variation cost via negotiation and the variation cost calculated using rates and methods within the contract represents the extra cost paid by the authority and the public to claim the variation. The uncertainty surrounding the extra cost, when discounted to time $i = 0$, gives the value of variation option.

7.4 Option establishment

An option that is available to order variation during post-construction introduces flexibility to the authority to deal with uncertainties of changing circumstances, and having such flexibility represents the value of the option.

The authority holds the option to order a variation during the post-construction stage of the concession period. A variation should include changes in the form of addition and subtraction or substitution to the original scope of work in the concession contract. The concession contract should establish built-in variations clauses that anticipate major possible variations and changes likely to be adopted, and provide rates and methods of valuing during the concession period. The established rates and methods in the contract are determined and are applicable to evaluate the needed future variations. In any year $i = T$, whenever the authority is interested in a variation, the authority requires the concessionaire to submit the quoted variation price and then enters into variation negotiation. Depending on future circumstances, that option may or may not be exercised. Generally, it would only be exercised if it was worthwhile to do so, based on the viewpoint of the authority. If the variation cost via the negotiation ends up higher than the variation cost calculated using the rates and methods within the signed contract, the authority has a right (without obligation) to exercise its option to order variation at the established variation cost, based on rates and methods within the contract. Having this option, the authority sets a threshold on the concessionaire's bargaining power via variation negotiation as the authority can order its variation at its favourably controlled price.

Alternatively, the concessionaire may establish its own option to order variation during the post-construction stage. However, the concessionaire, plays roles as both road operator and toll collector, is in an opportunistic position of bargaining strength in variation negotiation (Cruz et al., 2015; Sarmento and Renneboog, 2016; Yescombe, 2014; Zhu et al., 2016), and should design its variation option in a fair way to the authority. This is not considered in this chapter.

Establishing an option comes with a cost as the authority has to pay extra for cost and effort, at the present $i = 0$, to incorporate rates and methods to evaluate future variation within the concession contract. An option benefits the upside involved and limits any downside involved. The upside benefit can be achieved, in the case of exercising a variation option at year T, as the authority can claim its variation at the established variation cost, based on the predetermined rates and methods in the concession contract. This upside, discounted to time $i = 0$, gives the value of the option. This option value is then compared to the initial cost of incorporating rates and methods to evaluate future variations within the contract at time $t = 0$.

Viability of the variation option is established when the option value exceeds this initial cost.

Existing publications on PPPs stop short in valuing the variation option. The conventional discounted cash flow (DCF) analysis is not applicable in the valuing of variations because of the existence of uncertainty, and the variation may or may not take place at the discretion of the authority who initiates the variation. In this chapter, rational variation evaluation is done by using real option analysis based on the probabilistic cash flow approach.

7.5 Comments

The literature demonstrates that renegotiation is used as the main solution to deal with changes and variations in a PPP agreement. This is because there is no clause in the concession contract to instruct these variations. The renegotiation, dominated by the concessionaire, places the authority in an unequal bargaining position. By contrast, this chapter proposes the concession contract should establish built-in physical variations clauses that anticipate major possible variations and changes likely to be adopted, and provide a method of valuing them, during the concession period. This is likely an effective measure to address the renegotiation problems, and to minimise the potential for disputes in the valuation process. This facilitates the smooth functioning of the work without the need for additional contracts covering the changes. Since physical variations clauses are included in PPP agreements, options are available to deal with such kinds of variations, leaving only their extent and timing unknown.

The above proposal requires the following operational matters.

1. The PPP agreement provides express clauses which allow physical variations in the post-construction phase during the concession period. These clauses will be established with a high level of flexibility that demonstrates the ability to proactively anticipate and address possible contingencies and their method of valuation.

2. Variations clauses cover possible scenarios of major physical changes in PPP projects during the post-construction phase. These scenarios should include changes in the form of addition and subtraction or substitution to the original scope of work in the concession contract. For example, allowing an addition variation in a PPP agreement enables a party (either the concessionaire or the authority) to expand the existing road to a larger size, increase the number of road lanes, or open additional entrance and exit ramps of a toll road, adapting to favourable future circumstances. By contrast, a subtraction or substitution variation allows cutting back on road operations or selling part of the operation, resulting from the effects of an anticipated or real downturn of market or demand conditions.

3. The variation option will come with a cost, at time i = 0, which is paid to achieve the appropriate level of flexibility, corresponding to physical changes in the future. This expense includes the cost and effort to incorporate rates and methods to evaluate future variations within the contract. This is considered a 'sunk cost' which is incurred at the beginning of the concession period and may not be recovered, whether or not the built-in variations may be implemented. This initial cost should also cover all necessary other technical-related costs to achieve flexibility for future variations. For example, in the case of an addition variation, there is a need to establish reserved land at time i = 0, and this reserved land will be transformed to create the extra lanes in future road expansion. Accordingly, the initial cost should include the cost and effort of creating the reserved land, and this cost, while affecting project and option viability, does not enter the option value calculations.

4. The proposed option in this chapter is launched at the instigation of the authority. Once the variation is needed, the authority requires the concessionaire to submit a report, which assesses the full technical and financial impacts of the proposed variations, for the decision-making process. Then the two parties enter into negotiation covering, but not limited to, the variation scope, the quoted variation pricing, the potential of variation effects, cost and benefit analysis, and involved risks. An option is available for the authority to order a variation with the favourably controlled price. An alternative case is where the concessionaire requests a variation. However, this should be designed in a fair way to the authority in any negotiation, and must be approved by the authority.

5. The flexibility in the variation clause for addition and subtraction or substitution allows physical variations in any year where possible during the concession period. These two kinds of variations (addition and subtraction or substitution) may be either independent (single) or sequential (chain of variations). For the independent case, a variation application can be done independently from the other; whereas a variation may be a consequence of another in the sequential case. For example, a subtraction or substitution variation can be implemented at a specific time during the concession period to reduce the scale of the road operation, and maintain the ability to resume a former and greater level of operation by applying an addition variation in the future.

6. The variation clauses anticipate possible scenarios of major physical changes, either addition or subtraction; however, they leave extent and timing unknown. These clauses should provide the schedules of rate and pre-agreed quantities instruction as the changes occur. These schedules of rate and pre-agreed quantities instructions will facilitate the variation valuation process and minimise the potential for disputes related to the variation method of pricing. In a long concession period, the authority or concessionaire might think that these values may be 'out of date' or inappropriate to use, especially as variations might be needed far into the future. Therefore, they should establish values determined as flexibly as possible which may involve the most likely, optimistic and pessimistic estimates. Once a variation occurs, the concession contract will typically adopt

this approach so that the flexible rates in the original contract are used to calculate the variation cost.

7. For variation valuing purposes, there is no need to distinguish any types of variations, either addition, subtraction or substitution. The cash flow of a variation option is established based on the differences between the variation cost via negotiation and the variation cost based on the included rates and methods in the PPP contract that reflect the point of view of the authority. Both direct and indirect cash flows connected with variation are considered. The cash flow encompasses not only the direct needed cost but also some estimable 'opportunity costs' related to subsequent effects of the variation. For example, the cash flow in the addition variation may include the forgone revenues of blocking the road as a construction site and the initial investment cost of the demolished section may not been recouped fully at the time of expanding. However, only differences of cash inflows and outflows will be considered, and any similarity does not enter the calculation.

7.6 Option evaluation

7.6.1 Cash flow approach

The expected value, E[ ], and variance, Var[ ], are established to capture the uncertainty of the two variation costs: the variation cost via negotiation, and the variation cost established by rates and methods within the original contract.

Here, denoted that, at year i = T, the variation cost via negotiation is $Y|_{T1}$ and the variation cost established by rates and methods within the original contract is $Y|_{T2}$. T is allowed to vary to show the relationship between time of variation and the option value.

As presented in Figure 3.1, the extra cost that the authority and the public pay to claim the variation, $X|_{T}$ at time i = T, is the difference between the two variation costs, the variation cost via negotiation $Y|_{T1}$ and the variation cost established by rates and methods within the original contract $Y|_{T2}$. That is $X|_{T} = Y|_{T1} - Y|_{T2}$.

Estimates for $Y|_{T1}$ and $Y|_{T2}$ are based on similar assumptions, so it could be anticipated that there would be a very strong correlation between the estimates for the two variation costs.

For uncertainty in the extra cost,

$$E[X|_{T}] = E[Y|_{T1}] - E[Y|_{T2}] \tag{7.1}$$

$$\mathrm{Var}[X|_{T}] = \left(\sqrt{\mathrm{Var}[Y|_{T1}]} - \sqrt{\mathrm{Var}[Y|_{T2}]}\right)^2 \tag{7.2}$$

The present worth is obtained by discounting the extra cost $X\big|_T$ to i = 0,

$$E[PW] = \frac{E[X\big|_T]}{(1+r)^T} \tag{7.3}$$

$$Var[PW] = \frac{Var[X\big|_T]}{(1+r)^{2T}} \tag{7.4}$$

Calculation of a variation option is as follows,

$$\text{Variation option value} = \Phi M \tag{7.5}$$

Where Φ = P[PW] > 0 and is presented as the investment feasibility; P is probability, and M is the mean of the present worth upside measured from PW = 0. Any suitable distribution can be used to calculate Φ and M, and knowing E[PW] and Var[PW], but it is agreed that a normal distribution is the most common used (Hillier, 1963; Tung, 1992).

This option value is then compared to the initial cost and effort of incorporating rates and methods for future variations within the contract at time 0. Financial viability is established for the variation option when this option value exceeds the initial cost.

7.6.2 Option value

Outline

Consider the US example of Pocahontas Parkway toll road and its variation order, Richmond Airport Connector, of Gifford et al. (2014).

The 14.2 km Pocahontas Parkway connects the junction of Interstate 95 and State Route 150 in Chesterfield County with Interstate 925 near Richmond International Airport in Henrico County, Virginia, US. The Pocahontas Parkway was built in 1998 and opened to the public in 2002. In 2006, the authority initiated the variation order to construct a 2.6 km highway to connect the existing Pocahontas Parkway to Richmond International Airport, called Richmond Airport Connector.

The Richmond Airport Connector is a four-lane highway developed to improve airport access and reduce congestion on access roadways serving the airport and provides one of the first examples of a public-private partnership in the development of an airport access highway in the US. The Connector required the construction of three new bridges and the widening of an existing bridge to accommodate a ramp between the Parkway and the Connector.

The investment cost of the Richmond Airport Connector, that is considered a variation cost calculated using rates and methods within the contract, is estimated by Transurban Development at about USD 50 million (Freeman et al., 2012). It is assumed that the variation cost via negotiation is USD 48 million.

Example

It is assumed that an option to order variation is in place for the 25-year post-construction period. With this option, the authority has a right to order a variation to build this Connector at any time during the period.

The uncertainty of the two variation costs (variation cost via negotiation and variation cost calculated using rates and methods within the contract) is captured using variance in the probabilistic cash flow approach. This chapter makes variance assumptions of these variation costs based on estimates of the literature as discussed in Section 7.3.

The expected values and variances of variation cost estimates give the following:

- For the cost of this variation via negotiation at year T (USD million), $E[Y|_{T1}] = 48$, and using its standard deviation equal to 25% of its expected value, then $Var[Y|_{T1}] = 12^2$
- For the variation cost calculated using rates and methods within the contract at year T (USD million), using the planning technique PERT with optimistic (a) and pessimistic (c) values equal to ±50% each side of the most likely value (b) (USD 50 million), leading to the expected value =

(a+4b+c)/6 and variance = [(c-a)/6]^2 (see for example, Carmichael, 2006; Carmichael and Balatbat, 2008), then $E[Y|_{T2}] = 50$, and $Var[Y|_{T2}] = 8^2$

- Interest rate per annum, r = 6%
- Concession period, n = 25 years.

To calculate the variation option value, discounting these cash flows, $E[X|_T]$ = USD –2 million; $Var[X|_T]$ = (USD 4 million)^2. T is allowed to vary to show the relationship between time of variation and the option value.

Figure 7.1 shows how the option value changes with year of variation. Higher value of T, means that variation is required far into future, leads to lower present worth and, accordingly, to lower option values.

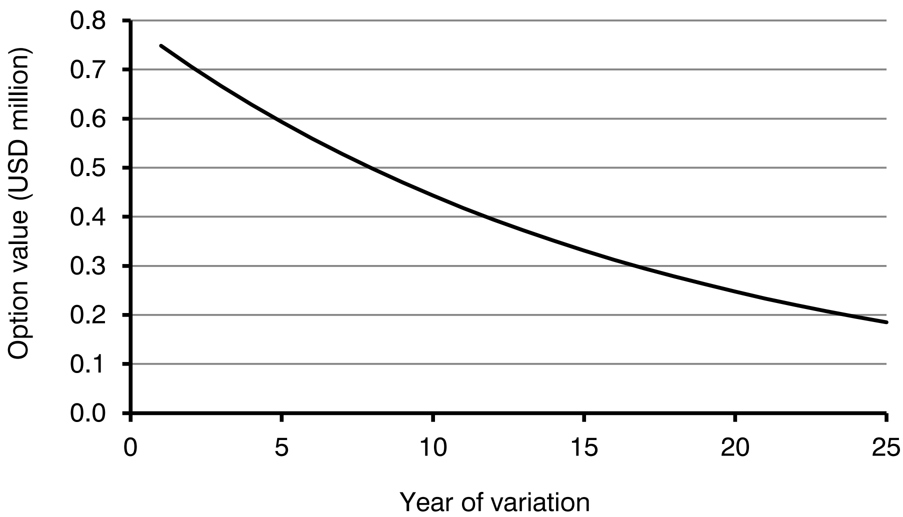

Figure 7.1 Addition variation example; option value versus year of variation.

Changing the interest rate values leads to different variation values (Figure 7.2). Higher interest rates lead to lower present worth, and in turn to lower option values.

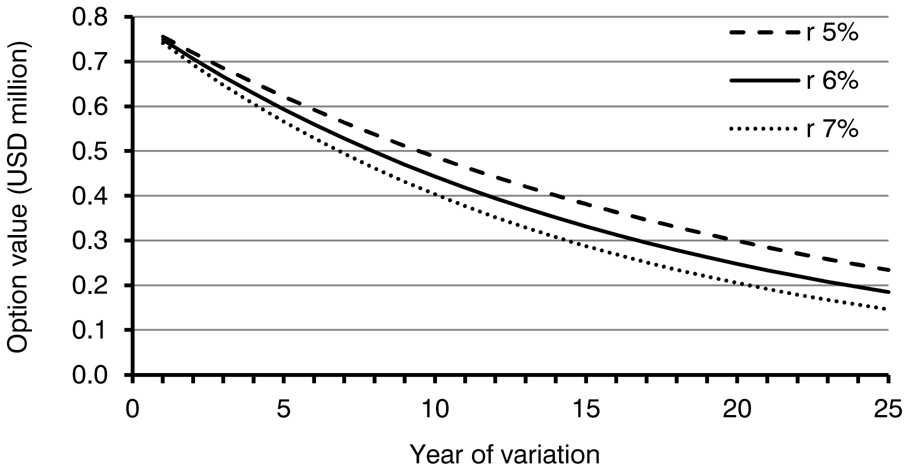

Figure 7.2 Addition variation example; option value trends with changing interest rate.

The option values change with the level of uncertainty associated with the variation costs as shown in Figure 7.3. The base case referred to in Figure 7.3 corresponds with the preceding example values. The alternative case referred to in Figure 7.3 has the increased level of uncertainty in variation cost via negotiation: using its standard deviation equal to 30% of its expected value, compared to that of 25% in the base case. It can be shown that the variation option value increases with the level of uncertainty. This trend is consistent with intuition and the trend given in all option scenarios covered in previous chapters.

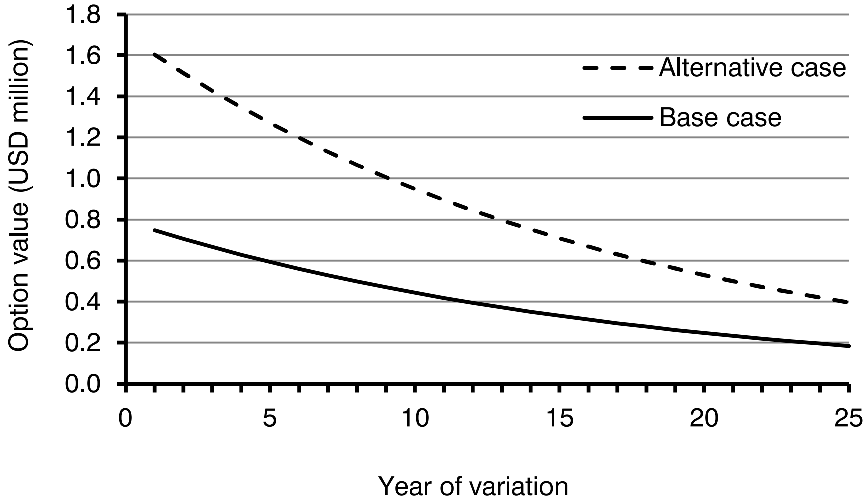

Figure 7.3 Addition variation example; option value – with changed input data.

7.7 Discussion

This chapter looks at the possible variations allowed in a PPP agreement, including addition and subtraction variations, in the post-construction phase during the concession period. It excludes any types of non-physical changes or adjustments in the concession contract, for example, financial agreements, toll pricing adjustment and others, that were addressed in Chapters 4, 5 and 6. To deal with these types of changes in PPPs, the literature adopted renegotiation as a primary tool because there is no clause in the concession contract to do so.

Renegotiation is criticised as creating unfair bargaining power against the authority and forcing the authority to pay extra costs or suffer losses to claim its variations. This chapter argued that these variations that are anticipated and established in the express clauses in a PPP contract, embedded with real option analysis, provide the authority with proactive responses to future circumstances.

The literature on PPP contracts suggests that renegotiation places the authority at a disadvantage, since the authority has to pay extra costs to claim its variation. There is the need for PPP contracts to incorporate flexibility, embedded with option analysis, to deal with such kind of variations. However, the literature stops short in quantifying such flexibility. The conventional deterministic approach is not applicable because it fails to capture the future uncertainty associated with the variation costs. This chapter presents real options analysis, based on the probabilistic cash flow approach, that gives the financial value of flexibility for the authority to order a variation during the post-construction stage of the concession period. Having this option, the authority sets a threshold on the concessionaire's bargaining power via variation negotiation as the authority can order its variation with pre-agreed costing. This provides a fair way forward for the implementation of PPP toll roads.

It is important to note that the conclusions reached in this particular example of an addition variation are based on certain designs of toll roads, assumptions and specific project circumstances. Thus, the approach, rather than the specific calculated numbers, is emphasised in this chapter. The numbers are indicative, but will vary with different inputs, assumptions, and other conditions. Other designed forms of variations, both addition and subtraction or omission, are possible, as they are influenced by the available design ideas, technical constraints and construction methods of particular projects. Accordingly, the proposed approach of valuing variations is general and applicable for any form of variations.

There is no need to distinguish variation type (addition and subtraction or substitution). Cash flows for option valuation purposes have been established based on the viewpoint of the option holder. As discussed in the above example from the authority's point of view, cash flows present a comparison between the variation cost resulting from negotiation and the variation cost established from the rates and methods included in the PPP contract upfront.

The flexibility in the variation clause allows physical variations in any year where possible during the post-construction stage of the concession period. This chapter comes up with the idea that variations, generally, can be formed either as independent (single) or sequential (chain of variations). For the independent case, a variation application can be made independently of the other; whereas for the sequential case, a variation may be a consequence of another variation.

The valuing of the variation option reflects from the point of view of whoever initiates the variation, whether this is the authority or the concessionaire. This chapter argues that the authority, placed in a bargaining power of weakness via negotiation, may suffer a loss or incur an extra cost to claim its variation, and thus establishes the authority-led variation. The cash flow analysis presented in this chapter is based on the authority's viewpoint where cash flows involve two variation costs: variation cost by negotiation and by pre-agreed rates and methods in the concession contract. This is more suitable for valuing the authority's option where the authority is in a position of weakness in negotiation and is cost conscious. Conversely, the concessionaire, in an opportunistic position of bargaining strength, may be less cost conscious and pays more attention to the benefits resulting from the implementation of variations rather than its claimed variation costs.

Variation costs possibly contain high levels of uncertainty, especially as variation may be needed far into the future, and this uncertainty needs to be captured in any analysis. With the probabilistic cash flow approach applied throughout the thesis, the uncertainty of variation costs is captured by estimating their expected value E[ ] and variance Var[ ]. This can be done by using the planning technique PERT with an optimistic, most likely and a pessimistic value or any other techniques which should appropriately cover the uncertainty and related risk.

The option value calculated in this chapter is then compared to the initial cost and effort to incorporate rates and methods to evaluate variations in PPP contract at time i = 0. Financial viability is established for variation when the option value exceeds this initial cost. However, when either the authority or the concessionaire has budget constraints at time 0 or prefers a reasonable initial investment cost for the project, this may restrict these parties from investing in this built-in variation option.

7.8 Conclusion

The literature on PPP agreements, but not limited to non-PPP contracts, suggests that variation renegotiation places the authority at a disadvantage, since the authority has to pay extra costs to claim its variation. There is the need for a PPP contract to incorporate flexibility, embedded with options analysis, to deal with these kind of variations. The chapter suggests that the PPP agreement proactively identifies a method by which variations should be priced, identifying major potential changes, leaving only their extent and timing unknown. Such variation can be analysed as an option, held by the authority. Having this option, the authority sets a threshold on the concessionaire's bargaining power via variation negotiation as the authority can order its variation at its controlled price.

The literature acknowledges that a flexible contract may offer the possibility of change for projects to cope with future uncertainty, however it stops short in quantifying flexibility to deal with physical variations in a PPP agreement. The conventional deterministic approach is inapplicable because it fails to capture the future uncertainty. This chapter presents the real options analysis, based on the probabilistic cash flow approach, that gives the financial value of flexibility for the authority to order variation during the post-construction stage of the concession period. This approach is straightforward and provides a fair way forward for the implementation of PPP toll roads.

The approach, rather than the presented numbers of the given example, is emphasised in this chapter. The numbers are suggestive, but vary with different inputs, assumptions and other conditions. Other designed forms of variations, both addition and subtraction or omission, are possible, as they are influenced by the available design ideas, technical constraints and construction methods of particular projects. The proposed approach of valuing variations is thus general and applicable for any form of variations.

The last chapter summarises the research findings and concludes the viability of options and flexibility for PPP toll roads, with respect to revenue guarantees, the concession period, and variation orders.

Chapter 8: Conclusions and recommendations

8.1 Overview

The aim of the research is to establish flexibility, embedded with options, in public-private partnership toll road projects, from the perspective of financial agreements, a flexible concession period and physical variations.

The thesis achieves the research aims by filling the research gap as follows:

- The first gap is the incoherence in the literature on options and flexibilities associated with revenue-related risk in PPP toll road projects. Chapters 4 and 5 demonstrate the single treatment for all guarantee options (both one-sided and two-sided protection) and they summarise the state-of-the-art literature on options in PPP toll road projects.

- The second gap is the inconsistency in using financial market options techniques to value 'real' infrastructure-based options. The thesis presents the probabilistic cash flow approach as an original unified approach for all PPP toll road options. The approach is a straightforward extension of conventional engineering viability analysis of projects, and does not rely on the financial market options literature. It offers a ready way to evaluate multiple options, requires minimal financial and mathematical knowledge, and hence can be readily implemented by practitioners.

- The third gap is fixed concession periods are currently used which lack the flexibility to deal with the 'long–short' conflict of the concession period, or to accommodate future uncertainties. Chapter 6 suggests a way forward, providing flexibility in establishing the period over which the concessionaire collects revenue based on actual project performance, while, beyond a calculated point in time, an option becomes available to the authority to take over the operation of the road. The implications of variability and uncertainty leading to establishing payback periods at pre-investment time, as well as, probabilistic payback periods are examined.

- The fourth gap is PPP agreements need to introduce the ability to allow for physical variations to the infrastructure and their method of pricing. Chapter 7 proposes that the PPP agreement should proactively identify a method by which variations should be priced, identifying potential change types, leaving only their extent and timing unknown. Such variation can be analysed as an option, held by the authority. Having an option introduces flexibility for the authority to order variations, dealing with changes of future circumstances.

8.2 Research findings

The main findings and contributions of the thesis to address the research gaps are presented:

- The thesis serves as a comprehensive summary related to revenue guarantee options in PPP toll road projects. Guarantees in PPP road project agreements are used by both the authority and the concessionaire to assist in improving project viability and to deal with risk and fairness. The guarantees are one way of addressing the uncertainty in use or demand that is experienced by roads. Such guarantees can be analysed as options. Previously, every different PPP guarantee was presented in terms of its own one-off options analysis, relying on the high level of mathematical skills of the analysts. The state-of-the-art literature summary in this thesis encompasses all existing PPP revenue-related guarantee options, both one-sided (minimum revenue guarantee, buyout, revenue sharing, restrictive competition guarantee, and toll adjustment mechanism) and two-sided protection (collar, traffic floor and ceiling guarantee and bound options).

- The probabilistic present worth cash flow approach provides an original unified approach to PPP toll road options. The probabilistic cash flow approach, developed by Carmichael et al. (2011) and Carmichael (2016), in valuing infrastructure-based options, makes no unrealistic assumptions, requires a minimal level of mathematics, and does not require knowledge of financial market options analysis techniques. Compared to the existing literature related to financial market techniques, the thesis demonstrates the consistency in applying the proposed approach for valuing all PPP toll road options. The approach is a straightforward extension of conventional engineering viability analysis of projects, and does not rely on the financial market options literature. It offers a ready way to evaluate multiple options, requires minimal financial and mathematical knowledge, and hence can be readily implemented by practitioners. The approach presented in this thesis permits options that can be exercised yearly or discretely throughout a project's concession period, and these can be treated in a single way. The approach can thus be applied to a wide variety of situations and locations. People involved in the infrastructure sector, such as investors, decision makers, project managers and engineers, can thus benefit from this approach.

- Consistently throughout the thesis, option valuation was performed from the option holder's point of view, whether this is the concessionaire or the authority. Cash flows were established from the option holder's viewpoint. Typically, cash flows are in terms of those that would exist without exercising the option, and those resulting from exercising the option. The cash flows, depending on the guarantee or agreement, may only be for the year in which the option applies, or over the years extending from the year of exercising the option to the end of the concession period. The approach is the same regardless of the PPP guarantee or agreement, for example, whether it is a minimum guarantee or a maximum guarantee. There is also no need to distinguish option type, as occurs in the financial markets literature.

- For all the different option cases analysed previously, when compared to the existing literature relevant to each case throughout Chapters 4 and 5, this thesis analysis gives option values that are essentially the same. Supplementary sensitivity-style analyses, conducted by changing the values of the case variables, showed option value trends to be the same as the existing literature. The differences between this thesis's option values and those of existing publications, as a proportion of similar exercise costs, are less than a few percent. Exact agreement would not be anticipated because of different assumptions applied between those in this thesis approach using variance and those of existing publications using volatility. Nevertheless, the thesis analysis made assumptions as compatible as possible with the existing literature.

- The thesis introduces the term 'bound options' which are developed as an advanced and superior version of the traffic floor and ceiling (Iyer and Sagheer, 2011) and the collar (Shan et al., 2010) to mitigate financial risk in PPP toll roads. For the associated bound options, there is no need for any upfront premium; the premium of the lower bound option can be used to cancel the premium of the upper bound option. The presence of the two yearly guarantees provides flexibility, with the levels of the option exercise prices set as constants or time-varying based on projected future cash flows. Both the concessionaire and the authority are readily able to evaluate, using this thesis's approach, the impact of any guarantees, providing a basis for the parties to fairly negotiate their PPP agreement.

- The study suggests a way forward, providing flexibility in establishing the period over which the concessionaire collects revenue based on actual project performance, while beyond a calculated point in time, an option becomes available to the authority to take over the operation of the road. The thesis's approach eliminates the controversial aspects existing in current PPPs associated with the lengths of concession periods. As a by-product, the approach also eliminates another controversial matter of the setting of tolls – toll formulae and toll adjustments over time.

- The thesis suggests that the PPP agreement proactively identifies a method by which variations should be priced, identifying major potential change types, leaving only their extent and timing unknown. This introduces an approach to incorporate variation orders into PPP agreements and their methods of pricing, based on real option analysis, to deal with major physical changes during the post-construction stage.

Overall, this thesis benefits academics, practitioners and stakeholders in the infrastructure sector by introducing options and flexibilities, and an approach to their pricing that helps establish the viability of flexible infrastructure, especially in the context of PPP toll road projects.

8.3 Future directions

Further research can be conducted based on either the research limitations or by extending the research summarised below as future directions.

- Guarantees within PPP road project agreements are used by both the authority and the concessionaire to improve project viability and to deal with risk and fairness. The guarantees are one way of addressing the uncertainty in use or demand experienced by roads. Such guarantees can be analysed as options. This thesis demonstrates these kinds of guarantees can be classified into two groups: one-sided and two-sided revenue protection. The general ideas of options given in Chapters 4 and 5 will not change, but the characterisation of the guarantees will. With creative thought, novel options may be adopted to create a win-win situation for the two parties, the authority and the concessionaire, by offering more flexibility to deal with revenue-based risks, in order to provide a fair way forward to implement PPP toll road projects.

- This thesis approach is extendable to all infrastructure types, not just toll roads, and to guarantees that are different from those covered in this thesis, and that may be proposed in the future. Heretofore, the possibilities have been limited because of the restrictive mathematics and assumptions of financial markets methods and difficulties in establishing analogies with infrastructure.

- Extension of the probabilistic cash flow approach might also be desirable when dealing with changes in model inputs and other assumptions. Future research could examine possible refinements, such as in choosing the present worth distribution and assumed interest rates and in examining special cases of compound options.

- Analysis of existing PPP toll road performance is difficult to undertake because public information on toll roads is not generally available from either concessionaires or authorities. Even within the public annual reports of companies, information is disguised, and often mixed with taxation, depreciation amortisation matters, and 'creative accounting'. More case studies, using appropriate data from a private sector concessionaire or public sector authority, would assist the take-up of the thesis proposal.

- Dealing with physical variations, the thesis takes the case where the authority orders an addition variation in a toll road as an example. There is the need to adopt more possible physical variations as well as non-physical variations, that reinforce the applicability of the thesis proposed approach.

- Among the challenges in establishing options to offer flexibility to deal with future uncertainties, the thesis highlights the financial and technical constraints associated with extra upfront costs. These constraints explain the reluctance of the option holder to invest and establish the options. Future research should be directed towards addressing these challenges, constraints and proposed adjustments.

References

Abigroup (2012), *Submission to the Department of Infrastructure and Transport in response to consultation Paper: Addressing issues in patronage forecasting for PPP/toll roads*, Department of Infrastructure and Regional Development, Canberra. Available at: https://infrastructure.gov.au/infrastructure/infrastructure_reforms/files/9-Abigroup.pdf (accessed September 24, 2018).

Ahadzi, M. and Bowles, G. (2004), Public-private partnerships and contract negotiations: An empirical study, *Construction Management and Economics*, Vol. 22, No. 9, pp. 967–978.

Ajak, A. D. and Topal, E. (2015), Real option in action: An example of flexible decision making at a mine operational level, *Resources Policy*, Vol. 45, pp. 109–120.

Akinsola, A. O., Potts, K. F. and Ndekugri, I. (1994), Variations on construction projects: A review of empirical studies, *Building Research and Information*, Vol. 22, No. 5, pp. 269–271.

Almarri, K. and Blackwell, P. (2014), Improving risk sharing and investment appraisal for PPP procurement success in large green projects, *Procedia–Social and Behavioral Sciences*, Vol. 119, pp. 847–856.

Almassi, A., McCabe, B. and Thompson M. (2013), Real options–based approach for valuation of government guarantees in public-private partnerships, *Journal of Infrastructure Systems*, Vol. 19, No. 2, pp. 196–204.

Alnuaimi, A. S., Taha, R. A., Mohsin, M. A. and Al-Harthi, A. S. (2010), Causes, effects, benefits, and remedies of change orders on public construction projects in Oman, *Journal of Construction Engineering and Management*, Vol. 136, No. 5, pp. 615–622.

Alonso-Conde, A. B., Brown, C. and Rojo-Suarez, J. (2007), Public private partnerships: Incentives, risk transfer and real options, *Review of Financial Economics*, Vol. 16, No. 4, pp. 335–349.

Amram, M. and Kulatilaka, N. (1999), *Real options: Managing Strategic Investment in An Uncertain World*, Harvard Business School, Boston, MA.

Ang, A. H-S. and Tang, W. H. (1975), *Probability Concepts in Engineering Planning and Design*, Vol. I, Wiley, New York.

Arain, F. M. (2005), Strategic management of variation orders for institutional buildings: Leveraging on information technology, *Project Management Journal*, Vol. 36, No. 4, pp. 66–77.

Arain, F. M. and Pheng, L. S. (2005), The potential effects of variation orders on institutional building projects, *Facilities*, Vol. 23, No. 11/12, pp. 496–510.

Arain, F. M. and Pheng, L. S. (2007), Modeling for management of variations in building projects, *Engineering, Construction and Architectural Management*, Vol. 14, No. 5, pp. 420–433.

Ashuri, B., Kashani, H., Molenaar, K., Lee, S. and Lu, J. (2012), Risk-neutral pricing approach for evaluating BOT highway projects with government minimum revenue guarantee options, *Journal of Construction Engineering and Management*, Vol. 138, No. 4, pp. 545–557.

Ashuri, B., Lu, J. and Kashani, H. (2011), A real options framework to evaluate investments in toll road projects delivered under the two-phase development strategy, *Built Environment Project and Asset Management*, Vol. 1, No. 1, pp. 14–31.

Athias, L. and Saussier, S. (2010), *Contractual Flexibility or Rigidity for Public Private Partnership? Theory and Evidence from Infrastructure Concession Contracts*, Discussion paper No. 2010-3, Chaire EPPP, Pantheon-Sorbonne.

Athias, L. and Saussier, S. (2018), Are public private partnerships that rigid? And why? Evidence from price provisions in French toll road concession contracts, *Transportation Research Part A,* Vol. 111, pp. 174–186.

Atkinson, A. V. (1992), *Civil Engineering Contract Administration*, 2nd ed, Stanley Thornes, Cheltenham, UK.

Attarzadeh, M., Chua, D. K. H., Beer, M. and Abbott, E. L. S. (2017), Options-based negotiation management of PPP–BOT infrastructure projects, *Construction Management and Economic*s, Vol. 35, No. 11–12, pp. 676–692.

Auriol, E. and Picard, P. M. (2013), A theory of BOT concession contracts, *Journal of Economic Behavior and Organization*, Vol. 89, pp. 187–209.

Aziz, R. F. (2013), Factors causing cost variation for constructing wastewater projects in Egypt, *Alexandria Engineering Journal*, Vol. 52, pp. 51–66.

Baeza, M. D. L. A. and Vassallo, J. M. (2010), Private concession contracts for toll roads in Spain: Analysis and recommendations, *Public Money and Management*, Vol. 30, No. 5, pp. 299–304.

Bain, R. (2009), Error and optimism bias in toll road traffic forecasts, *Transportation,* Vol. 36, No. 5, pp. 469–482.

Bajari, P. and Tadelis, S. (2001), Incentives versus transaction costs: A theory of procurement contracts, *RAND Journal of Economics*, Vol. 32, No. 3, pp. 287–307.

Bajari, P., Houghton, S. and Tadelis, S. (2006), *Bidding for Incomplete Contracts: An Empirical Analysis*, Working paper no. 12051, National Bureau of Economic Research, Cambridge, Massachusetts.

Bajari, P., Houghton, S. and Tadelis, S. (2014), Bidding for incomplete contracts: An empirical analysis of adaptation costs, *The American Economic Review*, Vol. 104, No. 4, pp. 1288–1319.

Bao, H., Peng, Y., Ablanedo-Rosas J. H. and Gao, H. (2015), An alternative incomplete information bargaining model for identifying the reasonable concession period of a BOT project, *International Journal of Project Management*, Vol. 33, No. 5, pp. 1151–1159.

Barton, K. and Lawryshyn, Y. (2011), Integrating real options with managerial cash flow estimates, *The Engineering Economist*, Vol. 56, No. 3, pp. 254–273.

Benjamin, J. R. and Cornell, C. A. (1970), *Probability, Statistics, and Decision for Civil Engineers*, McGraw-Hill, New York.

Berk, A. S. and Podhraski, D. (2018), Superiority of Monte Carlo simulation in valuing real options within public–private partnerships, *Risk Management*, Vol. 20, pp. 1–28.

Bitran, E., Nieto-Parra, S. and Robledo, J. S. (2013), *Opening the Black Box of Contract Renegotiations: An Analysis of Road Concessions in Chile, Colombia, and Peru,* OECD Development Centre Working Paper No. 317, Paris, France.

Black, F., and Scholes, M. (1973), The pricing of options and corporate liabilities, *Journal of Political Economy*, Vol. 81, No. 3, pp. 637–659.

Black, J. (2014), Traffic risk in the Australian Toll Road Sector, *Public Infrastructure Bulletin*, Vol. 1, No. 9, pp. 18–29.

Blank, F. F., Baidya, T. K. N. and Dias, M. A. G. (2009), Real options in public private partnership – Case of a toll road concession, in *Real Options Conference*, June 17–20, Braga, Portugal and Santiago, Spain. Available at: http://www.realoptions.org/papers2009/37.pdf (accessed September 24, 2018).

Borison, A. (2005), Real options analysis: Where are the emperor's clothes?, *Journal of Applied Corporate Finance*, Vol. 17, No. 2, pp. 17–31.

Brandao, L. E. T. and Saraiva, E. (2008), The option value of government guarantees in infrastructure projects, *Construction Management and Economics*, Vol. 26, No. 11, pp. 1171–1180.

Brandao, L. E. T., Bastian-Pinto, C., Gomes, L. L. and Labes, M. (2012), Government supports in public–private partnership contracts: Metro Line 4 of the São Paulo subway system, *Journal of Infrastructure Systems*, Vol. 18, No. 3, pp. 218–225.

Brandao, L. E. T., Penedo, G. M. and Bastian-Pinto, C. (2013), The value of switching inputs in a biodiesel production plant, *The European Journal of Finance*, Vol. 19, No. 7–8, pp. 674–688.

Buyukyoran, F. and Gundes, S. (2017), Optimized real options-based approach for government guarantees in PPP toll road projects, *Construction Management and Economics*, Vol. 36, No. 4, pp. 203–216.

Carbonara, N., Costantino, N. and Pellegrino, R. (2014), Revenue guarantee in public-private partnerships: A fair risk allocation model, *Construction Management and Economics*, Vol. 32, No. 4, pp. 403–415.

Carmichael, D. G. (2000), *Contracts and International Project Management*, A. A. Balkema, Rotterdam.

Carmichael, D. G. (2002), *Disputes and International Projects*, A.A. Balkema, Rotterdam.

Carmichael, D. G. (2006), *Project Planning, and Control*, Taylor & Francis, London.

Carmichael, D. G. (2014), *Infrastructure Investment: An Engineering Perspective*, CRC Press, Taylor and Francis, London.

Carmichael, D. G. (2016a), A cash flow view of real options, *The Engineering Economis*t, Vol. 61, No. 4, pp. 265–288.

Carmichael, D. G. (2016b), Risk – A commentary, *Civil Engineering and Environmental Systems*, Vol. 33, No. 3, pp. 177–198.

Carmichael, D. G. (2017), Adjustments within discount rates to cater for uncertainty – Guidelines, *The Engineering Economist*, Vol. 62, No. 4, pp. 322–335.

Carmichael, D. G. (2018), Estimating the value of built-in flexibility in infrastructure, *ASCE Construction Research Congress 2018: Sustainable Design and Construction and Education*, Wang, C., Harper, C., Lee, Y., Harris, R. and Berryman, C. (editors), pp. 613–622, ASCE Construction Research Congress, New Orleans, Louisiana, April 2–5.

Carmichael, D. G. and Balatbat, M. C. A. (2008), Probabilistic DCF analysis, and capital budgeting and investment – A survey, *The Engineering Economist*, Vol. 53, No. 1, pp. 84–102.

Carmichael, D. G. and Bustamante, B. L. (2014), Interest rate uncertainty and investment value – A second order moment approach, *International Journal of Engineering Management and Economics*, Vol. 4, No. 2, pp. 176–189.

Carmichael, D. G. and Handford, L. B. (2015), A note on equivalent fixed-rate and variable-rate loans; Borrower's perspective, *The Engineering Economist*, Vol. 60, No. 2, pp. 155–162.

Carmichael, D. G. and Taheriattar, R. (2018), Valuing deliberate built-in flexibility in houses – Exampled, *International Journal of Strategic Property Management*, Vol. 22, No. 6, pp. 479–488.

Carmichael, D. G., Hersh, A. M. and Parasu, P. (2011), Real options estimate using probabilistic present worth analysis, *The Engineering Economist*, Vol. 56, No. 4, pp. 295–320.

Carmichael, D. G., Nguyen, T. A. and Shen, X. (2018), Single treatment of PPP road project options, *ASCE Journal of Construction Engineering and Management,* Vol. 145, No. 2, p. 04018122, 11 pages.

Carpintero, S., Vassallo, J. M. and Soliño, A. S. (2015), Dealing with traffic risk in latin american toll roads*, Journal of Management in Engineering*, Vol. 31, No. 2, p. 05014016, 10 pages.

Caselli, S., Gatti, S. and Marciante, A. (2009), Pricing final indemnification payments to private sponsors in project-financed public-private partnerships: An application of real option valuation, *Journal of Applied Corporate Finance*, Vol. 21, No. 3, pp. 95–106.

Chang, C. Y. and Ive, G. (2007), Reversal of bargaining power in construction projects: Meaning, existence and implications, *Construction Management and Economics*, Vol. 25, No. 8, pp. 845–855.

Charoenngam, C. and Mahavarakorn, W. (2011), Collaborative negotiation behaviors in Thai construction projects, *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 3, No. 3, pp. 109–115.

Cheah, C. and Liu, J. (2006), Valuing governmental support in infrastructure projects as real options using Monte Carlo simulation, *Construction Management and Economics*, Vol. 24, No. 5, pp. 545–554.

Chen, Q., Shen, G., Xue, F. and Xia, B. (2017), Real options model of Toll-Adjustment Mechanism in concession contracts of toll road projects, *Journal of Management in Engineering*, Vol. 34, No. 1, p. 04017040, 11 pages.

Chiara, N. and Kokkaew, N. (2013), Alternative to government revenue guarantees: Dynamic revenue insurance contracts, *Journal of Infrastructure Systems*, Vol. 19, No. 3, pp. 287–296.

Chiara, N., Garvin, M. J. and Vecer, J. (2007), Valuing simple multiple-exercise real options in infrastructure projects, *Journal of Infrastructure Systems*, Vol. 13, No. 2, pp. 97–104.

Chung, D. (2009), Private provision of road infrastructure: Unveiling the inconvenient truth in New South Wales, Australia, *Road and Transport Research*, Vol. 18, No. 1, pp. 68–85.

Copeland, T. and Antikarov, V. (2001), *Real Options: A Practitioner's Guide*, Texere Publishing Limited, New York.

Cortazar, G. and Casassus, J. (1998), Optimal timing of a mine expansion: Implementing a real option model, *The Quarterly Review of Economics and Finance*, Vol. 38, pp. 755–769.

Cruz, C. O. and Marques, R. C. (2013a), Endogenous determinants for renegotiating concessions: Evidence from local infrastructure, *Local Government Studies*, Vol. 39, No. 3, pp. 352–374.

Cruz, C. O. and Marques, R. C. (2013b), Flexible contracts to cope with uncertainty in public-private partnerships, *International Journal of Project Management*, Vol. 31, No. 3, pp. 473–483.

Cruz, C. O. and Sarmento, J. M. (2019), Traffic forecast inaccuracy in transportation: A literature review of roads and railways projects, *Transportation*, Vol. 46, pp. 1–36.

Cruz, C. O., Marques, R. and Cardoso, P. (2015), Empirical evidence for renegotiation of PPP contracts in the road sector, *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 7, No. 2, p. 05014003, 9 pages.

Culik, M. (2016), Real options valuation with changing volatility, *Perspectives in Science*, Vol. 7, pp. 10–18.

Czerwinski, D. and Geddes, R. R. (2010), *Policy Issues in U.S. Transportation Public-Private Partnerships: Lessons from Australia*, MIT Report 09-15, Mineta Transportation Institute, San Jose, CA.

de Brux, J. (2010), The dark and bright sides of renegotiation: An application to transport concession contracts, *Utilities Policy*, Vol. 18, No. 2, pp. 77–85.

de Neufville, R. and Scholtes, S. (2011), *Flexibility in Engineering Design,* MIT Press, Cambridge, MA.

de Neufville, R., Scholtes, S. and Wang, T. (2006), Real options by spreadsheet: Parking garage case example, *Journal of Infrastructure Systems*, Vol. 12, No. 3, pp. 107–111.

Demirel, H. C., Leendertse, W., Volker, L. and Hertogh, M. (2017), Flexibility in PPP contracts – Dealing with potential change in the pre-contract phase of a construction project, *Construction Management and Economics*, Vol. 35, No. 4, pp. 196–206.

Deng, Y., Cardin, M. A., Babovi, V., Santhanakrishnan, D., Schmitter, P. and Meshgi, A. (2013), Valuing flexibilities in the design of urban water management systems, *Water Research*, Vol. 47, pp. 7162–7174.

Department of Infrastructure and Regional Development (Australia) (2013), *National Public Private Partnership Guidelines: Volume 5 Discount Rate Methodology Guidance*, Australian Department of Infrastructure and Regional Development, Canberra. Available at: https://infrastructure.gov.au/infrastructure/ngpd/files/Volume-5-Discount-Rate-Guidance-Aug-2013-FA.pdf (accessed October 04, 2018).

Desai, J. N., Pitroda, J. and Bhavsar, J. J. (2015), A review on change order and assessing causes affecting change order in construction, *Journal of International Academic Research for Multidisciplinary*, Vol. 2, No. 12, pp. 152–162.

Dias, M. A. G. (2004), Valuation of exploration and production assets: An overview of real options models, *Journal of Petroleum Science and Engineering*, Vol. 44, pp. 93–114.

Dimitrakopoulos, R. G. and Sabour, S. A. A. (2007), Evaluating mine plans under uncertainty: Can the real options make a difference?, *Resources Policy*, Vol. 32, pp. 116–125.

Dixit, A. (1992), Investment and hysteresis, *Journal of Economic Perspectives*, Vol. 6, No. 1, pp. 107–132.

Dixit, A. K. and Pindyck, R. S. (1994), *Investments Under Uncertainty*, Princeton University Press, Princeton, NJ.

Dobes, L. (2010), *Notes on Applying Real Options to Climate Change Adaptation Measures, with examples from Vietnam,* Centre for Climate Economics and Policy (CCEP), Research report No. 75, Crawford School of Public Policy, The Australian National University.

Dockendorf, J. and Paxson, D. A. (2015), Sequential real rainbow options, *The European Journal of Finance*, Vol. 21, No. 10–11, pp. 867–892.

Domingues, S. and Zlatkovic, D. (2015), Renegotiating PPP contracts: Reinforcing the 'P' in partnership, *Transport Reviews*, Vol. 35, No. 2, pp. 204–225.

Domingues, S., Zlatkovic, D. and Roumboutsos, A. (2014), Contractual flexibility in transport infrastructure PPP, *European Transport Conference*, Frankfurt, Germany, September 29 – October 1.

Erfani, T., Pachos, K. and Harou, J. J. (2018), Real-options water supply planning: Multistage scenario trees for adaptive and flexible capacity expansion under probabilistic climate change uncertainty, *Water Resources Research*, Vol. 54, pp. 5069–5087.

Eschenbach, T. G., Lewis, N. A., Henrie, M., Baker, E. and Hartman, J. C. (2007), Real options and real engineering projects, *Engineering Management Journal*, Vol. 19, No. 4, pp. 11–19.

European Commission (2003), *Guidelines for Successful Public-Private Partnerships*, Directorate-General, Regional Policy. Available at: http://ec.europa.eu/regional_policy/sources/docgener/guides/ppp_en.pdf (accessed October 04, 2018).

Evans and Peck (2012*), Addressing Issues in Patronage Forecasting for PPP/Toll Roads, Feedback and Comments*, Department of Infrastructure and

Regional Development. Available at: https://infrastructure.gov.au/infrastructure/infrastructure_reforms/files/Evens_Peck.pdf (accessed October 04, 2018).

Fatokun, A. O. (2018), *Value for Money Integration in the Renegotiation of Public Private Partnership Road Projects*, PhD thesis, the University of Central Lancashire, Preston, UK.

Fawcett, W., Urquijo, I. R., Krieg, H., Hughes, M., Mikalsen, L. and Gutiérrez, O. R. R. (2015), Cost and environmental evaluation of flexible strategies for a highway construction project under traffic growth uncertainty, *Journal of Infrastructure Systems*, Vol. 21, No. 3, p. 05014006, 14 pages.

Fernandes, C., Cruz, C. O. and Moura, F. (2019), Ex post evaluation of PPP government-led renegotiations: Impacts on the financing of road infrastructure, *The Engineering Economist*, Vol. 64, No. 2, pp. 116–141.

Finke, M. R. (1998), A better way to estimate and mitigate disruption, *Journal of Construction Engineering and Management*, Vol. 124, No. 6, pp. 490–497.

Fisk, E. R. (1997), *Construction Project Administration*, 5th ed, Prentice–Hall, New Jersey, US.

Flyvbjerg, B., Holm, M. K. S. and Buhl, S. L. (2005), How (in)accurate are demand forecasts in public works projects?: The case of transportation, *Journal of the American Planning Association*, Vol. 71, pp. 131–146.

Ford, D. N. and Sobek, D. (2005), Modeling real options to switch among alternatives in product development, *IEEE Transactions on Engineering Management*, Vol. 52, No. 2, pp. 1–11.

Ford, D. N., Lander, D. M. and Voyer, J. J. (2002), A real options approach to valuing strategic flexibility in uncertain construction projects, *Construction Management and Economics*, Vol. 20, No. 4, pp. 343–351.

Freeman, D., Wei, W. and Gosling, G. D. (2012), *Case Study Report: Richmond Airport Connector*, Mineta Transportation Institute, Research project 2503, San José State University, San José, CA. Available at https://transweb.sjsu.edu/sites/default/files/pdfs/research/2503-cs5-richmond-airport-connector.pdf (accessed June 04, 2019).

Fricke, E. and Schulz, A. P. (2005), Design for changeability (DfC): principles to enable changes in systems throughout their entire life cycle, *Systems Engineering*, Vol. 8, No. 4, pp. 342–359.

Galera, A. L. L. and Soliño, A. S. (2010), A real options approach for the valuation of highway concessions, *Transportation Science*, Vol. 44, No. 3, pp. 416–427.

Garvin, M. J. and Cheah, C. Y. J. (2004), Valuation techniques for infrastructure investment decisions, *Journal of Construction Management and Economics*, Vol. 22, No. 4, pp. 373–383.

Garvin, M. J. and Ford, D. N. (2012), Real options in infrastructure projects: Theory, practice and prospects, *Engineering Project Organization Journal*, Vol. 2, pp. 97–108.

Geltner, D. M. (2007), *Commercial Real Estate Analysis and Investments: Analysis and Investments,* Thompson South-Western, Mason, Oklahoma, US.

Gifford, J., Bolanos, L. and Daito, N. (2014), Renegotiation of transportation public-private partnerships: The US experience, *International Transport Forum Discussion Papers*, 2014/16, OECD Publishing, Washington, DC.

Glasserman, P. (2003), *Monte Carlo Methods in Financial Engineering,* Springer Science + Business Media, New York.

Grimsey, D. and Lewis, M. K. (2002), Evaluating the risks of public private partnership for infrastructure projects, *International Journal of Project Management*, Vol. 20, No. 2, pp. 107–118.

Grimsey, D. and Lewis, M. K. (2004), *Public Private Partnerships: the Worldwide Revolution in Infrastructure Provision and Project Finance*, Edward Elgar Publishing, Cheltenham, UK; Northampton, MA.

Grimsey, D. and Lewis, M. K. (2005), Are public private partnerships value for money? Evaluating alternative approaches and comparing academic and practitioner views, *Accounting Forum*, Vol. 29, No. 4, pp. 345–378.

Grossman, S. J. and Hart, O. D. (1986), The costs and benefits of ownership: A theory of vertical and lateral integration, *Journal of Political Economy*, Vol. 94, No. 4, pp. 691–719.

Guasch, J. L. (2004), *Granting and Renegotiating Infrastructure Concessions: Doing It Right*, WBI Development Studies, World Bank Publications, Washington, DC.

Guasch, J. L. and Straub, S. (2006), Renegotiation of infrastructure concessions: an overview, *Annals of Public and Cooperative Economics*, Vol. 77, No. 4, pp. 479–493.

Guasch, J. L., Benitez, D., Portabales, I. and Flor, L. (2014), The renegotiation of PPP contracts: An overview of its recent evolution in Latin America, *International Transport Forum Discussion Papers*, 2014/18, OECD Publishing, Paris.

Guasch, J. L., Laffont, J. J. and Straub, S. (2007), Concessions of infrastructure in Latin America: Government-led renegotiation, *Journal of Applied Econometrics*, Vol. 22, No. 7, pp. 1267–1294.

Guthrie, G. (2009), *Real Options in Theory and Practice*, Oxford University Press, New York, US.

Hahn, W. J. and Dyer, J. S. (2008), Discrete time modeling of mean-reverting stochastic processes for real option valuation, *European Journal of Operational Research,* Vol. 184, pp. 534–548.

Hanaoka, S. and Palapus, H. P. (2012), Reasonable concession period for Build-Operate-Transfer road projects in The Philippines, *International Journal of Project Management*, Vol. 30, No. 8, pp. 938–949.

Hanna, A. S. and Gunduz, M. (2004), Impact of change orders on small labor-intensive projects, *Journal of Construction Engineering and Management*, Vol. 130, No. 5, pp. 726–733.

Hanna, A. S., Russell, J. S. and Vandenberg, P. J. (1999), The impact of change orders on mechanical construction labour efficiency, *Journal of Construction Management and Economics*, Vol.17, No. 6, pp. 721–730.

Hart, O. (2003), Incomplete contracts and public ownership: Remarks, and an application to public–private partnerships, *Economic Journal*, Vol. 113, No. 486, pp. 69–76.

Hart, O. and Moore, J. (1988), Incomplete contracts and renegotiation, *Econometrica*, Vol. 56, No. 4, pp. 755–785.

Hawas, F. and Cifuentes, A. (2017), Valuation of projects with minimum revenue guarantees: A Gaussian copula–based simulation approach, *The Engineering Economist*, Vol. 62, No. 1, pp. 90–102.

Henckel, T. and McKibbin, W. (2010), *The Economics of Infrastructure in a Globalized World: Issues, Lessons and Future Challenges*, The Brookings Institution, Washington, DC.

Hensher, D. A. (2018), Toll Roads – A view after 25 years, *Transport Reviews,* Vol. 38, No. 1, pp. 1–5.

Herath, H. and Park, C. (2002) Multi-stage capital investment opportunities as compound real options, *The Engineering Economist*, Vol. 47, No. 1, pp. 1–27.

Hillier, F. S. (1963), The derivation of probabilistic information for the evaluation of risky investments, *Management Science*, Vol. 9, No. 3, pp. 443–457.

Hillier, F. S. (1965), Supplement to 'The derivation of probabilistic information for the evaluation of risky investments', *Management Science*, Vol. 11, No. 3, pp. 485–487.

HM Treasury (2012), *A New Approach to Public Private Partnerships*, The Stationery Office, London.

Ho, S. P. and Liu, L. Y. (2002), An option pricing-based model for evaluating the financial viability of privatized infrastructure projects, *Construction Engineering and Management,* Vol. 20, pp. 143–156.

Hodges, S. D. and Moore, P. G. (1968), The consideration of risk in project selection, *Journal of the Institute of Actuaries*, Vol. 94, pp. 355–378.

Hsieh, T. Y., Lu, S. T. and Wu, C. H. (2004), Statistical analysis of causes for change orders in metropolitan public works, *International Journal of Project Management*, Vol. 22, No. 8, pp. 679–686.

Huang, Y. L. and Chou, S. P. (2006), Valuation of the minimum revenue guarantee and the option to abandon in BOT infrastructure projects, *Construction Management and Economics*, Vol. 24, No. 4, pp. 379–389

Hucki, Z. and Kolokoltsov, V. N. (2007), Pricing of rainbow options: Game theoretic approach, *International Game Theory Review*, Vol. 9, No. 2, pp. 215–242.

Hull, J. C. (2002), *Options, Futures and Other Derivatives*, 5th ed, Prentice Hall, Upper Saddle River, NJ.

Hwang, B. G. and Low, L. K. (2012), Construction project change management in Singapore: Status, importance and impact, *International Journal of Project Management*, Vol. 30, pp. 817–826.

Ibbs, C. W., Lee, S. A. and Li, M. I. (1998), Fast-tracking's impact on project change, *Project Management Journal*, Vol. 29, No. 4, pp. 35–42.

Ingersoll, J. and Ross, S. (1992), The value of waiting to invest: Investment and uncertainty, *Journal of Business*, Vol. 65, No. 1, pp. 1–29.

Inthavongsa, I., Drebenstedt, C., Bongaerts, J. and Sontamino, P. (2016), Real options decision framework: Strategic operating policies for open pit mine planning, *Resources Policy,* Vol. 47, pp. 142–153.

Ipsmiller, E., Brouthers, K. D. and Dikova, D. (2019), 25 years of real option empirical research in management, *European Management Review*, Vol. 16, pp. 55–68.

Iyer, K. C. and Sagheer, M. (2011), A real options based traffic risk mitigation model for Build-Operate-Transfer highway projects in India, *Construction Management and Economics*, Vol. 29, No. 8, pp. 771–779.

Javed, A. A., Lam, P. T. I. and Chan, A. P. C. (2014), Change negotiation in public-private partnership projects through output specifications: An experimental approach based on game theory, *Construction Management and Economics,* Vol. 32, No. 4, pp. 323–348.

Johnston, D. (2012), *Traffic Forecasting for Australian Toll Roads,* Department of Infrastructure and Regional Development, Canberra. Available at: https://infrastructure.gov.au/infrastructure/infrastructure_reforms/files/johnston_services.pdf (accessed October 04, 2018).

Johnson, H. (1987), Options on the maximum or the minimum of several assets, *Journal of Financial and Quantitative Analysis*, Vol. 22, No. 03, pp. 277–283.

Jun, J. B. (2010), Appraisal of combined agreements in BOT project finance: Focused on minimum revenue guarantee and revenue cap agreements, *International Journal of Strategic Property Management*, Vol. 14, No. 2, pp. 139–155.

Kashani, H. (2012), *A real options model for the financial valuation of infrastructure systems under uncertainty*, PhD thesis, Georgia Institute of Technology, Atlanta, Georgia.

Kester, W. C. (1984), Today’s options for tomorrow's growth, *Harvard Business Review*, Vol. 62, No. 2, pp. 153–160.

Khanzadi, M., Nasirzadeh, F. and Alipour, M. (2012), Integrating System Dynamics and Fuzzy Logic Modeling to Determine Concession Period in BOT Projects, *Automation in Construction*, Vol. 22, pp. 368–376.

Kodukula, P. and Papudesu, C. (2006), *Project Valuation Using Real Options: A Practitioners Guide,* J. Ross Publishing, Fort Lauderdale, FL.

Kogut, B. (1991), Joint ventures and the option to expand and acquire, *Management Science*, Vol. 37, No. 1, pp. 19–33.

Kokkaew, N. and Chiara, N. (2013), A modeling government revenue guarantees in privately built transportation projects: A risk-adjusted approach, *Transport,* Vol. 28, No. 2, pp. 186–192.

Kozlova, M. (2017), Real option valuation in renewable energy literature: Research focus, trends and design, *Renewable and Sustainable Energy Reviews*, Vol. 80, pp. 180–196.

Krüger, N. A. (2012), To kill a real option: Incomplete contracts, real options and PPP, *Transportation Research Part A: Policy and Practice*, Vol. 46, No. 8, pp. 1359–1371.

Leiblein, M. J. and Ziedonis, A. A. (2007), Deferral and growth options under sequential innovation, *Real Options Theory, Advances in Strategic Management*, Reuer, J. J. and Tong, T. W. (editors), Vol. 24, pp. 225–245, Emerald Group Publishing, Bingley, UK.

Levin, P. (editor) (2016), *Construction Contract Claims, Changes, and Dispute Resolution,* American Society of Civil Engineers Press, Reston, Virginia.

Lewis, N. A., Eschenbach, T. G. and Hartman, J. C. (2008), Can we capture the value of option volatility?, *The Engineering Economist*, Vol. 53, No. 3, pp. 230–258.

Liou, F. and Huang, C. (2008), Automated approach to negotiations of BOT contracts with the consideration of project risk, *Journal of Construction Engineering and Management,* Vol. 134, No. 1, pp. 18–24.

Liu, J., Yu, X. and Cheah, C. Y. J. (2014), Evaluation of restrictive competition in PPP projects using real option approach, *International Journal of Project Management*, Vol. 32, No. 3, pp. 473–481.

Liu, S., Jin, H., Liu, C., Xie, B. and Mills, A. (2019), Government compensation and costs of non-competition guarantee for PPP rental retirement villages, *Engineering, Construction and Architectural Management,* Vol. 1, pp. 1–22.

Love, P. E. D., Holt, G. D., Shen, L. Y., Li, H. and Irani, Z. (2002), Using systems dynamics to better understand change and rework in construction project management systems, *International Journal of Project Management*, Vol. 20, No. 6, pp. 425–436.

Lu, W., Zhang, L. and Li, Z. (2014), Influence of negotiation risk attitude and power on behaviors and outcomes when negotiating construction claims, *Journal of Construction Engineering and* Management, Vol. 141, No. 2, p. 04014069, 11 pages.

Makovsek, D., Perkins, S. and Hasselgren, B. (2014), *Public Private Partnerships for Transport Infrastructure: Renegotiations, How to Approach Them and Economic Outcomes*, International Transport Forum Discussion Papers, No. 2014/25, OECD Publishing, Paris.

Manocha, N. and Babovic, V. (2018), Sequencing infrastructure investments under deep uncertainty using real options analysis, *Water*, Vol. 10, pp. 229–247.

Marques, R. C. and Cruz, C. O. (2012), *Can Management Contracts Avoid The PPP Renegotiations? Lessons From The Water Sector*, University of Lisbon, Portugal. Available at: http://www.ub.edu/graap/Final%20Papers%20PDF/Marques%20Oliveira.pdf (accessed August 04, 2019).

Marques, J., Cunha, M. and Savic, D. (2015), Using real options in the optimal design of water distribution networks, *Journal of Water Resources Planning and Management*, Vol. 141, No. 2, p. 04014052, 10 pages.

Martinez-Cesena, E. A., Mutale, J. and Rivas-Davalos, F. (2013), Real options theory applied to electricity generation projects: A review, *Renewable and Sustainable Energy Reviews*, Vol. 19, pp. 573–581.

Martins, J., Marques, R. C. and Cruz, C. O. (2015), Real options in infrastructure: Revisiting the literature, *Journal of Infrastructure Systems*, Vol. 21, No. 1, p. 04014026, 10 pages.

McCowan, A. K. (2004), *Decision Support System for the Evaluation and Comparison of Concession Project Investments*, PhD thesis, Griffith University, Brisbane.

McDonald, R. and Siegel, D. (1985), Investment and the valuation of firms when there is an option to shut down, *International Economic Review*, Vol. 26, No. 2, pp. 331–349.

McGowan, P. H., Malcolm, R., Horner, W., Jones, D. and Thompson, P. A. (1992), *Allocation and Evaluation of Risk in Construction Contracts*, CIOB Occasional Paper No. 52, The Chartered Institute of Building, Ascot, UK.

McKinsey Global Institute (2013), *Infrastructure Productivity: How to Save $1 Trillion A Year*, The McKinsey Infrastructure Practice. Available at: https://www.mckinsey.com/~/media/McKinsey/Industries/Capital%20Projects%20and%20Infrastructure/Our%20Insights/Infrastructure%20productivity/MGI%20Infrastructure_Executive%20summary_Jan%202013.ashx (accessed August 04, 2019).

Medda, F. (2007), A game theory approach for the allocation of risks in transport public private partnerships, *International Journal of Project Management*, Vol. 25, No. 3, pp. 213–218.

Meng, Q. J. and Ding, D. (2013), An efficient pricing method for rainbow options based on two-dimensional modified sine–sine series expansions, *International Journal of Computer Mathematics*, Vol. 90, No. 5, pp. 1096–1113.

Merton, R. C. (1973), Theory of rational option pricing, *Bell Journal of Economics and Management*, Vol. 4, pp. 141–183.

Mirzadeh, I. and Birgisson, B. (2016), Evaluation of highway projects under government support mechanisms based on an option-pricing framework, *Journal of Construction Engineering and Management*, Vol. 142, No. 4, p. 04015094, 9 pages.

Mody, A. (editor) (1996), *Infrastructure Delivery: Private Initiative and the Public Good,* EDI Development Studies, The International Bank for Reconstruction and Development/The World Bank, Washington, DC. Available at: http://documents.worldbank.org/curated/en/447681468739516774/pdf/multi-page.pdf (accessed October 04, 2018).

Monod, J. (1982), *The Private Sector and the Management of Public Drinking Water Supply*, The World Bank, Washington, DC.

Mun, J. (2002), *Real Options Analysis: Tools and Techniques for Valuing Strategic Investments and Decision,* John Wiley & Sons, Hoboken, NJ.

Murdoch, J. and Hughes, W. (2000), *Construction Contracts: Law and Management*, 3rd ed, Spon Press, Taylor & Francis Group, London.

Myers, S. C. (1977), Determinants of corporate borrowing, *Journal of Financial Economics*, Vol. 5, No. 2, pp. 147–175.

Myers, S. C. (1984), Finance theory and financial strategy, *Interfaces*, Vol. 14, No. 1, pp. 126–137.

Myers, S. C. and Majd, S. (1990), Abandonment value and project life, *Advances in Futures and Options Research*, Vol. 4, No. 1, pp. 1–21.

Nasirzadeh, F., Khanzadi, M. and Alipour, M. (2014), Determination of concession period in Build-Operate-Transfer projects using fuzzy logic, *Iranian Journal of Management Studies*, Vol. 7, No. 2, pp. 437–456.

Nembhard, H. B. and Aktan, M. (editors) (2010), *Real Options in Engineering Design, Operations, and Management*, CRC Press, Taylor & Francis, Hoboken, NJ.

Ng, A. and Loosemore, M. (2007), Risk allocation in the private provision of public infrastructure, *International Journal of Project Management*, Vol. 25, No. 1, pp. 66–76.

Ng, S. T., Xie J., Cheung, Y. K. and Jefferies, M. (2007), A simulation model for optimizing the concession period of public-private partnerships schemes, *International Journal of Project Management*, Vol. 25, No. 8, pp.791–798.

Ngee, L., Tiong, R. L. K. and Alum, J. (1997), Automated approach to negotiation of BOT contracts, *ASCE Journal of Computing in Civil Engineering,* Vol. 11, No. 2, pp. 121–128.

Nguyen, T. A. and Carmichael, D. G. (2018), Bound options in road infrastructure concession delivery, *The 22nd Annual International Real Options Conference, ROC 2018*, WHU Otto Beisheim School of Management, Dusseldorf, Germany, June 21–23.

Nikolaidis, N. and Roumboutsos, A. (2013), A PPP renegotiation framework: A road concession in Greece, *Built Environment Project and Asset Management*, Vol. 3, No. 2, pp. 264–278.

Niu, B. and Zhang, J. (2013), Price, capacity and concession period decisions of Pareto-efficient BOT contracts with demand uncertainty, *Transportation Research Part E: Logistics and Transportation Review*, Vol. 53, pp. 1–14.

NSW Audit Office (2000), *Review of Eastern Distributor*, NSW Audit Office, Sydney. Available at: http://www.audit.nsw.gov.au/ArticleDocuments/129/42_Eastern_Distributor_P1.pdf.aspx?Embed=Y (accessed October 04, 2018).

O'Brien, J. J. (1998), *Construction Change Orders*, McGraw-Hill, New York.

OECD (2008), *Public-Private Partnerships: In Pursuit of Risk Sharing and Value for Money*, OECD Publishing, Paris.

Okada, R. C., Simons, A. E. and Sattineni, A. (2017), Owner-requested changes in the design and construction of government healthcare facilities, *Procedia Engineering*, Vol. 196, pp. 592–606.

Oladapo, A. A. (2007), A quantitative assessment of the cost and time impact of variation orders on construction projects, *Journal of Engineering, Design and Technology*, Vol. 5, No. 1, pp. 35–48.

Oyewobi, L. O., Jimoh, R., Ganiyu. B. O. and Shittu, A. A. (2015), Analysis of causes and impact of variation order on educational building projects, *Journal of Facilities Management*, Vol. 14, No. 2, pp. 139–164.

Paddock, J., Siegel, D., and Smith, J. (1988), Option valuation of claims on real assets: the case of offshore petroleum leases, *Quarterly Journal of Economics*, Vol. 103, No. 3, pp. 479–508.

Pellegrino, R., Vajdic, N. and Carbonara, N. (2013), Real option theory for risk mitigation in transport PPPs, *Built Environment Project and Asset Management*, Vol. 3, No. 2, pp. 199–213.

Pollack, J. (2017), Change management as an organizational and project capability, *Cambridge Handbook of Organizational Project Management*, Sankaran, S., Müller, R. and Drouin, N. (editors), pp. 236–249, Cambridge University Press, Cambridge.

Potts, K. F. and Patchell, B. (1995), *Major Construction Works: Contractual and Financial Management*, Longman Scientific & Technical, UK.

Power, G. J., Burris, M., Vadali, S. and Vedenov, D. (2016), Valuation of strategic options in Public–Private Partnerships, *Transportation Research Part A: Policy and Practice*, Vol. 90, pp. 50–68.

Power, G. J., Tandja, C. D. M., Bastien, J. and Gregoire, P. (2015), Measuring infrastructure investment option value, *The Journal of Risk Finance*, Vol. 16, No. 1, pp. 49–72.

Pratap, K. V. and Chakrabarti, R. (2017), *Public-Private Partnerships in Infrastructure: Managing the Challenges*, India Studies in Business and Economics, Springer, Singapore.

Quiggin, J. (2005), Public–private partnerships: Options for improved risk allocation, *The Australian Economic Review*, Vol. 38, No. 4, pp. 445–450.

Rall, J., Reed, J. B. and Farber, N. J. (2010), Public-private partnerships for transportation: A toolkit for legislators, *The National Conference of State*

Legislatures 2010, The Forum for American's Ideas, Washington, DC. Available at: http://www.ncsl.org/Portals/1/Documents/transportation/PPPTOOLKIT.pdf (accessed September 24, 2018).

Rambaud, S. C. and Perez, A. M. S. (2016), Assessing the option to abandon an investment project by the binomial options pricing model, *Advances in Decision Sciences,* Vol. 16, p. 7605909, 12 pages.

Rambaud, S. C. and Perez, A. M. S. (2017), The option to expand a project: Its assessment with the binomial options pricing model, *Operations Research Perspectives*, Vol. 4, pp. 12–20.

Rhee, C. G. V., Pieters, M. and Voort, M. P. V. D. (2008), Real options applied to infrastructure projects: A new approach to value and manage risk and flexibility, First International Conference on Infrastructure Systems and Services: Building Networks for a Brighter Future (INFRA), Rotterdam, pp. 1–6. Available at: https://ieeexplore.ieee.org/document/5439633 (accessed September 24, 2018).

Rose, S. (1998), Valuation of interacting real options in a toll road infrastructure project, *The Quarterly Review of Economics and Finance*, Vol. 38, No. 3, pp. 711–723.

Rozenberg, J. and Fay, M. (2019), *Beyond the Gap: How Countries Can Afford the Infrastructure They Need while Protecting the Planet,* Sustainable Infrastructure, World Bank, Washington, DC.

Rubinstein, M. (1991), Somewhere over the rainbow, *Risk*, Vol. 4, No. 11, pp. 63–66.

Sabour, S. A. A., Dimitrakopoulos, R. G. and Kumral, M. (2008), Mine design selection under uncertainty, *Mining Technology,* Vol. 117, No. 2, pp. 53–64.

Samis, M. R. (2000), *Multi-Zone Mine Valuation using Modern Asset Pricing (Real Options) Techniques*, PhD thesis, The University of British Columbia, BC, Canada.

Saunders, H. (1996), Survey of change order markups, *Practice Periodical on Structural Design and Construction*, Vol. 1, No. 1, pp. 15–19.

Sarmento, J. M. (2014), *Public Private Partnerships*, PhD thesis, Tilburg University, Netherlands.

Sarmento, J. M. and Renneboog, L. D. R. (2016), *Renegotiating Public-Private Partnerships*, ECGI Working Paper Series in Finance No. 461/2016, Tilburg University, Netherlands.

Savolainen, J. (2016), Real option in metal mining project valuation: Review of literature, *Resources Policy*, Vol. 50, pp. 49–65.

Seeley, I. H. (1993), *Civil Engineering Contract Administration and Control*, 2nd ed, MacMillan Press, London.

Serag, E., Oloufa, A., Malone, L. and Radwan, E. (2010), Model for quantifying the impact of change orders on project cost for U.S. roadwork construction, *Journal of Construction Engineering and Management*, Vol. 136, No. 9, pp. 1015–1027.

Shan, L., Garvin, M. J. and Kumar, R. (2010), Collar options to manage revenue risks in real toll public-private partnership transportation projects, *Construction Management and Economics*, Vol. 28, No. 10, pp. 1057–1069.

Shen, L. Y. and Wu, Y. Z. (2005), Risk concession model for Build/Operate/Transfer contract projects, *ASCE Journal of Construction and Engineering Management*, Vol. 131, No. 2, pp. 211–220.

Shen, L. Y., Bao, H. J., Wu, Y. Z. and Lu, W. S. (2007), Using bargaining-game theory for negotiating concession period for BOT-type contract, *ASCE Journal of Construction and Engineering Management*, Vol. 133, No. 5, pp. 385–392.

Shen, L. Y., Li, H. and Li, Q. M. (2002), Alternative concession model for Build Operate Transfer contract projects, *ASCE Journal of Construction and Engineering Management*, Vol. 128, No. 4, pp. 326–330.

Shen, L. Y., Platten, A. and Deng, X. P. (2006), Role of Public Private Partnerships to manage risks in public sector projects in Hong Kong, *International Journal of Project Management,* Vol. 24, No. 7, pp. 587–594.

Shrestha, P. P. and Maharjan, R. (2018), Effects of change orders on cost growth, schedule growth, and construction intensity of large highway projects, *Journal of Legal Affairs and Dispute Resolution in Engineering and Construction*, Vol. 10, No. 3, p. 04518012, 9 pages.

Slaughter, E. S. (2001), Design strategies to increase building flexibility, *Building Research and Information*, Vol. 29, No. 3, pp. 208–217.

Smith, J. E. (2005), Alternative approaches for solving real options problems, *Decision Analysis*, Vol. 2, No. 22, pp. 89–102.

Song, J., Jin, L. and Dong, W. (2016), Excess revenue allocation for Build-Operate-Transfer highway projects, *Journal of Transport Economics and Policy*, Vol. 50, pp. 304–324.

Stulz, R. M. (1982), Options on the minimum or the maximum of two risky assets: Analysis and applications, *Journal of Financial Economics*, Vo. 10, No. 2, pp. 161–185.

Sun, M. and Meng, X. (2009), Taxonomy for change causes and effects in construction projects, *International Journal of Project Management*, Vol. 27, No. 6, pp. 560–572.

Sun, H., Wang, Y. and Meng, J. (2019), A trading and pricing method of expansion options for BOT freeway projects in China, *Engineering, Construction and Architectural Management*, Vol. 26, No. 7, pp. 1406–1423.

Sunday, O. A. (2010), Impact of variation orders on public construction projects, Egbu, C. (Ed), *Proceedings 26th Annual ARCOM Conference*, pp. 101–110, Leeds, UK, September 6–8.

Suttinon, P. and Nasu, S. (2010), Real options for increasing value in industrial water infrastructure, *Water Resources Management,* Vol. 24, pp. 2881–2892.

Syal, M. and Bora, M. (2016), Change order clauses in standard contract documents, *Practice Periodical on Structural Design and Construction*, Vol. 21, No. 2, p. 04015021, 6 pages.

Tan, Z., Yang, H. and Guo, X. (2010), Properties of Pareto-efficient contracts and regulations for road franchising, *Transportation Research Part B,* Vol. 44, No. 4, pp. 415–433.

Tang, L. Y., Shen, Q. and Cheng, E. W. L. (2010), A review of studies on Public-Private Partnership projects in the construction industry, *International Journal of Project Management*, Vol. 28, No. 7, pp. 683–694.

Thomas, H. R. and Napolitan, C. L. (1995), Quantitative effects of construction changes on labor productivity, *Journal of Construction Engineering and Management*, Vol. 121, No. 3, pp. 290–296.

Till, J. and Schneider, T. (2005), Flexible housing: the means to the end, *Theory*, Vol. 9, No. 3, pp. 287–296.

Tirole, J. (1999), Incomplete contracts: Where do we stand?, *Econometrica*, Vol. 67, No. 4, pp. 741–781.

Triantis, A. (2005), Realizing the potential of real options: Does theory meet practice?, *Journal of Applied Corporate Finance*, Vol. 17, No. 2, pp. 8–16.

Triantis, A. and Borison, A. (2001), Real options: State of the practice, *Journal of Applied Corporate Finance,* Vol. 14, No. 2, pp. 8–24.

Trigeorgis, L. (1993), Real options and interactions with financial flexibility, *Financial Management*, Vol. 22, No. 3, pp. 202–224.

Trigeorgis, L. (1996), *Real Options: Managerial Flexibility and Strategy in Resource Allocation*, MIT Press, Cambridge, MA.

Trigeorgis, L. (2005), Making use of real options simple: An overview and applications in flexible modular decision making, *The Engineering Economist*, Vol. 50, No. 1, pp. 25–53.

Trigeorgis, L. and Mason, S. (1987), Valuing managerial flexibility, *Midland Corporate Finance Journal*, Vol. 5, No. 1, pp. 14–21.

Trigeorgis, L. and Tsekrekos, A. (2018), Real options in operation research: A review, *European Journal of Operational Research,* Vol. 270, pp. 1–24.

Tung, Y. K. (1992), Probabilistic distribution for benefit/cost ratio and net benefit, *Journal of Water Resources Planning and Management*, Vol. 118, No. 2, pp. 133–150.

Ullah, F., Thaheem M. J., Sepasgozar, S. M. E. and Forcada, N. (2018), System dynamics model to determine concession period of PPP infrastructure projects: Overarching effects of critical success factors, *ASCE Journal of Legal Affairs and Dispute Resolution in Engineering and Construction,* Vol. 10, No. 4, p. 04518022, 12 pages.

Wang, L., Zhang, R., Yang, L., Su, Y. and Ma, F. (2018), Pricing geometric Asian rainbow options under fractional Brownian motion, *Physica A: Statistical Mechanics and its Applications*, Vol. 494, pp. 8–16.

Wibowo, A. (2004), Valuing guarantees in a BOT infrastructure project, *Engineering, Construction and Architectural Management*, Vol. 11, No. 6, pp. 395–403.

Wibowo, A., Permana, A., Kochendörfer, B., Kiong, R. T. L., Jacob, D. and Neunzehn, D. (2012), Modeling contingent liabilities arising from government guarantees in Indonesian BOT/PPP toll roads, *Journal of Construction Engineering and Management*, Vol. 138, No. 12, pp. 1403–1410.

World Bank (n.d.), *PPP Arrangements/Types of Public-Private Partnership Agreements*, Public-Private Partnership in Infrastructure Resource Centre (PPPIRC), World Bank Group. Available at: https://ppp.worldbank.org/public-private-partnership/agreements/concessions-bots-dbos (accessed September 24, 2018).

Wu, M., Chau, K. W., Shen, Q. and Shen L. Y. (2012), Net asset value–based concession duration model for BOT contracts, *ASCE Journal of Construction Engineering and Management*, Vol. 138, No. 2, pp. 304–308.

Wu, C. H., Hsieh, T. Y., Cheng, W. L. and Lu, S. T. (2004), Grey relation analysis of causes for change orders in highway construction, *Construction Management and Economics*, Vol. 22, No. 5, pp. 509–520.

Xiong, W. and Zhang, X. (2016), The real option value of renegotiation in public-private partnerships, *Journal of Construction Engineering and Management*, Vol. 142, No. 8, p. 04016021, 11 pages.

Xu, Y., Sun, C., Skibniewski, M. J., Chan, A. P. C., Yeung, J. F. Y. and Cheng, H. (2012), System Dynamics (SD)-based concession pricing model for PPP highway projects, *International Journal of Project Management*, Vol. 30, No. 2, pp. 240–251.

Ye, S. and Tiong, R. L. K. (2003), The effect of concession period design on completion risk management of BOT projects, *Construction Management and Economics*, Vol. 21, No. 5, pp. 471–482.

Yeo, K. T. and Qiu, F. (2003), The value of management flexibility – A real option approach to investment evaluation, *International Journal of Project Management,* Vol. 21, pp. 243–250.

Yescombe, E. R. (2007), *Public Private Partnership - Principles of Policy and Finance*, Elsevier, Oxford.

Yescombe, E. R. (2014), *Principles of Project Finance*, Elsevier, Oxford.

Yu, C. Y. and Lam, K. C. (2013), A decision support system for the determination of concession period length in transportation project under BOT contract, *Automation in Construction*, Vol. 31, pp. 114–127.

Yuan, X. X. and Li, Y. (2018), Residual value risks of highway pavements in Public–Private Partnerships, *Journal of Infrastructure Systems*, Vol. 24, No. 3, p. 04018020, 11 pages.

Zhang, X. (2011), Web-based concession period analysis system, *Expert Systems with Applications*, Vol. 38, No. 11, pp. 13532–13542.

Zhang, X. and AbouRizk, S. M. (2006), Determining a reasonable concession period for private sector provision of public works and services, *Canadian Journal of Civil Engineering,* Vol. 33, No. 5, pp. 622–631.

Zhang, S. X. and Babovic, V. (2012), A real options approach to design and architecture of water supply systems, *Journal of Hydroinformatics*, Vol. 14, No. 1, pp. 13–29.

Zhang, X. and Chen, S. (2013), A systematic framework for infrastructure development through Public Private Partnerships, *International Association of Traffic and Safety Sciences (IATSS) Research*, Vol. 36, No. 2, pp. 88–97.

Zhang, X. and Xiong, W. (2015), Renegotiation and early-termination in Public Private Partnerships, *International Journal of Architecture, Engineering and Construction*, Vol. 4, No. 4, pp. 204–213.

Zhang, X., Bao, H., Wang, H. and Skitmore, M. (2016), A model for determining the optimal project life span and concession period of BOT projects, *International Journal of Project Management*, Vol. 34, pp. 523–532.

Zhao, T. and Tseng, C. L. (2003), Valuing flexibility in infrastructure expansion, *Journal of Infrastructure Systems*, Vol. 9, No. 3, pp. 89–97.

Zhao, T., Sundararajan, S. K. and Tseng, C. L. (2004), Highway development decision making under uncertainty: A real options approach, *Journal of Infrastructure Systems*, Vol. 10, No. 1, pp. 23–32.

Zhu, L., Zhao, X. and Chua, D. K. H. (2016), Agent-based debt terms' bargaining model to improve negotiation inefficiency in PPP projects, *Journal of Computing in Civil Engineering*, Vol. 30, No. 6, p. 04016014, 11 pages.