Pontifícia Universidade Católica do Rio de Janeiro

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# Essays on road projects concessions: An approach to comprehending, assessing and determining Government Guarantees on Road Concession projects.

**Tese de Doutorado**

Thesis presented to the Programa de Pós- Graduação em Administração de Empresas of PUC-Rio in partial fullfilment of the requirements for the degree of Doutor em Administração de Empresas.

Advisor: Prof. Luiz Eduardo Teixeira Brandão

Rio de Janeiro
June 2023

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Bibliographic data

Sant'Anna, Rodrigo Lopes

Essays on road projects concessions: an approach to comprehending, assessing and determining Government Guarantees on Road Concession projects / Rodrigo Lopes Sant'Anna; advisor: Luiz Eduardo Teixeira Brandão. – 2023.

98 f. : il. color. ; 30 cm

Tese (doutorado)–Pontifícia Universidade Católica do Rio de Janeiro, Departamento de Administração, 2023.

Inclui bibliografia

1. Administração – Teses. 2. Opções reais. 3. Parceria público-privada. 4. Concessão rodoviária. 5. Passivos governamentais. 6. Garantia mínima de tráfego. I. Brandão, Luiz Eduardo Teixeira. II. Pontifícia Universidade Católica do Rio de Janeiro. Departamento de Administração. III. Título.

CDD: 658

In memory of my beloved mom Vera Lúcia.

## ACKNOWLEDGMENTS

To my parents for all the education, moral values, and, above all, the love they have given me throughout my life. I am grateful for all the support and encouragement I received during my academic life.

To my wife for the love, companionship, encouragement and support she has been giving me since we joined our lives together. Our little dog Bella gave us priceless love and pleasant moments of relaxation.

To my advisor Prof. Luiz Brandão, for all the trust, support, encouragement and guidance provided in the development of this thesis.

This study was financed in part by the Coordenação de Aperfeiçoaento de Pessoal de Nível Superior - Brasil (CAPES) - Finance Code 001..

## Abstract

Sant’Anna, Rodrigo Lopes; Brandão, Luiz Eduardo Teixeira (Advisor). **Essays on road projects concessions: An approach to comprehending, assessing and determining Government Guarantees on Road Concession projects**. Rio de Janeiro, 2023. 98 p. Tese de Doutorado - Departamento de Administração, Pontifícia Universidade Católica do Rio de Janeiro.

Public-Private Partnerships (PPPs) are used by governments to develop road projects that, generally, require high investments. However, uncertainty about future traffic levels represents the main cause of road project failures, which can be mitigated through government traffic guarantees and make them more attractive to private investors. These guarantees place a financial burden on the government’s budget that can significantly influence the deficit and, thus, the government’s risk and opportunities. This thesis carried out three different studies that address the importance of guarantees in road public-private partnership contracts by properly estimating these guarantees and their impact on project risk through Real Options Theory (ROT). The first analyzes the government traffic guarantee levels in the projects, limiting government exposure, and maintaining the benefits for the private investor. Then, the second studies focus on the potential government’s contingent liabilities caused by traffic guarantees and, for this, is analyzed the case of the Salvador–Itaparica Bridge system project and discusses the publicly available government reports on the project with our results. The last study cares about designing an adequate traffic guarantee mechanism for PPP contracts in Road Projects and, for this, we propose a model to determine the traffic guarantee's optimal level that creates favorable conditions for the development of the projects. This Thesis contributes to a better understanding of guarantee mechanisms for private partners and the importance of adequately pricing the contingent government liabilities in infrastructure projects, revealing that a properly designed guarantee mechanism can minimize the government’s contingent liabilities and provides adequate guarantees to the private partners. Moreover, also provides a methodology that assists policymakers in designing infrastructure PPP projects and understanding the contingent claims and fiscal costs involved.

## Keywords

Real Options Public-private partnership; Road Concessions; Government liabilities; Minimum traffic guarantee.

# Resumo

Sant'Anna, Rodrigo Lopes; Brandão, Luiz Eduardo Teixeira (Advisor). **Ensaios sobre concessões de projetos rodoviários: Uma abordagem para compreender, avaliar e determinar Garantias Governamentais em projetos de concessão rodoviária**. Rio de Janeiro, 2023. 98 p. Tese de Doutorado - Departamento de Administração, Pontifícia Universidade Católica do Rio de Janeiro.

As Parcerias Público-Privadas (PPPs) são utilizadas pelos governos para desenvolver projetos rodoviários que demandam altos investimentos. Porém, a incerteza sobre os níveis de tráfego futuros é a principal causa de falhas nos projetos rodoviários, que podem ser mitigados através de garantias de tráfego do governo, tornando-os mais atraentes para investidores privados. Essas garantias trazem um ônus financeiro para o orçamento do governo que pode altamente impactar o déficit e, portanto, o risco e as oportunidades do governo. Esta tese realizou três estudos que abordam a importância das garantias em contratos de PPPs de rodovias através da adequada estimação dessas garantias e seu impacto no risco do projeto por meio da Teoria das Opções Reais. O primeiro analisa os níveis de garantia de tráfego nos projetos, limitando a exposição do governo e mantendo os benefícios para o investidor privado. O segundo estudo aborda os potenciais passivos contingentes do governo causados pelas garantias de tráfego e, para isso, analisa o caso do projeto do sistema Ponte Salvador-Itaparica, discutindo-se os relatórios governamentais publicamente disponíveis do projeto com nossos resultados. O último estudo desenha um mecanismo de garantia de tráfego adequado para contratos de Projetos Rodoviários, sendo proposto um modelo para determinar o nível ótimo de garantia de tráfego que crie condições favoráveis para o desenvolvimento dos projetos. Esta Tese contribui para uma melhor compreensão dos mecanismos de garantia para os parceiros privados e a importância de precificar adequadamente os passivos contingentes do governo em projetos rodoviários, revelando que um mecanismo de garantia bem projetado pode minimizar os passivos contingentes do governo e fornecer garantias adequadas aos parceiros privados. Além disso, também fornece uma metodologia que auxilia os formuladores de políticas na elaboração de PPPs em projetos rodoviários e na compreensão dos custos fiscais envolvidos.

# Palavras-chave

Opções Reais; Parceria público-privada; Concessão rodoviária; Passivos governamentais; Garantia mínima de tráfego.

# Table of contents

# List of Figures

## List of Tables

## List of Abbreviation

AADV – Annual Average Daily Volume

BOT – Build-Operation-Transfer

BRL – Brazilian real

CVaR – Conditional Value at Risk

ECP – Extended CVaR Preference Funtional

GDP – Gross Domestic Product

GBM – Geometric Brownian Motion

MRC – Maximum Revenue Cap

MRG – Minimum Revenue Guarantees

MTG – Minimum Traffic Guarantees

NPV – Net Present Value

ROT – Real Options Theory

PPP – Public-Private Partnership

USD – United States dollar

WACC – Weighted Average Cost of Capital”

# 1
# Introduction

The development of the road network as well as the maintenance of its quality is an important aspect of economic development, increases social well-being, encourages social integration and attracts investments to a country. Thereby, governments wish to develop and manage their road networks to satisfy their economic, political and social needs, which implies building new roads, or just refurbishing, widening and extending the current road networks.

To develop these road projects, which often require significant investments, governments worldwide have partnered with private investors to build, finance, operate and maintenance these ventures. These arrangements, known as public-private partnerships (PPP), are not a new phenomenon and have been adopted worldwide to provide public infrastructure.

When this partnership is done correctly and under the appropriate circumstances, improves the quality and increases the efficiency of the project. Besides, offers numerous benefits for public partners, providing the necessary funds for crucial financial infrastructure projects, and for private partners, which are more interested in the economic viability and expected returns of the project.

Despite the attractiveness of the PPP structure, they may present problems due to the multiple uncertainties embedded in the projects. The sharing and allocation of risk in PPP investments in transport infrastructure have a substantial importance, given that these investments are capital-intensive and they often require large sunk investments whereby their recoup may exceed 30 years (Medda, 2007).

It is crucial that the PPP project be established on reliable technical, economic and financial assumptions. In this regard, the valuation process presents additional challenges for large infrastructure projects as the resources involved are often significant and the economic implications of an incorrect valuation can be substantial (Hawas & Cifuentes, 2016).

A road concession provides the private partner, named concessionaire, a long-term right to use all assets belonging to the project. It includes the responsibility for operations, maintenance and investment, whereas the asset ownership remains with the government, which will take the reverted assets at the end of the concession period.

In 2021, the Brazilian road network had a length of 1.74 million km, with only 213,500 km (12.4%) paved roads. These paved roads are mostly administrated by governments (89%), while few roads are granted to the private sector (11%). Concerning about the paved road network quality in Brazil, 61.8% of the road network had some problem, being considered regular, bad or very bad, and 38.2% are considered excellent or good. When comparing the roads under government administration with those under concession, it is observed that the roads considered excellent or good were 74.2% of the roads under concession and only 28.2% of the roads under public management. On the other hand, the portion of roads considered regular, bad or very bad reduced to 25.8% for roads under concession and increased to 71.8% for highways under public administration. Nonetheless, the recovery of highways in Brazil, with emergency, maintenance and reconstruction actions, would require R$ 62.9 billion (CNT, 2021).

In these types of concessions, the concessionaire normally obtains most of its revenue directly from the road users, through the toll model, which is regulated by the government authority. In this way, the concessionaires' revenues are directly impacted by the traffic demand on the roads, which turns the traffic forecasts into a one of major importance in the development of the projects. Road demand is highly dependent on economic circumstances and there is no managerial flexibility to deal with varying demands. In addition, there is the problem of optimism bias in demand forecasts, since, traditionally, the demand for roads has been overestimated (Cruz & Marques, 2013).

The overestimated traffic demand can cause the concessionaire may to never be able to obtain a sufficient return on its investment, becoming illiquid and insolvent. Uncertainty over the future revenues the project will generate is the leading risk in the external operating environment (Kokkaew & Chiara, 2013).

Although an infrastructure project may have a high social and economic impact, the positive externalities do not necessary brings the intended economic returns to project, making the public-private risk-sharing becomes critical. The private investors may require some form of risk-sharing with the government for high-risk projects (Carbonara et al., 2014).

The most commons Risk mitigation mechanisms are the minimum revenue guarantees (MRG) and the minimum traffic guarantees (MTG). In these mechanisms, the government provides concessionaire support contingent if revenues or traffic falls below a pre-established level, making the project more attractive to private investors and keeping the incentive to increase revenues or traffic. There is a variant of traffic guarantee, called “cap and floor”, whereby, in addition to the minimum traffic guarantees mechanism, the government receives revenues if the traffic is above a pre-established level.

The MRG mechanism was firstly implemented in Chile in the toll road concession program during the 1990s. This mechanism, considered successful, was used in 20 of the 26 Chilean highway concessions between 1992 and 2004 (Page, 2016). Since then, a lot of projects around the world has been using these guarantees mechanism to mitigate inaccuracies in traffic or cash flow forecasting’s, that tend to be overly optimistic (Flyvbjerg et al., 2006).

South Korea’s experience shows the importance of a risk-sharing well-structured. It started with a generous MRG mechanism for the Concessionaire perspective, which resulted in excessive returns being assured to them, while the government continued exposure to most revenue risks. Then, governments reformed their generous MRG and exposed Concessionaires to significant downside revenue risk, which is in the opposite direction of what other countries with revenue risk sharing have done (Page et al., 2016).

In Brazil, traffic or demand guarantee clauses have already been adopted in several infrastructure investment projects such as the projects of Lines 4, 5, 6, 17 and 18 of the São Paulo Metro; the VLT Carioca project and the Trans-Olimpica expressway in the city of Rio de Janeiro; and the Salvador – Itaparica Bridge project in Bahia; among others.

Although, these risk-mitigating mechanisms provides value to the private partner, making the project more attractive, they also place a financial burden on the government’s budget, which must be adequately priced because fiscal liabilities significantly influence the deficit and, thus, the government’s risk and opportunities. The correct measurement of risk in government deficits is crucial for institutions, legislative bodies, and society as a whole (Sundaresan, 2002).

The MRG and MTG support can be modeled as insurance or options since there is a set of pre-established conditions that trigger the guarantees obligations.

So, the valuation of the guarantees requires option pricing methods such as the Real Options Theory (ROT) (Brandao & Saraiva, 2008).

This methodology, which is used for the valuation of real asset investments based on the developed financial options methodology, provides an infrastructure management and assessment tool, allowing the incorporation of the value of flexibility into these mechanisms and the appropriate pricing of the government corresponding cost (Martins et al., 2015).

In short, Road Concessions are subject to uncertainties and, commonly, require forms of risk mitigation. However, they are used to be assessed by static methods that are not effective to volatility, uncertainties and flexibilities, which makes necessary the use of refined methods such as the Real Options Theory. What has been discussed so far will be summarized in the research questions and objectives that this thesis desires to achieve in the following sections.

This thesis performs research that presents the importance of guarantees in road public-private partnership contracts by properly estimating these guarantees and their impact on project risk through Real Options Theory (ROT), in addition to fomenting public policy by providing a methodology that assists policymakers in designing infrastructure PPP projects and understanding the contingent claims and fiscal costs involved.

The Thesis format is in the form of a series of three papers, in which the first two papers are already published in scientific journals. The first paper analyzes the government traffic guarantee levels in the projects, limiting government exposure, and maintaining the benefits for the private investor. The next paper focus on the potential government's contingent liabilities caused by traffic guarantees, providing a better understanding of the impact of guarantee mechanisms on the private partners' risk and on the government's budget and risk, showing the importance of adequately pricing the contingent government liabilities in infrastructure projects. Here, a methodology used to assess the government liabilities is applied in the case of Salvador–Itaparica Bridge system project and, then, the project is thoroughly analyzed and make a discussion comparing the publicly available government reports on the project with our methodology results. The last paper cares about designing an adequate traffic guarantee mechanism for PPP contracts in Road Projects to minimize the government's contingent liabilities while providing adequate guarantees to the private partners, that is, aims to solve the major problem presented in the previous paper. So, an optimization model is proposed to determine the traffic guarantee's optimal level that creates favorable conditions for the development of road projects that contain traffic guarantees.

## 1.1. Objectives

The thesis's major aim is to develop a methodology to find the optimal level of traffic guarantees in road PPP projects in order to minimize government liabilities, reduce project risks, and find the best ways to win private investments.

The specific objectives, which present in more detail the results to be achieved through the research, are:

i. Analyze the importance of guarantees in public-private partnership contracts;
ii. Estimate the value of these guarantees, their impact on project risk, and the expected value in the government budget;
iii. Determine the optimal level of these guarantees in public infrastructure contracts in the Road Projects;
iv. Develop a optimization model for pricing Real Options in contracts with traffic guarantees;
v. Support the development of public-private partnerships with the aim of attracting better investments and developing public infrastructure.

## 1.2. Research questions

Considering some aspects previously mentioned, some research questions arise and must be answered during the development of the proposed research, while intends to develop an approach that can help governments to develop fundamental road infrastructure projects of wide interest to the population. The research questions can be summarized as follows:

a. What are the phenomena involved in public infrastructure projects?

b. What do the government and the private partners, from their perspectives, expect from these projects?
c. How important are the guarantees in public-private partnership contracts?
d. Which contractual configuration of minimum traffic guarantee is more interesting?
e. What is the optimal level of these guarantees in public infrastructure contracts?
f. What should be the characteristics of the objective function to find this optimal level?
g. What constraints should enter into this modeling?
h. What would be the impact of this methodology developed if applied to contracts already signed?

## 1.3. Thesis Structure

Each of the following chapters corresponds to one such paper and intends to answer one (or more) of the Research questions and achieve the objectives previously defined. The first and second papers are already published in scientific journals of reference. The details about the papers are presented below:

**Paper 1:** Evaluation of Government Guarantees in Road Concession Projects

- **Status:** Published – Revista de Administração da Universidade Estadual de Goiás (ISSN 2236-1197)
- **Abstract:**

  Public-Private Partnerships (PPPs) are used by governments to develop infrastructure projects that require higher investments. Despite their attractiveness, there are several risks embedded in these projects, which can be mitigated through government guarantees making them more attractive to private investors. The purpose of this article is to analyze the cost-benefit of each level of government guarantee in Roads Concession projects, limiting government exposure, and maintaining the benefits for the private investor. The approach used through the Real Options theory generated two models: the first uses the Minimum Traffic Guarantee, and the second model combines the first model with the Maximum Traffic Limit. These models were applied in the analysis of a road lot concession called “Rodovia de Integração do Sul – RIS,” whose term is 30 years. By using the minimum traffic guarantees, the project had its risk reduced as the government started to assume it. When inserting the maximum traffic limits, it is noted that at a certain level, they reduced the risks of the project for both the private investor and the government. Finally, it was observed that the value of the proposed toll tariff could be lower, while still keeping the project economically viable.

- **Keywords:** Real Options. Infrastructure Projects. Government Guarantees. Public-Private Partnerships. Road Concession.

**Paper 2:** Liability Cost of Government Guarantees in Highway Concession Projects: Case of the Salvador–Itaparica Bridge

- **Status:** Published – Journal of Infrastructure Systems (ISSN print: 1076-0342 | ISSN online: 1943-555X)
- **Abstract:**

Public-private partnerships (PPPs) are adopted worldwide to provide public infrastructure yet may present problems due to the multiple uncertainties embedded in this class of projects. Therefore, in order to attract private investment, some form of mitigation of risks may be required. These risk mitigation mechanisms may take many forms and place contingent liabilities and financial burdens on the government budget that must be adequately priced. This article analyzes the case of the Salvador–Itaparica Bridge system concession project under the Real Options Theory and compares the results with publicly available government reports on the project. Our results indicate that the expected cost of the State of Bahia government’s contingent liabilities is undervalued by a factor of five and that the guarantees provided were excessive as they resulted in the total elimination of demand risk to the concessionaire. This article contributes to a better understanding of the effects of risk-mitigating mechanisms for

private investment in infrastructure projects and the importance of adequately calibrating and pricing these contingent government liabilities.

- **Keywords:** Real options; Government liabilities; Public-private partnerships (PPP); Highway concessions; Guarantee levels.

**Paper 3:** Determining the optimum Level of government guarantees in road concession projects

- **Abstract:** The minimum traffic guarantee (MTG) is a commonly used risk mitigation mechanism in public-private partnerships (PPP) projects to increase the attractiveness of the project for the private partner. This mechanism, however, also creates fiscal liabilities for the government. Therefore, both the design and a correct estimate the contingent cost of these guarantees is crucial for the viability of the project and its attractiveness for both PPP partners. In this study we propose a model based on the Real Options Theory to determine the optimal values of the traffic floor and cap levels, which consider the risk perspectives of lenders, government and private partners, and creates favorable conditions for the development of PPP projects. The real option-based model is applied to the case of the Salvador–Itaparica Bridge system concession project, demonstrating that an appropriately designed MTG can minimize the government’s contingent liabilities and provide adequate guarantees considering the risk tolerance of the concessionaire and lenders.
- **Keywords:** Real Options; Risk Sharing; Public-Private Partnerships; Government liabilities; Traffic Guarantees; Conditional Value-at-Risk.

# 2
# Evaluation of Government Guarantees in Road Concession Projects

## 2.1.
## Introduction

Developing infrastructure is essential for the healthy economy and plays an important role in supporting a nation's socioeconomic stability, promoting prosperity and attracting foreign investment (Almassi et al., 2013).

Infrastructure projects demands high investments from the government, whose population's need for these investments, respecting budget restrictions, leads governments to seek solutions through partnerships with the private sector, in order to be able to develop such projects, which are of great interest to the population.

The public-private partnership (PPP) offers a lot of benefits to public and private partners in the infrastructure projects. The main reason for governments to be interested in this type of cooperation is to obtain the necessary funds to finance important infrastructure projects, using partnerships with the private sector. Private partners are more interested in the financial viability of the project and, therefore, are especially sensitive to revenue risk (Buyukyoran & Gundes, 2018).

PPPs are adopted all over the world to provide public infrastructure, however, despite the attractiveness of the PPP structure, its implementation faces several problems due to the multiple uncertainties embedded in the projects. Private investors generally demand some mitigation of these risks via government support (Carbonara & Pellegrino, 2018).

Governments then seek to reduce project risk by providing guarantees. In this way, the government starts to share the project risks, while they become more attractive to private investors and, thus, the projects can be developed.

These guarantees' rights brings an added value to the project that cannot be captured through the traditional methodology of investment evaluation. In this way, an evaluation methodology that incorporates new variables, uncertainties and flexibilities to the process becomes necessary.

In the context of large infrastructure projects, their evaluations presents some additional challenges: the amounts of resources involved are often significant, and the political implications of incorrectly assessing a project's economic merits can be substantial (Hawas & Cifuentes, 2016).

Some arrangements of government support, such as guarantees and subsidies, can be interpreted as options, since obligations are triggered based on certain pre-established conditions. Thus, these options' values must be properly accounted for, in order to obtain a better balance between risk and benefit (Cheah & Liu, 2006).

Guarantees, however, place a financial burden on government budgets while providing value to the private party. Designing a guarantee contract that is cost-effective for the government and at the same time mitigates the project risk to an acceptable level for the private party is essential (Almassi et al., 2013).

The Real Options theory offers an approach to evaluate investments in real assets, based on the methodology developed for financial options. An important aspect of this investment evaluation method is to consider the managerial flexibilities of the projects, evaluating and incorporating them into the model to make decisions on an ongoing basis. These flexibilities translated into Real Options reflect the alternatives existing within a project, giving the right, but not the obligation, to a certain action on a real asset at a cost during the life of the option. The real asset can be an opportunity to invest in a project or in an existing asset, with the decision being whether or not to exercise one or more options.

In Brazil, traffic or demand guarantee clauses have already been adopted in several infrastructure investment projects such as the projects of São Paulo subway lines 4, 5, 6, 17 and 18, the VLT Carioca project and the Rodovia TransOlimpica in the city of Rio de Janeiro, and the Salvador – Itaparica Bridge project in Bahia, among others.

The purpose of this article is to analyze the cost-benefit of each level of government guarantee in Roads Concession projects, limiting government exposure and maintaining benefits for the private investor. For this, a Minimum Traffic Guarantee Real Options model was applied to assess the value of government guarantees, allowing the government to analyze the cost-benefit of each level of support, and a second model, combining the Maximum Traffic Limit, as an alternative, to limit government exposure while maintaining benefits for the private investor. These models were applied in the analysis of the concession of the road lot called “Rodovia de Integração do Sul – RIS”, whose term is 30 years.

This article is organized as follows: After this introduction, we have the literature review. Then, section three presents the methodology for evaluating government guarantees through the Real Options Theory, as well as the models used to analyze the impact of these guarantees on road concession projects. In section four, we apply this methodology to the case of a road concession in Brazil and discuss the results. Finally, in section 5, we conclude.

## 2.2. Literature Review

The Real Options theory (ROT) is a relatively recent but consolidated methodology for analyzing investments in real assets under conditions of uncertainty. The ROT emphasizes the value of flexibility decision makers have when changing the direction of a project or the operation of a real asset, especially under uncertainty conditions. It can be seen as an optimization problem under uncertainty, seeking to maximize the value of the real asset through the optimal exercise of relevant options, subject to physical, legal and other uncertainties and restrictions.

Myers (1977) coined the term “Real Options” in the 1970s, referring to the growth opportunities available to firms, using an analogy with financial options whose ideas were developed in the work of Black & Scholes (1973) and Merton (1973). With a great expansion of the ROT literature, in the 1990s were released the first books on the methodology, being the most important that of Dixit & Pindyck (1994). From these books came others, notably Trigeorgis (1995), Amram & Kulatilaka (1999), and Copeland & Antikarov (2001).

The Real Options theory emerged due to the need for a new approach to infrastructure management and assessment that captures the value of flexibility, which must be taken into account in infrastructure projects, insofar as not incorporating flexibility can significantly change the value of a project (Martins et al., 2015).

The Government interventions can take many forms. One of the most common of government support instruments is the Minimum Revenue Guarantee (MRG), in which the government guarantees a minimum amount of revenue for a project (Huang & Chou, 2006; Asao et al., 2013; Carbonara et al., 2014; Hawas & Cifuentes, 2016; Power et al., 2016; Buyukyoran & Gundes, 2018; Zapata Quimbayo et al., 2019).

The Minimum Traffic Guarantee Real Options (MTG) model can also be used to assess the value of government guarantees. (Cheah & Liu, 2006; Brandao & Saraiva, 2008; Brandão et al., 2012; Blank et al., 2016; Cabero Colín et al., 2017)

Other models are often used in infrastructure projects such as the Abandon Option (Huang & Chou, 2006; Rakić & Rađenović, 2014; Blank et al., 2016; Cabero Colín et al., 2017) and the maximum limit of Traffic (Blank et al., 2016; Buyukyoran & Gundes, 2018; Kim et al., 2019) and even maximum interest rate guarantees (MIRGs) (Pellegrino et al., 2019).

Huang & Chou (2006) used Real Options Theory to assess the minimum revenue guarantee (MRG), followed by the abandonment option of pre-construction of the infrastructure project, in an build-operation-transfer (BOT) model. First, two single-option pricing models were developed to assess the MRG and the abandon option. Then, a combined option model was developed, combining the MRG with the abandon option. The models used European options, which the practical application was carried out in the Taiwan High Speed Railway project. The authors observed that both the MRG and the abandonment option can bring significant results to the project, but when increasing the MRG level, the value of the abandonment option will be reduced until, at a certain level, the abandon option will be useless.

Brandao & Saraiva (2008) studied public-private partnerships (PPP) concerning government guarantees in infrastructure projects, with the purpose of evaluating such projects under the Real Options Theory. The authors presented a Real Options model with minimum traffic guarantee (MTG) to assess the value of these guarantees, allowing the analysis of how different levels of government support affect the project risk and its value, and proposed an alternative to limit the government risks without modifying the benefits of the private investor. The authors considered future traffic levels as the main source of project uncertainty and showed how the market parameters required for risk-neutral assessment can be determined. The model was applied to the BR-163 road project, which connects the Brazilian Midwest to the Amazon River, and they concluded that the use of guarantees with government spending limits in PPPs can be advantageously modeled through option pricing methods and a great way to attract private investment in high-risk public infrastructure projects.

Galera & Soliño (2010) when analyzing road concessions with minimum traffic guarantee contractual clauses, developed a methodology to evaluate these clauses of road concessions, which consider the traffic on the road as the underlying asset in an option contract. This methodology uses a risk-neutral approach and was applied in the case of a road concession already in operation, obtaining a value of a minimum traffic guarantee. The authors argue that this methodology is an appropriate tool for the evaluation of road concessions that have operational flexibility.

Carbonara et al. (2014) developed a Real Options model to define the level of revenue guaranteed by the government, which balances the desire for profitability to the private and public sectors, seeking fair parameters to structure the minimum revenue guarantees (MRG). The model used Monte Carlo simulation to option pricing, being applied to a toll road project in southern Italy, and a sensitivity analysis on the discount rate was performed to verify if the model maintains its robustness when the input parameters change. According to the authors, this model serves to support the decision maker in finding the ideal value of the 'revenue cap' (the minimum amount of revenue guaranteed by the government), which is capable of satisfying the interests of the public and private sectors, guaranteeing a fair risk allocation between the parties.

Rakić & Rađenović (2014) performed an abandonment option analysis of an investment project, in which a binomial option pricing model, with the risk-neutral probability approach, was implemented and used to evaluate the abandonment options in the European and American style for toll road investment projects in the build-operation-transfer (BOT) model. The results suggested that the value of the project with the American abandonment option is higher than that with the European abandonment option, implying greater flexibility and value of the American options for private investors.

Blank et al. (2016), proposed a hypothetical concession of toll roads in Brazil, using the minimum traffic guarantee, a maximum traffic limit and an implicit abandon option. They concluded that the abandon option affects the level of guarantee to be given, and, that governments must calibrate the optimal level of guarantees to avoid unnecessarily high costs, protect the sponsor's returns and decrease the probability of abandonment.

Hawas & Cifuentes (2016) carried out a study to evaluate projects with minimum revenue guarantees (MRG) through simulation based on the Gaussian copula (multivariate normal distribution). They presented a numerical simulation technique to do evaluations of infrastructure projects with MRG, assuming that the project's cash flows, in the absence of the MRG, could be described in a probabilistic way through a multivariate distribution function. Then, the Gaussian copula was used in combination with the MRG condition to generate a set of plausible cash flow vectors, which formed the basis of a Monte Carlo simulation.

Buyukyoran & Gundes (2018) proposed a real option model to identify the optimal upper and lower bounds of the Minimum Revenue Guarantee (MRG) and Maximum Revenue Cap (MRC) options, with the objective of establishing a risk allocation framework fair. The identified range of MRG and MRC allows the structuring of a flexible trading environment for both parties in a PPP. They concluded that the MRC allows the government to earn surplus revenue, while the MRG helps the private partner to reduce its risk and thus the impact on the public budget can be minimized.

Zapata Quimbayo et al. (2019) used the Mean Reversion Motion approach as an alternative to the Geometric Brownian Motion approach, more common in the literature, to model and estimate traffic on roads. This approach was applied to a road concession in Colombia, which contained Minimum Revenue Guarantees. Their results showed that the incorporation of these guarantees generated a good return for the private investor, while the government could assume the costs of the traffic risk without compromising its budget.

Kim et al. (2019) examined the effect of exercise conditions on the Minimum Revenue Guarantee amount and traffic cap through an urban rail PPP project in the Republic of Korea. Through the analysis of Real Options, they concluded that the MRG option could reduce the expected financial burden for the government, which could eventually contribute to the sustainability of PPP programs.

## 2.3. Methodology

### 2.3.1. Traffic modelling

One most common and widely used stochastic processes is the Geometric Brownian Motion (GBM) (Brandao & Saraiva, 2008). It's assumed that traffic and revenues will vary stochastically over time through the GBM. The stochastic equation for a traffic variable X, which varies over time in an GBM process, can be defined by the following stochastic equation:

$$dX = \alpha X dt + \sigma X dz$$

where: $dX$ → traffic incremental variation; $\alpha$ → traffic growth rate; $dt$ → time variation; $\sigma$ → traffic volatility; $dz$ = $\varepsilon\sqrt{\Delta t}$, with ε~$N(0,1)$ → standard Wiener process.

Thus, traffic modeling can be discretely modeled in annual periods as an exponential function:

$$X_{t+1} = X_t e^{\left(\alpha - \frac{\sigma^2}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}}$$

Considering a contractual guarantee in which the government have to compensate the concessionaire whenever the level of traffic falls below a previously established minimum in a given year and defining $X_{min}$ as the minimum traffic guaranteed by the government in that year, the resulting traffic for the concessionaire in the year $t$ is $X_C(t) = max(X_t, X_{min_t})$, while the traffic guarantee G(t) in year $t$ is $X_G(t) = max(0, X_{min_t} - X_t)$.

The risk-neutral measurement is used to evaluate the project's guarantees and, for this, the risk premium$\lambda_\sigma$ is subtracted from the expected rate of return on the underlying asset. So, the traffic risk neutral process found is the exponential function:

$$X_{t+1} = X_t e^{\left(\alpha - \lambda_\sigma - \frac{\sigma^2 X}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}}$$

### 2.3.2.
### Government Guarantees Calculation

The government guarantee values can be modeled as a series of independent European options with annual maturities, in which the guarantees options are determined by a Monte Carlo simulation of the level of stochastic traffic.

The government guarantees the minimum traffic demand ($D_{min}$), which will be guaranteed when the traffic demand ($D$) is less than this level. On the other hand, if the traffic demand ($D$) is greater than the maximum traffic limit ($D_{max}$), the government will withhold all traffic that exceeds this limit. Therefore, the guarantee options will be exercised for each year according to Table 2.1, in which the option value will be 0 (zero) when it does not satisfy the imposed condition.

**Table 2.1 –** Options' values in year *t*

| CONDICION | OPTION |
|---|---|
| $D_t \geq D_{max_t}$ | $CALL_t = D_t - D_{max_t}$ |
| $D_{max_t} > TRAFF_{real} \geq D_{min_t}$ | 0 |
| $D_t < D_{min_t}$ | $PUT_t = D_{min_t} - D_t$ |

Source: Author

In this way, the government will guarantee, over T years, the traffic given by:

$$Minimum\ Demand\ Guaranteed = \sum_{1=1}^{T} PUT_i$$

On the other hand, the government will be able to withhold traffic for T years given by:

$$Excesso\ de\ Demanda = \sum_{1=1}^{T} CALL_i$$

## 2.4. Numerical Application

### 2.4.1. “Rodovia de Integração do Sul”

We analyzed the economic-financial viability of granting a road concession by using the Minimum Traffic Guarantee and the Maximum Traffic Limits. For this, we used data from the road lot concession called "Rodovia de Integração do Sul - RIS", which includes stretches of Roads BR-101/290/386/448 in the state of Rio Grande do Sul. There are 7 toll plazas distributed along the road lot, and the tariff rates were calculated according to the "equivalent" Annual Average Daily Volume (AADV), that is, all categories of vehicles and respective rates are standardized for the AADV-equivalent. According to the Concession Traffic studies, there is an average deviation of AADV equivalents of about 9%, and the actual rate used to discount the Project Cash Flow to present value was 9.2% p.a. (ANTT, 2020).

The road lot auction for the Rodovia de Integração do Sul took place in November 2018, in which the winner should offer the lowest toll value, limited to R$ 7.24, and the bidding period would be 30 years. The CCR Group was the winner of the auction, offering the amount of R$ 4.30. The risk-free rate used in this article was 6.50% p.a., referring to the SELIC Tax (risk-free rate) on the auction date.

### 2.4.2. Results

When making the stochastic simulations, we found the average expected value of the project to be R$ 966 thousand with a probability of 74.7% of $NPV > 0$, that is, in ¾ of the simulations the project's NPV will be positive. Despite this result, there is a risk for the company to have a negative NPV, which is undesirable. However, this is a risk that the company that wins the auction is willing to take.

We then analyzed government support for project risk mitigation through a minimum traffic guarantee. The guarantee level refers to the permitted level of variation in the projected traffic, observing the impact of these guarantees on the value of the project and in relation to the government's costs, which will bear this risk.

The government guarantees evaluation was modeled as a series of independent European options with maturities between 1 and 30 years, where the value of the guarantee options is determined by a Monte Carlo simulation of the stochastic traffic level. The option will be exercised whenever the traffic demand falls below the established minimum.

It is observed that as lower the minimum allowed level of variation in traffic, as greater the average NPV of the project and the possibility of the NPV is positive. However, the guaranteed minimum demand value decreases with the increase in the level of guarantees. If, on the one hand, the company wants a lower level of guarantees to reduce its risk, on the other hand, the government does not want such a low level as these guarantees generate liabilities. Table 2.2 shows the impact of the minimum traffic guarantees on the Project's average NPV and on the average and maximum Liabilities values generated for the government.

**Table 2.2 –** The impact of Minimum Traffic Guarantee on project

| Guarantee level | Net Present Value | | Minimum Traffic Guarantees | |
|---|---|---|---|---|
| | Mean (R$) | NPV > 0 | Mean (R$) | Maximum (R$) |
| 10% | 1.457.847 | 100,0% | 477.634 | 2.919.043 |
| 20% | 1.255.980 | 100,0% | 278.379 | 2.181.497 |
| 30% | 1.119.358 | 84,0% | 144.206 | 1.768.458 |
| 40% | 1.031.389 | 77,4% | 64.725 | 1.315.523 |
| 50% | 991.964 | 75,2% | 23.686 | 859.006 |

Source: Author

Although the minimum guarantees are interesting for project risk mitigation, they generate a greater risk for the government, which will have a liability proportional to the level of these guarantees. To reduce this liability, the Maximum Traffic Limit can be inserted, which will imply a level from which excess project resources will be retained by the government to compensate the impact of the minimum guarantees.

The evaluation of the maximum limit was modeled similarly to the minimum guarantees, adjusting only that the option will be exercised whenever the traffic demand is above the established maximum.

It is observed that the greater the maximum allowed limit of variation in traffic, the greater will be the average NPV of the project. On the other hand, the excess demand value decreases with the increase in the level of guarantees. The odds of the NPV being positive do not change because they depend only on the minimum guarantees.

If, on the one hand, the company wants a higher guarantee limit to increase its earnings, on the other hand, the government does not want a limit so high that it does not compensate the liabilities generated by the minimum traffic guarantees. It can be seen in Table 2.3 the impact of maximum traffic limits on the mean NPV Project and on the mean and maximum value of government revenues.

**Table 2.3 –** Maximum traffic limits' Impact on the project

| Guarantees | Net present value | | Excess Demand | |
|---|---|---|---|---|
| levels | Mean (R$) | $\mathbf{NPV > 0}$ | Mean (R$) | Maximum (R$) |
| 10% | 1.111.410 | 100,0% | 351.785 | 8.250.513 |
| 20% | 1.016.867 | 100,0% | 224.550 | 6.256.443 |
| 30% | 948.568 | 84,2% | 163.350 | 6.924.011 |
| 40% | 919.172 | 77,2% | 107.454 | 6.241.250 |
| 50% | 907.486 | 75,2% | 80.633 | 7.824.416 |

Source: Author

The ideal level of minimum guarantees and the maximum limit is that which reduces the risk of the project for the winning company and that these amounts are compensated in a way that does not bring losses to the government. As shown in Figure 2.1, this value is around 30%, that is, the company that wins the auction will have a variation of 30% in relation to the projected traffic. This level reduces the risk to the project partners, despite reducing the average NPV of the project.

If the minimum guarantee and the maximum limit of 30% are used in relation to traffic, the average NPV of the project will be R$ 948 thousand, which is slightly lower than the NPV of the project without government interference in traffic, but we will have the probability of 84.2% of $NPV > 0$, which is significantly higher than the initial 74.7%.

When analyzing different toll tariff values involving the minimum guarantees with the maximum traffic limit, we observed that the tariff could be lower, while keeping the project viable and maintaining the level of risk compatible with that accepted by CCR, that is, the same probability of having a positive NPV.

Observing Table 2.4, we note that if the proposed tariff were R$ 4.10, we would have a probability of 75.3% of NPV > 0, which is higher than the initial 74.7%. Despite the reduction in risk and the mean NPV, which would be reduced to R$713 thousand, the project would still be viable and much more interesting from the government's perspective, which wanted the lowest feasible tariff.

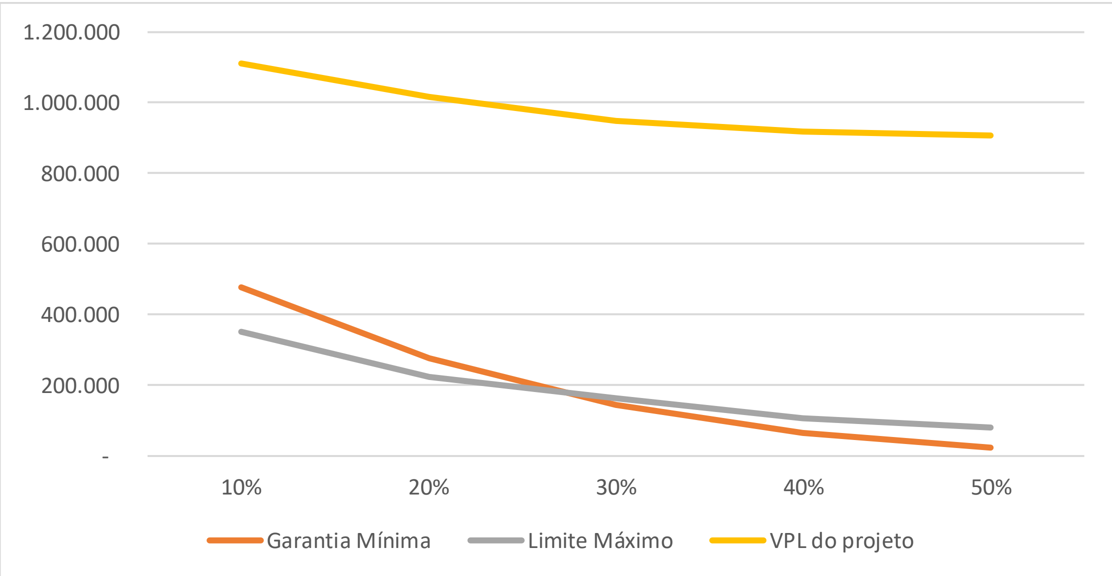


**Figure 2.1 –** Project NPV, Minimum Guarantee and Maximum Traffic Limit values.
Source: Author

**Table 2.4 –** Toll tariff sensitivity analysis

| TARIFAS (R$) | Net Present Value | |
|---|---|---|
| | Mean (R$) | NPV > 0 |
| 4,30 | 948.568 | 84,2% |
| 4,20 | 871.805 | 79,1% |
| 4,10 | 713.296 | 75,3% |
| 4,00 | 598.465 | 69,3% |
| 3,90 | 489.100 | 65,0% |

Source: Author

## 2.5. Conclusions

In this study, a Real Options model of Minimum Traffic Guarantee was applied to evaluate the value of government guarantees, and a second model, combined with Maximum Traffic Limit, as an alternative to limit government exposure. The relevance of this study is due to the fact that in recent years several infrastructure projects in all spheres of Brazilian public administration have been tendered with these types of guarantee clauses, which impacts both the risk and the return of these projects.

The application of these models took place through the analysis of the concession of the road lot called “Rodovia de Integração do Sul – RIS”, whose term is 30 years and includes 7 toll plazas distributed along the road lot in question.

We observe that different levels of government support affect project risk and value. By inserting the minimum traffic guarantees, the risk of the project was reduced as the government started to assume it. By inserting the maximum traffic limit, we noticed that at a certain level, we were able to reduce the risk of the project for the private investor and for the government.

Another important conclusion was that the proposed toll rate could be lower and the project would still be viable, which would be much more interesting from the government's perspective, which wanted the lowest possible rate.

It is important that governments share part of the project risk by providing guarantees, bringing added value to the project, which cannot be valued by the traditional methodology. For this, Real Options Theory offers a method for the evaluation of investments in real assets considering the managerial flexibility of the projects.

This study has some precision limitations as it uses estimated data in the Concession Notice, whose values must change with the entry of toll operations.

For future research, it is suggested that the models can be extended to cover other risks in addition to the traffic risk, in order to bring greater randomness and uncertainty around more exogenous variables.

# 3 Liability cost of government guarantees in highway concession projects: case of the Salvador–itaparica bridge

## 3.1. Introduction

Infrastructure projects are essential to increase social well-being and for the development of the country. Given that these projects frequently require significant capital to be implemented, governments worldwide have partnered with private investors to build, finance, and operate these ventures. These arrangements, known as Public-Private Partnerships (PPP), offer numerous benefits to the public and private partners in developing infrastructure projects.

PPPs are adopted worldwide to provide public infrastructure. Despite their perceived benefits, PPPs may present problems due to the multiple uncertainties embedded in the projects. One of the main factors contributing to the success of PPP projects is adequate risk allocation among stakeholders. The valuation process presents additional challenges for large infrastructure projects as the resources involved are often significant, and the economic implications of an incorrect valuation can be substantial (Hawas & Cifuentes, 2016). Uncertainty over the future revenues the project will generate is the leading risk in the external operating environment (Kokkaew & Chiara, 2013). Thus, private investors may require some form of risk-sharing with the government for high-risk projects (Carbonara et al., 2014).

While risk-mitigating mechanisms provide value to the private sector, they also place a financial burden on the government's budget, which must be adequately priced. Thus, governments must determine if the level of future obligations and financial burden these mechanisms entail are within the government's fiscal capacity (Almassi et al., 2013).

Risk mitigation mechanisms may take many forms. One of the most common is the Minimum Traffic Guarantee (MTG), which provided the concessionaire support contingent on-demand turning out to be lower than a pre-established level. In this way, the government shares a portion of the risk with the concessionaire, making the project more attractive to private investors. This class of flexible support can be modeled as insurance or options since, in both cases, there is a set of pre-established conditions that trigger the obligations.

Due to these characteristics, the valuation of government guarantees requires option pricing methods such as the Real Options Theory (ROT) (Brandao & Saraiva, 2008). Real options provide a tool for infrastructure management and assessment that allows the value of the flexibility embedded in these mechanisms and the corresponding cost to the government to be adequately priced (Martins et al., 2015). Real option analysis offers an approach to the valuation of investments in real assets based on the methodology developed for financial options. Fiscal liabilities significantly influence the deficit and, thus, the government's risk and opportunities. Therefore, the correct measurement of risk in government deficits is crucial for institutions, legislative bodies, and society as a whole (Sundaresan, 2002).

In this article, we discuss the case of the 35-year PPP concession contract for the construction and operation of a 13.2 km long bridge connecting the city of Salvador to the island of Itaparica Bridge System in the State of Bahia, Brazil. With a population of 2.8 million, Salvador is the third-largest city in Brazil. The bridge will significantly reduce travel time and directly connect the State of Bahia's southern and western regions. The contract included a Minimum Traffic Guarantee (MTG). The government agreed to compensate the concessionaire for any demand shortfall below a certain level, which the government estimated would cost up to US$ 64.5 million. We analyze the effect of these mechanisms on the value and risk of the project and the cost and impact of these contingent liabilities on the government´s budget. We value these mechanisms under the Real Options Theory and show that their cost to the government was significantly undervalued. This article contributes to the literature on the analysis of the fiscal impact of contingent government supports in PPP projects by showing how these supports may be optimally calibrated and draws attention to the need for government officials and policymakers to adequately price these contractual clauses.

This article is organized as follows. After this introduction, we provide a review of the literature, and in section three, we present the case of the Salvador-Itaparica toll bridge roadway system concession and the main specifications of the government contractual supports. In section 4, we introduce the model and methodology used to assess the government liabilities, and in section five, we present the results of the model and compare them to the values shown in the government report. Finally, we conclude.

## 3.2. Literature Review

The literature review addressed in this study was based on two subjects: risk allocation in highway concessions and Real Options application to PPP projects.

The problem of risk allocation in transport public-private partnerships was studied by Medda (2007), who analyzed through a game framework the players' behavior when confronted with opposite objectives in the allocation of risks. In this way, Vassallo et al. (2012) identified some deficiencies in how risk had been allocated in PPPs contracts in Spain when they analyzed the economic recession impact that started in 2008, caused on toll highway concessions performance and the government actions adopted.

The risk allocation on Road Concession was the object of interest of Cruz & Marques (2013), who assessed risk allocations in four Portuguese road concessions, discussing the types of incentive mechanisms used. They reveal that the public sector is taking more productive and commercial risks in the road development process. Thus, the amount of the concessionaires that are at risk decreases over time, and the grantor typically protects the Concessionaires' potential losses. Cruz et al. (2015) discussed the use of PPPs in the highway sector, focusing the analysis on the case study on the Brazilian highway MG-050, and drew attention to the misallocation of risks between the public and private sectors so that the public sector tends to assume most of the risks. In this line, Nguyen et al. (2018) studied the allocation of risks in U.S. highway PPPs projects from 2004 through 2016 using a systematic content analysis framework and showed that the majority of the risks were either transferred to the private sector or shared.

Nevertheless, none of these studies focuses on the assessment of the contingent liabilities of the government caused by the guarantees given from the PPP projects, and nor determined the impact of the risks borne by the government in these projects to the public budgets. Given that government risk-sharing mechanisms typically have option-like characteristics, their value can only be determined under option pricing methods such as the Real Options Theory.

Real Options theory (ROT) is a recent but consolidated approach for analyzing investments in real assets under uncertainty. Contrary to traditional Discounted Cash Flow (DCF) methods, ROT is able to capture the value of the flexibility that managers and decision-makers may have to change the operating strategy of a project as new information is revealed in time. This can be modeled as a problem of optimization under uncertainty, where the objective function is to maximize the value of a real asset by the optimal exercise of relevant options subject to physical, legal, and other constraints.

Myers (1977) coined the term “Real Options” in the 1970s, referring to the growth opportunities available to firms based on the seminal work on financial options developed by Black & Scholes (1973) and Merton (1973). A significant expansion of real options literature occurred in the 90s with the contributions of Dixit & Pindyck (1994), Trigeorgis (1995), Amram & Kulatilaka (1999), and Copeland & Antikarov (2001).

The literature on Real Options applications for infrastructure projects is vast. In one of the first papers on this topic, Ho & Liu (2002) developed a Real Options based model that uses a binomial tree to determine the financial viability of an infrastructure project. The model considered the uncertainties of construction costs and project net cash flows and assessed the impact of government debt guarantees on the project’s financial viability. Huang & Chou (2006) used Real Options to assess Minimum Revenue Guarantees (MRG) along with the abandonment option of infrastructure pre-construction project in the Built-Operate-Transfer (BOT) model. While the authors acknowledge that MRG involves substantial government budgetary commitments, they focus more closely on its benefits and impact on the project for the private partner.

Brandao & Saraiva (2008) developed a real options model to price a Minimum Traffic Guarantee (MTG) and applied it to the case of a planned toll road in Brazil. The authors show that such mechanisms are effective in mitigating demand risk in PPP projects but that the indiscriminate granting of these guarantees might generate significant contingent liabilities for the government in the future. Brandão et al. (2012) analyzed the Subway System Concession (Line 4) in São Paulo, Brazil, under the Real Options Theory, where a Minimum Traffic Guarantee provided support in case the number of passengers turned out to be lower than expected. The results indicated that the guarantees were effective in reducing the project’s risk and increased the project’s net present value at a reasonable cost to the government.

Buyukyoran & Gundes (2018) proposed a Real Option model to identify the optimum upper and lower boundaries of the Minimum Revenue Guarantee (MRG) and the Maximum Revenue Cap (MRC) options to establish a fair risk allocation structure where the optimal condition is based on the Eurostat model proposed by Carbonara et al. (2014) considering the net amount of the guarantees. Carbonara & Pellegrino (2018) also developed a real options model to determine the private partner's optimal minimum and maximum revenue values to create a “win-win” condition where the risk is shared fairly. Kim et al. (2019) also examined the effect of exercise conditions on the Minimum Revenue Guarantee (MRG) through the analysis of Real Options and concluded that the MRG option could reduce the financial burden expected for the government, which can eventually contribute to the sustainability of PPP programs. Blank et al. (2016) discussed a hypothetical concession of toll roads in Brazil using the minimum traffic guarantee, a maximum traffic limit, and an implicit abandonment option.

None of these works assessed the impact of PPPs on public accounts. Wibowo et al. (2012) were the first to present contingent liabilities assessment methodologies for three types of guarantees (land-capping instrument, full toll adjustment guarantee, and fair compensation guarantee in case of nationalization) granted to PPP toll road projects to protect project sponsors. The methodology included extensive modeling of several project risks and was applied in a toll road PPP project in Indonesia. Liu et al. (2017) proposed an approach to help government decisions on fiscal support mechanisms and compared the benefits and costs in sharing revenue risks for toll road PPPs. They concluded that MRGs are most applicable for projects with significant revenue volatility, while Availability Payments are more appropriate for projects with less revenue volatility.

In a work closer to ours, Contreras & Angulo (2017) developed an option pricing model to determine direct and contingent liabilities in PPPs that can be used for different transportation infrastructure projects to quantify government exposure in public-private partnerships projects. They applied the model to a hypothetical case and determined the magnitude of the contingent government debt derived from such guarantees. In this article, on the other hand, we analyze the actual case of an ongoing toll bridge roadway project under ROT and compare the contingent liabilities that arise from the inclusion of risk mitigating mechanisms to the expected amounts estimated by the government.

## 3.3. The Salvador – Itaparica Bridge

The Salvador – Itaparica Bridge is a 13.2 km long road system that encompasses two bridges, Salvador-Itaparica and Funil, making it the second-longest bridge in Latin America. The bridge system was auctioned by the Government of the State of Bahia in December 2019, and the concession contract was signed in November 2020. The winner was a consortium of three Chinese firms that will have five years to build the bridges and another 30 years to maintain and operate the system. The region where Salvador-Itaparica Bridge will be constructed is shown in Figure 3.1.


**Figure 3.1 –** Map of the region where Salvador-Itaparica Bridge will be constructed
Source: Adapted from Google (2022)

The city of Salvador, the first Brazilian capital, has over 2.8 million inhabitants and is the third most populous municipality in Brazil (Instituto Brasileiro de Geografia e Estatística, 2020). The geographical limitation that the ocean and the Bay of all Saints impose on the region contributes to creating a logistical bottleneck for the connection between the metropolitan area of Salvador, comprising ten municipalities, and the entire southern and western region of the state. This impacts traffic on the available highway, causing congestion and slowness. (Governo do Estado da Bahia & Sinergia, 2019).

The connection between the island of Itaparica and Salvador is usually made by water transport with ferry boats for vehicles, which take more than an hour, and speedboats for passengers, which take about 45 minutes. The frequency is low, and the ferry system has capacity problems, causing queues of up to 5 hours. Available roadway alternatives involve a 200 km three to four-hour drive around the Bay of All Saints (Governo do Estado da Bahia & Sinergia, 2019). The economic and financial assumptions are shown in Table 3.1.

Government traffic estimates consider an "annual equivalent volume" of vehicles where different types of vehicles and tariffs are standardized into a single equivalent type of vehicle, corresponding to the average toll amount of US$ 8.12 (R$ 32.71 – R$/USD Exchange rate of R$ 4.03 as of 31/12/2019) per equivalent vehicle.

**Table 3.1 –** Economic and financial assumptions

| Assumptions | Values |
|---|---|
| Construction Term | Five years |
| Concession Term | 30 years |
| CAPEX | US$ 1,325 million |
| OPEX | US$ 14.73 million (per year) |
| Reinvestments | US$ 2.18 million (per year) |
| Government Financial Support | US$ 372,2 million (during construction) |
| Government Financial Compensation | US$ 13.95 million (per year) |
| Average Tariff | US$ 8.12 |
| WAAC | 7.56% |
| Risk-free rate | 3.20% |

Source: Adapted from Governo do Estado da Bahia (2019)

A static valuation analysis was done to determine the baseline project's Net Present Value (NPV), which does not yet include the effect of any government supports. The expected project cash flows were obtained from Governo do Estado da Bahia & Sinergia (2019) and discounted at the risk-adjusted rate of return of 7,56% (WACC) to arrive at a Net Present Value (NPV) of US$ 37 million. The project cash flows are shown in Appendix A. Considering that the capital budget of the project is US$ 1.3 billion, a NPV of only US$ 37 million suggests the project may be risky, which we verify with a dynamic analysis.

The dynamic analysis of the project considers the stochastic uncertainty of future traffic levels. As is standard in the literature (Irwin, 2007; Brandão et al., 2012; Marques et al., 2021), traffic uncertainty was modeled as a stochastic geometric diffusion process (GBM), as shown in Eq. (3.1).

$$dS = \alpha S dt + \sigma S dz \tag{3.1}$$

were $dS$ is the incremental variation in traffic; $\alpha$ is the traffic growth rate; $dt$ represents a short interval of time; $\sigma$ is the volatility of the traffic and $dz = \varepsilon\sqrt{dt}$ is the standard Wiener process where $\varepsilon \approx N(0,1)$

The yearly drift rate of the process ($\alpha$) was obtained from the variations of the expected traffic over the life of the project. Since the Salvador – Itaparica toll bridge is a greenfield project, no historic traffic series data can be used to determine the traffic volatility. Thus, the volatility parameter (σ) was determined as the standard deviation of the log-returns of regional gross domestic product (GDP), which was taken as a proxy for the true traffic volatility of the toll Bridge (Brandao & Saraiva, 2008). The GDP series for government of Bahia from 2002 to 2018 from the Superintendência de Estudos Econômicos e Sociais da Bahia - SEI (Governo do Estado da Bahia & Sinergia, 2019) indicated a volatility of 3.16% per year.

The project was dynamically modelled with a Monte Carlo Simulation of the stochastic cash flows. This resulted in a Net Present Value (NPV) of US$ 36.963 million, which, as expected, is the same as the NPV of the static analysis. On the other hand, the probability distribution of the NPV indicates a 40.5% chance that the NPV is negative (Figure 3.2), which supports the government of Bahia's decision to include risk mitigation clauses in the concession contract.

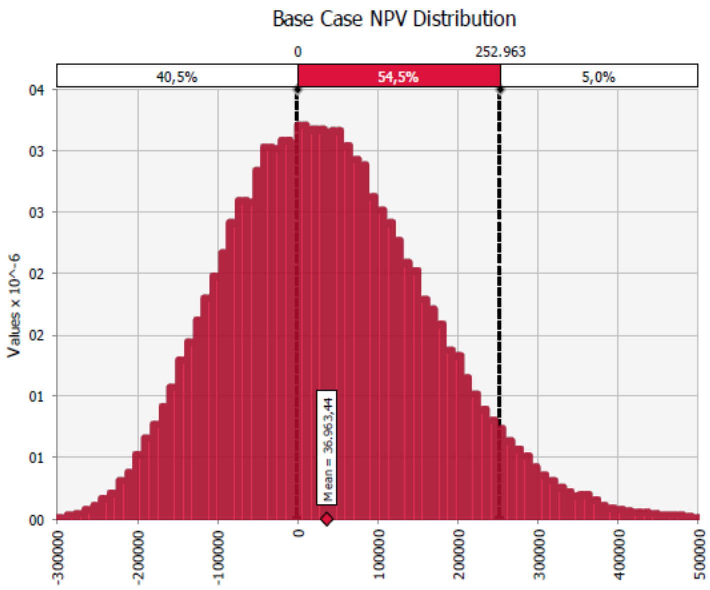


**Figure 3.2 –** Base Case NPV Probability Distribution

Source: Author

## 3.4. Model

The contract rules involved granting a two-tier Minimum Traffic Guarantee (MTG) to the concessionaire only for the Salvador-Itaparica Bridge. The sharing of traffic demand risk using guarantees is applied annually for the first 15 years of the concession. Two tiers of Upper and Lower traffic bounds were established, resulting in four traffic levels: $U_2$, $U_1$, $L_1$, and $L_2$, representing 120%, 110%, 90%, and 80% of the expected levels. However, it is not clear how these guarantee levels were determined. The operational rules, as stated in the bid documents, are as follows (Governo do Estado da Bahia, 2019):

a) If actual observed traffic in the period is greater than or equal to $L_1$ (90%) and less than or equal to $U_1$ (110%) of the expected level, there will be no government interference;
b) If actual observed traffic in the period is less than $L_1$ (90%) and greater than or equal to $L_2$ (80%) of the expected level for the period, the government will refund the concessionaire 70% of the difference between observed traffic and the $L_1$ level;
c) If actual observed traffic in the period is greater than $U_1$ (110%) and less than or equal to $U_2$ (120%) of the expected traffic level for the period, the

government will receive from the concessionaire 70% of the difference between observed traffic and the $U_1$ level;

d) If actual observed traffic in the period is less than $L_2$ (80%) of the expected traffic for the period, the government will refund the concessionaire of 100% of the difference between the observed traffic and the $L_2$ level, plus the 70% of the difference between $L_1$ and $L_2$;

e) If actual observed traffic in the period is greater than $U_2$ (120%) of the expected traffic for the period, the government will receive from the concessionaire 100% of the difference between observed traffic and the $U_2$ level, plus 70% of the difference between $U_2$ and $U_1$.

The traffic risk-sharing tiers from the traffic estimated by the government and the listed risk-sharing rules are shown in Figure 3.3.

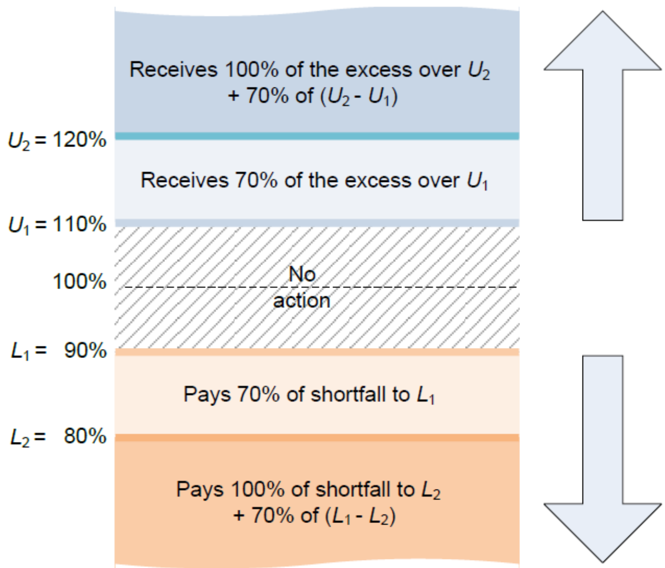


**Figure 3.3 –** Government Outlays and Inflows

Source: Author

The cost of the contingent supports provided to the winner of the auction according to the bid documents was estimated by the government to be US$ 64.6 million if actual traffic levels during the first 15 years fell between 80% and 90% of the expected value, or US$ 29.3 million if traffic fell below 80% (Governo do Estado da Bahia, 2019).

MTG provides the concessionaire insurance against low traffic levels, and a penalty in the case demand exceeds expectations. This can be modeled respectively as an option to abandon or put option in favor of the concessionaire and a call option for the government. These series of put and call options will be exercised, or not, each year according to Table 3.2, where $S(t)$ is the observed traffic level in year $t$.

**Table 3.2 –** Option Value in year *t*

| Tier | Option |
|---|---|
| $S(t) > U_2$ | $Call_2(t) = S(t) - U_2 + (U_2 - U_1) \times 0.70$ |
| $U_2 \geq S(t) \geq U_1$ | $Call_1(t) = (S(t) - U_1) \times 0.70$ |
| $U_1 > S(t) \geq L_1$ | 0 |
| $L_1 > S(t) \geq L_2$ | $Put_1(t) = (L_1 - S(t)) \times 0.70$ |
| $S(t) < L_2$ | $Put_2(t) = L_2 - S(t) + (L_1 - L_2) \times 0.70$ |

Source: Author

While the traditional Discounted Cash Flow method can be used to value a standard project, this approach is no longer possible when risk-mitigating government supports are involved. MTG modifies the project cash flows by adding or subtracting cash payouts whenever traffic falls below or above expected values. Given that this affects the risk of the project, the original risk-adjusted discount rate can no longer be used. Thus, determining the project's value and the corresponding put and call options under these circumstances requires the use of option pricing methods such as the Real Options Theory (ROT), where the MTG is modeled as a series of independent call and put European options. The present value of the cost to the government of a guarantee of $T$ years is shown in Eq (3.2):

$$\text{Cost} = \sum_{t=1}^{T} (Put_{1,t} + Put_{2,t}) e^{-rt} \tag{3.2}$$

On the other hand, the government will earn a revenue from the excess demand during $T$ years, as shown in Eq. (3.3).

$$\text{Revenues} = \sum_{t=1}^{T} (Call_{1,t} + Call_{2,t})\ e^{-rt} \tag{3.3}$$

Thus, the contingent liability for the government is the net difference between Eqs. (3.2) and (3.3).

$$\text{Liabilities} = \text{Costs - Revenues}$$

By means of an Itô process, it can be shown that the discrete-time version of the GBM process, which allows traffic to be modeled in discrete annual periods, is the one shown in Eq. (3.4):

$$S_{t+1} = S_t e^{\left(\alpha - \frac{\sigma^2}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}} \tag{3.4}$$

As is standard in the option pricing literature, we resort to the risk-neutral measure to value the project options. ROT states that such projects may be valued as long as the risk premium is subtracted from the traffic growth rates. This provides the expected risk-neutral traffic and corresponding risk-neutral project cash flows, which can then be discounted at the risk-free rate. Thus, the risk-neutral traffic model can be modeled as shown in Eq. (3.5).

$$SR_{t+1} = SR_t e^{\left(\alpha - \lambda - \frac{\sigma^2}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}} \tag{3.5}$$

where $SR_t$ is the risk-neutral traffic and $\lambda$ is the risk premium which is subtracted from the traffic growth rate in order to generate the risk-neutral process.

The fact that both risk-adjusted and risk-neutral approaches applied to the base case project provide the same result when discount respectively at the risk-adjusted and the risk-free rate can be used to determine the traffic risk premium $\lambda$. This is shown in Eq. (3.6) (Freitas & Brandão, 2010), where $n$ is the number of periods of the project, $f(S_t)$ and $f(SR_t)$ are respectively the project cash flows as a function of the stochastic risk adjusted and the risk neutral traffic levels of Eqs. (3.4) and (3.5), $\alpha$ is the risk-adjusted discount rate, and $r$ is the risk-free rate.

$$\int_{t=1}^{n} E[f(S_t)]\, e^{-\alpha t} dt = \int_{t=1}^{n} E[f(SR_t)]\, e^{-rt} \tag{3.6}$$

The key to Eq. (3.6) is the fact that the NPV of both the risk-adjusted and the risk-neutral cash flows is the same, as the use of the risk-neutral approach does not affect in any way the value of the project – it is simply a standard option pricing procedure. The full project cash flows from which the NPV is derived are shown in Appendix A.

The resulting risk premium was found to be $\lambda_\sigma = 4.07\%$. A more detailed discussion on the determination of the risk premium can be found in Freitas & Brandão (2010).

## 3.5.
## Results and Discussion

We determine the value of the contingent liabilities incurred by the government of the State of Bahia as a result of the MTG clauses in the concession contract of the Salvador-Itaparica Bridge Roadway System. All data for the project were obtained from official government bid documents from Governo do Estado da Bahia & Sinergia (2019).

Government payouts for low traffic levels each year were modeled as Put options as they represent potential cash outflows or contingent liabilities for the government. Expected government receipts from higher than expected traffic levels were modeled as Call options as they represent potential cash inflows. Both were modeled as a series of independent European options with annual maturities. This analysis was limited to the first 15 years of the concession, which is the duration of the guarantees.

A Monte Carlo simulation of the stochastic cash flows with these options under the risk-neutral measure was performed. Both the new value of the project and the government liabilities were determined following the rules shown in Table 3.2. The distribution of the Tier 1 MTG put value for year 6, which is the first year of operation of the concession, is shown on Figure 3.4 (a). The expected value of the government payout for this particular obligation is US$ 0.688 million. Note that there is a significant probability that this option will not be exercised and a small probability that the concessionaire will receive a value between US$ 0 and 5 million. This is because the values above US$ 5 million are captured by the Tier 2 Put option. Figure 3.4 (b) shows Tier 2 put probability distribution with an expected value of US$ 6.499 million. There is a probability that the concessionaire will receive a value between US$ 5 and 30 million, but zero probability that it will be between zero and US$ 5 million as these values are captured by the Tier 1 Put option.

The probability distribution of Tiers 1 and 2 guarantees for the government for all 15 years of the MTG is shown in Figure 3.5 and is expected to cost US$ 3.031 million and US$ 323.224 million, respectively. This value is significantly greater than government calculations.

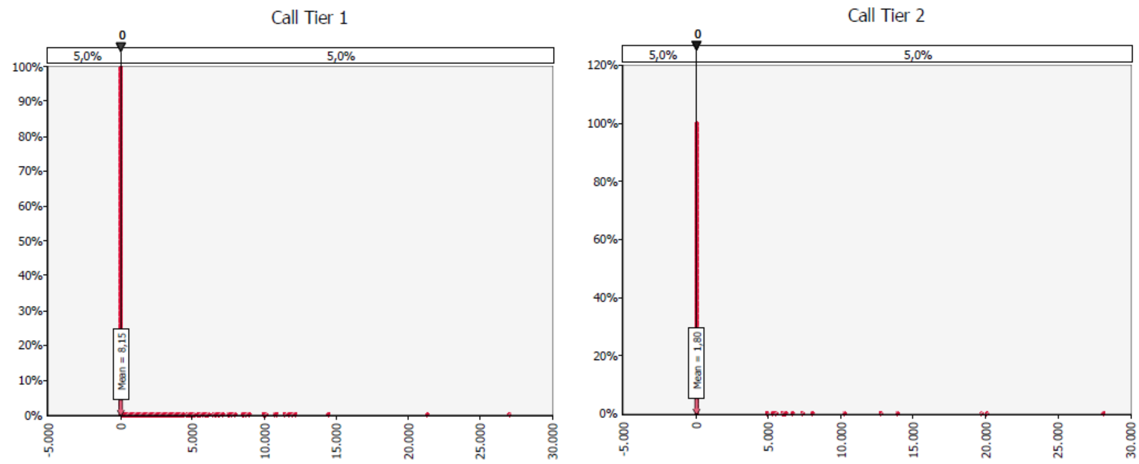


**Figure 3.4 –** MTG expected government outlays for year 6 only

Note: The probability distribution for Tier 1 and Tier 2 are shown are shown respectively on the left and the right

Source: Author

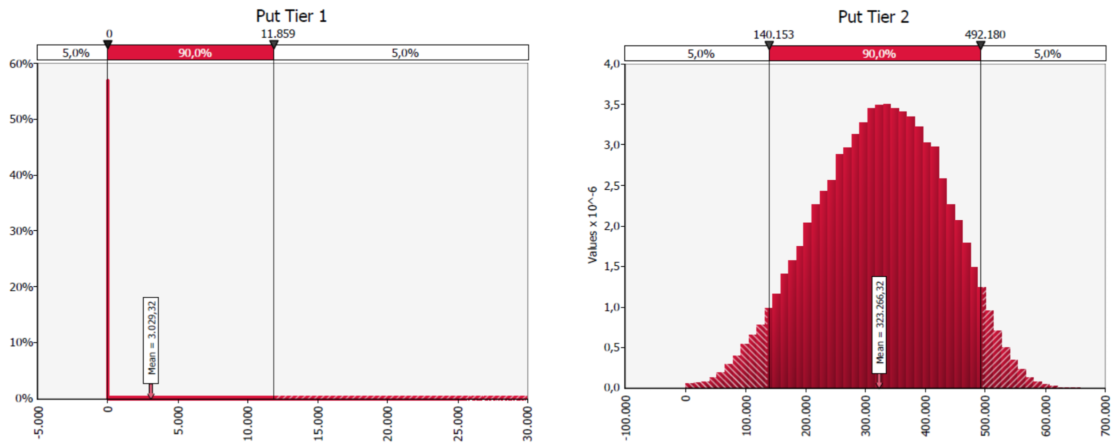


**Figure 3.5 –** Total MTG expected government outlays per Tier

Note: The total probability distribution for Tiers 1 and 2 put options are shown respectively on the left and the right

Source: Author

On the other hand, if traffic demand is significantly higher than expected, the government will receive payouts to compensate for any outlays due to periods of low traffic levels. Nonetheless, at US$ 8.4 thousand and US$ 2.31 thousand respectively for all of Tier 1 and Tier 2, this contribution is minimal and is shown in Figure 3.6.

The probability distribution for the total expected MTG costs and receipts are shown in Figure 3.7, respectively.

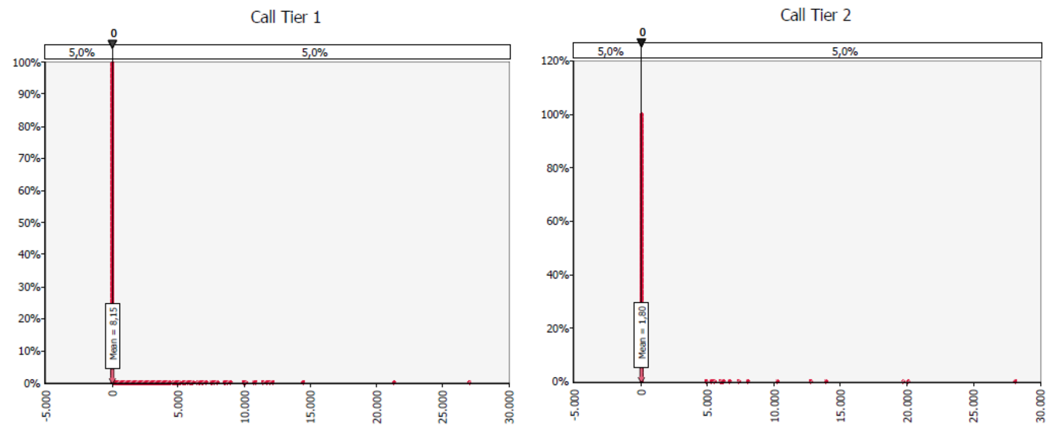


**Figure 3.6 –** Total MTG expected payouts received by the government per Tier.
Note: The total probability distribution for Tiers 1 and 2 call options are shown respectively on the left and the right.
Source: Author

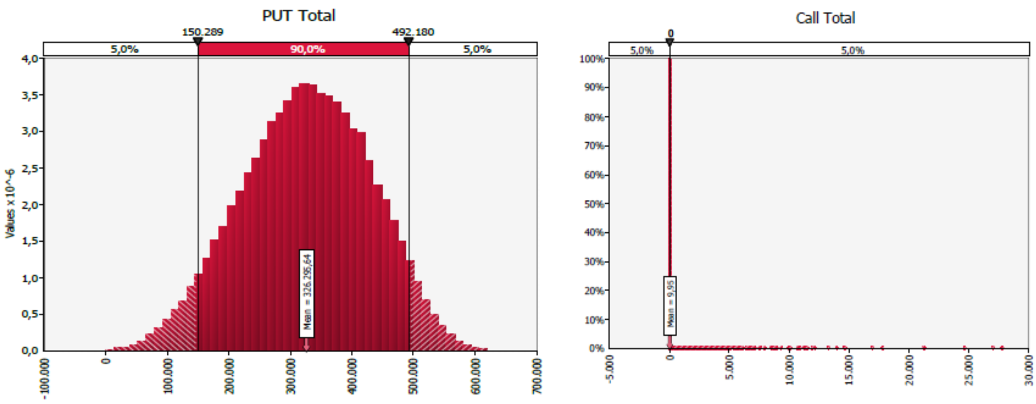


**Figure 3.7 –** Total MTG expected outlays and payouts received by the government for the entire contract period
Note: The total probability distribution for the outlays (put) and payouts received (call) are shown respectively on the left and the right.
Source: Author

The results are summarized in Table 3.3. The expected value of the government receipts is small (US$ 10,720) compared to the potential liabilities from the MTG mechanism (US$ 326.3 million). The net expected cost to the government for the 15-year duration of the MTG is the sum of all these options, or US$ 326.3 million. These values differ significantly from the values informed by the government in the bid documents. The difference is approximately an order of magnitude if the guarantee for traffic levels is lower than 70% of the expected values.

**Table 3.3 –** Government Liabilities: Expected cost of the MTG (values in USD millions)

| Government | Option | Expected Value |
|---|---|---|
| Revenues | $Call_2$ | US$ 0.008 million |
| | $Call_1$ | US$ 0.002 million |
| Payouts | $Put_1$ | US$ 3.031 million |
| | $Put_2$ | US$ 323.224 million |

Source: Author

The cost of the MTG guarantees represent future contingent liabilities for the government. In order to determine the cost of this liability, the State of Bahia government considered two distinct scenarios where traffic levels would either fall between 90% and 100% of expected levels or remain lower than 90% throughout the life of the concession. Following that, a deterministic valuation analysis under a few strong and arbitrary assumptions was made as follows:

1) Total traffic demand is the sum of the six distinct traffic flows that were modeled;
2) The maximum variation in the estimate of each of these flows was assumed to be 30%;
3) These six traffic flows are independent and uncorrelated and were modeled as a uniform distribution;
4) The uncertainty in the total traffic demand was modeled as a normal distribution;
5) Only the demand in the first year of the operation (year 6 of the contract) need to be modeled;

The results for the remaining years are assumed to be the same as those of the first year.

In the light of the significant errors in traffic demand estimation observed in many projects worldwide, limiting the traffic forecast error to 30% seems overly optimistic. Flyvbjerg et al. (2006) analyzed 210 transport infrastructure projects and showed with high statistical significance that estimates of future demand forecasts were incorrect by a much larger margin. For nine out of ten rail projects, passenger forecasts were overestimated by 106%, on average. For half of the road projects analyzed, the difference between actual and forecasted traffic was greater than ±20%, and for 25% of these, the difference was larger than ±40%. The assumption that variations from expected values between the six components of the total toll bridge traffic demand are uncorrelated also does not seem credible.

Given that one of the main drivers of road traffic is GDP, it is unlikely that a downturn in the economy will affect traffic on some bridge access roads but not others. This assumption significantly minimized the already conservative estimate due to the diversification effect well known in portfolio theory. A simple simulation comparison between a single uniform distribution with a ±30% variation and the portfolio of six independent uniform distributions shows that this results in a normal distribution with significantly less deviation and risk. It also does not make sense to model traffic uncertainty as a normal probability distribution, as this distribution allows for negative traffic values, which is impossible, nor assume that all years of the project will behave exactly as the first year.

With this analysis, the government arrived at two different results: If future traffic levels are above 90% of the expected demand, the total cost to the government will be US$ 64.5 million. If future traffic levels fall below 90% of the expected demand, the total cost will be US$ 29.2 million. It is not clear which of these values the government should consider, as there is no way of knowing beforehand what the future demand level will be. The main problem with this analysis, though, is that given that MTG guarantees have option-like characteristics, they cannot be valued with the traditional static discounted cash flow method, as was done in the report. Thus, independent of the assumptions used, the results will be incorrect. This can be observed by noting that the government report concluded that costs would be lower (US$ 29.3 million) if traffic levels remain below the 80% threshold, where government payouts are higher than if they are between 80% and 90% (US$ 64.6 million), where the payouts are lower, which does not seem reasonable. Both values, nonetheless, as significantly lower than the cost US$ 326.3 million determined by our model.

The value of the project without considering the MTG is US$ 36.971 million, as shown by Figure 3.2. Adding the MTG mechanism increases the project value by US$ 326.2 million, which is an eightfold increase that significantly changes the probability distribution of the project NPV to the point that there is a zero probability that the project has a negative NPV as can be seen in Figure 3.8. This indicates that the concessionaire is guaranteed to earn a positive return independent of the uncertainty in traffic demand, which suggests that the government may have provided excessive guarantees and taken the full risk of the project upon itself. This creates an arbitrage opportunity for the concessionaire as it can earn a risk-adjusted rate of 7.36% on a risk-free project instead of the risk-free rate of 3.2%.

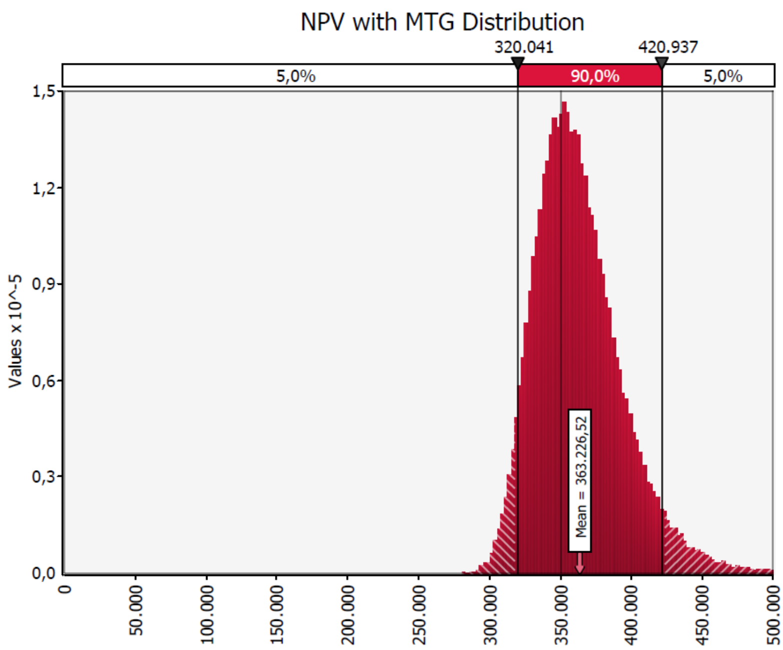


**Figure 3.8 –** Probability distribution of the project NPV with MTG guarantee
Source: Author

The impact of the MTG support mechanism on the feasibility of the project is illustrated by comparing the probability distribution profiles of the NPV with and without these supports. As shown in Figure 3.9, not only is there an increase in the NPV, but also the risk profile of the base case distribution has changed. While the standard deviation of the base case distribution is US$ 123.738 million, with the

MRG, this is reduced to US$ 31.824 million, which indicates that there was a significant reduction in the risk for the concessionaire.

The results of the ROT analysis are also a function of the main parameters adopted in the model and may vary for different values. The drift parameter was based on the information on the expected growth of traffic demand provided in the bid documents. The only new parameter to be estimated was the traffic volatility, which we assumed to be close to the volatility of the regional GDP. Nonetheless, we performed a sensitivity analysis on the traffic volatility parameter shown in Table 3.4.

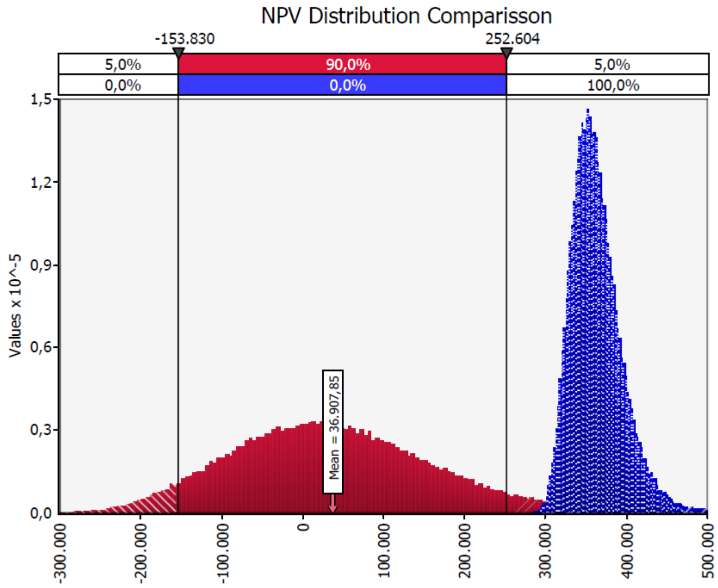


**Figure 3.9 –** Comparison of the project NPV probability distribution with and without the MTG

Source: Author

**Table 3.4 –** Government Liability: Expected cost of the MTG by Volatility (values in USD millions)

| Volatility | Payments | Revenues | Net Cost |
|---|---|---|---|
| 1% | 324.8 | 0.0 | 324.8 |
| 3,16% | 326.3 | 0.0 | 326.3 |
| 7% | 336.1 | 0.3 | 336.4 |
| 10% | 352,0 | 0.8 | 352.7 |
| 15% | 389.2 | 1.8 | 391.0 |

Source: Author

The variation in the results for the contingent liability costs for the government from the MTG supports grows with the volatility of the project, as expected for derivative assets such as options. If volatility is higher than assumed, the cost to the government increases by up to 20% for the case of a volatility of 15%, which indicates an even worse situation for the government. The result is robust even if volatility drops to 1%, as the net cost of the contingent liabilities to the government of Bahia is reduced by only 0.53%.

## 3.6. Conclusions

In this article, we analyzed the case of the Public-Private Partnership concession project for the construction, operation, and maintenance of the Salvador – Itaparica bridge system to determine the government's contingent liabilities due to the MTG clauses of the concession contract. The use of MTG and other support mechanisms in public-private partnership projects is common, reduces the risks, and makes such projects feasible or more attractive to private investors. On the other hand, these mechanisms place a financial burden on government budgets. The cost of these guarantees represents a potential liability contingent on the future behavior of traffic demand. According to the bid documents made publicly available, the government determined that the expected costs would be either US$ 29.288 million or US$ 64.567 million.

Since the government liabilities are caused by the government guarantees given in PPPs Concession, which have option-like characteristics, determining their cost requires the use of option pricing methods such as the Real Options Theory. We develop a simulation-based Real Options model under the risk-neutral measure to assess the value of these guarantees and provide a mechanism that allows the government to optimally calibrate the guarantee level. Our results indicate that the expected cost to the government will be US$ 326.2 million, which is seven times greater than the average value estimated by the government and five times higher than the government´s worst-case scenario. These results suggest that the expected value of the government’s liabilities may have been incorrectly measured in the report and that the government of the State of Bahia may have to honor payouts to the concessionaire that are significantly higher than expected. In addition, we show that the level of the guarantees is such that all the demand risk was transferred to the government, providing an arbitrage opportunity that allows the concessionaire to earn a risk-adjusted rate of return on a risk-free project. This implies that the State of Bahia government, which relied on models adopted in other projects, may have provided MRG guarantees far in excess and at a significant cost to the government.

This study has multiple implications. We show the importance of determining the impact in the public budget of the contract guarantees. These guarantees represent insurance contracts that provide contingent supports in case of excessive variations in expected demand and cannot be priced under traditional discount cash flow methods due to their option-like characteristics. In addition, the effectiveness of the guarantee mechanism to adequately share the project risks between the concessionaire and government must be verified. Finally, we show that rather than relying on models designed for projects with different characteristics, guarantees must be tailored to each case as the end results may be quite different. These results show the importance of designing guarantee contracts that reduce the project's risk to a level acceptable to the private partner at the least cost to the government. This helps governments use their limited resources to provide a wide range of projects rather than directly funding public infrastructure investments, expanding their investment capability.

The approach adopted in this article is well known in the literature and would have allowed the government to determine their future contingent liabilities and the effectiveness of their risk-sharing mechanisms. Nonetheless, the bid documents show that it was not used in this case, which may have led to the incorrect valuation of these future costs.

This work contributes to public policy and towards a better understanding of the contingent claims and fiscal costs involved in PPP projects that offer contractual risk-mitigating mechanisms by providing an approach that allows governments to calibrate the level of guarantees and determine their costs. These developments may be useful to government officials and agents involved in policymaking in infrastructure projects and to private investors interested in better understanding the impact of these mechanisms.

## 3.7. Appendix A

The project's cash flow for the five years of construction plus the 30 years of the concession is presented in Figure 3.10, considering the original data with a discount rate of 7.56%, as specified in table 3.1.

| | Year 1 | Year 2 | Year 3 | Year 4 | Year 5 | Year 6 | Year 7 | Year 8 | Year 9 | Year 10 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Income Statement** | | | | | | | | | | |
| Revenue | - | - | - | - | - | 84.650 | 89.731 | 94.803 | 99.862 | 104.896 |
| (–) SG&A | - | - | - | - | - | (14.729) | (14.729) | (14.729) | (14.729) | (14.729) |
| (=) Ebitda | - | - | - | - | - | 69.921 | 75.002 | 80.074 | 85.133 | 90.167 |
| (–) Depreciation | | | | | | (44.184) | (44.184) | (44.184) | (44.184) | (44.184) |
| (=) EBIT | - | - | - | - | - | 25.737 | 30.818 | 35.890 | 40.949 | 45.983 |
| (–) Tax | - | - | - | - | - | (10.661) | (11.436) | (12.210) | (12.981) | (13.749) |
| Net Income | - | - | - | - | - | 15.075 | 19.382 | 23.680 | 27.968 | 32.234 |
| **Cash Flow Statement** | | | | | | | | | | |
| Net Income | - | - | - | - | - | 15.075 | 19.382 | 23.680 | 27.968 | 32.234 |
| (+) Depreciation | - | - | - | - | - | 44.184 | 44.184 | 44.184 | 44.184 | 44.184 |
| (-) Change in NWC | - | - | - | - | - | (3.292) | (239) | (239) | (238) | (237) |
| (=) Cash from Operations | - | - | - | - | - | 55.967 | 63.327 | 67.625 | 71.914 | 76.181 |
| (–) Cash from Investing | (265.105) | (190.665) | (141.039) | (165.852) | (190.665) | 11.761 | 11.761 | 11.761 | 11.761 | 11.761 |
| (=) Free Cach Flow | (265.105) | (190.665) | (141.039) | (165.852) | (190.665) | 67.729 | 75.088 | 79.387 | 83.675 | 87.942 |

| | ... | Year 15 | ... | Year 20 | ... | Year 25 | ... | Year 30 | ... | Year 35 |
|---|---|---|---|---|---|---|---|---|---|---|
| **Income Statement** | | | | | | | | | | |
| Revenue | ... | 129.507 | ... | 154.290 | ... | 182.470 | ... | 217.427 | ... | 260.281 |
| (–) SG&A | ... | (14.729) | ... | (14.729) | ... | (14.729) | ... | (14.729) | ... | (14.729) |
| (=) Ebitda | ... | 114.778 | ... | 139.561 | ... | 167.741 | ... | 202.698 | ... | 245.551 |
| (–) Depreciation | ... | (44.184) | ... | (44.184) | ... | (44.184) | ... | (44.184) | ... | (44.184) |
| (=) EBIT | ... | 70.594 | ... | 95.377 | ... | 123.557 | ... | 158.514 | ... | 201.367 |
| (–) Tax | ... | (17.502) | ... | (47.445) | ... | (57.026) | ... | (68.911) | ... | (83.482) |
| Net Income | ... | 53.092 | ... | 47.932 | ... | 66.531 | ... | 89.602 | ... | 117.886 |
| **Cash Flow Statement** | | | | | | | | | | |
| Net Income | ... | 53.092 | ... | 47.932 | ... | 66.531 | ... | 89.602 | ... | 117.886 |
| (+) Depreciation | ... | 44.184 | ... | 44.184 | ... | 44.184 | ... | 44.184 | ... | 44.184 |
| (-) Change in NWC | ... | (228) | ... | (188) | ... | (223) | ... | 7.150 | ... | 8.678 |
| (=) Cash from Operations | ... | 97.048 | ... | 91.928 | ... | 110.493 | ... | 140.937 | ... | 170.748 |
| (–) Cash from Investing | ... | 11.761 | ... | 11.761 | ... | 11.761 | ... | 11.761 | ... | 11.761 |
| (=) Free Cach Flow | ... | 108.809 | ... | 103.690 | ... | 122.254 | ... | 152.698 | ... | 182.509 |

**Figure 3.10 –** Project Free Cash Flow (values in USD thousands)

Source: Author

# 4
# Determining the optimum Level of government guarantees in road concession projects

## 4.1.
## Introduction

The successful implementation of public-private partnerships (PPPs) in infrastructure projects may require effective risk-sharing mechanisms, as these initiatives may be unattractive to private investors if the risk is deemed to be excessive. However, while these mechanisms contribute to the viability of such projects, they also give rise to contingent liabilities for the granting authority, which may excessively burden the government. Thus, an adequate risk allocation framework is essential to create appropriate incentives for both parties, ensure the financial viability of PPP projects, and mitigate the costs of inefficiencies (Medda, 2007). If the risks are not well allocated, the benefits of PPP contracts will be reduced and the incidence of conflicts significantly increased (Guasch et al., 2014).

There are several examples that highlight the intricate nature of risk allocation in Public-Private Partnership Projects (PPP) (Medda, 2007; Vassallo et al., 2012; Nguyen et al., 2018). Among these, future demand stands out as one of the main risk factors due to the strong reliance on user-generated demand revenue for project profitability. However, the uncertainty over the future demand levels poses a significant challenge to the effective operation of these ventures and is often cited as the primary cause of failures in road projects (Nombela & de Rus, 2004). As noted by Flyvbjerg et al. (2006) and Trujillo et al. (2002), traffic demand forecasting is prone to significant inaccuracies, resulting in investment difficulties and potential insolvency of the concessionaire.

A common risk sharing mechanism in Public-Private Partnership (PPP) road projects is the Minimum Demand Guarantee (MDG), or Minimum Traffic Guarantee (MTG), where the government provides concessionaire support in the event that traffic demand volume falls below a pre-determined level, or a floor. Additionally, the government may estipulate that revenues exceeding a pre-established threshold, or cap, must be reverted back to the government. In these cap and floor models, the concessionaire is bound to hand over any amounts received above the cap level, while the government commits to reimburse the concessionaries for any shortfall in case demand is lower than the floor level.

MTG supports are derivate assets, as their payoff is contingent on future and uncertain traffic levels, and thus their valuation requires the use of option pricing methods such as the Real Options Theory. There is a large body of literature on MTG risk mitigation mechanisms, which show how this approach provides value and makes the project more attractive to the private partner (Cheah & Liu, 2006; Brandao & Saraiva, 2008; Brandão et al., 2012; Blank et al., 2016; Cabero Colín et al., 2017; Buyukyoran & Gundes, 2018; Kim et al., 2019). However, these mechanisms also have implications for the government’s future fiscal liabilities, potentially affecting the government's deficits and magnitude of its future obligations. Therefore, it becomes necessary to accurately assess the potential impact of the contract guarantees on the public budget (Wibowo et al., 2012; Sant’Anna et al., 2022).

The primary challenge in designing the MTG mechanism resides in determining appropriate Cap and Floor levels. These levels play a crucial role in ensuring that the risk sharing arrangement is adequately aligned, creating the necessary incentives for the successful development of the PPP project, as incorrectly levels can distort this mechanism. An example of this problem occurred with the Salvador Itaparica Bridge project, where the government defined an excessively high floor level, resulting in a risk sharing arrangement where the government ended up bearing the entirety of the project risk (Sant’Anna et al., 2022). A similar issue occurred in South Korea’s, where overly generous MRG mechanisms led to the concessionaire enjoying excessively high returns, while the government assumed most of the revenue risks (Page et al., 2016).

The literature on determining the optimum minimum level of guaranteed revenue to satisfy private and government partners is scarce. Carbonara et al. (2014) developed a model to determine the value of minimum revenue to be guaranteed by the government, which considers the interests of public and private partners and uses the concept of fairness for structuring MRGs. However, due to a lack of a cap level, they did not consider the possibility of the private party earning excess revenue, which the government could claim. A solution to this issue was proposed by Carbonara & Pellegrino (2018) who expanded the previous model with a revenue cap in which the risk borne by the parties was estimated through their probability of loss. However, the of the size of loss for either party was not taken into consideration in their model. Their method aimed to identify the pair of values for the revenue cap and floor which minimizes the difference of risks borne by both public and private parties that satisfies both parties and fairly allocates risk between. Therefore, the risk borne by the private partner was estimated as the probability that the NPV of the investment is not profitable for the concessionaire, while for the government it was estimated as the probability of the investment being on-balance sheet. Buyukyoran & Gundes (2018) proposed a real options model with Monte Carlo simulation to identify the fair values of boundaries of the Minimum Revenue Guarantees (MRGs) and the maximum revenue cap (MRC) options to limit the total guarantee exposure, but did not incorporate any loss measurement for either party in the model constraints.

According to Randall (2014), governments are assumed to be risk-neutral since they can distribute the risk associated with any investment among a large number of people, each of whom is benefitted by each project and is taxed for it. On the other hand, policymakers within the government and their agencies are risk-averse (Hood, 2002; Stewart et al., 2011; Howlett, 2014). Governments, represented by public managers, like to claim credit for successful policies but are averse to the risk of being blamed for failure (Harris, 2014). In this way, it becomes necessary to reduce the project's risk to a level acceptable to the private partner at the least cost to the government, so as not to compromise the government budget (Sant'Anna et al., 2022) and consequently, make the infrastructure PPP project a failure. Thus, it becomes desirable to represent the public managers' risk preferences, whose risk-neutrality to the project can be justified by the project's appeal.

Pellegrino et al. (2019) developed a methodology to determine the optimal maximum interest rate guarantee (MIRG) value above which the private investor will obtain repayment from the government, balancing the interests of the project partners. They applied this methodology to the case of the "Camionale di Bari" toll Road in Southern Italy, offering insights into guarantee definition and structuring that fairly allocates risks between the parties based on operational and financial conditions. Despite bringing important concepts and contributing to the literature in the field, their work differs from ours in that it does not address the mechanism of traffic guarantees, which is the focus of our work. Using also a different methodology and type of guarantee mechanism, Sun & Zhang (2015) introduced a model to determine the optimum minimum revenue guarantee (MRG) level and royalty rate for build-operation-transfer (BOT) projects. They adopted a revised net present value financial evaluation model combined with the Monte Carlo simulation. Their model was applied to a wastewater treatment BOT project in Dalian, China, and indicated that it was effective in balancing the risk and reward between public and private partners under demand uncertainty.

In a work more closely related to ours, Wu et al. (2022) proposed a model to determine the optimal cap and floor threshold levels for traffic guarantees. Their model is based on the optimal risk allocation between participants of a public–private partnership considering the perspective of lenders and the risk tolerances of the participants. They use an objective function to minimize the sum of the probabilities of the concessionaire's NPV being negative with the probability of the cost of government guarantees being greater than a given budget, subject to a maximum probability of default by the concessionaire.

In this article we develop a model to determine the optimal cap and floor traffic levels that minimize the government’s fiscal liabilities from the project while guaranteeing the attractiveness of the project for the concessionaire, fairly sharing the risk between the public and private partners. Our work differs from the current literature in the field, and from Wu et al. (2022) in particular, in that we consider the government and the concessionaire risks separately, and define the government risk through an objective function that considers both the expected value and the probability of incurring in the future liabilities from the project. This work contributes to the literature on the analysis of the fiscal impact of contingent government guarantees in PPP projects by showing how the calibration of these guarantees can be made and assisting government officials and policymakers to adequately price these contractual clauses.

This paper is organized as follows. After this introduction, we present the traffic floor and cap risk mitigation mechanism that we model under the real Options Theory, and in section three, we explain the modeling process of stochastic uncertainty of future traffic levels. In section 4, the model to determine the optimal values of the traffic floor and traffic cap is developed. Section five presents the application of the model to the case of the Salvador–Itaparica Bridge system and discusses the results. Finally, we conclude.

## 4.2.
## The traffic floor and traffic cap

The traffic floor and cap, or minimum traffic guarantee and maximum traffic limit, are risk mitigation mechanisms commonly used in many PPPs projects that are suggested to be modeled under the Real Options Theory, given the MTGs have option-like characteristics.

In this type of mechanism, let's suppose, in this paper, that the contract rules between the PPP parties involves granting a tiers of Upper (cap) and Lower (floor) traffic bounds, resulting in two traffic levels: $U$ and $L$, representing $(1+\beta)$ and $(1-\beta)$ of the expected levels, where $0 \leq \beta \leq 1$. The sharing of traffic demand risk using guarantees is applied annually only for a period of the first $T_G$ years of the concession, where $T_G$ is a period within the concession term. The operational rules are as follows:

a) If actual observed traffic in the period is greater than or equal to $L$ $(1-\beta)$ and less than or equal to $U$ $(1+\beta)$ of the expected level, there will be no government interference;
b) If actual observed traffic in the period is less than $L$ $(1-\beta)$ of the expected traffic for the period, the government will refund the concessionaire the entire value of the difference between the observed traffic and the $L$ level;
c) If actual observed traffic in the period is greater than $U$ $(1+\beta)$ of the expected traffic for the period, the government will receive from the concessionaire the entire value of the difference between observed traffic and the $U$ level.

Figure 4.1 shows the traffic risk-sharing tiers from the estimated traffic and the risk-sharing rules listed above.

These risk-sharing rules provide the concessionaire supports when the traffic levels are lower than expected, which are penalties for the government, and a penalty for the concessionaire in the case demand exceeds expectations, which are gains for the government. This can be modeled as a put option in favor of the concessionaire and a call option for the government. Table 4.1 shows, for each year, when these series of put and call options will be exercised, where $S(t)$ is the observed traffic level in year t.

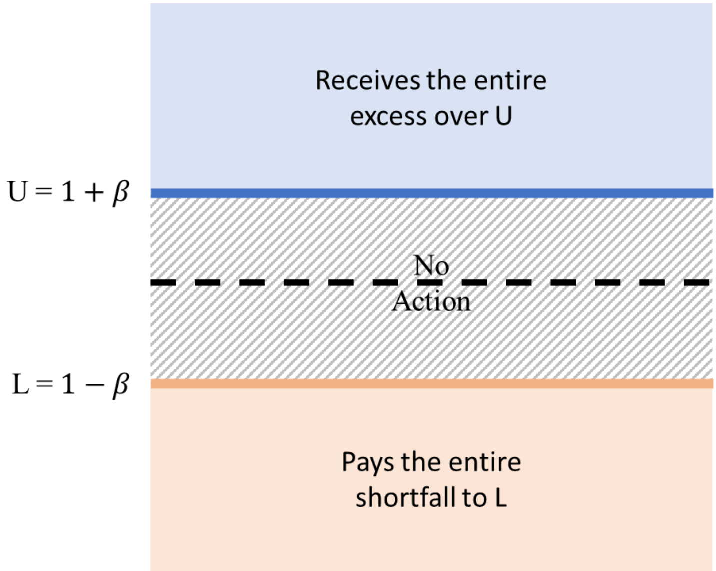


**Figure 4.1 –** Government Outlays and Inflows

Source: Author

**Table 4.1 –** Option Value in year t

| Tier | Option |
|---|---|
| $S(t) > U$ | $Call(t) = S(t) - U$ |
| $U > S(t) \geq L$ | 0 |
| $S(t) < L$ | $Put(t) = L - S(t)$ |

Source: Author

The provision of guarantees significantly impacts the risk profile of the projects, as it introduces modifications to the project cash flows through cash payouts in the event of traffic volumes deviating from expected values. Consequently, traditional valuation methods such as the Discounted Cash Flow approach using original risk-adjusted discount rate can no longer be used since the risk is affected by the MTG. Thus, it is necessary to use the Real Options Theory, which is an option pricing method, to determine the project's value and associated put and call options by modeling these guarantees as a series of independent call and put European options. The present value of the cost to the government of a guarantee of $T_G$ years and the excess demand during $T_G$ years are:

$$\text{Costs} = \sum_{t=1}^{T_G} Put_t \cdot e^{-rt} \tag{4.1}$$

$$\text{Revenues} = \sum_{t=1}^{T_G} Call_t \cdot e^{-rt} \tag{4.2}$$

Thus, the contingent liability for the government is the net difference between Eqs (4.1) and (4.2):

$$\text{Liabilities} = \text{Costs - Revenues} = \sum_{t=1}^{T_G} Put_t \cdot e^{-rt} - \sum_{t=1}^{T_G} Call_t \cdot e^{-rt} \tag{4.3}$$

## 4.3. Uncertainty Analysis

Uncertainty over the future traffic the project will generate is the leading risk in the external operating environment. Considering the stochastic uncertainty of future traffic levels, and as is standard in the literature, the traffic uncertainty is be modeled as a Geometric Brownian Motion diffusion process (GBM) (Irwin, 2007; Brandão et al., 2012).

$$dS = \omega S dt + \sigma S dz \tag{4.4}$$

were $dS$ is the incremental variation in traffic; $\omega$ is the traffic growth rate; $dt$ represents a short interval of time; $\sigma$ is the volatility of the traffic and $dz = \varepsilon\sqrt{dt}$ is the standard Wiener process where $\varepsilon \approx N(0,1)$

The discrete-time version, in discrete annual periods, of the GBM process, using Itô process will be:

$$S_{t+1} = S_t e^{\left(\omega - \frac{\sigma^2}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}} \tag{4.5}$$

ROT requires the use of the risk-neutral measure to value the project options. This involves determining the expected risk-neutral traffic and corresponding risk-neutral project cash flows by subtracting the risk premium from the traffic growth rates, which are then discounted at the risk-free rate. The risk-neutral traffic model is:

$$SR_{t+1} = SR_t e^{\left(\omega - \varphi - \frac{\sigma^2}{2}\right)\Delta t + \sigma\varepsilon\sqrt{\Delta t}} \tag{4.6}$$

where $SR_t$ is the risk-neutral traffic and $\varphi$ is the risk premium which is subtracted from the traffic growth rate in order to generate the risk-neutral process.

The traffic risk premium $\varphi$ may be determined, since the NPV of both the risk-adjusted and the risk-neutral cash flows have the same value, discounted, respectively, at the risk-adjusted and the risk-free rate. The risk-neutral approach does not affect the value of the project, which is shown in Eq. (4.7) (Freitas & Brandão, 2010):

$$\int_{t=1}^{n} E\left[f\left(S_t\right)\right]e^{-\omega t}dt = \int_{t=1}^{n} E\left[f\left(SR_t\right)\right]e^{-rt}dt \tag{4.7}$$

where $n$ is the number of periods of the project; $f\left(S_t\right)$ and $f\left(SR_t\right)$ are respectively the project cash flows as a function of the stochastic risk adjusted and the risk neutral traffic levels, from Eqs (4.4) and (4.5); $\omega$ is the risk-adjusted discount rate; and $r$ is the risk-free rate.

## 4.4.
## Model formulation

Accurately determining the appropriate level of risk sharing is of paramount importance to ensure that the Minimum Traffic Guarantee (MTG) effectively distributes the project risk fairly between the government and private investor.

Our model has as its objective to minimize the governmental impact, while guaranteeing a minimum attractiveness of the project for the private partner. Unlike the other works, we believe that the government must assess the risks not only from the financial perspective, but mainly from the social perspective, taking into account all the externalities caused by the investment, which affect different segments of the population in varying degrees. Thus, the government's objective is not to have a financial return or “not having financial losses”, but to minimize the impact of these guarantees to the public budget.

We assume that the primary concern for the private partner is the possibility of an unprofitable investment, where the Concessionaire net present value $\left(NPV_C\right)$ falls below zero. To mitigate this risk, we limit the concessionaire´s exposure to such a scenario by setting a limit to this risk, denoted as Θ, which acts as a threshold. The rate Θ represents then the acceptable probability of the $NPV$ being less than zero:

$$\text{Prob}\left[NPV_C < 0\right] \leq \Theta \text{ with } 0 \leq \Theta \leq 1 \tag{4.8}$$

The second restriction concerns the lender risk. As in Wu et al. (2022), we assume there is a probability of default (*PD*) that measures the credit risk for borrowers, that is, the probability that the predicted future cash flows are insufficient to repay the debt service in a given period. We assume $PD \leq \Psi$ as the condition for a lender providing a loan for a project, particularly $\Psi = 0.3\%$ (Wu et al., 2022). So, the risk for the lender, that provides the loan to be used to develop de PPP project, should satisfy:

$$PD = \frac{\text{Prob}\left(NPV_D < D\right)}{T_d} \leq \Psi \tag{4.9}$$

where $NPV_D$ is the net present value of the concessionaire during the debt service payment period; $D$ is the value of loan and interest payments in year t; $T_d$ is the repayment period.

A recurrent approach to optimizing investment portfolios is risk minimization, using some measure of risk, the most common being $VaR_\alpha$ and $CVaR_\alpha$ (or $ES_\alpha$). Street (2010) developed a risk performance measure, named Extended $CVaR_\alpha$ Preference – ECP, in which a linear combination between the expected value of the distribution and the $CVaR_\alpha$ of the distribution is considered, given a level of significance. So, the decision-maker exerts its risk preferences, taking into account the expected loss with the potential loss.

We propose a model that focuses on reducing the government's contingent liabilities while the investments remain attractive to the private partner, considering the public managers' risk preferences. So, we use the ECP risk performance measure as the objective function of the government's risk aversion measure:

$$ECP_{\alpha,\lambda} = (1-\lambda)\cdot E\left[X(\beta)\right] + \lambda \cdot CVaR_\alpha\left[X(\beta)\right] \tag{4.10}$$

where $E\left[X(\beta)\right]$ is the expected value of the contingent liability for the government from Eq. (4.3), that is, $X(\beta) = \sum_{t=1}^{T_G}\left(Put_t - Call_t\right)\cdot e^{-rt}$ ; and $\lambda$ is the government's risk aversion measure with $\lambda \in [0,1]$.

The purpose of this function is to allow the modeling of the government´s risk tolerance to the liabilities associated with the $\alpha\%$ worst-case scenarios, as measured by the $CVaR_\alpha$. If the government is assumed to be risk neutral, then $\lambda = 0$, and the objective function considers only the expected value of these liabilities. Conversely, if $\lambda = 1$, the objective function prioritizes government risk exclusively, indicating maximum risk aversion to the expected $CVaR_\alpha$ loss.

Thus, considering governments perspective, the risk for the concessionaire and for lender, the optimal model proposed is:

Minimize:

$$\left(1-\lambda\right)\cdot E\left[X\left(\beta\right)\right]+\lambda\cdot CVar_{\alpha}\left[X\left(\beta\right)\right] \tag{4.11}$$

Subject to:

$$\text{Prob}\left[NPV<0\right]\leq\Theta \tag{4.12}$$

$$PD\leq\Psi \tag{4.13}$$

$$0\leq\beta\leq1 \tag{4.14}$$

The objective function in Eq. (4.11) is the minimization of linear combination between the expected value and it's $CVaR_{\alpha}$ of the contingent liability for the government is minimized with the optimal tiers of traffic bounds $\beta$. The risk of the project becoming non-profitable should be less than the maximum risk accepted by the concessionaire in Eq. (4.12). The probability of default accepted by lender is limited to a maximum probability value in Eq. (4.13). The tier of traffic bounds $\beta$ is the decision variable, whose range values are in Eq. (4.14).

## 4.5. Numerical Application

The model developed in this work was applied to the case of Salvador–Itaparica Bridge, which composes a road system consisting of two bridges (Salvador–Itaparica and Funil), making it the second-longest bridge in Latin America and connecting the Itaparica island to Salvador City. This road system influences the flow of people and goods in the region, making it much faster and more predictable for the connection between the metropolitan area of Salvador and the entire southern and western region of the state of Bahia, furthermore, bringing development to these regions.

**Table 4.2 –** The project's assumptions

| Assumptions | Values |
|---|---|
| Construction Term | Five years |
| Concession Term | 30 years |
| MTG period | 15 years |
| CAPEX | US$ 1,325 million |
| OPEX | US$ 14.73 million (per year) |
| Reinvestments | US$ 2.18 million (per year) |
| Government Financial Support | US$ 372,2 million (during construction) |
| Government Financial Compensation | US$ 13.95 million (per year) |
| Average Tariff | US$ 8.12 |
| WAAC | 7.56% |
| Risk-free rate | 3.20% |

Source: Sant'Anna et al. (2022)

The case of the Salvador–Itaparica Bridge system concession project was first analyzed by Sant'Anna et al. (2022) under the real Options Theory and compared the results with publicly available government reports on the project. The project's assumptions are shown in Table 4.2 and the operational rules are as follows:

- The contract rules involved granting the concessionaire a two-tier MTG for the first 15 years of the concession only for Salvador–Itaparica Bridge traffic. The operational rules are as follows:
- If actual observed traffic in the period is greater than or equal to $L_1$ (90%) and less than or equal to 110% of the expected level, there will be no government interference;
- If actual observed traffic in the period is less than $L_1$ (90%) and greater than or equal to $L_2$ (80%) of the expected level for the period, the government will refund the concessionaire 70% of the difference between observed traffic and the $L_1$ level;
- If actual observed traffic in the period is greater than $U_1$ (110%) and less than or equal to $U_2$ (120%) of the expected traffic level for the period, the government will receive from the concessionaire 70% of the difference between observed traffic and the $U_1$ level;
- If actual observed traffic in the period is less than $L_2$ (80%) of the expected traffic for the period, the government will refund the concessionaire of $_1$00% of the difference between the observed traffic and the $L_2$ level, plus the 70% of the difference between $L_1$ and $L_2$;

- If actual observed traffic in the period is greater than $U_2$ (120%) of the expected traffic for the period, the government will receive from the concessionaire 100% of the difference between observed traffic and the $U_2$ level, plus 70% of the difference between $U_2$ and $U_1$.

### 4.5.1. Financial Analysis of the project

The static valuation analysis, considering no government support and discounted at the risk-adjusted rate of return of 7.56% (WACC), yields a base project's Net Present Value of US$ 33 million for the project. Given that the required investment is over 1 billion USD, this finding suggests that the project may entail considerable risk.

A dynamic valuation analysis was made from a Monte Carlo simulation of the stochastic cash flows, implemented in the R programming language (R Core Team, 2019) for 50,000 iterations. As parameters for this analysis, the traffic growth rate ($\varpi$) was obtained from the variations of the expected traffic over the life of the project, and the volatility parameter ($\sigma$) was 3.16% per year. The resulting risk premium was found to be $\varphi = 4.07\%$.

The Net Present Value (NPV) found was the same as the NPV of the static analysis and the probability distribution of the NPV to be negative was 41.5%, which shows that the project is very risky and supports the government of Bahia's decision to include risk mitigation clauses in the concession contract. on the other hand, when the guarantees were introduced, there was no chance of the NPV being negative and the expected NPV project was approximately $360 million, in addition, the expected liabilities of the project for the government were approximately $326 million. So, the government guarantees removed the concessionaire risk and significantly increased its NPV, demonstrating the use of excessive guarantees. Figure 4.2 compares the project NPV probability distribution with and without the MTG.

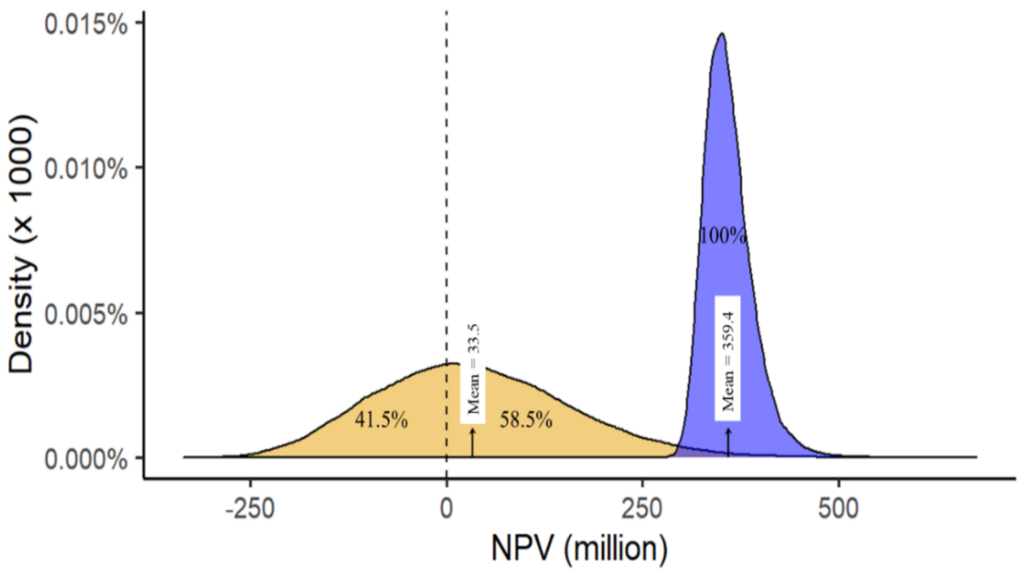


**Figure 4.2 –** Comparison of the project NPV probability distribution with and without the MTG.

Source: Author

### 4.5.2. Finding the optimal tiers of traffic Guarantees

Given the high traffic risk of the project, the government offers the mechanism of minimum traffic guarantees to mitigate these risks. However, the original guarantees provide were excessive as we have seen, and thus is non optimal. Our objective then is to determine the optimal guarantees level that ensures that the project remain viable feasible without imposing an undue financial burden on the government´s budget. To achieve this, we apply the model developed in Eqs. (4.11) to (4.14).

We assume that the project leverage (Debt/Asset ratio) is 70% of CAPEX Investments, with debt service interest rate of 5.38% and the repayment period of 20 years from the first year of concession term. We use a confidence level $(\alpha)$ equal a 10% to calculate the Conditional Value at Risk $(CVaR_{\alpha})$. The maximum probability of default $(\Psi)$ is limited to 0.30% and the maximum risk of project not being profitable for the concessionaire $(\Theta)$ is limited to 10%. The government's risk aversion measure $(\lambda)$ was assumed to be 0.5. These parameters are summarized in Table 4.3.

**Table 4.3 –** Model Parameters

| Parameters | Values |
|---|---|
| Debt/Asset ratio | 70% |
| Interest rate | 5.38% |
| Loan repayment period ($T_d$) | 20 years |
| Confidence level ($\alpha$) | 10% |
| Maximum probability of default ($\Psi$) | 0.3% |
| Maximum concessionaire risk ($\Theta$) | 10% |
| Government's risk aversion measure ($\lambda$) | 0.5 |

Source: Author

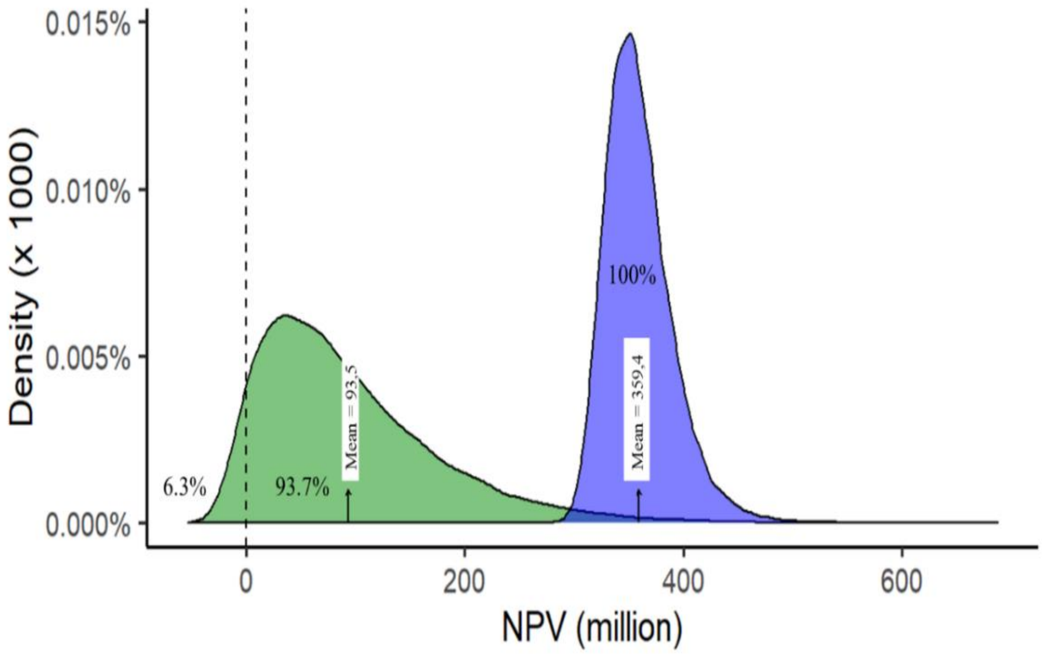


**Figure 4.3 –** Comparison between the project NPV probability distribution resulting from our model ($\beta = 42\%$) and with the project base case NPV with original MTG.

Source: Author

Applying the model proposed in section 4 to the Salvador-Itaparica Bridge project and considering the parameters in Table 4.3, we can determine the tier of traffic bounds $\beta$ that minimize Eq. (4.11) subject to the restrictions of Eqs. (4.12) - (4.14). The simulation results suggest that $\beta = 42\%$ is the optimal value of traffic bounds and consequently, the expected liability of the project for the government was \$60 million, with $CVaR_{10\%} = \$166.5$ million, the expected NPV of the project for the concessionaire was $93 million, with a 6.3% of risk of the project not being profitable, and the Probability of Default was 0%. As can be seen, the expected liabilities of the project for the government were significantly reduced by 81% of the government's original guarantees. At the same time, the concessionaire risk is very low, which maintain the project attractive for private investments. The Figure 4.3 presents a comparison between the probability distribution of NPV project when $\beta = 42\%$ from our model and the base case NPV project.

### 4.5.3. Sensitivity Analysis

We perform a sensitivity analysis on the MTG period with the other parameters previously presented for each MTG period, which varies from 1 to 30 years (concession Term), in order to find the optimal tier of traffic bounds $\beta$, which minimizes Eqs. (4.11) subject to the restriction of Eqs. (4.12)-(4.14), for each MTG period. The model results for each MTG period are summarized in Table 4.4.

As can be seen, the optimal solution of simulation was for the 7 years for the MTG period values and $\beta = 19\%$ as the optimal value of traffic bounds. In this case, the expected liabilities of the project for the government are approximately $66.7 million, with $CVaR_{10\%} = 148.5$ million, the expected NPV of the project for the concessionaire is $100 million, with a risk of 9,87% of the project not being profitable, and the Probability of Default is 0.02%. Therefore, the concessionaire NPV and the concessionaire risk has been increased.

The higher PD values, when MTG period is greater than 20 years, is due to the wider optimal bands $\beta$, which increase the risk as there is less government guarantee, despite covering the entire MTG period. The comparison between probability distribution of NPV project when MTG period is 7 years ($\beta = 19\%$) and when MTG period is 15 years ($\beta = 42\%$) is shown in Figure 4.4.

**Table 4.4 –** Model results for each MTG period

| **MTG Period** (years) | **Traffic Bounds** $\beta$ | **Obj. Function** (millions) | **Gov. Liab.** $E[X(\beta)]$ (millions) | **Gov. Risk** $CVaR_{10\%}[X(\beta)]$ (millions) | **NPV** (millions) | **Conc. Risk** $\text{Prob}[NPV < 0]$ (Eq. 4.12) | **Lender Risk** $PD$ (Eq. 4.13) |
|---|---|---|---|---|---|---|---|

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **1** | There is no viable solution in this region | | | | | | |
| **2** | | | | | | | |
| **3** | | | | | | | |
| **4** | | | | | | | |
| **5** | 6% | 110.9 | 79.4 | 142.3 | 112.9 | 9.74% | 0.06% |
| **6** | 13% | 110.5 | 73.8 | 147.3 | 107.2 | 9.34% | 0.03% |
| **7** | 19% | 107.6 | 66.7 | 148.5 | 100.1 | 9.87% | 0.02% |
| **8** | 23% | 109.6 | 64.9 | 154.2 | 98.3 | 9.06% | 0.00% |
| **9** | 27% | 108.2 | 61.0 | 155.3 | 94.5 | 9.53% | 0.00% |
| **10** | 30% | 109.8 | 60.4 | 159.2 | 93.9 | 8.88% | 0.00% |
| **11** | 33% | 109.3 | 58.7 | 159.9 | 92.2 | 8.94% | 0.00% |
| **12** | 35% | 113.9 | 61.4 | 166.5 | 94.8 | 6.77% | 0.00% |
| **13** | 38% | 109.9 | 57.9 | 161.8 | 91.4 | 8.49% | 0.00% |
| **14** | 40% | 112.0 | 59.3 | 164.8 | 92.7 | 7.11% | 0.00% |
| **15** | 42% | 113.3 | 60.1 | 166.4 | 93.5 | 6.31% | 0.00% |
| **16** | 44% | 113.6 | 60.3 | 166.9 | 93.8 | 5.98% | 0.00% |
| **17** | 46% | 113.2 | 60.1 | 166.3 | 93.5 | 6.20% | 0.00% |
| **18** | 48% | 112.0 | 59.3 | 164.6 | 92.8 | 6.99% | 0.00% |
| **19** | 50% | 110.0 | 58.1 | 161.8 | 91.5 | 8.40% | 0.00% |
| **20** | 51% | 116.4 | 62.8 | 170.0 | 96.3 | 4.98% | 0.00% |
| **21** | 53% | 113.0 | 60.6 | 165.4 | 94.1 | 7.16% | 0.01% |
| **22** | 55% | 109.0 | 58.0 | 159.9 | 91.4 | 9.80% | 0.25% |
| **23** | 55% | 124.0 | 69.0 | 179.0 | 102.4 | 2.46% | 0.25% |
| **24** | 55% | 140.1 | 81.1 | 199.0 | 114.6 | 0.03% | 0.25% |
| **25** | 55% | 157.1 | 94.3 | 219.8 | 127.8 | 0.00% | 0.25% |
| **26** | 55% | 175.0 | 108.6 | 241.5 | 142.0 | 0.00% | 0.25% |
| **27** | 55% | 193.9 | 123.9 | 264.0 | 157.3 | 0.00% | 0.25% |
| **28** | 55% | 213.7 | 140.1 | 287.3 | 173.6 | 0.00% | 0.25% |
| **29** | 55% | 234.4 | 157.4 | 311.4 | 190.8 | 0.00% | 0.25% |
| **30** | 55% | 255.8 | 175.6 | 336.1 | 209.0 | 0.00% | 0.25% |

Source: Author

The expected liabilities of the project for the government were reduced significantly, 80% from the original guarantees, while still allowing the concessionaire risk to be attractive for private investments. Despite the government's expected liabilities having increased, the government's risk reduction balanced the objective function, making this a better solution compared to results when the MTG period is 15 years ($\beta = 42\%$). Figure 4.5 compares the probability distribution of government liabilities when the MTG period is 7 years ($\beta = 19\%$) and when the MTG period is 15 years ($\beta = 42\%$).

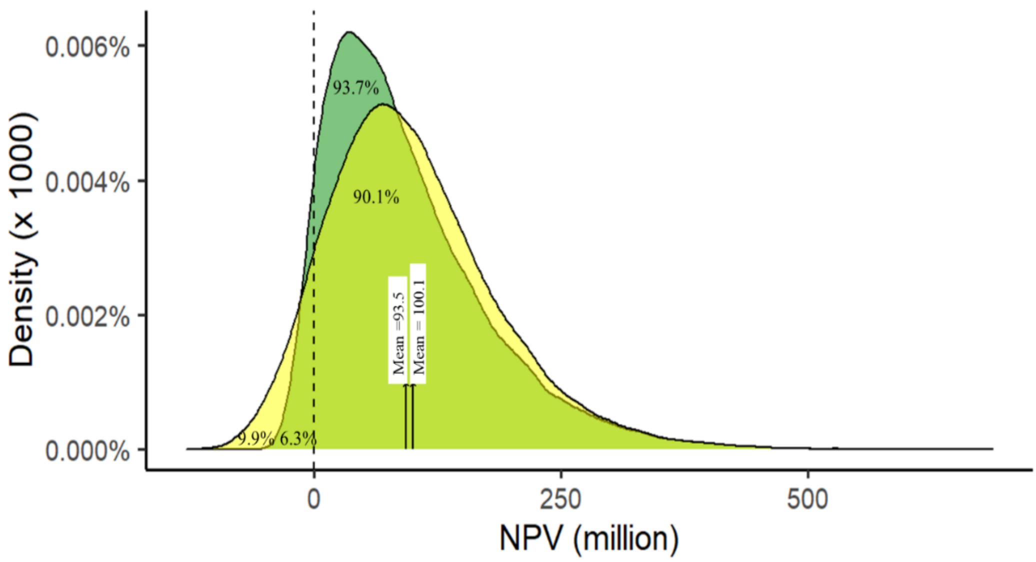


**Figure 4.4 –** Comparison between the project NPV probability distribution when MTG period is 15 years (green) and when MTG period is 7 years (yellow)

Source: Author

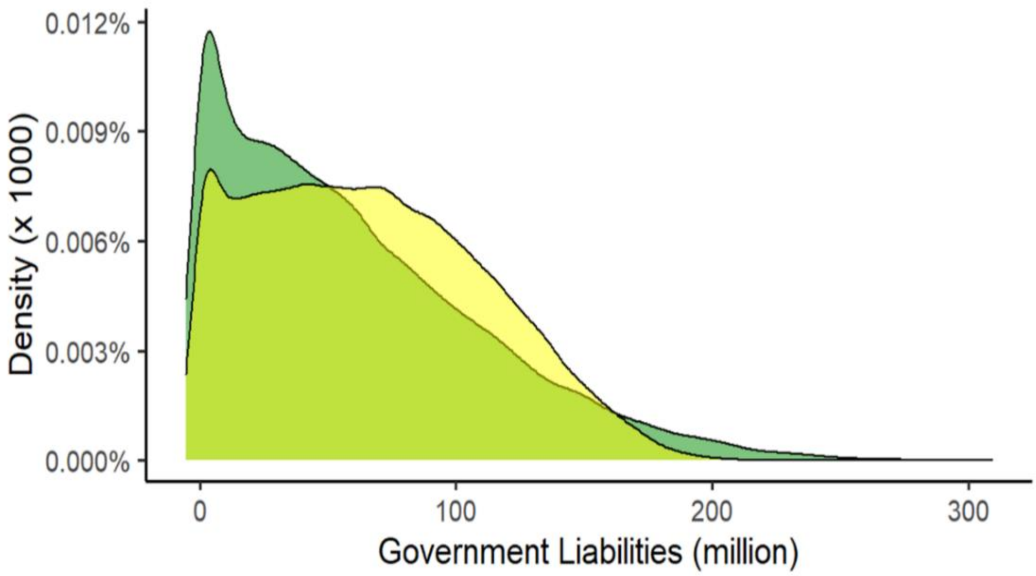


**Figure 4.5 –** Comparison between the project government liabilities probability distribution when MTG period is 15 years (green) and when MTG period is 7 years (yellow)

Note: The lack of smoothness in Figure 4.5 is due to the limitation on the granularity of the simulation

Source: Author

To better understand the effect of some key input parameters on the outputs of the model, we perform a sensitivity analysis on the concessionaire´s risk limit

$(\Theta)$ and the government's risk aversion measure $(\lambda)$. The results are shown in Table 4.5.

**Table 4.5 –** Optimal results for the Sensitivity Analysis of the concessionaire risk limit (θ) and the government's risk aversion measure (λ)

| **λ** | **Θ** | **MTG Period** (years) | **Traffic Bounds** $\beta$ | **Obj. Func.** (millions) | **Gov. Liab.** $E[X(\beta)]$ (millions) | **Gov. Risk** $CVar_{10\%}[X(\beta)]$ (millions) | **NPV** (millions) | **Conc. Risk** $\mathrm{Prob}[NPV_C < 0]$ (Eq. 4.12) | **Lender Risk** $PD$ (Eq. 4.13) |
|---|---|---|---|---|---|---|---|---|---|
| **0** | **0%** | 21 | 50% | 82.6 | 82.6 | 203.5 | 116.0 | 0.0% | 0.00% |
| | **5%** | 20 | 51% | 62.8 | 62.8 | 170.0 | 96.3 | 5.0% | 0.00% |
| | **10%** | 13 | 38% | 57.9 | 57.9 | 161.8 | 91.4 | 8.5% | 0.00% |
| | **20%** | 13 | 41% | 42.9 | 42.9 | 133.8 | 76.4 | 20.0% | 0.00% |
| **0.25** | **0%** | 21 | 50% | 112.8 | 82.6 | 203.5 | 116.0 | 0.0% | 0.00% |
| | **5%** | 20 | 51% | 89.6 | 62.8 | 170.0 | 96.3 | 5.0% | 0.00% |
| | **10%** | 22 | 55% | 83.5 | 58.0 | 159.9 | 91.4 | 9.8% | 0.25% |
| | **20%** | 8 | 28% | 64.0 | 43.8 | 124.5 | 77.2 | 19.9% | 0.16% |
| **0.50** | **0%** | 21 | 50% | 143.0 | 82.6 | 203.5 | 116.0 | 0.0% | 0.00% |
| | **5%** | 20 | 51% | 116.4 | 62.8 | 170.0 | 96.3 | 5.0% | 0.00% |
| | **10%** | 7 | 19% | 107.6 | 66.7 | 148.5 | 100.1 | 9.9% | 0.02% |
| | **20%** | 6 | 20% | 82.2 | 47.8 | 116.6 | 81.2 | 19.2% | 0.25% |
| **0.75** | **0%** | 21 | 50% | 173.3 | 82.6 | 203.5 | 116.0 | 0.0% | 0.00% |
| | **5%** | 20 | 51% | 143.2 | 62.8 | 170.0 | 96.3 | 5.0% | 0.00% |
| | **10%** | 5 | 6% | 126.6 | 79.4 | 142.3 | 112.9 | 9.7% | 0.06% |
| | **20%** | 5 | 14% | 98.3 | 52.8 | 113.4 | 86.2 | 18.2% | 0.28% |
| **1** | **0%** | 21 | 50% | 203.5 | 82.6 | 203.5 | 116.0 | 0.0% | 0.00% |
| | **5%** | 6 | 8% | 169.1 | 94.2 | 169.1 | 127.6 | 4.7% | 0.00% |
| | **10%** | 5 | 6% | 142.3 | 79.4 | 142.3 | 112.9 | 9.7% | 0.06% |
| | **20%** | 4 | 5% | 111.8 | 61.4 | 111.8 | 94.8 | 16.9% | 0.28% |

Source: Author

It can be observed that as the concessionaire risk limit $(\Theta)$ increases, the objective function value and the optimal period of the MTG decrease. Consequently, the concessionaire's net present value, the government's liabilities and the government's risk decrease. For example, when $\lambda = 1$, increasing the $\Theta$ value reduces the MTG period from 21 years to 4 years, and thus, the concessionaire's net present value, the government's liabilities and the government's risk were reduced by 18%, 25% and 42%, respectively. Another consequence of increasing the concessionaire risk limit value $\Theta$ is that the number of optimal results increases from only a single optimal result when $\Theta = 0\%$, to up to five different optimal results when $\lambda = 20\%$. This suggests that the $\Theta$ parameter has a large impact on the choice of optimal results.

When $\lambda = 0$ the model prioritizes reducing only the expected government liabilities, resulting in the smallest governments liabilities for all variables $\Theta$ chosen. For the a same MTG period, $\beta$ increases with $\Theta$. For example, for both $\Theta = 10\%$ and $\Theta = 20\%$ the MTG period was 13 years, but $\beta$ is larger for the latter. On the other hand, when $\lambda = 1$, the model prioritizes reducing only the expected government risk, resulting in the lowest $CVaR_{10\%}$ of government liabilities considering the worst 10% scenarios of government liabilities. In this case, compared with the other results from $\lambda$, the model shortens the MTG period, even if the government's liabilities increase, because the government´s liabilities probability distribution is longer-tailed on the right according to the increase of the MTG period. Thus, the longer the MTG period, the greater the incidence of extreme values for the government liabilities. For example, comparing the scenarios when MTG period is 7 and 15 years, we observe in Figure 4.5 that the government´s liabilities probability distribution is longer-tailed to the right for 15 years as MTG period.

For each concessionaire risk limit $\Theta = 0\%$, $\Theta = 10\%$ and $\Theta = 20\%$, the comparison between the objective function value and the concessionaire's net present value for λ = 0, λ = 0,5 and λ = 1, from each MTG periods, is shown in Figure 4.6.

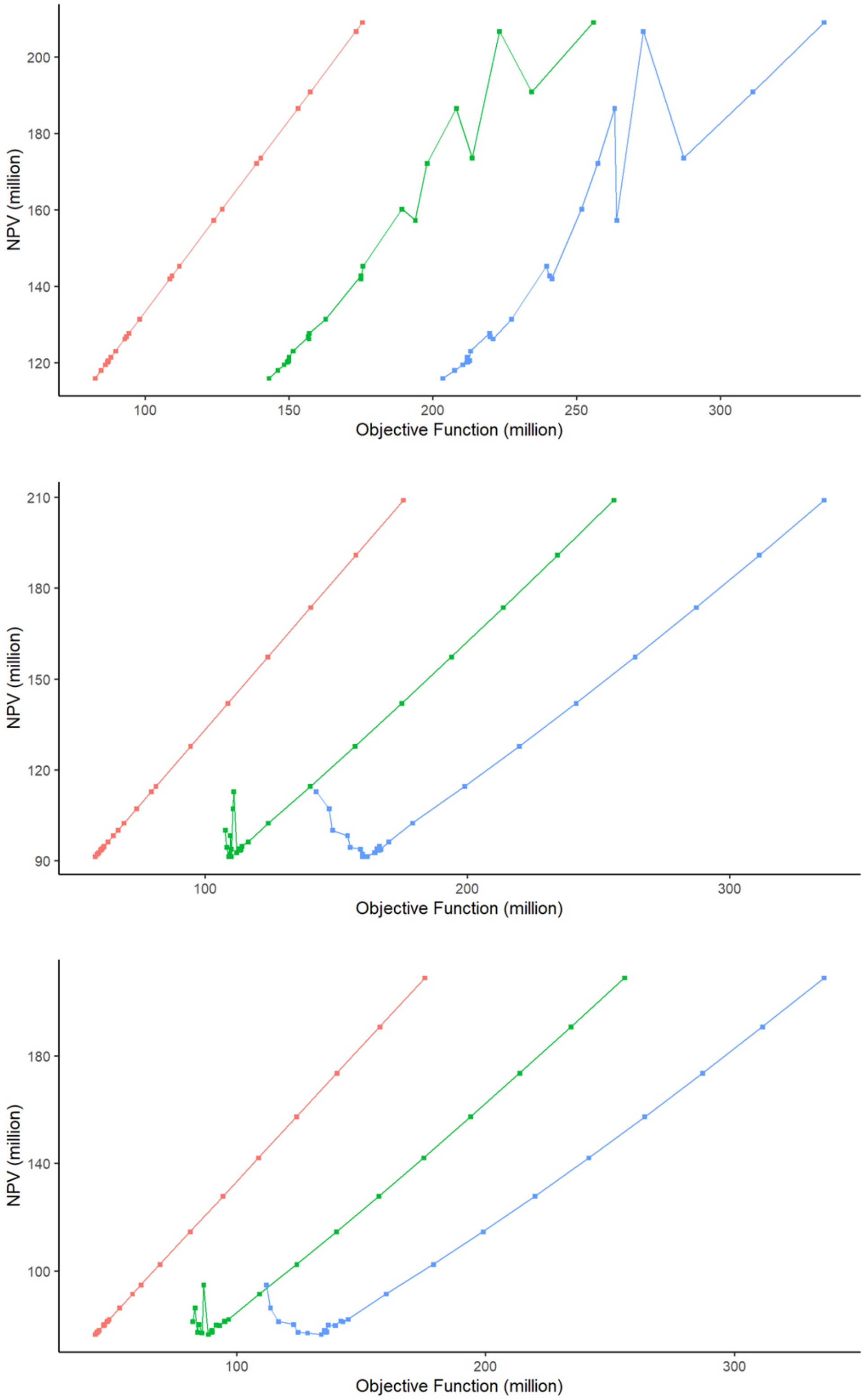


**Figure 4.6 –** Comparison between the objective function value and the concessionaire's net present value.

Note: The concessionaire risk limit $\Theta = 0\%$, $\Theta = 10\%$ and $\Theta = 20\%$ are shown respectively on the top, on the middle and the bottom. The red, green and blue lines represent λ = 0, λ = 0,5 and λ = 1 respectively.

Source: Author

## 4.6. Conclusions

Minimum Traffic Guarantees, also known as Demand Guarantees, have been a widely adopted risk sharing mechanism for PPP ventures as a way to attract private investments for high-risk projects. The choice of the cap and floor traffic levels in these models, however, has significant implications for the government´s future contingent liabilities. While these mechanisms can affect the government's deficits and the magnitude of its future obligations, this issue has been largely ignored by government officials and policymakers in general.

In this work, we propose an optimization model that addresses the issue of determining the optimal values of the traffic cap and floor of the MTG mechanism. Our model seeks to minimize the potential impact of these contract guarantees on the public budget, while also ensuring an appropriate risk sharing between the public and private partners for the implementation of the PPP project. We assume that the project is essential for society and the government´s objective is to minimize the impact on the public budget and associated risks. We also take into account the interests of both concessionaires and lenders by setting a maximum acceptable risk level that each will bear.

For a numerical example we apply the model to the case of the Salvador-Itaparica Bridge Road System, where incorrect cap and floor levels resulted on the government taking on excessive risk and significant future fiscal liabilities, as shown by Sant´Anna et al. (2022). Our results show that by adopting the optimal guarantee levels indicated by the model for a 15 years period, the expected government liabilities were reduced by 81%, or $300 million dollars, compared to the original contractual values. The optimal levels indicate that the project has a small probability (6.3%) of not being profitable for the concessionaire and no risk of default for the lender. A sensitivity analysis on the MTG period indicated that the project's MTG guarantees period should last only last 7 years, which would further reduce the risk of the financial burden on the government´s budget while the risk to the concessionaire and lender risks are still small enough to be attractive for private investments. Finally, we showed that by changing key input parameters such as the maximum risk limit accepted by the concessionaire and the government’s risk aversion measure, the optimal cap and floor levels can be tailored to the best interests of the government and policymakers.

By integrating various stakeholders' interests and aligning them with the project's importance, our optimization model offers a comprehensive approach to decision-making. Its outcomes can guide policymakers in creating the necessary incentives and risk mitigation strategies to facilitate the successful implementation of PPP projects. This work contributes to public policy on the analysis of the fiscal impact of contingent government guarantees in PPP projects by showing how to optimally determine the level of these guarantees and determine their costs. It can also assist policymakers in adequately pricing these contractual clauses in infrastructure projects, help governments allocate scarce resources for public infrastructure investment projects, and encourage private investors interested in better understanding the impact of these mechanisms.

## 4.7. Appendix

The R-code used to generate the models for this chapter is described in this appendix.

### 4.7.1 Function.R

```
TRIBUTOS.function <- function(EBTIDA) {
  LUCROTRIBUTAVEL <- EBTIDA
  IPCA <- rep(0.04,36)
  PREJUIZOSACOMPENSAR <- rep(0,36)
  PREJUIZOSACUMULADOSACOMPENSAR <- rep(0,36)
  PREJUIZOSCOMPENSAVEIS  <- rep(0,36)
  BASEIR <- rep(0,36)
  TRIBUTOS <- rep(0,36)
  for (i in 2:36) {
    if (LUCROTRIBUTAVEL[i]<0){
      PREJUIZOSACOMPENSAR[i] <- LUCROTRIBUTAVEL[i]
    }
    if (i>2){
      PREJUIZOSACUMULADOSACOMPENSAR[i] <-
(PREJUIZOSACUMULADOSACOMPENSAR[i-
1]+PREJUIZOSCOMPENSAVEIS [i-1])/(1+IPCA[i]) +
PREJUIZOSACOMPENSAR[i]
    } else {
      PREJUIZOSACUMULADOSACOMPENSAR[i] <-
PREJUIZOSACOMPENSAR[i]
    }
    if (LUCROTRIBUTAVEL[i]>=0 &
PREJUIZOSACUMULADOSACOMPENSAR[i]<0){
      if (-
PREJUIZOSACUMULADOSACOMPENSAR[i]>0.3*LUCROTRIBUTAVEL[i]
){
        PREJUIZOSCOMPENSAVEIS[i] <- 0.3*LUCROTRIBUTAVEL[i]
      } else {
        PREJUIZOSCOMPENSAVEIS[i] <- -
PREJUIZOSACUMULADOSACOMPENSAR[i]
      }
    }
    BASEIR[i] <- LUCROTRIBUTAVEL[i] - PREJUIZOSCOMPENSAVEIS[i]
    if (BASEIR[i]>0) {
      TRIBUTOS[i] <- BASEIR[i]*0.15
      if (BASEIR[i]>=240/4.0301) {
        TRIBUTOS[i] <- TRIBUTOS[i] + (BASEIR[i]-240/4.0301)*0.10
      }
      if (i<=16) {
```

```
      TRIBUTOS[i] <- TRIBUTOS[i]*0.25
     }
     TRIBUTOS[i] <- TRIBUTOS[i] + BASEIR[i]*0.09
   }
  }
  return(TRIBUTOS)
}


NCG.function <- function(RECbruta,CUSTOS, TRIBUTOS) {
  Nreceber <- 20
  Npagar <- 20
  Nrecolher <- 20
  NCG  <- rep(0,36)
  VAR.NCG <- rep(0,36)
  for (i in 2:(36-1)) {
    NCG[i] <- (Nreceber*RECbruta[i] - Npagar*PAR[[2]][i] -
Nrecolher*TRIBUTOS[i])/360
    VAR.NCG[i] <- NCG[i] - NCG[i-1]
  }
  VAR.NCG[36] <- NCG[36] - NCG[36-1]

  return(VAR.NCG)
}


lambda.function <- function(){
  lambda <- 0
  lambda <- optimize(function(lambda) abs(NEUTRO.function(lambda) -
NPVproj), tol = 0.00000001, lower=-1, upper=1)$minimum
  return(lambda)
}

NEUTRO.function <- function(lambda){
  TRAFEGOneutro <- rep(0,36)
  TRAFEGOneutro[1] <- TRAFEGOproj[1]
  for (i in 2:(36)) {
    TRAFEGOneutro[i] <- TRAFEGOneutro[i-1]*exp(TXCRESC[i] - lambda)
  }
  FCneutro <- FC.function(TRAFEGOneutro, PAR)
  NPV <- npv(r,FCneutro)
  return(NPV)
}



FC.function <- function(TRAFEGO, PAR){

  RECbruta <- TRAFEGO*TARIFita/1000 + PAR[[1]]*TARIFfun/1000
  RECbruta[1:6] <- 0
```

```
  IMPOSTOS <- RECbruta*(0.05+0.0065+0.03)
  FC <- RECbruta -IMPOSTOS
  EBTIDA <- FC - PAR[[2]]
  FC <- EBTIDA - PAR[[3]]
  TRIBUTOS <- TRIBUTOS.function(EBTIDA)
  FC <- FC-TRIBUTOS
  TRIBUTOS <- TRIBUTOS + IMPOSTOS
  FC <- FC +  PAR[[3]] - NCG.function(RECbruta,PAR[[2]], TRIBUTOS)
  FC <- FC +  PAR[[4]]
  return(FC)
}


NPV.function <- function(r, FC) {
  NPV <- 0
  for (i in 1:length(FC)) {
    NPV <- NPV + FC[i]*exp(-(i-1)*r)
  }
  return(NPV)
}

MC.function <- function(n) {
  TRAFEGOestneutro <- matrix(0,nrow = 36, ncol = n)
  TRAFEGOest <- matrix(0,nrow = 36, ncol = n)
  for (j in 1:n) {
    TRAFEGOestneutro[1,j] <- rtri(1, min = 0.7*TRAFEGOproj, max =
1.3*TRAFEGOproj, mode = TRAFEGOproj)
    TRAFEGOest[1,j] <- TRAFEGOestneutro[1,j]
    for (i in 2:(36)) {
      TRAFEGOest[i,j] <- TRAFEGOest[i-1,j]*exp(rnormTrunc(1, mean =
TXCRESC[i] - (vol^2)/2, sd = vol))
      TRAFEGOestneutro[i,j] <- TRAFEGOestneutro[i-1,j]*exp(rnormTrunc(1,
mean = TXCRESC[i] - lambda - (vol^2)/2, sd = vol))
    }
  }
  MC.list <- list(TRAFEGOestneutro, TRAFEGOest)
  return(MC.list)
}


OPCOES1.function <- function(TRAFEGOestneutro, B, PRAZO) {
  n <- dim(TRAFEGOestneutro)[2]
  BANDA_U <- rep(0,36)
  BANDA_L <- rep(0,36)
  for (i in 7:(PRAZO+6)) {
    BANDA_U[i] <- TRAFEGOproj[i]*(1+B/100)
    BANDA_L[i] <- TRAFEGOproj[i]*(1-B/100)
  }
  NPVopcoes <- rep(0,n)
  NPVcall <- rep(0,n)
```

```
  NPVput <- rep(0,n)
  FCopcoes <- matrix(0,36,n)
  CALL <- matrix(0,36,n)
  PUT <- matrix(0,36,n)
  for (j in 1:n) {
    for (i in 7:(PRAZO+6)) {
      if (TRAFEGOestneutro[i,j] > BANDA_U[i]) {
        CALL[i,j] <- TRAFEGOestneutro[i,j]-BANDA_U[i]
      } else if (TRAFEGOestneutro[i,j] < BANDA_L[i]) {
        PUT[i,j] <- BANDA_L[i] - TRAFEGOestneutro[i,j]

      }
    }
    NPVopcoes[j] <- NPV.function(r,FCopcoes[,j])
    CALL[,j] <- CALL[,j]*TARIFita/1000
    PUT[,j] <- PUT[,j]*TARIFita/1000
    NPVcall[j] <- NPV.function(r,CALL[,j])
    NPVput[j] <- NPV.function(r,PUT[,j])
    FCopcoes[,j] <- FC.function(TRAFEGOestneutro[,j], PAR)
    NPVopcoes[j] <- npv(r,FCopcoes[,j]) + NPVput[j] - NPVcall[j]
  }
  GOV <- NPVput-NPVcall
  H <- CVAR.function2(0.10, GOV)
  W <- NPVneg.function(NPVopcoes)
  OPCOES.lista <- list(mean(GOV),H,mean(NPVopcoes), W, FCopcoes,PUT,
CALL, NPVput, NPVcall, NPVopcoes, GOV)

  return(OPCOES.lista)
}


OPCOES2.function <- function(TRAFEGOestneutro, b1, b2, d, alfa, PRAZO) {
  n <- dim(TRAFEGOestneutro)[2]
  b1 <- round(b1)/100
  b2 <- round(b2)/100
  BANDA_U1 <- rep(0,36)
  BANDA_U2 <- rep(0,36)
  BANDA_L1 <- rep(0,36)
  BANDA_L2 <- rep(0,36)
  FCopcoes <- matrix(0,36,n)
  for (i in 7:(PRAZO+6)) {
    BANDA_U2[i] <- TRAFEGOproj[i]*(1+b1+b2)
    BANDA_U1[i] <- TRAFEGOproj[i]*(1+b1)
    BANDA_L1[i] <- TRAFEGOproj[i]*(1-b1)
    BANDA_L2[i] <- TRAFEGOproj[i]*(1-b1-b2)
  }
  NPVopcoes <- rep(0,n)
  NPVcall1 <- rep(0,n)
  NPVcall2 <- rep(0,n)
  NPVput1 <- rep(0,n)
```

```
  NPVput2 <- rep(0,n)

  for (j in 1:n) {
    CALL1 <- rep(0,36)
    CALL2 <- rep(0,36)
    PUT1 <- rep(0,36)
    PUT2 <- rep(0,36)
    for (i in 7:(PRAZO+6)) {
      if (TRAFEGOestneutro[i,j] > BANDA_U2[i]) {
        CALL2[i] <- TRAFEGOestneutro[i,j]-BANDA_U2[i]+(BANDA_U2[i]-
BANDA_U1[i])*d
      } else if (TRAFEGOestneutro[i,j] >= BANDA_U1[i] &&
TRAFEGOestneutro[i,j] <= BANDA_U2[i]) {
        CALL1[i] <- (TRAFEGOestneutro[i,j]-BANDA_U1[i])*d

      } else if (TRAFEGOestneutro[i,j] >= BANDA_L2[i] &&
TRAFEGOestneutro[i,j] < BANDA_L1[i]) {
        PUT1[i] <- (BANDA_L1[i]-TRAFEGOestneutro[i,j])*d
      } else if (TRAFEGOestneutro[i,j] < BANDA_L2[i]) {
        PUT2[i] <- BANDA_L2[i] - TRAFEGOestneutro[i,j] +(BANDA_L1[i]-
BANDA_L2[i])*d
      }
    }
    CALL1 <- CALL1*TARIFita/1000
    CALL2 <- CALL2*TARIFita/1000
    PUT1 <- PUT1*TARIFita/1000
    PUT2 <- PUT2*TARIFita/1000
    NPVcall1[j] <- NPV.function(r,CALL1)
    NPVcall2[j] <- NPV.function(r,CALL2)
    NPVput1[j] <- NPV.function(r,PUT1)
    NPVput2[j] <- NPV.function(r,PUT2)
    FCopcoes[,j]<-FC.function(TRAFEGOestneutro[,j], PAR)
    NPVopcoes[j] <- npv(r,FCopcoes[,j]) +  (NPVput1[j]+NPVput2[j]) -
(NPVcall1[j]+NPVcall2[j])
  }
  GOV <- NPVput1+NPVput2-NPVcall1-NPVcall2
  Y<- CVAR.NPVneg.function(NPVopcoes)
  W <- NPVneg.function(NPVopcoes)
  H<- CVAR.function2(alfa, GOV)
  OPCOES.lista <- list(mean(GOV), H, mean(NPVopcoes), W, Y, FCopcoes,
NPVopcoes, GOV)
  return(OPCOES.lista)
}

VAR.function <- function(alfa, MC) {
  MC <- sort(MC)
  x<-length(MC)*alfa
  return(MC[x])
}
CVAR.function <- function(alfa, MC) {
```

```
  MC <- sort(MC)
  x<-length(MC)*alfa-1
  if (x>0) {MC <- MC[1:x]}
  else {MC <- 0}
  return(mean(MC))
}

CVAR.function2 <- function(alfa, MC) {
  MC <- sort(MC,  decreasing = TRUE)
  x<-length(MC)*alfa-1
  if (x>0) {MC <- MC[1:x]}
  else {MC <- 0}
  return(mean(MC))
}

ALFA.function <- function(custo.max, MC) {
  x <- length(MC[MC<=custo.max])
  return(x/length(MC))
}

NPVneg.function <- function(MC) {
  x <- MC[MC<0]
  if (length(x)> 0) {x <- length(x)/length(MC)}
  else {x <- 0}

  return(x)
}

GOVneg.function <- function(GOV, MAXIMO) {
  z <- GOV[GOV>MAXIMO]
  if (length(z)> 0) {z <- length(z)/length(GOV)}
  else {z <- 0}
  return(z)
}

CVAR.NPVneg.function <- function(MC) {
  x <- MC[MC<0]
  if (length(x)> 0) {x <- mean(x)}
  else {x <- 0}

  return(mean(x))
}


PD.function <- function(FC, PUT, CALL,  td, debtratio) {
  n <- dim(FC)[2]
  PGTO <- pmt(rbndes,td,-investimentos*debtratio,0)
  D <- pv(r, td,0,-PGTO)
  x <- 0
  FC <- FC[(6+1):(6+td),]
```

```
  PUT <- PUT[(6+1):(6+td),]
  CALL <- CALL[(6+1):(6+td),]
  for (j in 1:n) {
    NPV <- npv(r,FC[,j]) + NPV.function(r, PUT[,j]) - NPV.function(r, CALL[,j])
    if (NPV < D) {
      x <- 1+x
    }
  }
  PD <- (x/n)/td
  return(PD)
}


MCest.function <- function(TRAFEGOest, td, debtratio) {
  n <- dim(TRAFEGOest)[2]
  PGTO <- pmt(rbndes,td,-investimentos*debtratio,0)
  D <- pv(wacc, td,0,-PGTO)
  x <- 0
  FCest<- matrix(0,36,n)
  NPVest <- rep(0,n)
  for (j in 1:n) {
    FCest[,j] <- FC.function(TRAFEGOest[,j], PAR)
    NPVest[j] <- npv(wacc,FCest[,j])
    FC <- FCest[(6+1):(6+td),j]
    NPV <- npv(wacc,FC)
    if (NPV < D) {
      x <- 1+x
    }
  }

  W <- NPVneg.function(NPVest) # PROB[NPV<0]
  PD <- (x/n)/td
  MCest <- list(NPVest, mean(NPVest), W,PD)
  return(MCest)
}


MCopcoes.function <- function(TRAFEGOestneutro) {
  n <- dim(TRAFEGOestneutro)[2]
  BANDA_U2 <- rep(0,36)
  BANDA_U1 <- rep(0,36)
  BANDA_L1 <- rep(0,36)
  BANDA_L2 <- rep(0,36)
  for (i in 7:21) {
    BANDA_U2[i] <- TRAFEGOproj[i]*(1+20/100)
    BANDA_U1[i] <- TRAFEGOproj[i]*(1+10/100)
    BANDA_L1[i] <- TRAFEGOproj[i]*(1-10/100)
    BANDA_L2[i] <- TRAFEGOproj[i]*(1-20/100)
  }
  NPVopcoes <- rep(0,n)
```

```
  NPVcall <- rep(0,n)
  NPVput <- rep(0,n)
  FCopcoes <- matrix(0,36,n)
  TRAFEGOopcoes <- matrix(0,36,n)
  for (j in 1:n) {
    CALL1 <- rep(0,36)
    CALL2 <- rep(0,36)
    PUT1 <- rep(0,36)
    PUT2 <- rep(0,36)
    for (i in 7:21) {
      if (TRAFEGOestneutro[i,j] > BANDA_U2[i]) {
        CALL2[i] <- TRAFEGOestneutro[i,j] - BANDA_U2[i] + (BANDA_U2[i] -
BANDA_U1[i])*0.7
      }
      if (TRAFEGOestneutro[i,j] >= BANDA_U1[i] & TRAFEGOestneutro[i,j] <=
BANDA_U2[i]) {
        CALL1[i] <- (TRAFEGOestneutro[i,j] - BANDA_U1[i])*0.7
      }
      if (TRAFEGOestneutro[i,j] <= BANDA_L1[i] & TRAFEGOestneutro[i,j] >=
BANDA_L2[i]) {
        PUT1[i] <- (BANDA_L1[i] - TRAFEGOestneutro[i,j])*0.7
      }
      if (TRAFEGOestneutro[i,j] < BANDA_L2[i]) {
        PUT2[i] <- BANDA_L2[i] - TRAFEGOestneutro[i,j] + (BANDA_L1[i] -
BANDA_L2[i])*0.7
      }
    }
    FCopcoes[,j] <- FC.function(TRAFEGOestneutro[,j], PAR)
    CALL1 <- CALL1*TARIFita/1000
    CALL2 <- CALL2*TARIFita/1000
    PUT1 <- PUT1*TARIFita/1000
    PUT2 <- PUT2*TARIFita/1000
    NPVcall[j] <- NPV.function(r,CALL1) + NPV.function(r,CALL2)
    NPVput[j] <- NPV.function(r,PUT1) + NPV.function(r,PUT2)
    NPVopcoes[j] <- npv(r,FCopcoes[,j]) + NPVput[j] - NPVcall[j]
  }
  GOV <- NPVput-NPVcall

  X<- mean(GOV)
  OPCOES.lista <- list(mean(GOV),mean(NPVopcoes), NPVopcoes)
  return(OPCOES.lista)
}
```

### 4.7.2
### Simulation.R

```
library(readxl)
library(EnvStats)
library(FinCal)
library(ggplot2)
library(scales)

PAR <- read_excel("DATA.xlsx", sheet = "PARAMETROS", range =
cell_cols("B:G"))
TRAFEGOproj <- PAR[[1]]
TXCRESC <- PAR[[2]]
PAR <- PAR[-(1:2)]
TARIFita <- 8.11642391007667
TARIFfun <- 1.24066400337461
r <- 0.032
rbndes <- (wacc+r)/2
wacc <- 0.0756
vol <- 0.0316
investimentos <- 953326
rmax <- 0.15
rmin <- 0.08

FCproj<-FC.function(TRAFEGOproj, PAR)
NPVproj <-npv(wacc,FCproj)
NPVproj

lambda <- lambda.function()
NPVneutro <- NEUTRO.function(lambda)
NPVneutro


TRAFEGOsimulado <- MC.function(50000)
TRAFEGOestneutro <- TRAFEGOsimulado[[1]]
TRAFEGOest <- TRAFEGOsimulado[[2]]

MCest <- MCest.function(TRAFEGOest, 20, 0)

MCopcoes <- OPCOES2.function(TRAFEGOestneutro, 10, 10, 0.7, 0.10, 15)

######################################################################
intervalo <- 1
MATRIZ <- matrix(0, 30, 8)
MATRIZ[ ,3] <- 10000000
k<-0
for (t in 1:30) {
  prazo <- t
  MATRIZ[t, 1] <- prazo
  i <- 0
```

```
  while (i <= 80/intervalo) {
    B <- intervalo*i
    MC <- OPCOES1.function(TRAFEGOestneutro, B, prazo)
    OBJ1 <- (1-0.5)*MC[[1]] + 0.5*MC[[2]]   #CVARgov
    PD <- PD.function(MC[[5]], MC[[6]], MC[[7]], 20, 0.7)
    if ((MC[[4]] > 0.0) | (PD > 0.003)) { i=100 }
    else if (OBJ1 <= MATRIZ[t ,3]) {
      MATRIZ[t ,2] <- B
      MATRIZ[t ,3] <- OBJ1
      MATRIZ[t ,4] <- MC[[1]]
      MATRIZ[t ,5] <- MC[[2]]
      MATRIZ[t ,6] <- MC[[3]]
      MATRIZ[t ,7] <- MC[[4]]
      MATRIZ[t ,8] <- PD
    }
    cat(" T=", t, "B=", B,  "\n")
    i <- i+1
  }
  k <- k+2
}
View(MATRIZ)

######################################################################
x1 <- round(MCest[[2]])
x2 <- round(MCopcoes[[3]])
df <- rbind(data.frame(NPV=MCest[[1]], CATEGORIA =
rep("NPVEST")),data.frame(NPV=MCopcoes[[7]],CATEGORIA =
rep("NPVNEUTRO")))
ggplot(df, aes(x = NPV, fill = CATEGORIA)) + geom_density(alpha = .5,
show.legend = FALSE) +
  scale_y_continuous(labels = percent_format(scale = 1000, accuracy = 0.001)) +
  scale_x_continuous(labels = number_format(scale = 0.001, big.mark=",")) +
  labs(y= "Density (x 1000)", x= "NPV (million)") +
  theme_classic(base_size = 18) + scale_fill_manual(values=c("#E69F00",
"blue"))+
  geom_vline(xintercept = 0, color="black", linetype="dashed") + # Linha x = 0
  geom_segment(aes(x = x1, y = 0, xend = x1, yend = 1e-06),arrow = arrow(length
= unit(0.1,"cm"))) +
  geom_segment(aes(x = x2, y = 0, xend = x2, yend = 1e-06),arrow = arrow(length
= unit(0.1,"cm")))


MCotimo1 <- OPCOES1.function(TRAFEGOestneutro, 42, 15)
PD1 <- PD.function(MCotimo1[[5]], MCotimo1[[6]], MCotimo1[[7]], 20, 0.7)
x1 <- round(MCotimo1[[3]])
x2 <- round(MCopcoes[[3]])
df <- rbind(data.frame(NPV=MCotimo1[[10]], CATEGORIA =
rep("NPVOTIMO")),data.frame(NPV=MCopcoes[[7]],CATEGORIA =
rep("NPVNEUTRO")))
```

```
ggplot(df, aes(x = NPV, fill = CATEGORIA)) + geom_density(alpha = .5,
show.legend = FALSE) +
  scale_y_continuous(labels = percent_format(scale = 1000, accuracy = 0.001)) +
  scale_x_continuous(labels = number_format(scale = 0.001, big.mark=",")) +
  labs(y= "Density (x 1000)", x= "NPV (million)") +
  theme_classic(base_size = 18) + scale_fill_manual(values=c("green4", "blue"))
+
  geom_vline(xintercept = 0, color="black", linetype="dashed") + # Linha x = 0
  geom_segment(aes(x = x1, y = 0, xend = x1, yend = 1e-06),arrow = arrow(length
= unit(0.1,"cm"))) +
  geom_segment(aes(x = x2, y = 0, xend = x2, yend = 1e-06),arrow = arrow(length
= unit(0.1,"cm")))


MCotimo2 <- OPCOES1.function(TRAFEGOestneutro, 19, 7)
PD2 <- PD.function(MCotimo2[[5]], MCotimo2[[6]], MCotimo2[[7]], 20, 0.7)

x1 <- round(MCotimo1[[3]])
x2 <- round(MCotimo2[[3]])
df <- rbind(data.frame(NPV=MCotimo1[[10]], CATEGORIA =
rep("NPVOTIMO1")),data.frame(NPV=MCotimo2[[10]],CATEGORIA =
rep("NPVOTIMO2")))
ggplot(df, aes(x = NPV, fill = CATEGORIA)) + geom_density(alpha = .5,
show.legend = FALSE) +
  scale_y_continuous(labels = percent_format(scale = 1000, accuracy = 0.001)) +
  scale_x_continuous(labels = number_format(scale = 0.001, big.mark=",")) +
  labs(y= "Density (x 1000)", x= "NPV (million)") +
  theme_classic(base_size = 18) + scale_fill_manual(values=c("green4",
"yellow")) +
  geom_vline(xintercept = 0, color="black", linetype="dashed") +
  geom_segment(aes(x = x1, y = 0, xend = x1, yend = 1e-06),arrow = arrow(length
= unit(0.1,"cm"))) +
  geom_segment(aes(x = x2, y = 0, xend = x2, yend = 1e-06),arrow = arrow(length
= unit(0.1,"cm")))

x1 <- round(MCotimo1[[1]])
x2 <- round(MCotimo2[[1]])
df <- rbind(data.frame(GOV=MCotimo1[[11]], CATEGORIA =
rep("OTIMO1")),data.frame(GOV=MCotimo2[[11]],CATEGORIA =
rep("OTIMO2")))
ggplot(df, aes(x = GOV, fill = CATEGORIA)) + geom_density(alpha = .5,
show.legend = FALSE) +
  scale_y_continuous(labels = percent_format(scale = 1000, accuracy = 0.001)) +
  scale_x_continuous(labels = number_format(scale = 0.001, big.mark=",")) +
  labs(y= "Density (x 1000)", x= "Government Liabilities (million)") +
  theme_classic(base_size = 18) + scale_fill_manual(values=c("green4",
"yellow"))

df1 <- data.frame(GOV = MCotimo1[[11]])
```

```
ggplot(df1, aes(x = GOV)) + geom_density(alpha = .5,  show.legend = FALSE,
color="white", fill = "green4") +
  theme_classic(base_size = 18) + geom_vline(xintercept = 0, color="black",
linetype="dashed") # Linha x = 0

df2 <- data.frame(GOV = MCotimo2[[11]])
ggplot(df2, aes(x = GOV)) + geom_density(alpha = .5,  show.legend = FALSE,
color="white", fill = "yellow") +
  theme_classic(base_size = 18) + geom_vline(xintercept = 0, color="black",
linetype="dashed") # Linha x = 0
```

# 5
# Conclusion

This thesis fills an important gap in the literature on risk-sharing mechanisms in road PPP projects, contributing to public policy by providing a methodology that assists policymakers in designing infrastructure PPP projects and understanding the contingent claims and fiscal costs involved. The specific objectives proposed in the Introduction were being reached according to the development of chapters 2, 3 and 4, as well as were answered the research questions. As for the main objective of this thesis was achieved in Chapter 4.

The second chapter analyzed the cost-benefit of government guarantee through two Real Options models, in which the first uses the Minimum Traffic Guarantee, and the second model combines the first model with the Maximum Traffic Limit. By applying these models to analyze the road lot concession called "Rodovia de Integração do Sul – RIS", was observed that the use of the minimum traffic guarantees reduces the project risk and when it is combined with the Maximum Traffic Limit, they reduced the risks of the project for both the private investor and the government. Finally, it was observed that the value of the proposed toll tariff could be lower, while keeping the project economically viable. Here, the specific objectives of analyzing the importance of guarantees in public-private partnership contracts and estimating the value of these guarantees, and their impact on project risk were reached.

The specific objective to support the development of public-private partnerships with the aim of attracting better investments and developing public infrastructure was, then, reached in Chapter 3, which also attained the goals of analyzing, more exhaustively, the importance of guarantees in public-private partnership contracts and estimating the value of these guarantees, their impact on project risk, and the expected value in the government budget. This chapter analyzes the case of the Salvador–Itaparica Bridge system concession project under the Real Options Theory, comparing the results with publicly available government reports on the project. Our results indicate that the expected cost of the State of Bahia government's contingent liabilities was overly undervalued and the guarantees provided were excessive as they resulted in the total elimination of demand risk to the concessionaire. This contributes to the understanding of risk-mitigating mechanisms' effects on private investment in infrastructure projects and sheds light on the importance of adequately calibrating and pricing these contingent government liabilities, and, at the same time, allowing the government to determine their future contingent liabilities and the effectiveness of their risk-sharing mechanisms.

Finally, the remaining specific objectives were reached in Chapter 4, which are the development of an optimization model for pricing Real Options in contracts with traffic guarantees and determining the optimal level of these guarantees in public infrastructure contracts in the Road Projects. Here, it was proposed a Real Options model to determine the optimal values of the traffic floor and cap levels, considering the risk perspectives of lenders, government and private partners that create favorable conditions for the development of Road PPP projects. The model has its numerical application in the Salvador–Itaparica Bridge system concession project, resulting in an appropriately designed MTG mechanism that reduced the government’s contingent liabilities, and provided adequate guarantees considering the risk tolerance of the concessionaire and lenders. At this point, the last object, which is to support the development of public-private partnerships with the aim of attracting better investments and developing public infrastructure, was reached and so fulfilled all specific objectives. In this way, the main objective of this thesis was finally attained, that is, we developed a methodology to find the optimal level of traffic guarantees in road PPP projects in order to minimize government liabilities, reduce project risks, and find the best ways to win private investments.

The suggestions may include the study on specifying some model parameters of the chapter 4, such as the Concessionaire risk appetite, which was considered in this study to be the maximum probability value acceptable of the NPV to be negative, and the adequate government’s risk aversion measure. Moreover, our model can be extended, with some adaptations, to the application to other kinds of PPP projects.

# 6
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