Quantifying qualitative information on risks (QQIR) in structured finance transactions

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**NANYANG
TECHNOLOGICAL
UNIVERSITY**

**Quantifying qualitative information on risks
(QQIR) in structured finance transactions**

**TILLMANN SACHS
SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING
2007**

Quantifying qualitative information on risks (QQIR) in structured finance transactions

POLITICAL RISK QUANTIFICATION IN PPP INFRASTRUCTURE PROJECTS

Tillmann Sachs

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

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ABSTRACT

Risks can impair the success of business transactions. Structured finance transactions are exposed to numerous risks.

Some of these risk factors are well studied. They have sufficient historical and numerical data and record to allow for projections and quantifications of their possible impact on the transaction. Other risk factors may lack such information and projections for quantification become difficult. A group of experts may have opinions on such risk factors. For quantifying these perceptions on risk factors, this doctoral research proposes a new methodology for quantifying qualitative information on risks (QQIR) in structured finance transactions. It contributes to the set of risk assessment methods by closing the gap between qualitative and quantitative risk assessment methods and adds value to all transaction participants.

The proposed QQIR method is a fuzzy set approach which allows the deriving of customized probability density functions based on expert opinion as well as ranking of such aggregated opinions. It is the interface between opinions experts generate based on available information in the market and stochastic cash flow modeling and simulation and other qualitative assessments.

In this research, the QQIR method is derived from theory, validated and tested through a survey, and applied in two case studies. All data in this research is primary data.

The contribution to the sphere of knowledge is the novel development of the QQIR method. The QQIR method is a systematic, comprehensive, and mathematically thorough approach for translating expert opinions on risk factors into customized probability density functions that can be used for stochastic simulations, rankings, or other applications.

In validating the QQIR method, the QQIR method has been used to quantify the perceived impact of political risk factors on financial decision criteria in project finance. The financial criteria were the expected internal rate of return, the project leverage, the risk premium on project loans, the minimum required debt service coverage ratio, and the insurance premium. The impact was assessed through an international survey across 14 Asian countries and 14 infrastructure sectors. The results of this QQIR survey assessment were then compared with absolute values that were also collected in the same survey. The two survey results were validated by triangulation with general country and sector risk perceptions, also collected in the same survey. The validation shows that in 77.5% of all observations, the QQIR method produces mean results that

Abstract

are within 0.85 standard deviations from the absolute values. Also the validation shows that with increasing perceived risks, costs of equity and debt finance as well as insurances increase as well.

The QQIR method has been applied in two case studies. The application supports its validity and commercial benefit.

The QQIR method has been applied for assessing the impact of governmental actions on demand and pricing in a power project in Asia. The impact was quantified as change in investment return ratios. The case study was carried out under confidentiality agreement with a Japanese power developer. This allowed full access to confidential financial data and contracts as well as decision makers involved. The presented information is not business sensitive.

In the second case study, the QQIR method has been applied to assess the risk exposure and recovery potential of the involved parties in a guarantee contract in a water project in another country in Asia. The case study was carried out under confidentiality agreement with the Asian Development Bank (ADB). This also allowed full access to confidential financial data and contracts as well as decision makers involved. The presented information is not business sensitive.

The commercial benefit and contribution of the QQIR method to risk assessment has been thoroughly demonstrated by its validation and application in the two case studies.

In the course of the development of the QQIR method, the relevance of its development, its modules, use-friendliness, applicability, and fit in the existing set of tool boxes of risk assessment has been thoroughly discussed in numerous individual and group presentations with investors, lenders, developers, lawyers, financial advisers, and insurers from the private and public sector in Asia and Europe.

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Abbreviations

LIST OF ABBREVIATIONS

A	Assets
beta, β	Measure for risk
BCI	Base-case integer
Bp	Basis points. 100bp 0 1%
CAPM	Capital Asset Pricing Method
D	Debt
DSCR	Debt-Service-Coverage-Ratio
E	Equity
I	Impact
IRR	Internal Rate of Return
L	Likelyhood
NPV	Net Present Value
PDF	Probability Density Function
PFI	Private Finance Initiative
PPA	Power Purchase Agreement
PPP	Public-Private Partnership
PSC	Public Sector Comparator
R, r	Return or interest
ρ	Interest rate, return (in the context of MM 1958)
RCI	Risk-case integer
SPV	Special Purpose Vehicle
T.F.N	Triangular fuzzy number
TrFN	Trapezoidal fuzzy number
V	Value (= D+E)
VfM	Value for Money
WACC	Weighted Average Cost of Capital
$\wedge$	logical symbol for “and”
μ	The degree of membership, 0 being the lowest and 1.0 the highest
$\in$	“Element of”
c_i, w_i	Used to express weights
A_i	A fuzzy number

CHAPTER 1: INTRODUCTION

1.1 Background

An estimated amount of US\$ 650 billions is needed for future long-term investment in Asia and 60% will constitute infrastructure investments (PRI Summit 2006). The public sector often lacks the funds to realize these infrastructures. Increasingly it invites the private sector to plan, finance, build, and operate such infrastructures under long-term contractual agreements in public-private partnerships (PPP).

The modern forms of PPPs were first introduced in the UK in terms of the Private Finance Initiative (PFI) in 1992. PPPs gained rapidly in popularity in Europe and Asia and in 2004, the Ministry of Finance in Singapore introduced a handbook on PPPs as best sourcing practice for projects exceeding SG\$ 50 million. Some countries have specific PPP procurement laws, others cater for PPPs under their current procurement laws and only introduce some PPP guidelines.

The success of PPPs depends on stable legal and political environments for executing the long-term contractual agreements between the public and the private sectors. In many countries, this environment is lacking and political risks stemming from governmental action or inaction may jeopardize the success of PPPs.

The relevance of political risks in PPPs is supported by results from a survey on risks and opportunities in transportation PPPs in Asia (Norton Rose 2006¹). The findings indicate that political, counterparty, and legal and regulatory risks are critical in Asian countries and across transportation PPP sectors. Another survey (Appendix 2) found that within the political risks, legal and regulatory risks are perceived as most critical across all Asian countries and PPP sectors.

Some political risks are directly attributable to governmental actions such as restrictions for transferring currencies, political violence, nationalization, or breach of contract. They are insurable by public and private political risk insurance providers. Other political risks such as changes in laws or governments, legal or regulatory changes are not insurable. They materialize as commercial risks and are commonly borne by the private sector.

¹ The survey can be downloaded at http://www.nortonrose.com/html_pubs/view.asp?id=11027

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Project participants in PPPs want to estimate the impact of these possible political risks on the project. They seek to determine the dollar value of the impact of such risks for valuing and pricing insurances, liquidity facilities, contingency budgets, or other risk mitigation instruments.

Many of these political risks factors lack historical or numerical data or records but are intuitively describable by individuals that are intimately familiar with a specific project and its environmental setting. Conventional risk assessment methods such as checklists, score cards, stress tests, or stochastic simulations may provide some information on the possible maximum impact or the criticality of specific factors, but they lack the ability to numerically incorporate such expert opinions and perceptions on risk factors.

For enabling more informed decision making on PPP investments in environments that are subject to political risks, an approach is needed that integrates the existing risk assessment methods and models perceptions on risks.

In this research, a novel methodology for quantifying qualitative information on risks (QQIR) in structured finance transactions is proposed. It adds value to comprehensive and due diligent risk assessment in PPPs by bridging the gap between qualitative and quantitative risk assessment methods. The QQIR method allows quantifying perceptions on risks.

1.2 Overview of research contribution and commercial relevance of research

The objectives of this research are the development, validation, and application of a new method for quantifying perceptions on risk factors in infrastructure projects to contribute to sustainable infrastructure development in emerging markets.

The proposed method for quantifying qualitative information on risks (QQIR) is presented as a new approach for providing a probability representation for the cash flow and financial parameters of interest. It allows assigning dollar values at probability levels based on perceptions on risk factors.

The relevance of this research is the development, validation, and application of a comprehensive method for quantifying qualitative information on risks (QQIR) in structured finance transaction. The QQIR method is generic and bridges the gap between qualitative and quantitative risk assessment methods. This research is concerned with the quantification of perceptions in problem solving. In particular, the focus is on political risk quantification in infrastructure projects. In this research, the QQIR method is validated with and applied to political risks in infrastructure projects.

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Information on risks in structured finance transactions is often perceived qualitatively and lacks robust and precise historical and numerical records to base finance decisions on. This is in particular relevant when assessing risks in infrastructure projects in emerging markets. Often, the concession contracts and other contractual agreements in infrastructure projects are signed between private entities and sub-sovereign or local governmental entities in local jurisdictions. These governmental entities may threaten successful project execution by actions that have a negative impact on the commercial viability of the project.

1.3 Problem identification and research questions

Structured finance transactions refer to financial transactions through intermediaries which are often called special purpose vehicles (SPV) (Caselli and Gatti 2005). Project finance is one example of a structured finance transaction. In structured finance transactions under public-private partnership (PPP) schemes, project investors, lenders, and governmental agencies often base their engagement decision on their perceived level of risk exposure and expected returns. Each participant may perceive and evaluate risks differently, reflecting his or her risk averseness. In the decision process, they try to anticipate, predict and estimate the effect of these risks on their specific and financial decision criteria.

While for some risk categories, there exist exhaustive numerical records and data to allow for statistical analysis at significant levels to support decision making (Grimsey and Lewis 2002), in other risk categories such records and data may not exist and the decision makers need to rely on opinions, experiences, vague and imprecise knowledge, and intuition.

In structured finance transactions, the transaction participants want to assign a price, costs, or contingent budgets to such qualitative risks. This allows risk mitigation and management by budgeting for the event that the risk may occur, to insure the risk, or to "sell" and transfer the risk to another party that is willing to take it. Assigning a dollar value at some probability to specific risks is the basis for successful risk mitigation and management.

The impact of risk factors can be quantified by determining the change in financial ratios such as project values, returns, or coverage ratios and estimating the dollar value equivalent to off-set these risks.

There are two established quantitative methods: one is the sensitivity analysis or stress testing and the other the Monte Carlo simulation. In a sensitivity analysis, one input factor such as taxes is changed in a range of for example +30% to -30%, while all other parameters are kept unchanged and the effect of that change on some finan-

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cial decision criteria is calculated and recorded. In a more sophisticated approach, a probability density function (PDF) can be assigned to or determined for the input factor. This PDF provides the most likely change (mean) and range of possible changes of that parameter. For that probabilistic input, a probable outcome at some confidence level can be calculated. A Monte Carlo simulation samples these PDF input parameters and allows recording the effects on specific output parameters. The conventional sensitivity analysis can be viewed as a special case of Monte Carlo simulation with a uniform PDF.

The research questions are:

- How can a PDF for stochastic simulation be derived in the absence of historical or numerical records and data?
- In the absence of such records and data, what other source of information can be used and under what conditions?
- How can that information be translated into a meaningful PDF for stochastic simulation?

The proposed QQIR method allows deriving a customized PDF based on perceptions and expert opinions. The research questions are relevant to all parameters for which historical data is not available. Even if historical data was available, the dynamic nature of projects limits to certain extends the value of past data.

1.4 Proposed problem solution

The research questions will be addressed by the following proposed solution:

- In the absence of historical and numerical records and data, another source of information can be expert opinions and judgments.
- Expert opinions and judgments can be regarded as reflecting and considering all available information the expert has when providing his opinion and judgment. This is derived from the Markov property used for projections.²

² In probability theory, a stochastic process has the Markov property if the conditional probability distribution of future states of the process, given the present state and all past states, depends only upon the present state and not on any past states, i.e. it is conditionally independent of the past states (the *path* of the process) given the present state.

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- The available information may be perceived vague, ambiguous, incomplete, and imprecise, but it is somehow aggregated in the final expert opinion and judgment.
- Fuzzy set theory provides a framework within which such information can be analyzed in a structured and comprehensive way for quantifying perceptions. Fuzzy sets allow for small sample sizes.
- The possibility/probability conversion principle and the uncertainty invariance principle set the framework for converting the information contained in the fuzzy sets into probability density functions.

Different experts may have different opinions on risks and the information they are provided with. The proposed solution for the research question therefore is a risk and expert specific solution for quantification of perceptions. It allows quantifying qualitative information on risks (QQIR) and may be applied to any structured finance transaction.

1.5 Research objectives and methodology

The identified research problem and the proposed solution resulted in the proposed method for quantifying qualitative information on risks (QQIR). The research on the QQIR method comprises method development, validation and application. The research objectives and methodologies that were applied are:

1. Derive and develop the proposed method for quantifying qualitative information on risks (QQIR): A thorough literature review was conducted with focus on financial theory and fuzzy set theory for deriving the QQIR method theoretically. The focus in the financial theory review was the understanding of the nature of risks and the financial objectives of the transaction participants that drive a project. The focus on the review of fuzzy set theory was on fuzzy number construction, fuzzy risk analysis, fuzzy arithmetic operations, and possibility and probability theory conversion principles.
2. Validate the QQIR method: For validating the QQIR method, a survey was conducted to collect three data sets on qualitative information impacting finance decisions. The three datasets were tested by triangulation to demonstrate their consistency.
3. Demonstrate the fitness for purpose of the QQIR method: The fitness for purpose was demonstrated by comparing the results of the two collected data sets against each other. It is shown that in 77.5% of all

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cases, the absolute value polls fall within 0.85 standard deviations from the mean values calculated with the QQIR method.

4. Demonstrate the applicability of the QQIR method: The applicability of the QQIR method was demonstrated by conducting two case studies on real infrastructure projects. The case studies were conducted under confidentiality agreements. The findings supporting the validation of the QQIR method and strongly suggest its applicability.

In the course of this research, close collaboration and exchange with the industry and senior professionals was sought. Among the organizations and firms that the research was discussed and developed with are the Asian Development Bank (ADB), KfW-IPEX Bank, The World Bank Group, National Audit Office (NAO, UK), Ernst & Young, Deloitte, PricewaterhouseCoopers, J-Power, Keppel, Marsh, Willis, JLT, Chubb, Zurich, and many others.

1.6 Structure of thesis

The thesis is structured in eight chapters (Figure 1). First, the introduction substantiates the relevance of the research, introduces the research problem identification and proposed solution as well as the research objectives and methods. The second, third, and fourth chapters comprise the literature review. The literature review provides the theoretical background and presentation of the state-of-the art in those fields that are relevant to this research. Fifth, the method for quantifying qualitative information on risks (QQIR) will be derived from theory and sample calculations are provided. In the sixth chapter, the QQIR method will be validated through triangulation of survey findings. After validation, the QQIR method will be applied to political risk quantification in two case studies in Chapter Seven and the results discussed. The thesis closes with conclusions, limitations, and recommendations for future research in Chapter Eight. There are detailed appendices supporting the research findings.

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Background and relevance of research

Problem identification and research questions

Proposed problem solution

Research objectives and methodologies

Chapters 2, 3, 4: Literature review

Financial theory and risks

Fuzzy set theory

Chapter 5: QQIR method building

From theory

Sample calculations

Chapter 6: QQIR method validation

Survey results

Triangulation of results

Chapter 7: QQIR method application

Political risk quantification

Risk exposure and recovery assessment

Chapter 8: Conclusions& recommendations for future research

Figure 1: Structure of thesis

CHAPTER 2: STRUCTURED FINANCE TRANSACTIONS UNDER PPP SCHEMES – FINANCIAL OBJECTIVES AND RISKS

The literature review consists of three chapters. Chapter Two reviews principles of structured finance transactions for infrastructure projects under public-private partnership schemes. In Chapter Three, financial theory is reviewed with respect to the objectives of the participants in such transactions. In Chapter Four, risk factors and risk management are reviewed.

2.1 Structured finance transactions

Structured finance is applied in a number of different transactions such as project finance, securitization such as asset backed securities, leasing, or leveraged buy outs. Typically, structured finance transactions involve a large debt portion. In this thesis, the focus is on project finance under public-private partnership schemes.

2.1.1 Characteristics of structured finance

Structured finance transactions are often referred to as “off-balance sheet financing” as they differ from classical corporate lending. Structured finance involves (Caselli and Gatti, 2005)

1. A unit that receives funds which is independent from the entity sponsoring the transaction. Commonly, this unit is referred to as special purpose vehicle (SPV). The SPV has to secure cash receipts and payments.
2. The financiers grant financing only to the SPV and not to the sponsors, so the SPV is liable for all economic consequences, not the sponsors.
3. The SPV has therefore its own net worth and the SPV's assets and cash flows serve as collaterals to lenders.

2.1.2 Project finance

The prime characteristic of project finance is that the SPV that is being funded does not rely on the creditworthiness of its sponsors. It is the project's ability to honor its debt service obligations to lenders and allow for remuneration to the sponsors. The equity return will depend on the degree of risks and the size of the debt portion in-

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Structured finance transactions under PPP schemes

volved. The success of the SPV depends on its ability to generate secure revenue stream and thereby repay its debt financiers and equity sponsors.

2.1.2.1 Features of project finance

The distinctive features in project finance are (Caselli and Gatti, 2005)

1. the SPV is independent from its sponsors
2. debt financiers have no or only limited recourse to the sponsors
3. sponsors commit to the SPV time, capital, and quality such as management or technical skills
4. project risks are allocated in an appropriate manner to the parties involved
5. the generated revenue cash flows are sufficient to cover debt service obligations and capital repayments with return.

Commonly project finance is used in the absence of specific high-level technological risks, and the presence of a captive market involving large and financially strong buyers. With project finance structures, projects that have a lower or less effective market risk cover can be realized. Under off-balance-sheet project financings, also projects that have government involvement to promote the realization of public works can be promoted (Caselli and Gatti 2005). This is the reason for engaging in public private partnerships (PPP).

2.1.2.2 Differences between corporate and project finance

The key difference between corporate and project finance is that in corporate finance, the lenders have direct recourse to all of the assets and sponsors of the company, while in project finance, lenders have no or only limited recourse to the sponsors. Therefore, lenders in project finance need to evaluate the risks associated with the revenues and cash flows that the underlying asset is generating. If a project defaults on debt service obligations, the value of the asset devaluates and becomes insignificant as collateral to the lenders (Finnerty 1996).

Gatti (2003) summarized the main differences between corporate and project finance as shown in the following Table 1.

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	Corporate finance	Project finance
Collateral for financing	Assets of the borrower	Project assets
Effect of financial flexibility	Reduces the borrower's financial flexibility	Non-existent or very reduced as regards the sponsors flexibility
Accounting treatment	On-balance sheet	Off-balance sheet (the only effect is the cash outlay to subscribe the equity in the SPV or disbursement of subordinated loans)
Main variables considered when granting credit	Customer relations, financial soundness, profitability	Future cash flows
Sustainable leverage	Depends on the effects on the borrower's balance sheet	Depends on cash flow generated by the project (leverage is usually greater)

*Table 1: Corporate vs. project finance (source: Gatti 2003)***2.2 Public private partnerships (PPP)**

Public-private partnerships are a special type of project finance arrangements in structured finance transactions.

In public-private partnerships (PPPs), public services and assets are provided through the collaboration of the private sector, public agencies, and consumers. They cover the total or part of the value chain and project life-cycle. The public and the private sector are brought together for a long-term partnership and mutual benefit.

2.2.1 Definition of PPPs

There exists no single, definite, and comprehensive definition of PPPs. In 2000, the UK government published "Public Private Partnerships – The Government's Approach" which identifies public private partnerships (PPPs) in three categories (HM Stationery Office 2000). The three categories are:

1. the introduction of private sector ownership into state-owned businesses, using the full range of possible structures (whether by flotation or the introduction of a strategic partner), with sales of either a majority or a minority stake;
2. the Private Finance Initiative (PFI) and other arrangements where the public sector contracts to purchase quality services on a long-term basis so as to take advantage of private sector management skills, incentivised by having private finance at risk. This includes concessions and franchises, where a private sector partner takes on the responsibility for providing a public service, including maintaining, enhancing or constructing the necessary infrastructure; and

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- 3. selling government services into wider markets and other partnership arrangements where private sector expertise and finance are used to exploit the commercial potential of Government assets.

2.2.2 Development of PPPs

Historically, forms of PPPs can be found whenever a government grants the right to a private entity to deliver a public or sovereign service. Monod (1982) claims the first “concession” was granted in 1782 to the Perrier brothers in France and was concerned with water distribution in Paris. Another more prominent historic example is the 99 years concession for planning, building, financing, and operating the Suez-Canal with two ports at each end. The concession agreement was signed and granted in 1858 by Said, the Pasha of Egypt, to Ferdinand de Lesseps. The capital of the *Compagnie Universelle du Canal* was set at 200 million gold francs and divided into 400,000 shares.

The introduction of build-operate-transfer schemes by the Turkish Prime Minister Turgut Ozal in the early 1980s was not successful in Turkey at that time. PPPs in the “modern” form were successfully introduced in the UK in 1992 under the Private Finance Initiative (PFI). Until to the present, the UK serves as a role model for other countries when introducing PPPs. There is a variety of acronyms to describe concession contracts (Merna and Cyrus 2002, p. 90). Each of the acronyms describes different ownership-relations over the life cycle of a project (Table 2).

Abbreviation	Acronym
FBOOT	finance-build-own-operate-transfer
BOO	build-own-operate
BOL	build-operate-lease
DBOM	design-build-operate-maintain
BOD	build-operate-deliver
BOOST	build-own-operate-subsidies-transfer
BRT	build-rent-transfer
BTO	build-transfer-operate
BOT	build-operate-transfer
DBFM	design-build-finance-maintain
ROT	rehabilitate-operate-transfer
DBFO	design-build-finance-operate

Table 2: Acronyms to describe concession contracts

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2.2.3 Project and contract structure

The project structure for each PPP project is unique. It follows the nature of service procured, the different involved parties, and the various agreements these parties engage into with each other. It is a web of contracts, ownership, and advisory relations.

Project finance is a strong tool for structuring PPPs (Tinsley 2000, p.2). Lenders and investors wish to have strong control over the continuing operations, and the cash flow generation. Therefore they seek for full entitlement to that enterprise in the event of default. This is the legal collateral over all of the project's assets, rights, and interests. The contract structure follows the risk allocation among the stakeholders.

The PPP contract structure in Singapore may serve as an example for a DBFO project structure. Here, the project company, the special purpose vehicle (SPV), is awarded the concession contract from a governmental agency. The characteristic is the single-point responsibility between the governmental agency and the SPV. The SPV then employs construction contractors, operators, and contractors for maintenance. The financial sources are attracted by debt finance or equity installments by shareholders of the SPV and other equity investors. Thus the stakeholders can be categorized into three groups: the governmental agency, the project sponsors and investors, and the lenders.

A DBFO project structure is shown in the following Figure 2.

Figure 2: DBFO project structure (Source: Ministry of Finance, Singapore, PPP Handbook, 2004, Fig. 1.2, p.9)

In practice, the project structure becomes more complex. Figure 3 is an example for the contractual structure of a BOT power plant project in China.

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Figure 3: Contractual structure of BOT power plant project in China (Source: Tiong et al. 1999, Fig. 4, p.70)

For details on project structures, contractual agreements, and project financing in PPPs, refer to Finnerty (1996), Tinsley (2000), Merna and Cyrus (2002), Grimsey and Lewis (2002 and 2005), and Her Majesty's Treasury, UK (<http://www.hm-treasury.gov.uk>).

2.3 Financial objectives

This section will show why revenue generation is regarded as the most sensitive parameter in assessing the viability of structured finance transactions under PPP schemes. Risks in the revenue generation have a strong impact on the critical financial decision criteria of the stakeholders.

In PPPs, there are three key stakeholder groups: The public sector entity, commonly referred to as the government, the private sector entity, commonly referred to as the sponsor or investor, and the debt financiers, commonly referred to as the lenders. The enabling role of public and private insurers and debt facilitators such as private political risks insurers or the multi lateral agencies must not be disregarded, especially in emerging markets.

The financial objectives of the stakeholders differ from each other. The *government* is interested in positive value for money (VfM): The concept of VfM is to be a measure for how much the delivery of services and assets by the private sector costs less than procuring them through conventional government procurement. The *investors* and project sponsors (referred to as "investors" in this thesis) are interested in a return on their investment that exceeds returns in alternative investments. This is measured by the

*Literature review**Structured finance transactions under PPP schemes*

internal rate of return (IRR) on equity. *Lenders* are concerned about the repayment of their issued debt and interest. For in non-recourse project financing, lenders have no recourse on the sponsors' parent companies and the coverage of debt is solely generated out of the project. Unlike corporate finance, the values of assets in PPPs are assumed to contribute little to the overall credit quality. That is due to the questionable reselling price of such assets, for example "Who wants to buy a tunnel if it has proven not to be economically viable"? Therefore, debt and interest coverage is dependent on the revenue and the resulting operating cash flow. Financing in PPPs is not based on the credit rating of the sponsor or the value of the project's physical assets, but depends on the anticipated financial performance of the project (Grimsey and Lewis 2002, Schaufelberger 2003). Lenders will place their main attention on this debt-service-coverage-ratio (DSCR). Each stakeholder looks at the project cash flow from his perspective only. However, all stakeholders will only engage in a project when the net present value (NPV) is positive. A positive NPV indicates the overall economic viability of the project.

Since IRR, DSCR, and NPV are dependent on the revenue, all parties would consider the generation of revenue as critical. Only a sufficiently secured revenue stream will allow bankability, determine the cost of debt and allow for leveraged return on equity. The governmental agency therefore is in the need to secure such a revenue stream in order to attract private sector involvement. The project under consideration either generates enough revenue without any further support by the government, or else, the government is forced to issue guarantees, subsidies, and assurances, to change laws, or to engage in other forms of agreements and mitigating measures.

In the following section, the financial objectives of the project stakeholders are explained in details.

2.3.1 Government

The decision criterion for the public sector on whether to tender a service under a PPP scheme is the additional value the private sector involvement generates as opposed to traditional public procurement. There are various approaches in determining this value for money (VfM). They range from complex to straight forward pragmatic approaches and from qualitative to quantitative methods.

Figure 4 shows the VfM "created" by comparing the traditional governmental procurement against private sector PPP solutions.

Figure 4: VfM - difference between governmental and PPP procurement (Source: partially adopted from HM Treasury, —, Box 1, p. 6)

2.3.1.1 Definition and assessment of VfM

The definition of VfM from the HM Treasury (2004, p. 3) is:

“Value for money is the optimum combination of whole life cost and quality (or fitness for purpose) to meet the user’s requirement, and does not always mean choosing the lowest cost bid.”

The HM Treasury states clearly (HM Treasury 2004, p. 3) that PFI should only be pursued where it delivers VfM. It should not be chosen to secure a particular balance sheet treatment.

2.3.1.2 Different approaches to VfM

Grimsey and Lewis (2005) identified different approaches to VfM assessment. The most advanced is the combined qualitative/ quantitative cost benefit and cash flow analysis including risk stress testing. The others are a PSC-PPP comparison calculation with risk stress testing before bids are invited, a UK-style PSC-PPP VfM test after bids are invited. The least complex and most efficient assessment of VfM is the sheer reliance on a competitive bidding process with a market feedback period. The market

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feedback period allows the advantages of the private sector solution to be made clear in order to ensure the implementation of an effective PPP (Sachs et al. 2005).

A detailed analysis on the assessment of VfM, its implications, the strength and weakness of employing a public-sector comparator (PSC) is outside the scope of this research. (For additional information refer to Grimsey and Lewis (2005), Lamb and Merna (2004), and publications from Her Majesty's Treasury, UK).

2.3.1.3 Budgeting for contingent liabilities by assessing risks affecting the VfM

When assessing value for money, the government should also budget for contingent liabilities that arise due to triggered guarantees.

The government may issue guarantees on minimum take-off, minimum compensation, tax-exemptions, or other items that secure a minimum revenue stream for attracting private sector investment and ensuring bankability of the project (Finnerty 1996, Tinsley 2000). Contingent liabilities due to triggered guarantees expose the guarantor to unexpected and substantial obligations over a short period of time which can lead to severe financial constraints. The issuing of guarantees by the government does not involve any instant costs. Therefore contingent liabilities are seldom budgeted for (Lewis and Mody 1998). According to the online Investopedia (2000), contingent liabilities can be defined as:

1. The possibility of an obligation to pay certain sums dependent on future events,
2. Defined obligations by a company that must be met, but the probability of payment is minimal
3. A good example of a contingent liability would be an outstanding lawsuit.

In the context of PPPs, contingent liabilities refer to possible costs that the government must endure in the event that an issued guarantee comes due. Contingent liabilities are triggered by a discrete but uncertain event. An integrated risk management system is needed to enable governments to recognize and be able to set aside reserves for political calls or unexpected losses (TOR 2005). Real options are one tool by which unpredictable events can be managed and (given the probability of trigger) be priced. Evaluating guarantees in terms of real options add value to the project. They also may serve as liabilities to the sponsors and lenders (Ho and Liu, 2002). The payment mechanism and penalty structure of a PPP contract can be described in terms of real options and event trees.

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2.3.2 Investors

Project sponsors, strategic and institutional equity investors and other shareholders will be referred to in the following as “investors”. Investors are concerned with two key issues regarding their investment decision. First is the expected return on their invested capital, second is the impact of that particular PPP project in their overall investment portfolio.

Proposition III of Modigliani and Miller (1958) states the simple rule for optimal investment policy:

“If a firm in [risk] class k is acting in the best interest of the stockholders at the time of decision, it will exploit an investment opportunity if and only if the rate of return on investment, say ρ^* , is as large as or larger than ρ_k . That is, the cut-off point for investment in the firm will in all cases be ρ_k and will be completely unaffected by the type of security used to finance the investment.”

ρ_k is the average reference return of investments in the same risk class k .

The invested capital is, at project default, the source of fund for honoring obligations to the lenders, suppliers, and other contractual obligations. Equity is therefore considered as “capital at risk”. It is not only exposed to the risk of default but also to the project revenue risks. Its equity returns depend on the effect of such risks. The higher costs of risk capital is compensated for by the higher expected returns and more risk averse investors expect less return and also want their risk capital less exposed to risks.

In this section, the inter-dependencies of risk and return, and the resulting capital structure with respect to the leverage effect are examined. Finally, a process for measuring single risk is proposed.

2.3.2.1 Risk and return

The understanding of the relationship between *risk* and *return* is fundamental to the following argument on the leverage effect and capital structure. The key notions for deriving that relationship are:

“For consumption plans y and z that have the same expectation, y is riskier than z if and only if every risk-averse agent prefers z to y ” (Leroy and Werner, 2001, p. 101). It is worth noticing “that if one consumption plan is riskier than another, then it also has higher variance. The converse is not true: a consumption plan that has higher variance than another consumption plan need not be riskier” (Leroy and Werner, 2001, p. 104).

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Therefore, the expected return of an agent from a particular consumption plan will increase as the risk increases: the expected return depends on the risk exposure, and not the perceived risk exposure on the level of return, which is a common misconception between “expected” and “actual” returns.

The misconception is that an investor may believe he is entitled to higher returns just because he is exposed to greater risks. He expects a higher return because of perceived higher risks. The actual return from a risky investment, however, may also fall short of the expectations. The risky investment may fail. In return, it is wrong to assume that the reason for a high return is because one assumes lots of risk. There also can also be a high “actual” return with considerably little risk exposure.

The return on equity (ROE) is determined in textbooks as (Brealey and Myers 2003, p. 830):

$$ROE = \frac{EBIT - tax - interest}{equity} \tag{1}$$

EBIT is the *Earnings Before Interest and Tax*. The ROE can be rewritten in profitability and efficiency ratios. This is commonly referred to as the Dupont system (2) and is written as:

$$ROE = \frac{assets}{equity} * \frac{sales}{assets} * \frac{EBIT - tax}{sales} * \frac{EBIT - tax - interest}{EBIT - tax} \tag{2}$$

↑
leverage
ratio

↑
sales – to –
asset ratio

↑
profit
m arg in

↑
"debt
burden"

From this discourse, by intuition, it follows that in a project which exhibits a specific risk exposure, the “bravest” or “first mover” investor faces most risks and for this “bravery” he demands to be rewarded most for his willingness to be exposed to such risk.

In PPPs, two main risk phases can be distinguished: the construction phase and the operation phase. In the construction phase, the risk exposure is higher due to uncertain cost and schedule overruns, whereas the revenue risk in the operation phase is smaller due to better “controllable” contractual relationships such as supply or take-off contracts (Schaufelberger 2003). This, however, is only the case if revenue risks can be successfully mitigated and the demand and price does not decline, resulting in project default.

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When following down the waterfall of seniority of funding, the more risk averse the money providers become, the less they will demand in return. Risk-averse money providers, such as commercial banks and other financial institutions, therefore want to be able to clearly estimate the level of risk exposure of the debt they issue. Lenders also will check for investors that are willing and capable to a) assume such risks and b) place their capital at risk. Consequently, a project that is considered to have a very good credit quality needs less investment of equity at risk than a project that is regarded as very risky and therefore displays a higher level of credit risk. From the perspective of the lenders, such projects need more investment of equity to lower the necessary portion of debt commitment. The market value of a project does not depend on its capital structure (Modigliani and Miller 1958). The overall return of a project will be consumed by its costs for compensating the less risk averse equity investor as well as the debt providers. Therefore, if the project manages to draw debt at a low interest rate because lenders consider it as very creditworthy, the margin of return on the capital at risk can increase considerably. This phenomenon is called the leverage effect and has strong implications on the capital structure, structure of finance, and over- and under-investment of the project (Finnerty 1996, p. 14 ff.)

2.3.2.2 Leverage effect and capital structure

The leverage effect and consequently the capital structure are closely intertwined.

Assuming that there are no taxes, the Modigliani-Miller Proposition I says (Modigliani and Miller 1958 p. 286):

“The market value of any firm is independent of its capital structure and is given by capitalizing its expected return at the rate ρ_k appropriate to its [risk] class”.

The method of financing is irrelevant to the value of the project. The value of a firm is seen independent (aside from tax considerations) of how its liabilities (debt and equity) are partitioned (Copland et al. 2005, p. 563). This implies that the weighted average cost of capital (WACC) is assumed constant for any $\frac{D}{E}$ gearing ratio, where D stands for debt, and E for equity. The value $V = D + E$ is not affected by the capital structure and gearing ratio. Under that proposition, the cost of debt must decrease as the cost of (= return on) equity increases. The Modigliani-Miller Proposition II shows this leverage effect with respect to the equity return (Brealey Myers 2003, p. 473)

$$r_E = r_A + \frac{D}{E}(r_A - r_D). \quad (3)$$

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"The expected yield of a share of stock is equal to the appropriate capitalization rate ρ_k for a pure equity stream in the class, plus a premium related to financial risk equal to the debt-to-equity ratio times the spread between ρ_k and r ." (Modigliani and Miller 1958)

As the amount of equity decreases, debt will increase. The provision of debt becomes riskier to the lenders, because at the same time the collateral in terms of equity decreases. Equity is seen by the lenders as call option. As a result, the cost of debt r_D also increases, resulting in a slowing of the increasing return on equity r_E while the return on the total asset r_A is constant (c.p. Modigliani and Miller 1958, Brealey and Myers 2003, p. 474).

An investor in a PPP project is interested in a high return on his invested equity and a NPV > 0 for additional dividends. These two goals are at conflict. The NPV increases as the WACC decreases but with decreasing WACC and unchanged cost of debt, his return on equity ceteris paribus also decreases. Therefore the investor is interested in low costs of debt r_D so that his return on equity r_E can escalate, even though the WACC decreases (r_A is no longer constant but decreasing) for the sake of an increasing NPV.

2.3.2.3 Measuring investment risk

In finance, risks are measured in terms of variance in returns of the investment project against some variance in some reference portfolio or portfolios. This relationship is calculated as "beta" (β_i). Beta β_i measures the relative risk-exposure of investment i with respect to an alternative investment λ . Beta is determined as the covariance of the expected return r_i on an investment with the expected return r_λ of some alternative reference investment λ over the variance of return on that reference investment, it is (Leroy and Werner 2001, p. 190):

$$\beta_i = \frac{\text{cov}(r_i, r_\lambda)}{\text{var}(r_\lambda)}.$$

The reference portfolio λ against which he measures his risk exposure can be the market portfolio (i.e. CAPM) or some other reference portfolio (beta pricing) he seeks comparison with.

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Instead of using one single reference portfolio λ to measure the respective risk associated with the return on the investment i , one can also employ multiple factors for reference such as the gross domestic product, consumer price index, inflation rate, bond rates, and other indices. This factor pricing approach is commonly referred to as the Arbitrage Pricing Theory (APT) (Leroy Werner 2001, 214).

2.3.3 Lenders

The financial objectives of lenders are to recover the debt they have issued to the project company plus the interest they charge. In the following it is assumed that lenders act solely as debt providers. The interest that lenders charge on loans and the amount of debt they are willing to issue depends on their perceived risk exposure and recovery potential in case of project default.

2.3.3.1 Debt service coverage

Debt service includes principal, interest as well as service of rental payments. The debt service coverage ratio (DSCR) accounts for all debt service payments. The DSCR is the strongest ratio among other financial cover ratios for lenders, because failing to service debt and rentals may lead into forced bankruptcy.

The DSCR can be defined as (Finnerty 1996, p. 108):

$$\text{Debt service coverage} = \frac{\text{EBITDA} + \text{Rentals}}{\text{Interest} + \text{Rentals} + \frac{\text{Principal repayments}}{1 - \text{Tax rate}}} \quad (4)$$

For lenders, the DSCR must be above 1 ($\text{DSCR} \geq 1$) for the project to service its debt out of the cash flow. Unlike in corporate finance, where assets serve as collateral to the lender, in non- and limited recourse project finance arrangements, assets often do not have a capital worth. It is unlikely that the PPP facility could simply be sold to realize value and cover the debt (Grimsey and Lewis 2002, Schaufelberger 2003). Therefore, lenders will look only at the downside risks that can affect the cash flow. If the DSCR falls below 1, the project company needs to raise funds or short-term equity contributions to cover the shortfall in debt coverage (Finnerty 1996, p. 108).

In some literature, the ability to service debt is referred to "EBITDA Coverage Ratio". EBITDA stands for earnings before interest, tax, depreciation, and amortization. In the case the project is in financial difficulties, taxes approximate zero. It therefore can be argued to omit tax from the considerations (Brigham and Ehrhardt 2005).

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Also, the EBIT does not represent true values of available cash flows to service debt obligations as in accounting, depreciation and/or amortization (DA) may have been deducted even though for paying the debt service obligations, the total EBITDA is available.

Lenders will only provide debt at low rates, if they are convinced of the good credit quality of the project; the lower the probability of project default, the lower is the cost of debt. The probability of project default and its associated default loss depend, however, on the risk profile of the project.

The opinion of lenders on the credit quality of the entity that they are lending to is the adequate approach to assess the cost of debt r_D .

2.3.3.2 Credit risk assessment

Credit risk assessment is commonly referred to as credit rating and serves as assessing project risks and pricing of loans.

The credit ratings of Moody's, Standard & Poor's, and Fitch play a key role in the pricing of credit risk and in the delineation of investment strategies. Their credit ratings provide an opinion on the creditworthiness of a company which influences the cost of debt. The rating also serves to monitor changes in the credit quality. Altman's Z-score model (Altman 1968, 1993) separates defaulting firms from non-defaulting firms based on the discriminatory power of a linear combination of financial ratios.

2.3.4 Discussion on discount rates

The goals of high return on equity r_E and low WACC are at conflict. In either way, equity investors will seek projects with low costs of debt.

The choice of discount rate deserves strong attention. While the choice of discount rate determines the project value, it is difficult to determine the fair discount rate or rates that reflect the level of risks adequately. Public sector funding is lower than private sector funding. Also the risk profile of a project changes over its lifecycle. This may result in different discount rates during the different project phases. Grout (2003) assesses public and private sector discount rates in PPPs and shows that it is inappropriate to assume similar discount rates for public and private provision. Dias and Ioannou (1995) derived an optimal capital structure based on the CAPM approach for deriving an adequate discount rate. They show that the amount of debt that a project can accommodate is less than 100% debt financing, that the amount of debt that maximizes the investor's return is less than the project's debt capacity, and that the amount of debt that maximizes the projects NPV is even smaller. Grimsey and Lewis

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(2005) discuss the choice of public and private sector interest rates when determining the fair value for money (VfM) of PPPs, and PricewaterhouseCoopers (PWC 2002) studied into rates of return of PFI projects. When it comes to discount rates in real options, Amram and Kulatilka (1999) suggest referring to Hull (1997) from a market rate point of view. Miles and Ezzell (1980) introduced an approach for obtaining the value of a levered stream by discounting the unlevered stream by a single discount rate and prove that it is equal to the textbook WACC.

There is no single best approach to determining a “fair” discount rate that reflects a “true” value of a project. Also the choice of the discount rate can be subject to perception as, among other, this thesis will show in Chapter 6 and Appendix 2.

CHAPTER 3: RISKS IN INFRASTRUCTURE PROJECTS

3.1 Definition of risk

What risk and uncertainty have in common is that their outcome is unknown. The difference is that risk can be attributed with some probability, while uncertainty cannot (Knight 1921). In the context of quantifying qualitative information on risks (QQIR), “qualitative risks” refer to Knight’s classification of uncertainty where there exists no historical, numerical track record that allows a statistically significant derivation of probability. Qualitative risks are therefore seen as risks that are vague, ambiguous, and imprecise and can be described by intuition, expert knowledge, and experience.

3.2 Risk management process

A comprehensive risk management process consists of risk identification, risk allocation, risk assessment, risk mitigation, and finally the controlling and monitoring of risks. In each phase, different tools and concepts are applied.

Risks are an integral part in the whole PPP procurement process. The risk exposure depends on the risk analysis to effectively assess the risk and risk mitigation depends on the negotiation strategy to lower one owns risk exposure. A comprehensive risk management process and risk awareness is needed for realizing successful PPP solutions. Tinsley (2000, p. 67) cautions with reference to risk allocation and management:

“The idea for some that ‘risk is best borne by the party best able to bear it’ is a great nonsense as risk is best negotiated as far away from oneself as possible. Extra caution is needed when one hears the phrases ‘risk allocation’ or ‘risk mitigation’ as these give the false impression that the risk in question has been settled, as though from that moment forward one doesn’t need to worry further about it.”

3.3 Risk identification - risk categories and structures

Tinsley (2000) distinguishes 16 risk categories. Each category may affect the cash flow differently. In the QQIR method, the impact of the qualitative risk factors is assessed by their impact on a specific cash flow position such as “tariff” or “dispatch”. Tinsley introduces the “cash flow risk matrix” shown in Table 3 to map the effect of risks on the cash flow positions.

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16 risks	Supply traffic/reserve	Market	Foreign exchange	Operating: technical	Operating: cost	Operating: management	Environmental	Infrastructure	Force majeure	Completion	Engineering	Political	Participant	Funding/interest	Syndication	Legal
Output number/qty	x	x					x		x							
Times: Price		x	x													
Equals: Revenue																
Less: Cash Costs			x	x	x	x	x	x			x					
Royalties								x				x				
Overheads						x							x			x
Equals: Net operating cash flow																
Plus: Project loan			x											x	x	
Equity													x			
Equals: Total sources																
Less: Capex			x							x	x			x		
Increase in wkg cap		x			x											
Interest (I)			x							x				x	x	-
Income tax												x				x
Principal (P)			x						x							
Equals: Total uses																
Total sources – total uses = net net cash flow (NNCF)																
Net net cash flow + Interest + Principal = available cash flow (ACF)																

Table 3: Cash flow risk matrix (Source: Tinsley 2000, Exhibit 6.1)

Penalties will reduce the net revenue. In PPPs, the cash flow matrix should be extended to fully map the penalty structure in the payment mechanism that may reduce the expected returns.

3.3.1 Risk categories

As mentioned earlier, Tinsley (2000) provides 16 risk categories that affect different cash flow positions across the project life cycle. These are supply risk, market/demand risk, foreign exchange risk, operating risks (technical, cost, managerial), environmental risk, infrastructure risk, force majeure risk, completion risk, engineering risk, political risk, participant risk, interest rate risk, syndication risk, and legal and regulatory risks.

Tah et al. (1993 and 2001) categorize risks by segregating them into project external and internal risks and then subdivide them into local and global risks. For assessing the risks, they look on the single risk factors that influence a specific risk category.

*Literature review**Risks in infrastructure projects***3.3.2 Risks containing qualitative information – political risks**

Tinsley (2000) further structures the category of political risks into 16 subcategories. Political risks can be subdivided into risks that can be covered by political risk insurers, and those risks that cannot be covered. Details on the insurable and not insurable political risks will be presented during validation and the two case studies. Commonly, political risks such as changes in regulations that materialize as commercial risks cannot be insured. Political risks are chosen in this thesis for risk factors that may lack historical and numerical data and records but on which a group of experts may have some opinion on them. The political risks that need to be addressed and may affect the project's cash flow are war and insurrection/civil disturbance, currency inconvertibility and transfer, nationalization and creeping expropriation, landowner/indigenous people's disturbance, terrorism and sabotage, willful breach of contract, change of government, corruption, unions, environmental activists, approvals/bureaucratic risks, conflict of authority, United States and EU, religious fundamentalism/ethnic tension, taxation changes, and change in law.

A detailed discussion on each risk factor is outside the scope of this thesis. Some of these risk categories are insurable, while others are not. The particular insurable and uninsurable categories of political risks will be addressed in the context of the case studies and surveys. Figure 30 in Section 7.1.2.6 shows a generic structure of influencing political risks.

3.4 Risk mitigating strategies

Risk exposure can be mitigated by avoiding, retaining, transferring or allocating the risks, or by purchasing insurances or guarantees.

Political risks can best be mitigated by governmental support (Tinsley, 2000, p. 218). This support can be in the form of guarantees, assurances, agreements, or indemnities. There also exist insurances and financial structures to counteract some of the identified political risks.

Tiong (1995) shows the necessity for private bidders to provide guarantees as a competitive success factor in BOT tenders and for structuring innovative financial packages. When governments issue guarantees to attract investors for BOTs, most fail to actually budget for these pending liabilities (Wibowo 2004). Guarantees can reduce the risk to one party, but the cost for such a "risk transfer" then needs to be born by the guarantor in terms of contingent liabilities.

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The method for quantifying qualitative information on risks (QQIR) allows budgeting for such contingent claims. It also allows monitoring the impact of these risks on financial criteria that determine the trigger point at which a guarantee is exercised.

3.5 Risk assessment methods in structured transactions

The QQIR method is designed to bridge the gap between quantitative and qualitative risk assessment methods.

3.5.1 Qualitative risk assessment methods

Qualitative risk assessment methods comprise generic empirical risk analysis methods such as PEST analysis (political, economical, social, and technical environment), SWOT analysis (strength, weakness, opportunities, and threats), or Porter's five competitive forces (Porter 1998) (buyers, suppliers, substitution, new entrants and rivalry). Often, qualitative risk assessment is conducted in terms of check lists, score cards, or comprehensive reports. Information is drawn from public information and industry experts. The information collection is qualitative, but the processing of the information is considered quantitative.

3.5.2 Quantitative risk assessment methods

Quantitative risk assessment methods commonly refer to cash flow spreadsheet modeling and simulation of the various financial input parameters.

With cash flow modeling, the concerns of lenders and investors are addressed. Lenders will look at the time series or their debt services, and investors on their return. Out of the cash flow modeling, the borrowing capacity, annual coverage, interest rate risk, the return to limited partnership equity, and return to sponsor equity can be derived. It also determines the DSCR, IRR, NPV, payback period, and break-even point. In a sensitivity analysis, the effect of changes in the input parameters on the financial ratios are examined (Finnerty 1996).

Microsoft Excel is the common software to build up the spreadsheets. The spreadsheets on the project's cash flow (income statement), sources and uses of funds, retained earning, and cash flows should be linked to the balance sheet to make sure that all links are correctly placed (Tinsley 2000, p. 37). This constitutes the base case.

The excel sheets then can be linked to programs such as @RISK from Palisade or Crystalball. These are simulation software to perform Monte Carlo simulation on the effect of changes in the input parameters on the critical output parameters. Input parameters can be taxes, discount rate, tariff, dispatch, interest rates, operational costs,

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and other expenses that affect the project performance. The output parameters can be financial ratios and the critical decision factors of the stakeholders.

@RISK and Crystalball are the two most widely used software programs for cash flow simulation. Both programs allow the simulation of risks by assigning to them a probability density function from the menu or commanding it oneself. Among the predefined distributions are uniform, triangular, normal, lognormal, student, and others. These programs also allow for "Best Fit" which assigns the distribution function to a set of data, which best fits the distribution of that set.

3.5.2.1 Monte Carlo simulation

@RISK and Crystalball allow for Monte Carlo simulation. Monte Carlo is a simulation technique that uses random digits to sample a population. In Monte Carlo simulation, the given distribution is first rewritten in associated serial numbers that run from 01 to 00 (=100). From the table of random double digits, a sample of e.g. $n=5$ observations are taken. These 5 observations are matched to the action that they represent. From this the sample mean is taken. By running this sampling process of sampling 5 observations over and over again, a sampling distribution with a mean average value is built up (Wonnacott and Wonnacott 1990).

With Monte Carlo simulation, the interaction of the input parameters is simulated on the critical financial ratios. It is the result of random scenarios such as "if x is high and y is high, then the result z is low".

The PDF on a cash flow position which is the input parameter to any cash flow simulation and can either be derived from historical and numerical data and records or base on subjective quantitative estimates such as best guesses. In the absence of such estimates, data and records, the proposed QQIR method can be used for deriving a customized PDF based on expert opinion on a specific cash flow position that is at risk.

3.5.2.2 Spearman Rank Correlation Coefficient and Significance

Often, information is grouped and ranked. Using Spearman rank correlation allows the comparison of two groups by comparing the difference in rankings of the different categories.

The Spearman rank correlation coefficient ρ_s or r_s is calculated by determining the correlation between rankings in two data sets. The rankings between each member of a pair is compared.

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$$\rho_s = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \text{ where} \quad (5)$$

d = the difference between the ranks of corresponding values x and y of a pair, and

n = number of pairs of values.

The correlation between two rank statistics is positive when $0 < \rho_s \leq 1.0$ and negative when $-1.0 \leq \rho_s < 0$. When $\rho_s = 0$, the two rank statistics are uncorrelated (Freund and Perles 2007).

The significance of the correlation result is determined by calculating the t -value and by using the Student's t -distribution for determining the level of significance.

$$t = \frac{\rho}{\sqrt{\frac{1 - \rho^2}{n - 2}}} \quad (6)$$

This method is applied for validating the QQIR method ranking results in triangulation with the general country and sector rankings and the absolute value polls.

3.6 Risk management with real options

Real options are a proactive approach in managing uncertainty (Ford et al. 2002). Conventional risk management focuses on identification, management and mitigation of risks. In risk mitigation, avoidance, reduction, shifting or transfer, and assumption of risks are the four commonly used methods (CII 1989).

In real options, the “strike price” at which an option may be exercised is usually some contractual term, for example performance measure and durations.

Taking guarantees as a real option for example, the strike price at which the guarantee may be called is some defined condition in the guarantee contract that first must occur before the guarantee is triggered. The value of such a real option would be equal to the amount of contingent compensation that needs to be issued.

The technique of real options describes this mechanism for managing and pricing such contingent claims and liabilities. A guarantee such as a minimum off-take guarantee comes into effect when a certain trigger point is reached. This is for example the case when a guaranteed minimum off-take is not fulfilled. Then the guarantor, in this case

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the public agency, is obliged to step in and compensate for the project company such that a minimum revenue stream is guaranteed to the project company.

Real options are one tool by which unpredictability can be managed and (given the probability of trigger), be priced. Evaluating guarantees in terms of real options adds value to the project. They also may serve as liabilities to the sponsors and lenders (Ho and Liu, 2002). The payment mechanism and penalty structure of a PPP contract can be described in terms of real options and event trees. They can be binary in nature and can be timely discrete (European style option) or multi-date (American style option).

Risks, expressed in terms of real options, can be allocated to the different parties and thereby priced and managed. Real options represent reactions to events that somehow have happened and somehow have influenced the project cash flow in such a way that at some trigger point, the option (guarantee) is exercised. These can be either call or put options. Real options do not ask for the cause, they react to changes that induced some trigger. The trigger point is subject to negotiations and documented in the contract documents.

The fundamentals to (real) option pricing can be found in Black and Scholes (1973) on pricing of options and corporate liabilities and Cox et al. (1979) on simplified approach to option pricing, and in textbooks such as Copeland et al. (2005), Brealey and Myers (2003), and Duffie (1996).

CHAPTER 4: FUZZY RISK ANALYSIS AND FUZZY SET THEORY

Fuzzy set theory is a methodology for capturing vagueness, uncertainty, imprecision, embedded human knowledge, human behavior and intuition. Fuzzy logic allows computing with words and words are used in place of numbers (Zadeh 1996). It is "a theory in which everything is a matter of degree, or elasticity" (Zadeh 1973). "Fuzzy logic is a tool for embedding structured human knowledge into workable algorithms" (Kecman 2001, p. 365). Fuzzy sets translate vagueness into quantifiable measures (Chiu 1994). It is the association of a given state being a member of a linguistic value such as "extremely low", "medium" or "very high". Each linguistic value is mapped by one distinct membership function, the fuzzy number. Zadeh's "Fuzzy Sets" (1965) and subsequent publications are perceived as the fundamentals for research into fuzzy sets and fuzzy logic.

4.1 Membership function

The membership function associates with each quantified linguistic value a grade of membership belonging to the interval $[0, 1]$ (Kaufmann and Gupta, 1988). A fuzzy set is defined as:

$$\forall x \in X, \mu_A(x) \in [0,1] \quad (7)$$

where $\mu_A(x)$ is the degree of membership, ranging from 0 to 1, of a quantity x of the linguistic value, A , over the universe of quantified linguistic values, X . X is a real number. The more x fits A , the larger the degree of membership of x .

Figure 5 provides an example for three membership functions describing three perceptions on age. Here, the age is represented along the horizontal axis. For example, a 5-year old child may be perceived to be definitely young but definitely not middle age. Definitely middle age may be a 40-year old, and a 25-year old might be perceived as somewhat young or middle age.

Figure 5: Example for membership functions resembling linguistic terms of age

Membership functions must fulfill the condition of normality and convexity.

4.1.1 Normalization and convexity

Fuzzy numbers must satisfy the condition of normality and convexity (Schmucker 1984, Kecman 2001)

normality: $\mu_A(x) = 1$, for at least one $x \in R$ (8)

convexity: $\mu_A(x') \geq \mu_A(x_1) \wedge \mu_A(x_2)$ (9)

where $\mu_A(x) \in [0,1]$ and $\forall x' \in [x_1, x_2]$.

Figure 6 contrasts normalized and non-normalized fuzzy sets.

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Figure 6: Normal and not-normal fuzzy sets

4.1.2 Triangular and trapezoidal fuzzy numbers

Membership functions can have any shape. The most commonly used shapes are triangular or trapezoidal shaped functions (Figure 7).

Figure 7: Triangular fuzzy number (T.F.N)

Membership functions can have any shape as long as they satisfy the conditions of normalization and convexity. However, fuzzy arithmetic operations become very complex and laborious when applied to any shape of fuzzy numbers. There are established fuzzy arithmetic operations that can handle triangular and trapezoidal shaped fuzzy numbers well. In the current state of development of the QQIR method, trapezoidal fuzzy numbers (Tr.F.N) will be used. The membership properties of a TrFN are shown in Figure 8.

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$$\mu_A(x) = \begin{cases} 0, & x < a \\ \frac{x-a}{b-a}, & a \leq x \leq b \\ 1, & b \leq x \leq c \\ \frac{d-x}{d-c}, & c \leq x \leq d \\ 0, & x > d \end{cases} \quad (11)$$

Figure 8: Trapezoidal fuzzy number (TrFN)

In a nutshell, the properties of a trapezoidal fuzzy number is determined by the values of the quadruples a, b, c , and d that are ascending on a scale, where the membership of a and d is zero and that of b and c is one. It is:

$$a \leq b \leq c \leq d \quad \text{and} \quad \begin{cases} \mu(a, d) = 0 \\ \mu(b, c) = 1 \end{cases} \quad \text{for } \{a, b, c, d\} \in R^+.$$

Triangular membership functions are constructed by setting b and c equal.

4.1.3 Defuzzification

Defuzzification is the process for converting a fuzzy number into a crisp number. One common approach is the center-of-gravity method (Figure 9).

Figure 9: Defuzzification with “center-of-gravity”

Other methods for defuzzification are first-of-maxima or middle-of-maxima. Center-of-gravity is sometimes also referred to as center-of-area (Kecman 2001, p. 393). The different methods yield slightly different results but have no impact on the information provided in terms of ranking. The method of “center of gravity” is chosen for ranking of different fuzzy numbers. It is the method which is most widely used and considers the actual shape of the fuzzy number better than first-of-maxima or middle-of-maxima methods.

4.1.4 Construction of fuzzy numbers

Fuzzy numbers can be constructed based on single or multiple opinions of experts. In case of multiple opinions i , the resultant fuzzy number is constructed in such a way that each quadruple a, b, c , or d reflects the average of all opinions provided.

$$A = \sum_{i=1}^n c_i A'_i(x) \quad \text{with} \quad \sum_{i=1}^n c_i = 1 \quad (13)$$

4.2 Fuzzy arithmetic operations

Fuzzy operations allow for the arithmetic combination of fuzzy numbers. Arithmetic operations such as addition (+), subtraction (-), multiplication (*), or division (/) can be performed on fuzzy numbers. There are two methods for conducting these operations. One is referred to as Zadeh’s extension principle. The other one is a further develop-

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ment of the extension principle and bases on findings of Dubois and Prade (1979, 1980). It is commonly referred to as the simplified arithmetic operations. For deconvolution, Minkowski operations can be applied to the operation of division ($/$) in the fuzzy weighted average calculation and of subtraction ($-$) to respect the influence of risk mitigating measures.

Detailed sample calculations on fuzzy arithmetic operations are in Kaufmann and Gupta (1985, 1988), Schmucker (1984), Kangari and Riggs (1989) Tah et al. (1993), and Chen (1996).

4.2.1 Fuzzy union, intersection, and complementation

Fuzzy sets can be combined. The basic operations are union, intersection, and complement (Schmucker 1984, p. 2). Figure 10 shows set unions and intersections.

Figure 10: Set union and intersection

The process of fuzzy combination and convex closure is shown in the following figure 11.

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Figure 11: Convex closure after fuzzy union combination

After fuzzy combination, the conditions of normalization and convexity must be satisfied.

4.2.2 Zadeh's extension principle

Zadeh introduced the arithmetic operations of addition, subtraction, multiplication and division for fuzzy numbers. They are commonly referred to as "Zadeh's extension principle". Let A and B be two fuzzy numbers. Following the notation of Schmucker (1984) it can be applied over the universe $\{0, 0.1, 0.2, \dots, 0.8, 0.9, 1.0\}$ as follows:

$$\begin{aligned} \text{Let: } A &= \{a(i)/i \mid 0 \leq i \leq 1.0\} \\ B &= \{b(j)/j \mid 0 \leq j \leq 1.0\} \end{aligned} \quad (14)$$

$$\begin{aligned} A + B &= \max \{ \min(a(i), b(j)) / [i + j] \mid i \leq 1, j \leq 1.0 \} \\ A - B &= \max \{ \min(a(i), b(j)) / [i - j] \mid i \leq 1, j \leq 1.0 \} \\ \text{then: } A * B &= \max \{ \min(a(i), b(j)) / [i * j] \mid i \leq 1, j \leq 1.0 \} \\ A / B &= \max \{ \min(a(i), b(j)) / [i / j] \mid i \leq 1, j \leq 1.0 \} \end{aligned} \quad (15)$$

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Zadeh's extension principles can be applied to any shape of a fuzzy number. The extension principles yield the same results for trapezoidal and triangular fuzzy numbers as the simplified arithmetic operations. In addition, the extension principles are very laborious and therefore are not applied in the QQIR method.

4.2.3 Simplified arithmetic operations

Dubois and Prade (1979, 1980) introduced algorithms for fuzzy operations that are simpler and faster than those derived from Zadeh's extension principles. Kaufmann and Gupta (1988) summarized the simplified approach based for arithmetic operations on trapezoidal fuzzy numbers A and B:

$$\begin{aligned}
 A(+)B &= (a_1, b_1, c_1, d_1)(+)(a_2, b_2, c_2, d_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2) \\
 A(-)B &= (a_1, b_1, c_1, d_1)(-)(a_2, b_2, c_2, d_2) = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2) \\
 A(*)B &= (a_1, b_1, c_1, d_1)(*)(a_2, b_2, c_2, d_2) = (a_1 * a_2, b_1 * b_2, c_1 * c_2, d_1 * d_2) \\
 A(/)B &= (a_1, b_1, c_1, d_1)(/)(a_2, b_2, c_2, d_2) = (a_1 / d_2, b_1 / c_2, c_1 / b_2, d_1 / a_2)
 \end{aligned} \tag{16}$$

The simplified approach applies to interval calculations of triangular or trapezoidal shaped fuzzy numbers only. For operations on triangular fuzzy numbers, the same values are assigned to b and c.

4.2.4 Application of Minkowski operations

Kaufmann and Gupta (1988) refer to operations introduced by Minkowski (1903) for deconvolution of equations with fuzzy numbers. For determining X in

$$A(*)X = B, \tag{17}$$

Minkowski's division is applied with

$$X = B(/)_m A. \tag{18}$$

For fuzzy numbers with quadruples greater than zero, the solution

$$X = \left(\frac{b_1}{a_1}, \frac{b_2}{a_2}, \frac{b_3}{a_3}, \frac{b_4}{a_4} \right) \tag{19}$$

exists, if the condition

$$\frac{b_1}{a_1} \leq \frac{b_2}{a_2} \leq \frac{b_3}{a_3} \leq \frac{b_4}{a_4} \tag{20}$$

is satisfied (Kaufmann and Gupta 1988).

4.3 Translating fuzzy numbers into linguistic values

After fuzzy operations, one can translate the result back into human language. There exist two methodologies. One is by calculating the Euclidian distance the other the similarity function F .

4.3.1 Euclidian distance

The Euclidian distance between the calculated fuzzy number X and the predefined grades (e.g. A) such as low, medium, high, is determines by:

$$d(X, A) = \sqrt{\sum_i [x(i) - A(i)]^2}. \quad (21)$$

The smallest distance indicates that the calculated fuzzy number X is closest to that particular predefined grade (e.g. medium).

4.3.2 Similarity function F

The other method is introduced by Chen (1996) by determining the similarity function F . It measures the similarity between two trapezoidal fuzzy numbers A and B. The greater F , the greater the similarity between the calculated fuzzy number X and the predefined grade (e.g. B):

$$F(X, B) = 1 - \frac{|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|}{4}. \quad (22)$$

In QQIR, the similarity function F will be applied for generating a feeling of the overall impact of that qualitative risks on the cash flow position. The numerical justification will be provided in Section 5.2.2.

4.4 Application of fuzzy set theory in risk analysis

There are several approaches to fuzzy risk analysis. All approaches have in common, that they assess the risk by the fuzzy weighted mean³ method. The QQIR method also uses the fuzzy weighted mean method:

³ A weighted mean is an average in which each quantity to be averaged is assigned a weight. These weightings determine the relative importance of each quantity on the average. Weightings are the equivalent of having that many like items with the same value involved in the average.

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$$R = \frac{\sum_i W_i (*) R_i}{\sum_i W_i} \quad (23)$$

The fuzzy weighted mean is created along the branches of event trees that visualize which risk factors influence what risk category how strong (R_i) and with what likelihood (W_i). Figure 12 shows an example of such influence diagram tree structures to determine the severity of loss S .

Figure 12: Example for fuzzy weighted mean risk assessment

The influence diagram is evaluated by the fuzzy weighted mean method. The linguistic calculation for the fuzzy weighted mean calculation is following:

$$S = \frac{[high(*)low](+)[medium(*)high]}{low(+)high} \quad (24)$$

Such tree structures may be far more complex which makes the fuzzy operations time consuming and complex, as well. Schmucker 1985 and Kangari (1989) employ Zadeh's extension principles for determining the risk severity in their sample calculations. They translate the risk into human language with the Euclidian distance.

Chen (1996) proposes to run that fuzzy weighted mean methodology with the simplified fuzzy operations and the similarity function F . He shows in three cases that using the simplified fuzzy number arithmetic operations and the similarity function, that this is

faster and more efficient than using Zadeh's extension principle, α -cuts, and Euclidean distance calculations. These methods will also be applied in the QQIR.

4.5 Conversion of fuzzy numbers into probability density functions

Neither fuzzy set theory nor probability theory is uniquely defined. One way to interpret fuzzy set theory is by possibility theory. For conversion from one theory into the other, the possibility/probability consistency principle as well as the uncertainty invariance principle is applied.

4.5.1 Possibility/probability consistency principle

Zadeh (1978) states the "possibility/probability consistency principle" which serves as theoretical framework for transforming a fuzzy number into a probability distribution function. It is "the heuristic observation that a lessening of the possibility of an event tends to lessen its probability – but not vice-versa" (Zadeh 1978). The principle states that for any f and g , fuzzy subsets exist in such a way that

$$Prob(X \text{ is } f | X \text{ is } g) \leq Poss(X \text{ is } f | X \text{ is } g). \quad (25)$$

An event that is probable to some degree must be possible at least to the same degree; however, not every possible event is probable.

Probability and possibility measures are uniquely represented by distribution functions, but their normalization requirements are different. While values of each probability distribution are required to sum up to 1.0, 1.0 must be the largest value in any possibility distribution, which is the normalization requirement for fuzzy numbers (Klir and Yuan 1995, p. 203).

The weakest consistency condition is expressed formally by the inequality

$$Prob(A) \leq Poss(A) \quad (26)$$

for all $A \in P(X)$. The strongest consistency condition in contrary requires that any event with nonzero probability must be fully possible. It is

$$Prob(A) > 0 \Rightarrow Poss(A) = 1 \quad (27)$$

for all $A \in P(X)$. Other consistency conditions may be formulated that are between the weakest and strongest condition. The degree of probability/possibility consistency c between the probability distribution function p and possibility distribution function r can be measured by (Klir and Yuan 1995, p. 206)

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$$c(p, r) = \sum_{x \in X} p(x) * r(x).$$

4.5.2 Uncertainty invariance principle

Wonneberger (1994) introduced the generalization of an invertible mapping between probability and possibility that contains a parametrical function T_g , which can be chosen such that the probability/possibility consistency relation and the uncertainty-invariance principle are fulfilled simultaneously. It accounts for the “principle of uncertainty-invariance” (Klir and Yuan 1995, p. 275) that when transforming a representation from one theory T_1 into another theory T_2 :

1. the amount of uncertainty associated with the situation be preserved when moving from T_1 to T_2 ; and
2. the degrees of belief in T_1 be converted to their counterparts in T_2 by an appropriate scale, at least ordinal.

When moving from one theory to the other theory, the type of information in the one theory is replaced with an equal amount of information of the other type. In the QQIR method, it is the movement from the possibility distribution function (the fuzzy number) to the probability distribution function. Principle 1 is guaranteed by not changing the intervals that represent the meaning and amount of uncertain information contained in the fuzzy number. Therefore, no information is added or omitted. The same applies to principle 2: when the scale is not changed, there is no scaling problem.

Klir and Yuan (1995, p. 276) listed the following results that have been found regarding uncertainty-invariant transformations $p \leftrightarrow r$:

1. transformations based on ratio and difference scales do not have enough flexibility to preserve uncertainty and, consequently, are not applicable;
2. for interval scales, uncertainty-invariant transformations $p \rightarrow r$ exist and are unique for all probability distributions, while the inverse transformations $r \rightarrow p$ that preserve uncertainty exist (and are unique) only for some possibility distributions;
3. for log-interval scales, uncertainty-invariant transformations exist and are unique in both directions;
4. ordinal scale transformations that preserve uncertainty always exist in both directions, but, in general, are not unique.

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Klir and Yuan (1995, p. 276) concluded, that the log-interval scale is thus the strongest scale under which the uncertainty invariance transformations $p \leftrightarrow r$ always exist and are unique. In the current state of development of the QQIR method, the chosen transformation method of the fuzzy number involves no adjustment of scaling. The scale from 0 to 1.0 is ordinal and it is not based on ratios or differences, intervals or log-intervals. This discussion is important to support the choice of conversion method as demonstrated in the following.

There are two possible methods for converting a fuzzy number into a probability distribution function (PDF).

- Uniform conversion: The shape of the fuzzy number is adopted as the same shape for the PDF, which is a uniform expansion or contraction of the shape in which all proportions of the angles and side-length ratios of the shape are kept, or
- Proportional conversion: The intervals of the fuzzy number are adopted as the same intervals for the PDF, so that only the height of the shape is proportionally either increased or decreased.

The QQIR method employs trapezoidal fuzzy numbers (Tr.F.N). The height h of the trapezoid is 1.0. Key in the transformation process is that the area under the adjusted function becomes equal to one, and that the centers of gravity (defuzzification) of the initial and converted function are the same.

4.5.3 Uniform conversion

In the uniform conversion, the shape of both functions is the same (Figure 13). It is similar to the linear transformation of uniform probability density function (updf) as introduced by Kaufmann and Gupta (1985). However, here in this applied conversion method, the integers "b" and "c" also change position. It is, in the process of adjusting the area of the initial TrFN to 1.0, that the ratios among the angles and length of the sides of the trapezoid are not changed. Hereby the height of the trapezoid changes as well as the intervals of the TrFN. The weakness of that method is that information is added or omitted as the intervals change which changes the range and domain of the resulting distribution (Sheen 2005a). This is in conflict with the uncertainty-invariance principle which demands that no information is added or omitted when transforming.

Figure 13: Uniform conversion by keeping the proportions

The mathematical process for conversion is rather laborious and as follows:

1. set $k = c - b$, $l = d - a$, $m = b - a$, and $n = d - c$. Adjusted parameters are indicated with the superscript ('')

2. determine area A of initial TrFN by $A = \frac{1}{2}(k + l)h$ and $h=1$

3. the adjusted area A' must be 1.0, thus

$$A' = \frac{1}{2}(k' + l')h' \quad (28)$$

4. from the theorem of intersecting line, it is known that

$$\frac{h}{m} = \frac{h'}{m'} \text{ and } \frac{h}{n} = \frac{h'}{n'}$$

5. from this theorem, following relation can be derived:

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$$h' = \frac{k'}{k} = \frac{l'}{l} = \frac{m'}{m} = \frac{n'}{n}$$

6. thus

$$A' = 1 = \frac{1}{2} \frac{l'}{l} \left(\frac{kl'}{l} + l' \right)$$

7. it follows that

$$l' = \sqrt{\frac{1}{\frac{k}{2l^2} + \frac{1}{2l}}}, \text{ yielding } h', k', m' \text{ and } n'$$

8. determine transition coordinates with a' as origin:

$$a' = 0, b' = a' + m', c' = b' + k', \text{ and } d' = a' + l'$$

9. determine center of gravity g of TrFN with respect to a for the initial TrFN:

$$g_a = \frac{\sum_i A_i g_i}{\sum_i A_i} = \frac{\frac{2}{3} \frac{(b-a)^2}{2} + (c-b) \left(\frac{c-b}{2} + b-a \right) + \left(\frac{d-c}{2} \right) \left(\frac{d-c}{2} + c-a \right)}{\frac{b-a}{2} + (c-b) + \frac{d-c}{2}} \quad (29)$$

10. determine distance of g_a from the origin by adding a :

$$r = g_a + a$$

11. determine center of gravity g' of TrFN with respect to a' for the adjusted TrFN:

$$g'_{a'} = \frac{\sum_i A'_i g'_i}{\sum_i A'_i} \quad (30)$$

12. determine new coordinates for the adjusted TrFN with same center of gravity as initial

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$$a'' = r - g'_{a'}, b'' = a'' + m', c'' = b'' + k', \text{ and } d'' = a'' + l'$$

13. For control, calculate and prove:

$$A'' = 1.0 \text{ and } g''_{a''} + a'' = r \quad (31)$$

4.5.4 Proportional conversion

In the proportional conversion method, the intervals that were estimated for the TrFN are kept the same for the PDF and only the height of the trapezoid changes (figure 14). Kaufmann and Gupta (1985) introduced this proportional conversion into the proportional probability density function (ppdf) in which only the height of the fuzzy number changes but not its intervals.

Figure 14: Proportional conversion by keeping the intervals

The new height h is derived from:

$$A = 1 = \frac{1}{2}((c - b) + (d - a))h \text{ thus } h = \frac{2}{(c - b) + (d - a)}. \quad (32)$$

Sheen (2005a) recommends using the proportional conversion when transforming a fuzzy number into a PDF. By using the proportional conversion, information is neither added nor omitted as the domain and vertex are the same for both functions. This satisfies the uncertainty invariance principle discussed above, as well.

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4.5.5 Testing of the validity of conversion by their linguistic value

Table 4 sums up the numerical conversion of the TrFNs into probability distribution functions. The initial fuzzy number was arbitrarily chosen.

	a	b	c	d	Area A	Center of gravity g from a	Center of gravity g' from origin 0	height h, h'
Fuzzy number	0.1750	0.3846	0.7100	1.4857	0.8181	0.6035	0.7785	1.0000
PDF from method 1	0.1112	0.3430	0.7028	1.5604	1.0000	0.6673	0.7785	1.1056
PDF from method 2	0.1750	0.3846	0.7100	1.4857	1.0000	0.6035	0.7785	1.2224

Table 4: Numerical summary on the transformation of the TrFN into PDFs

As discussed above, the linguistic representation can be checked by either determining the Euclidian distance or by determining the similarity function F.

Table 5 shows the comparison of both methods for converting TrFN into PDFs.

Linguistic value	Euclidian Distance			Similarity function F		
	Fuzzy number	PDF from M1	PDF from M2	Fuzzy number	PDF from M1	PDF from M2
extremely low (EL)	1.4845	1.5310	1.4845	0.3862	0.3957	0.3862
very low (VL)	1.1775	1.2367	1.1775	0.5612	0.5707	0.5612
low (L)	1.0371	1.1072	1.0371	0.6487	0.6263	0.6487
medium (M)	0.9447	1.0351	0.9447	0.6410	0.5978	0.6410
high (H)	0.7889	0.8918	0.7889	0.6910	0.6478	0.6910
very high (VH)	0.7945	0.9011	0.7945	0.6460	0.5991	0.6460
extremely high (EH)	0.9881	1.0895	0.9881	0.5210	0.4741	0.5210

Table 5: Linguistic value and comparison of uniform and proportional conversion method

It is obvious that the linguistic value for the fuzzy number and the PDF from proportional conversion must be the same, as they have the same intervals, scale values, and both trapezoidal shapes rest on the same vertical center of gravity line.

This comparison of both methods shows no significant difference in the accuracy in determining the linguistic value. Both, the Euclidian distance and similarity function F, yield the same results.

4.5.6 Justification of choice of proportional over uniform conversion

In light of the uncertainty-invariance principle discussed above, for the proportional conversion method, the intervals and values on the scale of the Tr.F.N as well as the PDF are not altered, but kept the same. There is no need to rescale the PDF. With the uniform conversion method, however, the values on the scale (x-axis) are altered and it demands rescaling. Rescaling would again change the resulting area under the curve from not equal to 1.0, and new adjustments would be necessary. In addition, the

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proportional conversion method is less laborious and requires less computation time than the uniform conversion method.

The QQIR method therefore employs the proportional conversion method as it is keeping the same intervals and values on the impact severity. The proportional conversion method is chosen over the uniform conversion method.

4.5.7 Statistical properties of converted TrFN and PDF

The mean μ is

$$\mu = \int_{-\infty}^{+\infty} xf(x)dx \quad (33)$$

Therefore, the mean of the converted TrFN can be formulated as

$$\mu = \int_a^b \frac{hx(x-a)}{b-a} dx + \int_b^c hxdx + \int_c^d \frac{hx(d-x)}{d-c} dx \quad (34)$$

After solving, the mean is

$$\mu = \frac{h}{6}(c^2 + dc + d^2 - a^2 - ab - b^2) \quad (35)$$

The variance of the PDF is determined by

$$\begin{aligned} \sigma^2 &= \int_{-\infty}^{+\infty} (x-\mu)^2 f(x)dx = \frac{h}{12}[(c+d)(c^2+d^2) - (a+b)(a^2+b^2)] \\ &\quad - \frac{h\mu}{3} \left[\frac{(b^3-a^3)(d-c) + (d^3-c^3)(a-b)}{(a-b)(d-c)} \right] + \frac{h\mu^2}{2}(c+d-a-b) \end{aligned} \quad (36)$$

and the standard deviation s is

$$s = \sqrt{\sigma^2} \quad (37)$$

For the “fitness-of-purpose-test” the mean value of the financial decision criteria determined with the QQIR method is compared against the absolute value polls and their difference is measured in standard deviations.

CHAPTER 5: THE DEVELOPMENT OF THE METHOD FOR QUANTIFYING QUALITATIVE INFORMATION ON RISKS (QQIR)

5.1 Summary of the QQIR method

The method for quantifying qualitative information on risks (QQIR) combines several methods from fuzzy set, possibility, and probability theory.

First, the cash flow positions $i = [1, 2, \dots, n]$ that are at risk must be identified. A cash flow position is a number with in a financial model. This number can represent for example the number of units sold, the prices per unit, or any other parameter that may influence the financial performance. For risk exposure and recovery assessments, this may be cash flow modeling input parameters such as demand or pricing risks or recovery scenarios.

Second, the risk factors $t = [1, 2, \dots, k]$ that may influence each cash flow position must be identified and structured in influence diagrams. Chapter 6 and 7 elaborates on examples.

For each influencing risk factor, the weight (likelihood L) and the anticipated consequence (impact I) on the financial parameter is collected in terms of expert opinions or judgments. Here the “weight” or “likelihood” indicated the relative importance of a risk factor. These opinions are coded with fuzzy numbers. Multiple opinions on the same factor are aggregated for each quadruple by

$$A(x) = \sum_{i=1}^n c_i A_i(x), \text{ with } \sum_{i=1}^n c_i = 1 \quad (38)$$

where $A_i(X)$ denotes the valuation of the proposition “ x belongs to A ” by expert i , c_i is the weight attributed to each expert, and n is the number of expert opinions collected.

Experts are asked to provide their opinion on a range. For example a reply to the question “Where on a scale of 0 to 1 is 0.9?”, the answer might be “Close to 1.0!” On the question “Where on a scale of 0 to 2 is 0.9?”, the answer might be “Close to medium!”. Thus by using the experts gut feeling to describe some risk factor on a scale allows locating its possible impact.

Third, the opinions collected from the experts on the weightage and consequences are aggregated by the fuzzy weighted mean method for each tier in the influence diagram.

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$$I_i = \frac{\sum_{t=1}^k I_{i,t} * L_{i,t}}{\sum_{t=1}^k L_{i,t}} \quad (39)$$

In calculating the fuzzy weighted mean, the simplified arithmetic operations (Kaufmann and Gupta 1989) are chosen for addition, multiplication, and subtraction. The division follows a Minkowski's operation.

$$\begin{aligned} A(+)B &= (a_1, b_1, c_1, d_1)(+)(a_2, b_2, c_2, d_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2) \\ A(-)B &= (a_1, b_1, c_1, d_1)(-)(a_2, b_2, c_2, d_2) = (a_1 - a_2, b_1 - b_2, c_1 - c_2, d_1 - d_2) \\ A(*)B &= (a_1, b_1, c_1, d_1)(*)(a_2, b_2, c_2, d_2) = (a_1 * a_2, b_1 * b_2, c_1 * c_2, d_1 * d_2) \\ A(/)B &= (a_1, b_1, c_1, d_1)(/)(a_2, b_2, c_2, d_2) = (a_1 / a_2, b_1 / b_2, c_1 / c_2, d_1 / d_2) \end{aligned} \quad (40)$$

Fourth, the aggregated TrFN is converted into a PDF with proportional conversion. In proportional conversion, the intervals of the TrFN and PDF are the same, only the height of the distribution changes respectively with the condition that the area under the PDF curve must be equal to 1.0. While the height of the TrFN is 1.0, the new height of the PDF is $h = 2 / [(c - b) + (d - a)]$ and the quadruples a, b, c , and d remain unchanged.

Also, determine the linguistic value of the aggregated risks and its influencing factors by using the similarity function F

$$F(X, B) = 1 - \frac{|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|}{4} \quad (41)$$

Fifth, the statistical properties of the PDF can be calculated. The mean value μ of the converted TrFN and PDF is determined by:

$$\mu = \int_{-\infty}^{+\infty} xf(x)dx = \frac{h}{6}(c^2 + cd + d^2 - a^2 - ab - b^2) \quad (42)$$

The variance of the PDF is determined by

$$\begin{aligned} \sigma^2 &= \int_{-\infty}^{+\infty} (x - \mu)^2 f(x)dx = \frac{h}{12} [(c + d)(c^2 + d^2) - (a + b)(a^2 + b^2)] \\ &\quad - \frac{h\mu}{3} \left[\frac{(b^3 - a^3)(d - c) + (d^3 - c^3)(a - b)}{(a - b)(d - c)} \right] + \frac{h\mu^2}{2}(c + d - a - b) \end{aligned} \quad (43)$$

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and the standard deviation s is

$$s = \sqrt{\sigma^2} \quad (44)$$

Following step two and/or step three, the aggregated fuzzy numbers can be compared against the underlying the linguistic values. The linguistic value that is most similar to the aggregated fuzzy number is determined by the similarity function F . The greatest F value, closest to 1.0, indicates the greatest similarity.

$$F(X, B) = 1 - (|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|) / 4. \quad (45)$$

Also after step two and/or step three, the center of gravity, or centroid, of the fuzzy number can be calculated. This allows ranking of the fuzzy numbers. The centroids are calculated by

$$x' = \frac{\sum x_i \mu_i}{\sum \mu_i} \quad (46)$$

The methods from non-parametric statistics such as the Spearman rank correlation coefficient can then be used to compare different groups of rankings against each other.

The output of the QQIR Method can be used in two main applications: 1) It can be used for rankings of, and may serve as, input to non-parametric statistical methods. 2) It provides a mean value, maximum, minimum and other statistical properties of a probability density curve that may serve as input for stochastic simulation. Also, the output fuzzy number of the QQIR Method can again be translated into linguistic terms to provide a feeling for the severity of the risk impact.

Novelty of the QQIR is a) the comprehensive process and b) the application Minkowsky principles and proportional conversion to create the PDF. In the context to this thesis, fuzzy risk analysis has also not been applied to political risks before. So, there is computational novelty as well as novelty in application.

Figure 15a provides a conceptual and computational overview of the QQIR method in terms of modules of a knowledge based expert system.

Figure 15b shows the position of the QQIR method in transaction appraisal. Section 5.4 will elaborate on some possible applications of the QQIR method in finance and transaction structuring.

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Figure 15a: The QQIR method bridging the gap between qualitative and quantitative risk assessment methods

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Figure 15b: Positioning of the QQIR method in a financial appraisal process

5.2 Applied fuzzy set principles, methods, and operations in the QQIR method

5.2.1 Constructing fuzzy numbers representing linguistic values

The QQIR method uses trapezoidal membership functions which are characterized by the quadruples a , b , c , and d .

Saaty (1977) describes that experts can best distinguish between seven plus or minus two alternatives. Schmucker (1984) and Chen (1996) limit expert opinion to five alternatives or extend the spectrum to nine (Chen 1996) with crisp boundaries of “absolutely low” $(0, 0, 0, 0)$ or “absolutely high” $(1, 1, 1, 1)$.

In the QQIR method, seven linguistic terms are chosen to represent the expert’s opinion on impact and likelihood of the risk factors. These seven alternatives are: “extremely low” (EL), “very low” (VL), “low” (L), “medium” (M), “high” (H), “very high” (VH), and “extremely high” (EH). For the purpose of the QQIR method, the scale for the quadruples a , b , c , and d is chosen in the range from 0 to 1,0.

Constructing the fuzzy numbers that represent the linguistic values of the expert opinion is a problem of knowledge acquisition, commonly referred to as knowledge engineering. Generally, it is differentiated between direct and indirect methods, acquiring knowledge from a single or from multiple experts (Klir 2006).

When choosing the direct method and multiple experts, the opinions of the individual experts must be properly combined. Any averaging method can be used. Commonly, the simple weighted average is employed:

$$A(x) = \sum_{i=1}^n c_i A_i(x). \quad (47)$$

Here, $A_i(x)$ denotes the valuation of the proposition “ x belongs to A ” by expert i , n denotes the number of experts involved, and c_i denote the weights by which the relative significance of the individual experts can be expressed. It further is assumed, that all weights sum up to one (Klir 2006), i.e.

$$\sum_{i=1}^n c_i = 1. \quad (48)$$

In the QQIR method, for building up the knowledge base on the fuzzy linguistic value representations, the direct knowledge acquisition method with multiple experts was chosen and each expert equally weighted.

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The data was collected in class room sessions. In each session, the respondents were first trained on the concept of fuzzy numbers and the meaning of the quadruples a, b, c, and d. Then, The respondents were presented with the survey questionnaire which contained an example on fuzzy linguistic value representations, a graph for scratch, and a table to numerically fill in their perceptions on the asked linguistic values. Now, the respondents were asked to provide their opinion by filling in the survey questionnaire (Appendix 1).

There were two class room sessions in February 2006. One was with 21 master degree students from the Bauhaus University Weimar, Germany. The other session was with 14 master and doctoral degree students from the Asian Institute of Technology, Bangkok, Thailand. All participants were trained before answering the questionnaire on the principles of fuzzy sets and how fuzzy numbers can be constructed. Out of the total number of 35 survey participants, four responding survey questionnaires were found to be filled out wrongly and therefore excluded from the data analysis. The four survey response forms were either not filled out at all or copy & pasted from the example and therefore no good evidence of someone putting his or her thought into it. The sample size for the data evaluation is 31 respondents. The statistical analysis is provided in Appendix 1. The average response had an average standard deviation of 4.66%. The population of students is considered as representative for collecting TrFNs on perceptions as the question only regarded their perception on terms such as “low” or “extremely high”, but not on, “how do you perceive the likelihood of expropriation in Venezuela”.

Each quadruple for each linguistic value was evaluated with the weighted average method. Here, all respondents were weighted equally as their knowledge on fuzzy sets and ability to follow the instructions were the same. Table 6 shows the resultant fuzzy coded linguistic terms.

Linguistic values	TrFN representation			
	a	b	c	d
extremely low (EL)	0.000	0.000	0.073	0.148
very low (VL)	0.085	0.158	0.227	0.311
low (L)	0.206	0.305	0.363	0.461
medium (M)	0.389	0.481	0.526	0.613
high (H)	0.553	0.647	0.709	0.794
very high (VH)	0.702	0.776	0.840	0.914
extremely high (EH)	0.847	0.928	1.000	1.000

Table 6: Numerical representation of expert opinion

This numerical representation is graphically represented in the following figure.

Figure 16: Graphical representation of the quadruple representing expert opinion

Based on these linguistic values, experts would provide their opinion during interviews or surveys on the severity of impact and likelihood of occurrence of a risk. The expert provides his answer in terms of one of these seven linguistic values. The corresponding questions may be of the form of: “What is the likelihood that the risk factor occurs?” and “If the risk factor occurs to the anticipated degree, what is the impact on the cash flow position?”

5.2.2 Linguistic value of fuzzy numbers

With reference to predetermined fuzzy numbers, other fuzzy numbers can be translated into linguistic values. There exist two methodologies. One is by calculating the Euclidian distance the other is by calculating the similarity function $\bar{F}$. Both allow for ranking of fuzzy numbers and determining their linguistic values.

5.2.2.1 Euclidian distance

The Euclidian distance between the calculated fuzzy number X and the linguistic value A is determined by:

$$d(X, A) = \sqrt{\sum_i [x(i) - A(i)]^2}. \quad (49)$$

The smallest distance indicates that the calculated fuzzy number X is closest to that particular linguistic value.

5.2.2.2 Similarity function F

Chen (1996) introduced the similarity function F . It measures the similarity between the two fuzzy numbers X and B . The greater the value of F , the greater the similarity between the calculated fuzzy number X and the linguistic value B :

$$F(X, B) = 1 - \frac{|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|}{4}. \quad (50)$$

In the sample calculation in the next section, both methods are applied. Both methods yield the same linguistic results. However, the similarity function F involves less computation and is easier to handle than the Euclidian distance (Chen 1996). Therefore, the QQIR method will use the similarity function F for determining the linguistic value of aggregated risks.

5.2.3 Fuzzy weighted average calculation

In fuzzy risk analysis, the QQIR method uses the fuzzy weighted average method for assessing the aggregated impact I_i of multiple risk factors $t = [1, 2, \dots, k]$ on the cash flow position i . Each risk factor t is expressed in terms of its severity of possible impact $I_{i,t}$ on the cash flow position i and its likelihood of occurrence $L_{i,t}$ of that risk factor, often referred to as weight, relevance, or importance. The aggregated risk impact I_i on cash flow position i is calculated with fuzzy arithmetic operations as:

$$I_i = \frac{\sum_{t=1}^k I_{i,t} * L_{i,t}}{\sum_{t=1}^k L_{i,t}} \quad (51)$$

The fuzzy weighted mean is calculated for each knot in the tree diagram. The tree diagram visualizes which risk factors $t = [1, 2, \dots, k]$ have influence on the cash flow position i that is under investigation. Again, each risk factor t can be influenced by yet other factors. The tree diagram can have sub-structures.

Figure 17: Tree diagram for risk analysis and fuzzy weighted mean calculation

5.2.3.1 Chosen arithmetic operations

When performing the calculation on the fuzzy weighted mean, one has the choice between using Zadeh’s extension principle, the simplified arithmetic operations, or Minkowski’s operations.

The draw back of using the simplified arithmetic operations is that it only can be applied to triangular shaped or trapezoidal shaped fuzzy numbers whereas the extension principle can be applied to any shape of a fuzzy number. However, the simplified arithmetic operations are faster than using Zadeh’s extension principle. Applying the extension principle to trapezoidal numbers yields the same result as the simplified arithmetic operations.

At the current state of the QQIR development, trapezoidal fuzzy numbers are used to represent expert opinion. Therefore it is more convenient to choose the simplified arithmetic operations over the extension principle.

For risk mitigating strategies, subtraction with the simplified arithmetic operation is applied. For the fuzzy weighted mean calculation, Minkowski’s division is used.

5.2.3.2 Numerical justification of applied operations

Chen (1996) demonstrated the simplified arithmetic operations in three examples on fuzzy weighted average calculations by referring to calculations in other papers (Liou and Wang 1992a, 1992b, 1994, Schmucker 1984, Kangari and Riggs 1989) in which the calculations were conducted using Zadeh's extension principle. Chen (1996) argued that the simplified arithmetic operations were more efficient than Zadeh's extension principle. He applied Minkowski's division in example one and performed division with the simplified arithmetic operation for example two and three. Chen (1996), however, failed to reason for his choice between Minkowski's division and the simplified arithmetic division operation. Also he failed to compare the resulting fuzzy numbers of his calculations with the quadruples to the examples in the original papers. A major weakness is that Chen (1996) did not use the same membership functions for his calculations as they were in the original papers, which make his results difficult to evaluate and compare.

This shortcoming is overcome in the following comparative fuzzy weighted average calculation. By using five scenarios (also see next section demonstrating a sample calculation), the results from applying the simplified arithmetic operations and the alternative Minkowski's division are compared. It will be shown that by applying Minkowski's division, more reliable results are achieved.

Assume there are only two risk factors. It is assumed that their respective severity of impact and likelihood of occurrence is either "very high" (VH) or "very low" (VL) or a combination of these. The assignment of fuzzy numbers to these linguistic values follows the above stated assignment. For the sake of simplicity, five scenarios are tested. They are:

- Scenario A: The risk scenario is "very low" (VL) for both risk factors: VL impact and VL likelihood that it happens.

$$A = \frac{(VL * VL) + (VL * VL)}{VL + VL} \quad (52)$$

- Scenario B: The risk scenario is "very high" (VH) for both risk factors: VH impact and VH likelihood that it happens.

$$B = \frac{(VH * VH) + (VH * VH)}{VH + VH} \quad (53)$$

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- Scenario C: The scenario is mixed. One risk factor has a perceived input and likelihood of VH, the other of VL.

$$C = \frac{(VH * VH) + (VL * VL)}{VH + VL} \quad (54)$$

- Scenario D: Both risk factors have VH impact but VL likelihood.

$$D = \frac{(VH * VL) + (VH * VL)}{VL + VL} \quad (55)$$

- Scenario E: Both risk factors have VL impact but VH likelihood.

$$E = \frac{(VL * VH) + (VL * VH)}{VH + VH} \quad (56)$$

In the next section, the calculation for scenario A is numerically demonstrated.

Figure 18: Example with two risk factors and different VH or VL combinations

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For numerical presentation, one could assign the crisp values $\{1, 2, 3, \dots, 7\}$ to the seven linguistic values from “extremely low” to “extremely high”. Substituting the crisp values of 2 for “very low” (VL) and 6 for “very high” (VH) in the above stated five equations for the five scenarios, scenario A and E yield the expected “2” which can be read as “very low” and scenario B and D yield the expected “6” which can be read as “very high”. Scenario C yields a numerical “5” which can be read as “high”.

The same linguistic results are expected when performing these calculations with fuzzy numbers. The fuzzy numbers that were derived above are being used.

Table 7 shows the results of the fuzzy weighted average calculation for all the five scenarios by using either only the simplified arithmetic operations (SAO) or employing Minkowski’s division (MD). In section 5.3, there is one numerical sample calculation for scenario A.

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	a	b	c	d	Area A	Center of Gravity g from "a"	Center of gravity from origin "0"	Hight h' of PDF after conversion
Tr.F.N Membership Function								
extremely low (EL)	0.000	0.000	0.073	0.148	0.1105	0.0617	0.0617	
very low (VL)	0.085	0.158	0.227	0.311	0.1476	0.1146	0.2000	
low (L)	0.206	0.305	0.363	0.461	0.1565	0.1326	0.3390	
medium (M)	0.389	0.481	0.526	0.613	0.1347	0.1177	0.5064	
high (H)	0.553	0.647	0.709	0.794	0.1508	0.1260	0.6792	
very high (VH)	0.702	0.776	0.840	0.914	0.1385	0.1096	0.8113	
extremely high (EH)	0.847	0.928	1.000	1.000	0.1126	0.0945	0.9413	
Fuzzy weighted mean (Minkowski)								
A (VL*VL+VL*VL)/(VL+VL)	0.085	0.158	0.227	0.311	0.1476	0.1146	0.2000	6.7760
B (VH*VH)+(VH*VH)/(VH+VH)	0.702	0.776	0.840	0.914	0.1385	0.1096	0.8113	7.2177
C (VH*VH+VL*VL)/(VH+VL)	0.635	0.671	0.710	0.761	0.0824	0.0628	0.6975	12.1300
D (VH*VL+VH*VL)/(VL+VL)	0.702	0.776	0.840	0.914	0.1385	0.1096	0.8113	7.2177
E (VH*VL+VH*VL)/(VH+VH)	0.085	0.158	0.227	0.311	0.1476	0.1146	0.2000	6.7760
Fuzzy weighted mean (simplif. Arithh)								
A (VL*VL+VL*VL)/(VL+VL)	0.023	0.110	0.327	1.134	0.6637	0.4970	0.5205	1.5067
B (VH*VH)+(VH*VH)/(VH+VH)	0.538	0.716	0.910	1.191	0.4233	0.3208	0.8592	2.3622
C (VH*VH+VL*VL)/(VH+VL)	0.408	0.587	0.812	1.185	0.5009	0.3723	0.7799	1.9966
D (VH*VL+VH*VL)/(VL+VL)	0.193	0.539	1.209	3.329	1.9031	1.4174	1.6101	0.5255
E (VH*VL+VH*VL)/(VH+VH)	0.066	0.146	0.246	0.406	0.2202	0.1634	0.2290	4.5413

	Fuzzy weighted mean (Minkovski)					Fuzzy weighted mean (simpl. Arith)				
Euclidian Distance										
Linguistic interpretation of impact	A	B	C	D	E	A	B	C	D	E
extremely low (EL)	0.2878	1.5067	1.2786	1.5067	0.2878	1.0237	1.6100	1.4599	3.4258	0.3492
very low (VL)	0.0000	1.2249	1.0000	1.2249	0.0000	0.8320	1.3256	1.1799	3.1980	0.0990
low (L)	0.2775	0.9487	0.7265	0.9487	0.2775	0.7244	1.0544	0.9193	2.9992	0.2486
medium (M)	0.6132	0.6121	0.3907	0.6121	0.6132	0.7625	0.7484	0.6485	2.8082	0.5810
high (H)	0.9604	0.2653	0.0909	0.2653	0.9604	0.9115	0.4513	0.4343	2.6117	0.9239
very high (VH)	1.2249	0.0000	0.2364	0.0000	1.2249	1.1022	0.3343	0.4429	2.5065	1.1886
extremely high (EH)	1.4979	0.2777	0.5023	0.2777	1.4979	1.3482	0.4296	0.6155	2.4591	1.4640
Similarity function F										
Linguistic interpretation of impact	A	B	C	D	E	A	B	C	D	E
extremely low (EL)	0.8597	0.2473	0.3610	0.2473	0.8597	0.6567	0.2162	0.3074	-0.2622	0.8394
very low (VL)	1.0000	0.3876	0.5014	0.3876	1.0000	0.7419	0.3565	0.4478	-0.1219	0.9637
low (L)	0.8617	0.5259	0.6397	0.5259	0.8617	0.7285	0.4948	0.5861	0.0095	0.8820
medium (M)	0.6935	0.6940	0.8078	0.6940	0.6935	0.6362	0.6630	0.7542	0.0865	0.7139
high (H)	0.5198	0.8677	0.9653	0.8677	0.5198	0.5528	0.8293	0.8250	0.1239	0.5401
very high (VH)	0.3876	1.0000	0.8862	1.0000	0.3876	0.4809	0.8576	0.8044	0.1177	0.4079
extremely high (EH)	0.2519	0.8643	0.7505	0.8643	0.2519	0.3880	0.7997	0.7116	0.1047	0.2722

Table 7: Minkowski's division vs. simplified arithmetic operations

In the QQIR method, Minkowski's division is chosen over the simplified arithmetic operation. This choice is supported by two reasons.

First, all five scenarios that are calculated with Minkowski's division match exactly the expected linguistic interpretation, which was calculated both with the Euclidian distance as well as with the similarity function F. However, when applying the simplified arithmetic operation, scenarios A and D do not yield the expected result when using the Euclidian distance. Furthermore, scenario D also does not yield the expected lin-

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guistic value when using the similarity function F . This observation also suggests that the similarity function F is more reliable than the Euclidian distance method. The similarity function F is chosen over the Euclidian distance method.

Second, when applying Minkowski's division, the results of scenarios A, B, D, and E match exactly the quadruples of the linguistic values "very low" and "very high", respectively. C is very close to the linguistic value "high". When calculation the five scenarios with the SAO, the resulting fuzzy numbers diverge considerably from the fuzzy numbers that represent their linguistic values. This is attributed to the method of division in the simplified arithmetic operation. When dividing for example the quadruple d_1 of fuzzy number A_1 by the quadruple a_2 of fuzzy number A_2 the result may be a fairly large number when a_2 is very much smaller than d_1 , $a_2 \ll d_1$. This becomes evidential in particular in scenario D. Here, the quadruples range from $a_D = 0.193$ to $d_D = 3.329$ and the center of gravity from the origin is with $g_D = 1.6101$ far beyond the boundaries of the interval of $[0, 1]$ within which reasonable financial modeling is supposed to occur. The quadruples of scenarios A, B, and C also stretch over a wide range and exceed the boundary value of 1.0. Only scenario E is within a reasonable range and the center of gravity only differing by 0.029 from the center of gravity of its linguistic representation "very low".

From these observations, it is concluded that fuzzy weighted average calculations which employ the simplified arithmetic operations of addition, subtraction, and multiplication and Minkowski's operations for division yield the most promising resulting fuzzy numbers that allow for reasonable modeling in the here chosen interval of $[0, 1]$.

5.2.4 Evaluating mitigating strategies

The QQIR method can incorporate the effect of risks as well as the mitigating measures or factors that have a risk decreasing influence on the risk factor. An example in the second case study I the question what is the risk impact with and without ADB's mediation. For example, if the risks affecting a cash flow position are perceived as "high", one would call for some mitigating measure that has a minimum effect of also "high" to off-set that risk. The QQIR will employ the simplified arithmetic operations and not Minkowski's subtraction for evaluating the impact of mitigating strategies on risks, as will be shown.

Minkowski's subtraction of two fuzzy numbers A_1 and A_2 is defined as (Kaufman and Gupta, 1988):

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$$\begin{aligned} A_1(-)A_2 &= (a_1, b_1, c_1, d_1)(-)(a_2, b_2, c_2, d_2) \\ &= (a_1 - a_2, b_1 - b_2, c_1 - c_2, d_1 - d_2) \end{aligned} \quad (57)$$

Minkowski's subtraction can be used to obtain the solution of the equation

$$A_2 + X = A_1. \quad (58)$$

For subtraction using Zadeh's extension principle or the simplified arithmetic operations, the result would be

$$(A_1(-)A_2) + (A_2) \neq A_1. \quad (59)$$

But when using Minkowski's subtraction, the result is

$$(A_1(-)A_2)(+)A_2 = A_1 \quad (60)$$

Solving the equation for X with ordinary numbers yields the same results for both methods, but that is not true for fuzzy numbers.

The quadruples (a, b, c, d) of "high" were previously determined as (0.553, 0.647, 0.709, 0.794).

Applying Minkowski's subtraction to "*high(-)high*" will result in the fuzzy number quadruples (0, 0, 0, 0). That is the case, if the actual risk within the category of "high" is matched by exactly the same power of the mitigating strategy which also falls within the category of perceived "high". In reality, though involved parties will always try to match the exact risk impact by their mitigating strategy, this is unlikely to happen,

Recall subtraction of two fuzzy numbers with the simplified arithmetic operation which is:

$$A(-)B = (a_1, b_1, c_1, d_1)(-)(a_2, b_2, c_2, d_2) = (a_1 - d_2, b_1 - c_2, c_1 - b_2, d_1 - a_2) \quad (61)$$

Now, if a mitigating strategy of "high" is used to mitigate a "high" risk, the result will be (-0.240, -0.061, 0.061, 0.240) with center of symmetry being zero. This result is plausible as the term "high" describes a possible range. It is possible that the actual risk is at the lower end of the spectrum "high" where as the applied power of the mitigating strategy is on the higher end of "high". Hence, there is more power in the mitigation than actually needed to set the risk off. The risk is over-compensated; it turns into a chance (exercise a put option). Likewise it is the other way around. A "high" risk may mature at the higher end of "high" where as the mitigating strategy falls short in de-

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playing its highest possible potential of “high” and may just be perceived to be effective with the power at the lower end of “high”. The risk is then not successfully mitigated and additional effort is needed (exercise a call option).

Employing the simplified arithmetic operations would allow the mapping of the full interval within which the effect of mitigating strategies fall, whereas Minkowski’s subtraction does not. Therefore, the simplified arithmetic subtraction is used to incorporate the impact of mitigating strategies and chance.

5.2.5 Conversion of the aggregated fuzzy number into a probability distribution function

The “quality” of the QQIR method depends on the “quality” of the customized probability distribution function for running the subsequent cash flow modeling and stochastic cash flow simulation. The outcome of the fuzzy risk analysis is a fuzzy number. The fuzzy number is converted into a probability distribution function with respect to the possibility/probability consistency principle and the uncertainty-invariance principle.

In the case of converting the fuzzy number into a reasonable probability distribution function (PDF) as input for a stochastic simulation, the fuzzy number is treated as a possibility function and is altered such that

- the linguistic value of the fuzzy number is the same as of the PDF by keeping the same center of gravity
- it complies with the characteristic of a probability function, i.e. the area under the curve sums up to 1,
- Zadeh’s possibility/probability consistency principle is followed by arguing that the changed shape of the former fuzzy number is still representing a relative possibility and the function is still “superior” to the probability distribution function. Therefore, the converted possibility function can then be regarded as probability distribution function since now the sum under its curve adds up to 1.
- The uncertainty-invariance principle is followed by using proportional conversion. Here, the values of the quadruples are not changed. No information is added nor omitted and no rescaling is necessary.

5.3 Sample calculation

The following section is a simplified sample calculation referring to Scenario A in the above discussion. This sample calculation is to demonstrate all applied fuzzy operations in the QQIR method.

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Scenario A: The risk scenario is “very low” (VL) for both risk factors: VL impact and VL likelihood that it happens.

$$X = \frac{(VL * VL) + (VL * VL)}{VL + VL} \quad (62)$$

Where the division is a Minkowski operation.

5.3.1 Fuzzy weighted average

First, calculate $(VL * VL)$ by using the simplified arithmetic operation for multiplication. This was

$$A(*)B = (a_1, b_1, c_1, d_1)(*)(a_2, b_2, c_2, d_2) = (a_1 * a_2, b_1 * b_2, c_1 * c_2, d_1 * d_2) \quad (63)$$

In scenario A, fuzzy number A happen to be the same as fuzzy number B. The quadruples a , b , c , and d for the linguistic term “very low” were determined as $(0.085; 0.158; 0.227; 0.311)$. Therefore,

$$\begin{aligned} VL(*)VL &= (0.085 * 0.085; 0.158 * 0.158; 0.227 * 0.227; 0.311 * 0.311) \\ &= (0.007225; 0.024964; 0.051529; 0.096721) \end{aligned} \quad (64)$$

The next step is to sum the nominator by also using the simplifies arithmetic operations

$$A(+)B = (a_1, b_1, c_1, d_1)(+)(a_2, b_2, c_2, d_2) = (a_1 + a_2, b_1 + b_2, c_1 + c_2, d_1 + d_2). \quad (65)$$

Now the numerator becomes,

$$\begin{aligned} VL * VL + VL * VL &= (0.007225 + 0.007225; \\ &0.024964 + 0.024964; 0.051529 + 0.051529; 0.096721 + 0.096721) \\ &= (0.01445; 0.049928; 0.103058; 0.19344) \end{aligned} \quad (66)$$

And the denominator sums up to

$$VL(+)VL = (0.085 + 0.085; 0.158 + 0.158; 0.227 + 0.227; 0.311 + 0.311) = (0.17; 0.316; 0.454; 0.622) \quad (67)$$

In the final step, the division is performed by employing Minkowski's division.

$$\begin{aligned} X_m &= B(/)A = \left(\frac{b_1}{a_1}, \frac{b_2}{a_2}, \frac{b_3}{a_3}, \frac{b_4}{a_4} \right) \\ &= (0.01445 / 0.17; 0.049928 / 0.316; 0.103058 / 0.454; 0.19344 / 0.622) \\ &= (0.085; 0.158; 0.2277; 0.311) \end{aligned} \quad (68)$$

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In contrast, the application of the simplifies arithmetic division operation (SAO) yields following results:

$$\begin{aligned} X_{SAO} &= A(/)B = (a_1, b_1, c_1, d_1)(/)(a_2, b_2, c_2, d_2) = (a_1 / d_2, b_1 / c_2, c_1 / b_2, d_1 / a_2) \\ &= (0.01445 / 0.622; 0.049928 / 0.454; 0.103058 / 0.316; 0.19344 / 0.17) \\ &= (0.023; 0.11; 0.327; 1.134) \end{aligned} \quad (69)$$

The solution derived with the simplified arithmetic operation (SAO) for X_{SAO} demonstrates that the SAO yield longer tails than with the Minkowski division.

5.3.2 Linguistic value calculation

The linguistic value is determined by using the similarity function F . It determines with which linguistic value X_m is most similar with.

The similarity between X_m and "extremely low" (EL) is: (70)

$$F(X_m, EL) = 1 - \frac{|0.085 - 0.0| + |0.158 - 0.0| + |0.227 - 0.073| + |0.311 - 0.148|}{4} = 0.8597$$

The similarity between X_m and "very low" (VL) is: (71)

$$F(X_m, VL) = 1 - \frac{|0.085 - 0.085| + |0.158 - 0.158| + |0.227 - 0.227| + |0.311 - 0.311|}{4} = 1.0$$

The similarity between X_m and "low" (L) is: (72)

$$F(X_m, L) = 1 - \frac{|0.085 - 0.206| + |0.158 - 0.305| + |0.227 - 0.363| + |0.311 - 0.461|}{4} = 0.8617$$

The similarity between X_m and "medium" (M) is: (73)

$$F(X_m, M) = 1 - \frac{|0.085 - 0.389| + |0.158 - 0.481| + |0.227 - 0.526| + |0.311 - 0.613|}{4} = 0.6935$$

The similarity between X_m and "high" (H) is: (74)

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$$F(X_m, H) = 1 - \frac{|0.085 - 0.553| + |0.158 - 0.647| + |0.227 - 0.709| + |0.311 - 0.794|}{4} = 0.5198$$

The similarity between X_m and “very high” (VH) is: (75)

$$F(X_m, VH) = 1 - \frac{|0.085 - 0.702| + |0.158 - 0.776| + |0.227 - 0.840| + |0.311 - 0.914|}{4} = 0.3876$$

The similarity between X_m and “extremely high” (EH) is: (76)

$$F(X_m, EH) = 1 - \frac{|0.085 - 0.847| + |0.158 - 0.928| + |0.227 - 1.0| + |0.311 - 1.0|}{4} = 0.2519$$

The similarity between X_m and “very low” (VL) is the greatest. It is 1.0. Therefore, one can interpret scenario A as being most similar with “very low”. In fact, in this example, X_m is identical to “very low”.

The calculation to determine the linguistic value of X_m by employing the Euclidian distance is accordingly and here only demonstrated for the very first term of “extremely low” (EL).

The distance between X_m and “extremely low” (EL) is:

$$d(X_m, EL) = \sqrt{(0.085 - 0.0)^2 + (0.158 - 0.0)^2 + (0.227 - 0.073)^2 + (0.311 - 0.148)^2} = 0.2878 \quad (77)$$

When repeated for the remaining six linguistic values, the shortest distance will be found with “very low” as well.

5.3.3 Conversion into PDF

The resultant fuzzy number of scenario A was

$$X_m = (0.085; 0.158; 0.2277; 0.311). \quad (78)$$

As fuzzy number, X_m has the height of 1.0. After converting the fuzzy number into a probability distribution function following the proportional conversion, the new height h is:

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$$h = \frac{2}{(c-b) + (d-a)} = \frac{2}{(0.227 - 0.158) + (0.311 - 0.085)} = 6.776. \quad (79)$$

5.4 Applications of the QQIR method

5.4.1 Relevance of QQIR to the structured finance industry

The generic QQIR method bridges the gap between qualitative and quantitative risk assessment methods. It adds value by quantifying perceptions on risks and thereby allowing more thorough due diligence project assessments.

5.4.1.1 Relevance of QQIR to public sector

With the proposed method for quantifying qualitative information on risks (QQIR), the financial planner in the governmental agency can monitor and budget for such contingent liabilities. In the first step, one needs to identify the issued guarantees and other governmental support. Then one needs to identify the risk factors that may lead to triggering such a liability. Assigning severity of impact and likelihood of occurrence to the risk factors influencing the trigger, one finally can derive the PDF for that trigger and simulate its impact on his budget. In that way, contingent claims and losses can be priced. Observing the change in the discriminatory factors allows monitoring the impact of such qualitative risks on the trigger of the contingent claim.

5.4.1.2 Relevance of QQIR to investment risk measurement

Assuming that an individual equity investor has multiple investment opportunities, the cumulative risk in investment portfolio reflects his attitude towards risk. The investor may want to assess the impact of some qualitatively perceived risk R in an investment project on his total investment portfolio. The equity beta for a single investment with respect to his reference portfolio and the single qualitative risk R in one project would be:

$$\beta_{E_R} = \frac{\text{cov}(ROE_R, r_A)}{\text{var}(r_A)}. \quad (80)$$

ROE is the return on investment in that particular project. With the QQIR method, the impact of single qualitatively perceived risks on such an investment can be modeled and ROE with respect to that risk R derived.

This approach for determining an individual investor's equity beta is "emergent" from within the project structure. It is more realistic than the equity beta. The equity beta is

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derived from previously determined asset beta and debt beta. The textbook equity beta β_E is given as (Brealey Myers 200, p. 475)

$$\beta_E = \beta_A + \frac{D}{E}(\beta_A - \beta_D). \quad (81)$$

The value β_E depends on the $\frac{D}{E}$ level, the gearing ratio. The higher the debt participation, the lower the equity participation can be. However, a lower equity share implies less controlling right and power of the equity investor. The investor has less chance to influence the course of the project and hence is exposed to greater risks which he cannot influence. For this increased risk exposure, the equity investor demands higher return. In converse, risk averse lenders may demand to see more “capital at risk” invested before they are willing to issue loans. This relationship is expressed in the leverage effect and was elaborated on in detail earlier.

5.4.1.3 Relevance of QQIR to credit risk assessment

The QQIR method can be used to measure the effect of perceived risks on project financial ratios impacting the project rating.

Kong (2004) developed a model for determining the default risk and bankability of BOTs. In here, Moody's Credit Rating Transition Matrix to determine the likelihood of change in creditquality is being “conditionalized” (transferred to a project's specific characteristics) by the use of the net present value (NPV) technique to estimate the maximum default loss in the event of default. This Conditionalized Credit Rating Transition Matrix (CCRTM) shows the probability of a project to change its credit quality from one to another rating based on an initial rating.

The key in this credit rating process is the power of the selected discriminatory factors. Discriminatory factors are financial ratios that serve best observing a firm's financial health and allow early indication of adverse developments.

The discriminatory factors are derived from financial statement analysis. It is in this process, the identified and quantified qualitative risks are being translated into changes of the credit rating.

Kong (2004) determined the critical discriminatory factors by running a linear regression analysis and employing Mallows' Cp-statistics. He identified the most critical financial ratios as:

- Revenue / Assets (R/A)

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- Earnings before interest and tax, depreciation and amortization (EBITDA) / Assets
- Debt service coverage ratio (DSCR)
- Debt / equity (D/E)

5.4.2 Novelty of QQIR and delineation against existing academic works

The novelty of this research will be reasoned for by delineating it against existing academic works on risk assessment and evaluation in structured finance transactions under PPP schemes.

Most assessment approaches consider the classical critical decision criteria of VfM, DSCR, NPV, IRR, and ROE. They commonly focus on effects of the risks of construction schedule and cost overruns on the PPP performance. They incorporate sensitivity analyses on impact factors such as exchange rates, interest rates, load factors, taxes, tariffs, and other input factors.

The novelty of the QQIR Method is its broad application of fuzzy sets to project finance. It allows observing the change in a variable when the whole range of possible risk factors may come into action.

5.4.2.1 Tiong's BOT evaluation

Tiong has extensively investigated the BOT tender process and evaluation from the private sector's point of view. Tiong investigated the critical success factors for winning BOT tenders (1992), competitive advantage of equity commitment in BOT tenders (1995), the role of risks and guaranteed that the private competitor needs to offer for winning BOT bids (1995), the advantage of a competitive financial package over the technical solutions in BOT tenders (1995), and the evaluation procedure of governments on BOT proposals (1997). These works support the importance of the decision criteria such as the NPV, IRR, DSCR, and ROE, and they also show that risks have impact on these criteria. They do not, however, reveal a quantitative approach to determine the impact of risks on such criteria. Tiong et al. (1999, p. 78) addresses this deficiency after thoroughly qualitatively evaluating and ranking the risks and risk mitigating strategies in a Chinese BOT power plant concession contract. This analysis was a main contribution in the motivation for developing this QQIR method as "missing link" and contribution to risk assessment in BOT/PPP projects.

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5.4.2.2 Ye's NPV-at-risk method

Ye (2001) developed a methodology for determining the NPV of a project at a specific confidence level or the confidence level at which a specific NPV occurs. The assumptions are similar to the ones underlying the developed QQIR:

"Risk has two attributes: the likelihood of occurrence and severity of damage if eventually occurred. Similarly, return has two attributes: the magnitude of profit and the likelihood of being realized. This leads to the development of NPV-at-risk." (Ye, 2001, p. 38)

Ye (2001) employed normal distributions as PDFs for running the Monte Carlo simulation on some risk input parameters such as completion time, exchange rate, coal price, inflation, and interest rate in order to determine the NPV-at-risk. Ye, however, does not investigate the impact of any specific risks. He considers risk as an aggregated lump.

The QQIR method, in contrary, targets at simulating the impact of specific risk factors on project decision parameters and determining the PDF of these risk factors prior to simulation. It does not limit its consideration to just the NPV at risk, but allows determining the DSCR, IRR and equity beta at a specific confidence level. This is a further development and aims to fulfill what Ye (2001, p. 36) highlighted as missing in the current state of practice. It allows stakeholders to design specific financial products such as contingency budgets, the value for asset backed securities on that project (e.g. selling expected future return from project operation), or pricing an insurance for such qualitative risks.

5.4.2.3 McCowan's evaluation and comparison of CPIs

McCowan (2004) developed a decision support system (DSS) that incorporates financial and non-financial aspects. The DSS is for the evaluation and comparison of concession project investments (CPI). It also employs the fuzzy weighted mean for combining the importance of e.g. two factors that were estimated in intervals with trapezoidal fuzzy numbers. It allows ranking of projects and employs Saaty's (Saaty 2001) analytical network process (ANP) for rating the projects. In the DSS, general financial factors such as changes in the interest rate, tax, equity fraction, cost escalation, etc. were Tr.F.N or crisp input factors, as well as questions on impact and likelihood of non-financial factors such as corruption, approval, local partner's creditworthiness etc. were included into a sensitivity analysis on the financial relevant output factors.

However, this DSS does not investigate the effects of non-financial factors on one specific cash flow position that would allow for pricing and budgeting for such a risk. It

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also does not employ and fuzzy risk analysis process for assessing the impact of non-financial risks to its full extent.

Another shortcoming is that McCowan applies trapezoidal fuzzy numbers also for financial risk factors, that have historical and numerical record and therefore allow for financial variance modeling (the question, how for such financial series, the correct functions are derived, is out of the scope of this report).

The QQIR methodology focuses on only non-financial, qualitative risk factors that yet impact at some stage financial input factors such as the tariff or dispatch quantity. It considers the other factors *ceteris paribus* as constant for only then, this specific qualitative impact can be priced and budgeted for.

5.4.2.4 Fuzzy risk assessment and project evaluation

Fuzzy risk assessment in construction and PPP/BOT projects commonly employ the fuzzy weighted mean method and tree structures for showing the interdependencies of the risk factors. Tah et al. (1993) employs the same methodology to determine the severity of loss due to the risk factors "site" and "labor". In subsequent papers (Tah and Carr 1999, 2001, Carr and Tah 2001) they develop software applications. Kangari and Riggs (1989) investigate the total risk of a construction project by the risk factors "contractual risk" and "construction risk" with their subsequent tree-structured risk factors. Paek et al. (1993) priced construction risks by assigning \$ values to intervals with most likely and largest likely interval of loss and seeking the minimum and maximum loss. Blair et al. (—) analyze with a fuzzy stochastic approach the cost and schedule risk along the critical path method (CPM) for a Mobile Offshore Base (MOB). Pochampally and Gupta (2004 a, b) employ fuzzy logic approaches for determine costs and benefits in supply chain design. Chiu and Park (1994) perform a fuzzy cash flow analysis using the present worth criterion but employing the more complicate method of α -cuts and extension principles instead of using the simplified fuzzy arithmetic.

What these approaches have in common is that they lack in assigning specific changes in the decision criteria to the impact of specific qualitative risk factors. They also do not consider the full life cycle of a project and are not dynamic (static view point), The QQIR overcomes that deficiency by simulation of the qualitative risk impacts over the life cycle of the project.

5.4.2.5 Probabilistic approaches

There are a number of works that address uncertainty in construction projects. Again, these approaches fall short in considering the whole project life cycle, and have their root in the probability theory.

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Ranasinghe (1990) for example investigates into uncertainty in the construction phase. He uses a truncated Taylor series expansion to assess subjective probabilities. He asks experts at a 5%, 25%, 50%, 75% and 95% level of confidence for their estimation on e.g. productivity estimates or construction costs, etc. as deviating from a given base estimate. Ranasinghe investigates into the uncertainty underlying the estimates for e.g. labor productivity. This approach does not address the impact of factors on the project performance that are outside the engineering scope of the project.

In probabilistic approaches, the problem and source for bias is the chosen shape of the input probability density function (PDF). The QQIR method tries to overcome this by deriving the PDF from a bottom-up approach. It is recognized that the currently used TrFNs may not be the ideal shape either to represent any probability in risk factors.

The QQIR can incorporate such factors through contract analysis and expert interviews. It is not limited to investigating confidence values to existing and known parameters, but the show the impact of unknown, soft parameters on the cash flow.

5.4.2.6 Other relevant evaluation approaches

Other relevant research of the effect of risks on the capital structure, returns, bankability, and credit worthiness, Risk management and analysis has been conducted by Kong (2004), Dias and Ioannou (1995), Bakatjan (2003), Grimsey and Levis (2002), and PWC (2002), Bhatt (1995), Marthinsen (1993), Li (2003).

These studies and methodologies contribute partially to the concept behind the QQIR method. The QQIR encompasses these studies and methodologies and is an enhanced risk assessment tool. By adding the discriminant analysis for monitoring, an integrated risk assessment method for qualitative risks can be built.

CHAPTER 6: VALIDATION OF THE QQIR METHOD

6.1 Validation approach

6.1.1 *Applied validation*

The validation of the QQIR method in this thesis is accomplished by survey and the details are provided in Appendix 2. Results from a pilot survey⁴ supported the decision to use surveys for validating the QQIR method. Some results of the survey for the QQIR validation have also been published⁵.

In the survey, three data sets were collected and triangulated against each other to demonstrate that the findings in each data set were coherent. Then two of the data sets were directly compared with each other to determine the fitness for purpose of the QQIR method. The three datasets, triangulation, and fitness for purpose test are introduced below. For the triangulation, Spearman rank correlation is used to compare rankings in these three data sets. For the fitness of purpose test, the standard deviations of QQIR results are compared against absolute value polls. In 77.5% of all observations, these results fall within 0.85 standard deviations and including the other 22.5% of observations, it is 1.6 standard deviations. This means that using a sample size of only 4 respondents, with a chance of 77.5% (3 out of 4), one can produce results with the QQIR method, that fall within 0.85 standard deviations and theoretically with "100%" certainty, results generated with the QQIR are within 1.6 standard deviations.

The weaknesses of validation through surveys lie in the number of responses and the goodness and accuracy of responses. In this validation, no response was eliminated from evaluation. It is likely that with greater accuracy of responses and larger sample size, even better results could be achieved.

6.1.2 *Alternative validation approach*

Another ideal and also statistically sound validation of the QQIR method would be analyzing 30 projects that had their financial close 5 to 15 years in the past and that had

⁴ The results of the pilot survey are published in: Sachs, T., Tiong, R., Wagner, D. (2006) Balancing risks against returns. fDi Magazine, Financial Times Group, August/September 2006, pp. 99-101

⁵ Some results of the survey for the QQIR validation will be published in: Sachs, T., Tiong, R., Wagner, D. (2007) Balancing risks against returns – Part II: The impact of political risks in public-private partnerships (PPP) in Asia. fDi Magazine, Financial Times Group, December/January 2007

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full documentation on the due-diligence risk assessment in terms of perceived likelihood and impact of risk factors on the project cash flows. One would then apply the QQIR method based on this historical data and record, calculate the impact of those risks with the QQIR method on the cash flows, and compare the results to actual data from today. The deviation between actual data and forecasted data would then indicate the fitness for purpose of the QQIR method and hopefully validate its accuracy.

However, in pursuing such an approach, two difficulties are encountered: first, access to financial project data, models, and reports is often denied with the valid excuse of client confidentiality, and the second difficulty is the absence of such detailed risk assessment reports that tell something about the perceived likelihood and possible consequence of specific risk factors.

In future validation, one could apply the QQIR method when structuring new transactions as a second assessment to the practices and accepted assessment and then compare after some years and multiple projects, if the QQIR assessments were reasonable.

6.2 Survey structure and objectives

Political risks are one of the most important risks affecting public-private partnerships (PPP). Governmental action influences the costs and therefore the success of PPPs significantly.

In this QQIR validation, results are used from a survey to quantify the impact of political risks on financial decision criteria in PPPs. The purpose of the survey is to demonstrate the applicability and relevance of the QQIR Method by quantifying the impact of perceived political risks on financial criteria in infrastructure projects. The financial criteria are the expected internal rate of return (IRR), the project leverage, the risk premium on project loans, the minimum required debt service coverage ratio, and the insurance premiums. The survey addresses 14 Asian countries and 14 infrastructure sectors. It shows that with increasing perceived risks, the costs of equity investment, debt finance, and insurance also increase. The detailed analysis of the survey is presented in Appendix 2.

The survey objectives are the collection of expert opinions on the influence of political risk factors on financial decision criteria in PPPs for quantifying that influence. While project specific data may allow for interesting interpretations, the focus in this research is on using the survey responses for validating the QQIR method and testing its fitness for purpose.

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The survey was structured in such a way that three independent data sets could be collected for the purpose of validating the survey results through triangulation. It compares the results generated by the QQIR method with results generated with existing methodologies. The triangulation result shows that in 77.5% of all observed absolute values that serve as a benchmark, the QQIR Method produces mean results that are within 0.85 standard deviations of these benchmarks.

The survey was carried out in collaboration with James Neal, Ernst & Young, Partner, Global Head of Project Finance. The survey has been supported by Daniel Wagner, Senior Guarantees and Syndications Specialist, Office of Cofinancing Operations, the Asian Development Bank (ADB), Bela Onken, Senior Project Manager, Team Project Finance, KfW-IPEX Bank, Prof. Dr. Hans Wilhelm Alfen, Chair of Construction Economics, Bauhaus University Weimar (BUW) and head of EU-Asia network for PPP.

6.2.1 Survey response

In total, 29 survey responses were collected. The survey was sent by electronic mail without delivery failure to approximately 400 contacts provided by the survey partners and own contacts. The respondents come from various backgrounds.

The following table shows the origin of responses:

Background	No	Location	no	Sector	no
Investor/developer	7	USA/Canada	2	Public	7
Lender	8	Europe	3	Private	22
Insurer	5	Asia	24		
Professional advisor	8				
Contractor	1				

Table 8: Information on respondents

6.2.2 Scope of Survey

The political risk categories that influence financial decision criteria can be distinguished into insurable and not insurable. The definitions for insurable political risks as noted below in categories 'A' to 'D' are derived from the Multilateral Investment Guarantee Agency Convention (MIGA 1985) and in categories 'E' and 'F' from Tinsley (2000):

A: Currency inconvertibility and transfer restriction (CI/TR)

Any action attributable to host government restrictions on the conversion and transfer of currency outside the host country into a freely usable currency, including the failure

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of a host government to act within a reasonable period of time on an application for such transfer.

B: Expropriation

Any legislative or administrative action from the host government which has the effect of depriving an investor of its ownership or control of or substantial benefit from its investment, with the exception of non-discriminatory measures of general application.

C: Breach of contract

Any repudiation or breach of a contract by a host government a_ when there is no recourse to judicial or arbitral forum to determine the claim, or b) a decision by such forum is not rendered within reasonable period of time, or c) such decision cannot be enforced.

D: Political violence

Acts of war, civil war, insurrection/civil disturbance, terrorism, sabotage, or landowner and/or indigenous people's disturbance in the host country.

E: Legal, regulatory, and bureaucratic risks

Risks within the administrative process that cannot be directly attributed to one of the above. These include the legal enforceability and execution of laws, conflict of authority, corruption, transparency, issuing of approvals and consents, change of government causing changes in law, policy, and taxation, and obstruction during arbitration process.

F: Non-governmental action risks

"Non-governmental action risks" are those risks which the government has no direct influence on and do not fall within any of the above categories. These include actions by environmental and union activists, religious fundamentalism, ethnic tension, interventions by United States and/or European Union, and foreign exchange risks.

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Figure 19: Influence of political risks on PPPs

The survey covers Bangladesh, Cambodia, the People's Republic of China, India, Indonesia, Japan, Korea, Malaysia, Pakistan, the Philippines, Singapore, Taiwan, Thailand, and Vietnam.

It covers the sectors of

- Utilities: power, water and waste water, and waste treatment and management;
- Infrastructure: toll roads, railways, sea ports, and airports; and
- Social infrastructure and public real estate: mail delivery, IT and telecommunications, education, health, leisure and sports, administration, and security.

The respondents were asked to select one country and one sector to comment on. That allows for project specific risk assessment. Some respondents selected multiple sectors within one country that they feel had the same risk profile.

Respondents were asked to provide an absolute value and their perceptions of the impact of the six different political risk categories on financial decision criteria with the survey scale. The criteria are:

- investment appetite to determine the leverage
- minimum expected internal rate of return (IRR)
- minimum required debt service coverage ratio (DSCR)
- risk margin on loans
- insurance premium

6.2.3 Survey questions

As mentioned earlier, three data sets were collected (Appendix 2, section A2.1, general and specific questionnaire set). The first one serves for quantifying perception on political risks with the QQIR method. For determining the weight of the risk factors, the

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respondents were asked, with respect to each financial criteria and political risk factors, to indicate the degree of relevance of that risk factor in their consideration by using the survey scale for their judgment.

Then, for determining the impact of each risk factor, the respondents were asked respectively to provide their judgment with the survey scale on the following questions:

1. Because of that possible risk factor, out of a maximum US\$ 100 million, how high is your investment appetite?
2. Because of that possible risk factor, out of maximum 30%, how high is your expected minimum IRR?
3. Because of that possible factor, out of 1.0 to 1.5 how high is your expected minimum annual DSCR?
4. Because of that possible risk factor, out of max. 350bp⁶, how much would you charge on a US\$ 100 million loan?
5. Because of that possible risk factor, out of 200bp, how much would you charge on an insurance covering US\$ 100 million?

The second data set was collected as absolute values on each of these financial criteria. The respondents were asked to provide one absolute value that represents the total influence of the aggregated political risk perception on the financial criteria.

The third data set was collected to determine the aggregated impact of political risks on PPP opportunities in Asian countries and sectors.

- What is the negative impact of political risk factors on PPP opportunities in these Asian countries?
- What is the negative impact of these political risk factors on PPP opportunities in these sectors?

In this chapter, the detailed country and sector analysis is not presented, but the aggregated results only which are necessary for the triangulation of the QQIR validation.

Risk categories other than political risks that may affect PPPs are not considered. These non-considered risk categories include demand, supply, market, construction, technical, operational, engineering, completion, environmental, currency devaluation, counterparty, syndication, interest rate, or infrastructure risks. Some may also be trig-

⁶ bp: basis points; 100bp = 1%.

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gered by governmental action but in this survey, they are considered as already being successfully mitigated.

Not all respondents answered for each possible country and sectors combination. Therefore, most project-specific observations are single opinions.

6.2.4 Survey scale

The respondents were asked to indicate their perceptions by using a seven-grade scale:

Scale	Description
0	None, not applicable
1	Extremely low
2	Very low
3	Low
4	Medium
5	High
6	Very high
7	Extremely high

Table 9: Survey scale

The linguistic values in this survey scale are coded by fuzzy sets (Figure 20).

Figure 20: Fuzzy sets coding a seven-grade survey scale

The distribution of these fuzzy numbers was introduced in Chapter 5.2.1.

6.3 Survey evaluation and validation methodology

Several techniques from fuzzy set theory and non-parametric statistics have been combined to evaluate the survey responses and to validate the QQIR method by triangulation. In total, three value sets were collected: general perception on political risks in Asian countries and sectors, absolute value polls on the financial decision criteria, and perceptions on the political risk factors influencing the financial decision criteria that were evaluated with the QQIR method (Figure 21).

Figure 21: Triangulation of survey results and “fitness for purpose” test of the QQIR method

The multiple opinions expressed by the respondents are aggregated by determining the weighted average on the quadruples of the fuzzy numbers.

$$A(x) = \sum_{i=1}^n c_i A_i(x), \text{ with } \sum_{i=1}^n c_i = 1 \quad (83)$$

The ranking of the different aggregated results is achieved by the centroid x' which is determined by

$$x' = \frac{\sum x_i \mu_i}{\sum \mu_i} \quad (84)$$

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The linguistic value is determined by the similarity function F (Chen 1996)

$$F(X, B) = 1 - (|a_1 - a_2| + |b_1 - b_2| + |c_1 - c_2| + |d_1 - d_2|) / 4. \quad (85)$$

The QQIR method is used for determining the impact of multiple risk factors on the financial decision criteria.

For the fitness-for-purpose-test, the mean value of the financial decision criteria determined with the QQIR method is compared against the absolute value polls and their difference is measured in standard deviations. The statistical properties are the mean value

$$\mu = \int_{-\infty}^{+\infty} xf(x)dx = \frac{h}{6}(c^2 + cd + d^2 - a^2 - ab - b^2), \quad (86)$$

and the standard deviation s

$$s = \sqrt{\sigma^2} \quad (87)$$

while the variance of the PDF is determined by

$$\begin{aligned} \sigma^2 = \int_{-\infty}^{+\infty} (x - \mu)^2 f(x)dx = & \frac{h}{12} [(c + d)(c^2 + d^2) - (a + b)(a^2 + b^2)] \\ & - \frac{h\mu}{3} \left[\frac{(b^3 - a^3)(d - c) + (d^3 - c^3)(a - b)}{(a - b)(d - c)} \right] + \frac{h\mu^2}{2}(c + d - a - b) \end{aligned} \quad (88)$$

The triangulation of the three collected data sets is conducted by applying the Spearman rank correlation coefficient that allows pair-wise comparisons of rankings of the survey results and determining correlations and levels of significance of these correlations between the rankings.

The Spearman rank correlation coefficient ρ_s or r_s is calculated by determining the correlation between rankings in two data sets. The rankings between each member of a pair is compared.

$$\rho_s = 1 - \frac{6 \sum d^2}{n(n^2 - 1)} \text{ where} \quad (89)$$

d = the difference between the ranks of corresponding values x and y of a pair, and

n = number of pairs of values.

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The correlation between two rank statistics is positive when $0 < \rho_s \leq 1.0$ and negative when $-1.0 \leq \rho_s < 0$. When $\rho_s = 0$, the two rank statistics are uncorrelated.

The significance of the correlation result is determined by calculating the t-value and by using the Student's t-distribution for determining the level of significance.

$$t = \frac{\rho}{\sqrt{\frac{1-\rho^2}{n-2}}} \quad (90)$$

6.4 Quantification of perceived impact of political risk factors on financial decision criteria in PPPs

Depending on the survey responses, for each country and sector, investment appetite, minimum IRR, minimum DSCR, risk margin on loans, and insurance premium with respect to the perceptions of political risks have been calculated based on the respondent's risk perception. The results derived with the QQIR method and the corresponding absolute value that were surveyed, are presented together.

Not all respondents were capable to fill in each question on the questionnaire. Also not every respondent answered to each question, so that it might well be, that some data points are left blank.

The results correlate with the general findings on political risk perceptions in Asian countries and sectors.

6.4.1 General country and sector ranking

In this section, the aggregated results of general political risk perception are presented in Table 10. These are necessary for the triangulation and QQIR method validation.

The detailed responses, centroid calculations, rankings and results are presented in Appendix 2.

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Rank	Countries	Sectors
1	Cambodia	Rail
2	Bangladesh	Waste treatment & management
3	Pakistan	Power
4	Indonesia	Water/waste water
5	Philippines	Toll roads
6	China	Airport
7	Vietnam	Sea port
8	India	Security
9	Thailand	Leisure/sports
10	Malaysia	Mail
11	Taiwan	IT/Telecommunications
12	South Korea	Education
13	Japan	Health
14	Singapore	Administration

Table 10: Ranking of countries and sectors with respect to political risk perceptions

The following are the results generated with the QQIR methodology and collected from absolute value polls.

6.4.2 Investment Appetite in PPPs

PPPs require stable political, legal, and regulatory environments in order to attract investments. The amount of money investors are keen to invest depends on the perceived level of risk.

In this survey, investment appetite refers to the volume of equity commitment of a single equity shareholder. The lower the perceived risk with the investment, the higher is the investment appetite.

The survey questions are:

“What is the degree of relevance of that political risk factor in your consideration?” And: “Because of that possible risk factor, out of a maximum US\$ 100 million, how high is your investment appetite?”

6.4.2.1 Quantification of Political Risk Perception

The investment appetite, equity commitment, or leverage are quantified with the QQIR method by indicating the minimum, maximum and mean value for each available project case. Also, the absolute value from the survey is shown. In the Tables 11 and 12, the values shown are in percentages [%].

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Country	Bangladesh				India				Indonesia				Korea, Rep.			
	min	mean	Max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																
Power	7.95	14.77	23.98						12.78	20.69	30.69					
Toll road	5.55	14.21	24.09		9.38	15.13	22.33	10.00					54.07	66.61	79.31	62.50
Airport					16.27	24.97	35.81	12.00								
Health					8.69	19.20	29.68	32.50								
Aggregated	7.28	15.19	24.90		10.75	18.95	28.33	18.16								

Table 11: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on investment appetite [%] (1/2)

Country	Philippines				Singapore				Taiwan				Aggregated			
	Min	mean	Max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																
Power	43.66	53.69	65.27	58.00					4.55	16.72	31.66	26,67	19.15	28.46	39.52	
Water/Waste					54.05	66.61	79.11	80.00	15.41	26.09	38.31		26.70	38.25	50.88	
Water																
Waste treatment /management									4.55	16.72	31.66	26,67				
Toll road									4.55	16.72	31.66	26,67	17.81	27.60	38.63	
Railways									4.55	16.72	31.66	26,67				
Sea ports									4.55	16.72	31.66	26,67				
Education									4.55	16.72	31.66	26,67				
Health									4.55	16.72	31.66	26,67				
Leisure/Sports									4.55	16.72	31.66	26,67	7.32	18.79	31.44	
Aggregated									7.17	19.22	33.85		17.74	28.28	40.12	

Table 12: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on investment appetite [%] (2/2)

6.4.2.2 Ranking

Based on this QQIR assessment, the centroids for each dataset were calculated and the ranking is derived. It is shown by project type, country, and sector in the following table. The strongest investment appetite is listed first.

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Rank	Project Specific	By county	By Sector
1	India – Manufacturing	China	Water/waste water
2	China – Manufacturing	Singapore Korea	Power
3	Korea – Toll road Singapore – Water/Waste water	Philippines	Toll road
4	Philippines – Power	India	Airport
5	Taiwan – Water/Waste Water	Indonesia	Health
6	India – Airport	Taiwan	Waste management & treatment, education, lei- sure/sports
7	Indonesia – Power	Bangladesh	
8	India – Health		
9	India – Toll road		
10	Bangladesh – Power		
11	Bangladesh – Toll road		

Table 13: Ranking from greatest to lowest investment appetite

Manufacturing projects in China and India are not included in the country and sector assessment as they do not fall within the PPP sector classification.

6.4.3 Expected Minimum IRR

The expected minimum internal rate of return (IRR) is the marginal return at which the project breaks even for the investor. It is the discount rate by which the project’s net present value (NPV) equals zero.

A high expected minimum IRR indicates that the project must break even in a relatively short period of time as the investor might otherwise consider an investment risky and difficult to predict in the future. In stable and predictable environments, the investor may be satisfied with lower expected IRR.

In this survey, the IRR is chosen as indicator of the level of perceived risks to the investors.

The survey questions are:

“What is the degree of relevance of that political risk factor in your consideration?” And: “Because of that possible risk factor, out of maximum 30%, how high is your expected minimum IRR?”

6.4.3.1 Quantification of Political Risk Perception

The minimum expected IRR is quantified with the QQIR method by determining the minimum, maximum and mean value for each available project case. Also, the abso-

QQIR method validation

lute values from the survey are shown in Table 14 and 15. The values are presented in percentages [%].

Country	India				Indonesia				Korea, Rep. of				The Philippines			
	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																
Power					21.08	24.24	27.38	25.00					20.05	23.48	26.79	24.20
Water/Waste Water																
Toll roads	2.52	5.00	8.10	10.00					11.72	15.05	18.38	16.50				
Airports	5.49	7.49	10.16	12.00												
Health	11.71	15.05	18.34	13.50												
Aggregated	6.39	12.04	9.03	11.83												

Table 14: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on expected min. IRR in [%] (1/2)

Country	Singapore				Taiwan				Aggregated			
	Min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project												
Power					6.28	11.53	17.30	13.80	15.32	19.31	23.47	
Water/Waste Water	6.20	10.02	13.80	15.00	11.87	15.99	20.24		9.68	13.80	18.01	
Waste treatment /Management					6.28	11.53	17.30	13.80				
Toll roads					6.28	11.53	17.30	13.80	7.45	10.95	14.84	
Railways					6.28	11.53	17.30	13.80				
Sea ports					6.28	11.53	17.30	13.80				
Education					6.28	11.53	17.30	13.80				
Health					6.28	11.53	17.30	13.80	8.97	13.23	17.76	
Leisure/Sports					6.28	11.53	17.30	13.80				
Aggregated					7.10	12.21	17.77		10.35	14.32	18.52	

Table 15: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on expected min. IRR in [%] (2/2)

6.4.3.2 Ranking

Based on this QQIR assessment, the ranking is derived and shown by project type, country, and sector in the following table. The PPP opportunities with the least expected IRRs are listed first.

QQIR method validation

Rank	Project Specific	By Country	By Sector
1	India – Toll roads	India	Airport
2	India – Airports	Singapore	Toll roads
3	Singapore – Water/Waste Water	Taiwan	Waste management & treatment, rail, sea ports, education, leisure/sports
4	Taiwan – General	Korea	Health
5	Korea – Toll Roads	Philippines	Water/waste water
6	Taiwan – Water/Waste Water	Indonesia	Power
7	Philippines – Power		
8	Indonesia – Power		

Table 16: Ranking from lowest to greatest expected minimum IRR

6.4.4 Minimum Required DSCR

The debt-service-coverage-ratio (DSCR) indicates how well loan repayment obligations of principal and interest are met by the cash flows. The amount of excess coverage required serves as a buffer for lenders in the event that project cash flows fall short of the debt repayment requirements.

In this survey, the DSCR is chosen as an indicator of risk levels how lenders perceive the security of cash generation of projects for their debt service. When projects are perceived “risky”, lenders typically would demand to see higher DSCRs. While for European PPPs, average DSCRs are generally between 1.1 to 1.3, minimum required DSCRs in some developing Asian countries may be higher before lenders feel comfortable committing funds.

The survey questions are:

“What is the degree of relevance of that political risk factor in your consideration”? And: “Because of that possible factor, out of 1.0 to 1.5, how high is your expected minimum annual DSCR?”

6.4.4.1 Quantification of Political Risk Perception

The minimum required DSCR is quantified by determining the minimum, maximum and mean value for each available project case. Also, the absolute values from the survey are shown in Table 17 and 18.

QQIR method validation

Country	Bangladesh				China				India				Indonesia				Pakistan			
Project	min	mean	Max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Power	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35					1.31	1.36	1.41	1.56	1.38	1.45	1.49	1.40
Water/Waste Water	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35					1.33	1.39	1.44	1.38	1.38	1.45	1.49	1.40
Toll Roads	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35					1.33	1.39	1.44	1.38	1.38	1.45	1.49	1.40
Railways	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35					1.33	1.39	1.44	1.38	1.38	1.45	1.49	1.40
Airports	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35					1.33	1.39	1.44	1.38	1.38	1.45	1.49	1.40
IT/Telecommunications	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35	1.12	1.19	1.26	1.20	1.33	1.39	1.44	1.38	1.38	1.45	1.49	1.40
Health	1.37	1.44	1.49	1.40	1.26	1.34	1.41	1.35					1.33	1.39	1.44	1.38	1.38	1.45	1.49	1.40
Aggregated													1.32	1.37	1.43	1.41				

Table 17: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on minimum DSCR in [-] (1/2)

Country	Philippines				Taiwan				Thailand				Vietnam				Other				Aggregated			
Project	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	Abs	min	mean	max	abs	min	mean	max	abs
Power	1.35	1.40	1.46	1.35	1.22	1.29	1.36	1.30	1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35	1.30	1.37	1.44	1.36	1.29	1.35	1.41	1.34
Water/Waste Water	1.35	1.40	1.46	1.35	1.17	1.26	1.22	1.31	1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35					1.29	1.35	1.41	0.82
Waste treatment /mgmt					1.22	1.29	1.36	1.30									1.32	1.38	1.44	1.36	1.26	1.33	1.39	1.38
Toll Roads	1.35	1.40	1.46	1.35	1.22	1.29	1.36	1.30	1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35					1.30	1.37	1.43	0.83
Railways	1.35	1.40	1.46	1.35	1.22	1.29	1.36	1.30	1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35					1.30	1.37	1.43	0.83
Sea ports					1.22	1.29	1.36	1.30																
Airports	1.35	1.40	1.46	1.35					1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35					1.32	1.38	1.45	0.95
IT/ Telecommunications	1.35	1.40	1.46	1.35					1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35					1.29	1.36	1.42	0.99
Education					1.22	1.29	1.36	1.30																
Health	1.35	1.40	1.46	1.35	1.22	1.29	1.36	1.30	1.21	1.30	1.39	1.30	1.35	1.40	1.46	1.35					1.30	1.37	1.43	0.83
Leisure/Sports					1.22	1.29	1.36	1.30																
Aggregated					1.21	1.28	1.34	1.30									1.31	1.38	1.44	1.36	1.29	1.36	1.42	1.34

Table 18: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on minimum DSCR in [-] (2/2)

6.4.4.2 Ranking

Based on this QQIR assessment, the ranking is derived and shown by project type, country, and sector in the following table, from least to highest minimum-required DSCR.

QQIR method validation

Rank	Project specific	By Country	By Sector
1	India – IT/Telecommunications	India	Sea Ports, Leisure/Sport, Education
2	Taiwan – Water/Waste Water	Taiwan	Waste Management/Treatment
3	Taiwan – most sectors	Thailand	Power
4	Thailand – most sectors	China	IT/Telecommunications
5	China – most sectors	Indonesia	Health, Toll Roads, Railways
6	Indonesia – Power	Philippines	Airports
7	Indonesia – most sectors	Vietnam	
8	Philippines – most sectors	Bangladesh	
9	Vietnam – most sectors	Pakistan	
10	Bangladesh – most sectors		
11	Pakistan – most sectors		

Table 19: Ranking from lowest to greatest minimum-required DSCR

6.4.5 Risk Margins on Loans

The cost of debt is a controlling parameter and has significant impact on project economics. While risk margins on loans in PFIs in the United Kingdom are generally below 100 basis points (bps), for Asian PPPs they are above 100 bps. Lenders charge higher premiums with higher levels of perceived risks.

In this survey, the risk margins on loans are used as indicators of the perceived levels of risk.

The survey questions are:

“What is the degree of relevance of that political risk factor in your consideration?” And: “Because of that possible risk factor, out of max. 350 bps, how much would you charge on a US\$100 million loan?”

6.4.5.1 Quantification of Political Risk Perception

The risk margin is quantified by determining the minimum, maximum and mean value for each available project case. The absolute value from the survey is shown. Values in Tables 20 and 21 are expressed in basis points [bp].

QQIR method validation

Country	Bangladesh				China				India				Indonesia				Pakistan			
	Min	mean	max	abs	min	mean	max	abs	Min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																				
Power	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60	162.15	187.36	213.80		215.45	254.72	289.73	288.67				
Water/Waste Water	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60					229.88	270.17	307.79	166	160.14	215.05	269.36	210.00
Toll Roads	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60					229.88	270.17	307.79	166	160.14	215.05	269.36	210.00
Railways	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60					229.88	270.17	307.79	166	160.14	215.05	269.36	210.00
Airports	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60					229.88	270.17	307.79	166	160.14	215.05	269.36	210.00
IT/ Telecommunica-tions	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60					229.88	270.17	307.79	166	160.14	215.05	269.36	210.00
Health	150.28	188.52	226.36	200.0	81.28	136.60	191.19	141.60					229.88	270.17	307.79	166	160.14	215.05	269.36	210.00

Table 20: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on loan margins in [bp] (1/2)

Country	Philippines				Taiwan				Thailand				Vietnam				Other				Aggregated			
	Min	mean	max	Abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																								
Power	120.94	169.43	217.35		246.43	299.63	343.27	326.00	35.94	83.04	131.99	104.00	155.54	205.85	253.78	158.00	269.35	302.38	331.25	316.70	157.08	203.59	248.00	196.00
Water/Waste Water	95.51	161.78	227.37	158.30	217.68	257.37	292.57	275.33	35.94	83.04	131.99	104.00	84.15	156.54	226.67	158.00					139.88	189.71	238.06	176.00
Waste treatment /management	159.72	183.56	208.67		246.43	299.63	343.27	326.00					84.15	156.54	226.67	158.00					165.81	216.64	264.68	242.00
Toll Roads	95.51	161.78	227.37	158.30	246.43	299.63	343.27	326.00	35.94	83.04	131.99	104.00	84.15	156.54	226.67	158.00					133.04	185.79	237.11	182.00
Railways	95.51	161.78	227.37	158.30	246.43	299.63	343.27	326.00	35.94	83.04	131.99	104.00	84.15	156.54	226.67	158.00					133.04	185.79	237.11	182.00
Sea Pports					246.43	299.63	343.27	326.00																
Airports	95.51	161.78	227.37	158.30					35.94	83.04	131.99	104.00	84.15	156.54	226.67	158.00					116.60	169.55	221.76	162.00
IT/Telecom-munications	95.51	161.78	227.37	158.30					35.94	83.04	131.99	104.00	84.15	156.54	226.67	158.00					116.60	169.55	221.76	162.00
Education					246.43	299.63	343.27	326.00																
Health	95.51	161.78	227.37	158.30	246.43	299.63	343.27	326.00	35.94	83.04	131.99	104.00	84.15	156.54	226.67	158.00					133.04	185.79	237.11	182.00
Leisure/Sports					246.43	299.63	343.27	326.00																
Aggregated	117.44	178.39	237.05		232.04	283.15	325.71	320.37													136.88	188.30	238.20	

Table 21: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on loan margins in [bp] (2/2)

6.4.5.2 Ranking

Based on this QQIR assessment, the ranking is derived and shown by project type, country, and sector in the following table, from least to greatest risk margin.

QQIR method validation

Rank	Project Specific	By Country	By Sector
1	Thailand – most sectors	Thailand	Airport, IT
2	China – most sectors	China	
3	Vietnam – most sectors	Vietnam	Toll Roads, Railways, Health
4	Philippines – most sectors	Philippines	Water/waste water
5	Philippines – Power	India	Power
6	Philippines – Waste Management/Treatment	Bangladesh	Waste Management/treatment
7	India – Power	Pakistan	Sea Ports, Education, Leisure/Sports
8	Bangladesh – most sectors	Indonesia	
9	Vietnam – Power	Taiwan	
10	Pakistan		
11	Indonesia – Power		
12	Taiwan – Water/Waste Water		
13	Indonesia – most sectors		
14	Taiwan – most sectors		

Table 22: Ranking from lowest to greatest minimum required DSCR

6.4.6 Insurance premium

A key element in project structuring is the allocation and mitigation of risks. Project participants may seek insurance against risks they feel exposed to. Insurance premiums are the cost of obtaining such insurance, being the rate at which an underwriter is willing to assume specific risks. The higher the level of perceived risk, the higher will be the insurance premium.

In this survey, the insurance premium rate is used as an indicator of perceived levels of risk.

The survey questions are:

“What is the degree of relevance of that political risk factor in your consideration?” And: “Because of that possible risk factor, out of 200 bps, how much would you pay for on insurance covering a US\$100 million exposure?”

6.4.6.1 Quantification of Political Risk Perceptions

The insurance premium is quantified by determining the minimum, maximum and mean value for each available project case. The absolute value from the survey is shown. Values in Tables 23 and 24 are expressed in percentages [%].

QQIR method validation

Country	Bangladesh				China				Indonesia				Pakistan				Philippines			
	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																				
Power	113.68	136.22	158.37		79.57	101.02	122.53		136.06	156.25	172.88						84.17	106.98	129.40	
Water/aste Water	113.68	136.22	158.37		79.57	101.02	122.53		108.68	128.44	148.37		119.22	141.28	162.96		88.32	111.00	133.37	
Toll Roads	113.68	136.22	158.37		79.57	101.02	122.53		108.68	128.44	148.37		119.22	141.28	162.96		92.49	122.85	148.47	
IT/Telecom-munications	113.68	136.22	158.37		79.57	101.02	122.53		108.68	128.44	148.37		116.25	138.60	160.60		88.32	111.00	133.37	
Aggregated									118.30	137.58	157.64		118.07	140.18	161.97		87.55	113.34	137.02	

Table 23: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on insurance premium in [bp] (1/2)

Country	Singapore				Taiwan				Thailand				Vietnam				Aggregated			
	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs	min	mean	max	abs
Project																				
Power	78.04	100.35	122.17	100.0	136.48	152.39	164.95	174.33	46.42	70.96	95.27		78.09	100.35	122.20		96.25	117.25	137.42	
Water/Waste Water					161.83	178.94	191.09	183.00												
Waste Treatment /Management					161.83	178.94	191.09	183.00	46.42	70.96	95.27		78.09	100.35	122.20		96.62	120.76	143.11	
Toll Roads					161.83	178.94	191.09	183.00												
Mail Delivery									46.42	70.96	95.27		78.09	100.35	122.20		89.37	112.03	134.17	
IT/Telecom-munications					161.83	178.94	191.09	183.00												
Education					161.83	178.94	191.09	183.00												
Health					161.83	178.94	191.09	183.00												
Aggregated					149.14	166.88	180.06	182.03	118.30	137.58	157.64		118.07	140.18	161.97		93.73	115.64	136.50	

Table 24: Absolute values vs. minimum, mean, and maximum value calculations with the QQIR method on insurance premium in [bp] (2/2)

6.4.6.2 Ranking

Based on this QQIR assessment, the ranking is derived and shown by project type, country, and sector in the following table.

QQIR method validation

Rank	Project Specific	By Country	By Sector
1	Thailand – most sectors	Thailand	IT/Telecommunications
2	Singapore – Water/Waste Water, Vietnam – most sectors	Singapore, Vietnam	Power
3	China – most sectors	China	Water/Waste Water
4	Philippines – Power	Philippines	Toll Roads
5	Philippines – Water/Waste Water, IT/Telecommunications	Bangladesh	Waste Management/Treatment, Railways, Sea Ports, Education, Health, Leisure/Sports
6	Philippines – Toll Roads	Indonesia	
7	Indonesia – most sectors	Pakistan	
8	Bangladesh – most sectors	Taiwan	
9	Pakistan – IT/Telecommunications		
10	Pakistan – Power, Water/Waste Water, Toll Roads		
11	Taiwan – Water/Waste Water		
12	Indonesia – Power		
13	Taiwan – most sectors		

Table 25: Ranking from lowest to highest insurance premium

6.4.7 Summary of Political Risk Quantification

On average, and aggregated across the Asian countries and sectors, the investment appetite in PPPs is 28% (leverage 72%) and the minimum expected IRR is 14%. The minimum required DSCR is 1.36 while the risk margin is 188 bps. The average insurance premium is 115 bps.

6.5 Validation of Survey Findings and of the QQIR Method

The general rankings among Asian countries and PPP sectors with respect to political risks have been determined. The QQIR method has been applied to derive minimum, maximum, and mean values for project specific financial criteria that are influenced by political risk perceptions. Also absolute values on the financial criteria were obtained. Thus, there are three independent sets of values, which are triangulated against each other by their respective rankings. This triangulation shows the coherence of the survey findings. The validation is complemented by a fitness for purpose test in comparing the QQIR distribution results with the absolute values in terms of standard deviations.

The detailed survey responses, centroids, rankings, and tables of comparisons are documented in Appendix 2.

QQIR method validation

6.5.1 Correlation between QQIR Rankings and General Political Risk Rankings

In the survey, the respondents were asked to check ‘true’ or ‘false’ on hypothesis statements. Statements one to five are tested by calculating the Spearman rank correlation coefficient and corresponding level of significance between the rankings determined by the project specific QQIR assessment and the general country and sector assessment (Table 26).

	Direct Survey Response			QQIR Validation	
	No. of Responses	True [%]	False [%]	Correlation	Level of Significance
1. If the perceived political risks increase, the amount of investment decreases	21	90.48%	9.52%	0.51	90%-95%
2. If the perceived political risks increase, the expected IRR will increase	22	81.82%	18.18%	0.6	90%-95%
3. If the perceived political risks increase, the minimum annual DSCR will increase	23	82.61%	17.39%	0.71	97.5% - 99%
4. If the perceived political risks increase, the risk margin on a project loan will increase	21	95.24%	4.76%	0.21	<75%
5. If the perceived political risks increase, the insurance premium will increase	20	100.00%	0.00%	0.43	75%-90%

Table 26: Statements on political risk and return

The respondents support that in theory, all tests on the hypotheses and assumption statements should yield positive correlations. In fact, with increasing political risks, the investment appetite should decrease and the minimum expected IRR, minimum required DSCR, risk margin on loans, and insurance premiums increase across projects, countries, and sectors. The level of significance may vary, depending on the number of comparable pairs available and quality of underlying survey responses.

	Level of Significance				Total
	<75%	75%-90%	90%-95%	>95%	
r>0	4	3	2	1	10
r<0					0
Total	4	3	2	1	10

Table 27: Correlation tests at different levels of significance

There are only positive correlations supporting the hypotheses. Six out of the ten positive correlation tests are significant at a level of above 75 percent (Table 27).

6.5.2 Correlations among financial criteria and QQIR rankings

The survey findings support that with increasing political risks, investment appetite decreases, and the expected minimum internal rate of return (IRR), minimum required debt-service-coverage-ratio (DSCR), the risk margin on loans and the insurance premiums increase. Details on the response rate, centroid calculation, and ranking for these project specific financial criteria may be found in Appendix 2 (Table 28).

QQIR method validation

	Direct Survey Response			QQIR Validation	
	No. of Responses	True [%]	False [%]	Correlation	Level of Significance
1. There is zero or a negative correlation between risk margin on loans and insurance premiums	21	14.29%	85.71%	0.85	99.90%-99.95%
2. With decreasing equity commitment, the risk margin on a project loan increases	22	90.91%	9.09%	0.65	90%-95%
3. With decreasing equity commitment, the insurance premium increases	21	66.67%	33.33%	0.71	90%-95%
4. With decreasing investment appetite, the minimum required DSCR increases				0.68	90%-95%
5. There is a positive correlation between increasing investment appetite and expected IRR		n.a.		0.17	<75%
6. There is a positive correlation between increasing minimum required DSCR and risk margin on loans				0.40	75%-90%

Table 28: Correlations between financial criteria

The correlations between the financial criteria have been tested and found to have different levels of significance.

	Level of Significance				Total
	<75%	75%-90%	90%-95%	>95%	
r>0	5	2	4	5	16
r<0		1		1	2
Total	5	3	4	6	18

Table 29: Levels of significance of correlation tests

Only two out of 18 tests yielded negative correlations. As will be shown below, these negative correlations relate to sector specific tests where the project specific and country testing yield positive correlations. The negative correlations can be explained by either the number of pairs available for comparison or poor survey responses. The same reasons apply for explaining low positive correlations or levels of significance of below 75 percent. However, by majority decision, the positive correlations prevail and all hypotheses can be proven correct. 11 out of the 16 positive correlation tests are significant, at a level of above 75 percent (Table 29).

6.5.3 Correlations between Absolute Values and General Political Risk Ranking

The next step in the survey and QQIR validation is to check if the polls on the absolute values are coherent with the general risk assessment. This is achieved by comparing the rankings of the countries and sectors for each financial parameter. Again, the Spearman rank correlation coefficient 'r' is being determined as well as the level of significance at which the correlation takes place (Table 30).

QQIR method validation

	Level of Significance						Total
	<60%	60%-75%	75%-90%	90%-95%	95%-97.5%	>97.5%	
r>0	1	2	2	1		3	9
r<0	1						1
Total	2	2	2	1	0	3	10

Table 30: Summary of correlation tests between absolute value and general ranking

6.5.4 Correlation between QQIR Results and Absolute Value Polls

Comparing the rankings between the QQIR results and those derived with the absolute values, all five financial criteria correlate positively between QQIR and absolute values, at a level of significance of above 97.5 percent, as shown below.

	Level of Significance					Total
	<75%	75%-90%	90%-95%	95%-97.5%	>97.5%	
r>0					5	5
r<0						0

6.5.5 “Fitness for Purpose” of QQIR Results

The quality of the QQIR method is determined by comparing the resultant distribution of the QQIR method with the absolute crisp values collected, as shown below.

	Total	Within Range	Outside Range
Number of observations	40	31	9
Percentile	100%	77.50%	22.50%
Average distance in terms of [s]:	1.60	0.85	4.20

In 77.5% of all cases, these results fall within 0.85 standard deviations and including those outside the range, it is 1.6 standard deviations. This means that using a sample size of only 4 respondents, with a chance of 77.5% (3 out of 4), one can produce results with the QQIR method, that fall within 0.85 standard deviations and theoretically with “100%” certainty, results generated with the QQIR are within 1.6 standard deviations. One out of the four observations may be 4.2 standard deviations off.

6.5.6 Comparison of QQIR Results with Market Data.

The results of the political risk assessment with the QQIR method can be compared with generalized market data presented by the project finance department of the UK based commercial bank HSBC (Tho 2006). Here, the QQIR results are aggregated across all sectors and countries.

QQIR method validation

HSBC Market Data Presentation	Survey Results with QQIR Method		
	UK PFI	"Asia" PPP	Impact of Political Risks on PPPs in Asia
Leverage	> 90%	60% – 80 %	72%
Bank Risk Margins	< 100 bps	> 100 bps	188 bps
Base case equity risk premiums	12% - 30%	10% - 20%	14%
Annual DSCR	Min. 1.18 – 1.2	1.2 – 1.4	1.36
Tenor	> 30 years	12 – 15 years – subject to market	n.a.
Maturity	1 – 2 years	2 – 5 years	n.a.
Insurance premium	n.a.	n.a.	115 bps

Table 31: "UK PFI vs. "Asia" PPP – Financing Snapshot" [HSBC] in comparison to QQIR results (partial source: Tho 2006)

6.6 Conclusions of survey

The sample size for the general political risk assessment in countries and sectors varies between 5 and 20. For the project specific QQIR assessment and absolute value polls, these were often single-point responses. The coherence in general trends in the answers were shown by correlations even though single observations may have contradicted the trend.

As the QQIR method validation relies entirely on the survey responses, and the quality of responses was uncontrolled and therefore varies widely, there is reasonable hope that the application of this QQIR method under supervised collection of expert opinion will yield reliable results and prove to be a valid and new approach in bridging the gap between qualitative and quantitative risk assessment methods, especially for project specific risk quantification. Certainly, the survey results and validation appear to validate this expectation.

The survey findings and QQIR method have been validated in three comparative tests with multiple correlations and fitness for purpose tests. These tests were between the general political risk assessment for PPP opportunities in countries and sectors, the quantification of perceptions on the impact of political risks on financial parameters with the QQIR method, and the absolute value polls on the financial decision criteria. The calculated numerical results were then compared with PPP market data presented by HSBC. In conclusion, the QQIR method yields robust results and is "fit for purpose"

Therefore, it is concluded, that the method for QQIR is a valid tool for relatively reliable quantification of perceptions of political risks.

QQIR method validation

The QQIR method can be applied for risk exposure assessment to underwriters, investors, sponsors, lenders, governments, and other PPP stakeholders. Applications may include political risk assessment, credit risk assessment, contingent claim assessment, and other quantitative risk assessments. The method may play a significant role in all settings in which reliable numerical data is missing and expert opinions are the next best source of information.

The current presentation of survey results is not exhaustive. In future derivative projects, more correlations and implications between these survey findings can be drawn.

Also, in future surveys for assessing project specific PPP opportunities, one may add survey only one specific to Asian country and/or PPP project sector. Also, the absolute value polls can be more standardized to generate statistically significant poll results.

While this survey evaluation strongly suggests that the QQIR method may work and be a powerful tool for generating reasonable results, the QQIR method is more suitable for project specific risk assessments rather than mass-surveys in which respondents can find difficulty in answering correctly QQIR questions without prior training or tutorial.

QQIR method application

Case study 1: Demand and pricing risks in a power project

CHAPTER 7: QQIR METHOD APPLICATION IN TWO CASE STUDIES

The QQIR method has been applied in two case studies to determine the impact of political risks on returns in a power project and the risk exposure and recovery potential under a political risk guarantee.

The case studies have been conducted in collaboration with a power developer in Japan and the Asian Development Bank (ADB) under confidentiality agreements. Therefore, neither project name nor names of counterparties involved or countries involved are being mentioned.

7.1 Case study 1: Impact assessment of governmental actions on pricing and demand in a power project in an Asian country

7.1.1 Summary

There is a power project in an Asian country and an equity investor from Japan holds 40% of the shares. The equity investor is concerned that the political risks may affect the tariff and dispatch in the power project. The objective of this case study is to quantify the impact of governmental actions on the returns and debt service capacity of the project.⁷

The risk quantification is conducted with the method for quantifying qualitative information on risks (QQIR) in order to quantify expert opinions and perceptions on political risk factors in the power project.

In this case study, the perceived impact of political risks causes a reduction in returns but is not critical for honoring the debt service obligations.

The details regarding the risk assessment and evaluation by questionnaire are presented in Appendix 3.

7.1.1.1 Objective

The objective of this case study is to quantify the impact of political risks on the tariff and dispatch, or power off-take, and subsequently on the returns and debt service ca-

⁷ The case study is published in: Sachs, T., Rosa, A., Tiong, R. (2007) "Impact quantification of political risks on demand and pricing in a power project – a case study". Journal of Structured Finance, Spring 2007 issue.

QQIR method application

Case study 1: Demand and pricing risks in a power project

capacity of the project. It is assumed that technical, operational, maintenance or supply risks are successfully hedged and cause no losses to the project at the time of the case study.

7.1.1.2 Method

The risk exposure quantification consists of analysis of the power purchase agreement (PPA), two surveys, and cash flow modeling and simulation.

The PPA and financial model were provided by the foreign investor of the project on anonymous and confidential bases. First, the PPA was analyzed to identify which risk events have impact on demand and pricing. Then, by questionnaire, factors that may influence these events were identified. In a second questionnaire, these identified factors were assessed by expert opinion provided by a senior staff and his team in terms of likelihood of occurrence and possible consequence. The risk perceptions were quantified with the method for quantifying qualitative information on risks (QQIR) which uses trapezoidal fuzzy numbers (TrFN) to map human intuition (Sachs and Tiong 2006) and converted into a probability density function. The results of this assessment were then simulated on the cash flow model with the commercial software @RISK from Palisade.

The difference between the base case and the case of political risks is the investors risk exposure.

7.1.2 Political risk perceptions and modeling assumptions

7.1.2.1 Project structure

The foreign investor holds 40% of the total equity. The power off-taker and the fuel supplier of liquified natural gas (LNG) are state owned enterprises (SOE). These SOEs have direct impact with their actions on the investment returns. The following Figure 22 shows the project and risk structure.

QQIR method application

Case study 1: Demand and pricing risks in a power project

Figure 22: Project and risk structure

7.1.2.2 Forced outage

Based on the PPA, there are three risk cases that may cause forced outage. Forced outage may be caused by dispatch instruction, strikes, or losses in the transmission. In the base case cash flow model, the forced outage is assumed with 0%. This assumption is challenged in the case study. The foreign power developer indicated that the maximum forced outage could be 7.5% due to political risks. The challenge was to find the probability of forced outage in this range.

7.1.2.2.1 Risk identification

The risk events that can cause forced outage were identified from the power purchase agreement. The risk factors that may trigger such an event were identified by questionnaire. The maximum possible range of forced outage was provided with 7.5%.

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Case study 1: Demand and pricing risks in a power project

Figure 23: Influence diagram on forced outage

7.1.2.2.2 Risk assessment and modeling assumptions

The investor provided comments on forced outage for the risk assessment as follows:

"In general, war, civil disturbance, terrorism and unions covering an area beyond the plant do not affect contractual forced outage and the plant is deemed available; plant specific unions triggering strikes impact forced outage; sabotage may impact forced outage but is also generally privately insurable"

The causes listed are generally not affecting contractual forced outage although the plant may in fact be shut down; plant specific unions triggering strikes or other kind of protests will be part of forced outage; indigenous people's disturbance may or may not, depending on whether the project company has followed and maintained all necessary steps to have community support.

Only sabotage to the transmission line inside the power plant boundaries may affect forced outage, although it is insurable; distribution is a downstream issue for which the plant owner is certainly not affected."

These comments are reflected in the weighting of the risk factors and are documented in Appendix 3.

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In aggregation, the total impact of political risks on forced outage is perceived as “high” and the following functions represent this perception (Figure 24).

Figure 24: TrFN and PDF on forced outage

The risk PDF is modeled directly with 7.5% multiplied by the risk PDF. Table 32 shows the properties of the PDF on forced outage.

PDF h	min	mean	max	Variance	Stand. Dev.
10.8539	0.6404	0.7212	0.7875	0.0010	0.0314

Table 32: Properties of the PDF on forced outage

7.1.2.3 Fuel costs escalation

The fuel costs are escalated by applying the same escalation rate year on year. From the PPA, three risk cases that impact on the fuel price escalation and in which governmental actions plays a role have been identified. These are: 1) the LNG prices set by the state owned fuel supplier, 2) market changes, and 3) changes in the government, laws, and regulations. In the base case, a fuel cost escalation of 1.6% was assumed by the investor. The challenge was to find out the impact these events could have on a possible range of fuel price escalation.

7.1.2.3.1 Risk identification

The risk events that can cause fuel cost escalation were identified from the power purchase agreement (Figure 25). The risk factors that may trigger such an event were identified by questionnaire. The maximum fuel cost escalation was assumed at 3.5%

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Figure 25: Influence diagram on fuel costs

7.1.2.3.2 Risk assessment and modeling assumptions

In aggregation, the total impact of political risks on fuel cost escalation is perceived as “very high” and following functions represent this perception (Figure 26).

Figure 26: TrFN and PDF on fuel cost escalation

The risk PDF is modeled with the maximum range of 3.5% multiplied by the risk PDF. Table 33 shows the properties of the PDF on fuel cost escalation.

PDF h	min	mean	max	Variance	Stand. Dev.
16.1193	0.7417	0.7988	0.8377	0.0005	0.0213

Table 33: Properties of the PDF on fuel cost escalation

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Case study 1: Demand and pricing risks in a power project

7.1.2.4 Capacity charge rate

Based, on the PPA, the capacity charge rate is influenced by three risk cases. These are the tariff rate adjustment, and unilateral adjustments. In the base case of the developer, the sensitivity was assumed to be +/- 0%.

7.1.2.4.1 Risk identification

The risk events that can cause shortfall in the capacity charge were identified from the power purchase agreement (Figure 27). The risk factors that may trigger such an event were identified by questionnaire. A shortfall of maximum 10% in capacity charge is assumed.

Figure 27: Influence diagram on capacity charge rate

7.1.2.4.2 Risk assessment and modeling assumptions

In aggregation, the total impact of political risks on capacity charge is perceived as “medium” and the following functions represent this perception (Figure 28).

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Figure 28: TrFN and PDF on capacity charge rate

The risk PDF is modeled with the maximum anticipated shortfall of -10% multiplied by the risk PDF. Table 34 shows the properties of the PDF on capacity charge rate.

PDF h	min	mean	max	Variance	Stand. Dev.
10.5207	0.5099	0.5869	0.6638	0.0010	0.0323

Table 34: Properties of the PDF on capacity charge rate

7.1.2.5 Summary of linguistic risk perception of total impact

In summary, the impact of political risks on cash flow positions in the power purchase agreement is perceived in total as “high” and in detail as following (Table 35):

	Forced outage	Fuel escalator	Capacity charge	Total
Perception	high	very high	medium	high

Table 35: Perceptions on risk impact

The total impact of political risk could not be modeled on the cash flow as the financial model provided did not consider political risks. Therefore a counter calculation comparing this result with the aggregated earlier results is not possible.

The function for the total aggregated impact of political risks on the three above parameters is shown in Figure 29.

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Figure 29: Total political risk perception

The properties of the probability density function are:

PDF h	min	mean	max	Variance	Stand. Dev.
9.3208	0.5130	0.6032	0.6881	0.0013	0.0367

Table 36: Properties of the PDF of total political risk perception

7.1.2.6 Generic assessment of political risks in the project

Other than in the previous assessment, the aggregated political risks can be assessed in a generic approach. Here, the risks are broken down into six categories: the four insurable risk categories according to MIGA Convention (1985) (currency inconvertibility and transfer restriction CI/NT, breach of contract, political violence PV, and expropriation), then legal and regulatory risks (L&R), and finally other risks that are not within the span of control of the government (Tinsley 2000). Each category is influenced by multiple factors (Figure 30).

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Figure 30: Influence diagram of for generic political risk assessment

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As the political risks were not incorporated in the original financial model that was provided by the Japanese power developer for this project, these risks could not be lumped together.

The following function represents the perceptions on the general political risks (Figure 31) and the perceptions on the risk factors are presented in Table 37.

Figure 31: General political risk perception

	CI/NT	Breach of contract	Expropriation	PV	L&R	Other	total
EL	0.112	0.248	0.112	0.483	0.350	0.525	0.319
VL	0.252	0.388	0.252	0.623	0.490	0.665	0.459
L	0.390	0.527	0.390	0.761	0.628	0.803	0.598
M	0.558	0.695	0.558	0.930	0.797	0.972	0.766
H	0.732	0.869	0.732	0.897	0.964	0.855	0.939
VH	0.864	0.986	0.864	0.764	0.897	0.722	0.928
EH	1.000	0.863	1.000	0.629	0.762	0.587	0.793
Perception	extremely high	very high	extremely high	medium	high	medium	high

Table 37: Perception on generic political risk categories

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7.1.3 Comparison between PPA specific and generic results

The perception of the total political risk is “high” in both cases: it is “high” for the aggregated results that were derived with the QQIR method based on the risk factors identifies in the power purchase agreement as well as with the generic political risk assessment approach. This may allow the conclusion that with the QQIR method, same results in terms of perception can be achieved, using how ever two different risk breakdown approaches.

The numerical comparison of these two assessments is not possible as the initial financial model does not incorporate any analysis of political risks.

Also, the investor did not provide current project data as it is business sensitive. The QQIR results could not be numerically compared against actual IRR developments of the project. However, the investor indicated that the results are in line with the actual development:

“As to the un-answered question regarding actual returns, it is a bit difficult for me to reply, as my company is a publicly listed company and such info is very sensitive. However, your analysis is pretty much in line with the actual results.”

The numerical results are presented in the next section.

7.1.4 Quantification of political risk impact

To the investor, the critical financial ratios are the minimum debt-service-coverage ratio (DSCR) and the internal rates of return (IRR) on the dividends, equity, and the entire project.

The probability distribution functions of the political risk impact on forced outage, fuel cost escalation, and capacity charge rate were modeled on the input parameters with the commercial software “@RISK” from Palisade. The stochastic simulation settings are 5000 iterations, sampling with Monte Carlo and sample recalculation with Latin Hypercube. The results are shown in Table 38.

The “base case” are the results from the financial model provided by the investor, and the “political risk case” are the results calculated with the QQIR method. The “risk exposure” is the difference between the two cases.

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	Base Case	Political Risks Case			Risk Exposure		
		min	mean	max	min	mean	Max
Dividend IRR	8.17%	3.42%	3.91%	4.40%	3.78%	4.26%	4.75%
Equity IRR	12.60%	7.04%	7.58%	8.11%	4.48%	5.02%	5.55%
Project IRR	10.28%	7.53%	7.80%	8.07%	2.21%	2.48%	2.75%
Min. DSCR	1.34	1.036	1.059	1.081	0.26	0.28	0.30

Table 38: Base case vs. risk case: comparison of the financial indicators

In absolute terms and judging by the mean values only, the greatest impact is on the equity IRR, then dividend IRR and finally total project IRR. The min DSCR does not fall below 1.0 which indicates that even in the event of the perceived political risks, the project does not default on its debt service obligations.

7.1.5 Conclusion

The method for quantifying qualitative risks (QQIR) has been applied to quantify the impact of the political risks on the returns and debt service.

Such risks have an impact on the returns and debt service capacity of the power project. The impact however does not cause project default on debt service obligations but causes a drop in equity, dividend, and project returns between 2.21% and 4.75%.

The total perception of the impact of political risks on the projects is “high”. This result was determined by two independent datasets, one on political risk factors affecting specific cash flow positions in the financial model, the other on a general political risk assessment in this project.

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Case study 2: Risk exposure and recovery assessment under a guarantee

7.2 Case study 2: Risk exposure and recovery assessment under a guarantee

7.2.1 Project description

An Asian host government agency runs a new state-owned water project company (WPC). A foreign lender in this new water supply project demands for a guarantee from the Ministry of Finance (MOF) of this host government for covering debt service payment obligations of this state owned water project company. The foreign lender also wants the ADB to issue a guarantee against breach of contract from the MOF. The ADB guarantee is covering MOF's guarantee obligations towards the foreign lender. ADB will issue the guarantee only on the condition of a counter guarantee from the MOF.

The objective of the second case study is to carry out risk exposure assessment of the Ministry of Finance (MOF), a foreign lender, and of the Asian Development Bank (ADB) under a guarantee in a water project in an Asian country. ADM may engage in mediation before the water project company falls short in repaying the foreign lender. Also, the intention is to determine the added value to all three parties that ADB's mediation may offer⁸.

The risk exposure assessment uses the method for quantifying qualitative information on risks (QQIR). The QQIR method translates expert opinions on perceived risk factors into probability density functions which are the input to stochastic simulations and recovery rate determination.

The details on the risk exposure and recovery assessments of this case study are presented in Appendix 4.

7.2.2 Case study outline

7.2.2.1 Project structure and participants

The guarantee may be issued by ADB to the foreign lender under the condition of a counter guarantee from the MOF.

In the water project, the Asian Development Bank (ADB) is considering issuing a guarantee to a foreign lender against breach of contract by the Ministry of Finance (MOF). The foreign lender is a commercial bank that is asked to extend a US\$ 15 mil-

⁸ Findings from this case study are published in: Sachs, T., Bellinger, C., Tiong, R. (2007) "Risk exposure and recovery assessment under a guarantee in a water project". Journal of Structured Finance, Winter 2007 issue.

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Case study 2: Risk exposure and recovery assessment under a guarantee

lion loan to the water project company (WPC) with expected US\$ 8 million interest payments. The project company is a state owned enterprise (SOE) by the Ministry of Construction and might be privatized in the course of the project.

The foreign lender has asked the MOF for a guarantee of the debt service payments by the project company. The MOF guarantee will be called in the event that the WPC cannot honor its debt service obligations. The ADB guarantee will be called by the foreign lender if the MOF does not honor its MOF guarantee to the foreign lender. The ADB will issue the guarantee to the foreign lender on the condition that it receives a counter guarantee from the MOF. The same would apply if ADB was to offer guarantees to local lenders. The project and guarantee structure is shown in the following figure.

Figure 32: Project structure of water project

Without the ADB guarantee, the foreign lender might charge commercial interest rates above LIBOR on its loan which would include a commercial political risk insurance (PRI). The foreign lender would be willing to charge less with ADB's guarantee, taking into account an improved risk profile of the project. The lower interest rate charge is the result of higher confidence in receiving debt service payments with ADB's involvement. ADB's guarantee therefore allows the project company to borrow from a foreign lender at "senior" conditions at a lower spread. However, it may still treat the foreign

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Case study 2: Risk exposure and recovery assessment under a guarantee

lender “junior” to the local lenders when it might have to decide on whom to pay first. This risk is covered effectively by ADB’s guarantee. That credit enhancement mechanism is in the interest of both, the project company and the foreign lender.

7.2.2.2 Method of assessment

The revenue risks and recovery rates are assessed by expert opinion with questionnaires since historical and reference data is missing. The QQIR method is applied for evaluation of the expert opinion. For determining the risk exposure and recoveries of ADB, the foreign lender, and MOF, the risk assessment is divided into three phases with three corresponding questionnaires.

Three senior staff from the Office of Cofinancing Operations of ADB provided their opinions on the risk factors with respect to likelihood of occurrence and potential consequence of the risk factors in terms of: “extremely low”, “very low”, “low”, “medium”, “high”, “very high”, and “extremely high”. These opinions are the input to the fuzzy risk analysis in the QQIR method.

The financial modeling is performed with MS Excel. The stochastic simulation is run with the Palisade software @RISK 3.5.2 with 10,000 iterations, sampling type “Latin Hypercube”, and standard recalculation “Monte Carlo”.

7.2.2.3 Risk exposure sequence

The risk exposure assessment is divided in three sequential parts with corresponding questionnaires.

1. What is the risk exposure of the MOF in the event that the project company defaults fully or in part on debt-service and the MOF guarantee is called by the foreign lender?
2. What is the risk exposure of the foreign lender in the event that the MOF does not or just in part honor the guarantee to the foreign lender?
3. What is the risk exposure of ADB in the event that ADB pays the foreign lender under the guarantee but the MOF does not or just in part honor the counter guarantee to ADB?

7.2.2.4 Scenario analysis and modeling assumptions

The Asian country is a member of the ADB. Therefore ADB has some mediation power with the Asian country’s government. ADB may want to use its mediation power

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to lower the risk of project default. ADB's added value to the project mediation is evaluated in two scenarios.

7.2.2.4.1 Valuation of ADB mitigation

In this section, the value added by ADB's mitigation is determined for MOF, the foreign lender, and ADB. Mediation can take place at any point in time of the risk sequence process. The value of ADB's mediation is evaluated for the event of before the project company defaults on debt service repayments to the foreign lender. Scenario (A) considers mediation of ADB before default by project company on the foreign lender loan. Scenario (B) is without any mediation attempt of ADB before default on the foreign lender's loan. Based on the difference between the two scenarios, the value added to the MOF, the foreign lender, and ADB by ADB's mediation is determined.

It also allows determining the marginal cost of mediation to ADB. Once the foreign lender calls the guarantee, it is assumed that ADB will always engage in mediation.

7.2.2.4.2 Seniority of loans

In addition, scenario (1) assumes that the foreign lender is treated (though not contracted) junior to the local loans in terms of debt-service repayments (interest and principal) and scenario (2) assumes that all three lenders are equal in seniority of loans. What is at risk is the total debt-service of all loans.

In scenario (1), the foreign lender is junior to the local lenders. It is assumed, that the debt of each of the three lenders is always serviced as principal and interest payment. The option to just pay interest only and reschedule payment on the principal is not considered. Therefore, the foreign lender' debt is serviced only from the unused cash that is still free after servicing the local lenders.

In scenario (2), the total risk exposure to all debt service obligations are considered as a lump sum and there is no seniority among the three lenders involved.

7.2.2.4.3 Modeling periods

The risk exposure assessment of ADB, the foreign lender, and MOF is performed for two time periods. One time period is from 2006 to 2012. By 2012, the project is assumed to be fully operational. The second time frame covers from 2013 to 2018. By 2018, the foreign lender loan is supposed to be fully repaid (interest and principal) to the foreign lender.

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7.2.2.4.4 Risk modeling criteria

The guarantee is called if the debt service obligations to the foreign lender are not fully honored by the government (Ministry of Finance, MOF). This scenario depends on the seniority status of the foreign lender.

In this case study, it is assumed that the debt service obligations are in default when the DSCR falls below 1.0. The debt service coverage ratio is calculated by following formula:

$$\text{Debt service coverage} = \frac{EBITDA + \text{Rentals}}{\text{Interest} + \text{Rentals} + \frac{\text{Principal repayments}}{1 - \text{Tax rate}}} \quad (91)$$

Some underwriting guidelines may require a minimum debt-service-coverage ratio (DSCR) of, for example, 1.25. The risk exposure and claim amounts are derived from the mandatory assumption that a minimum debt-service-coverage-ratio of 1.0 can be met and the consequential risk exposure is the missing amount to cover these obligations.

The tax rate is provided with 10%. The annual claim amount is the difference between the available EBITDA and the amount needed to cover the debt. The maximum claim amount is capped by the annual debt service obligation of interest plus principal repayments (DSCR=1.0).

7.2.2.5 Data collection

The financial modeling uses a MS Excel spreadsheet by the foreign lender and the project company.

The risk exposure assessment depends on probability density functions derived with the QQIR method and following the risk sequence. Each risk and recovery event is influenced by factors which have been assessed by survey opinion of the three senior staff of the ADB, who are closely familiar with the project, on relevance and anticipated impact of the factors.

There are three survey responses. The QQIR method is designed to handle small sample sizes by using fuzzy sets. It quantifies possibility ranges and therefore represents the possible range indicated by the respondents. The responses on some survey questions covered the extreme spread from "extremely low" to "absolutely high".

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Case study 2: Risk exposure and recovery assessment under a guarantee

On other questions, the responses were completely uniform. This indicates that the three respondents may strongly disagree on some questions but agree on others.

The numbers presented in this case study are the mean values. All values do have corresponding distributions and are presented in Appendix 5.

7.2.3 Risk exposure assessment

The risk assessment uses the QQIR method. For assessing the risk exposure of ADB, the foreign lender, and MOF, three risk and recovery events have been identified. These are

1. the case that the project company defaults in its debt service obligations to the foreign lender due to insufficient revenues;
2. the MOF does not fully honor its guarantee to the foreign lender; and that
3. the MOF does not fully honor the counter guarantee to ADB.

These events are shown as a risk sequence and then assessed based on the survey responses.

7.2.3.1 Risk sequence

The risk exposure of ADB is determined by the potential loss ADB may suffer if the MOF does not fully honor the counter indemnity. This is the case of country default, and ADB is the "last line of defense" and may engage in country loan rescheduling.

This happens during the following sequence of risk events. The first question is that the project company defaults on its debt service obligations to the foreign lender. The project cannot fully honor its obligations of debt and interest payment but probably in part. Based on that probable short fall in debt service, the foreign lender will call the MOF guarantee on the missing amount. This is the risk exposure to the MOF.

Second question is on the amount by which the MOF will honor its guarantee to the foreign lender. That is the recovery rate of the foreign lender under the MOF guarantee. If the MOF does not fully honor the guarantee, the foreign lender will call ADB's guarantee which covers 95% of the foreign lender's exposure. It is assumed, that ADB pays the foreign lender 95% of the claim amount, i.e. the remainder that the MOF has not honored. Thus, 5% of the unrecovered debt service payments are the foreign lender's risk exposure.

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Case study 2: Risk exposure and recovery assessment under a guarantee

In the third step ADB calls the counter guarantee from the MOF to cover its payments to the foreign lender. Again, the MOF may not fully indemnify ADB. The remainder that ADB cannot recover from the MOF is the risk exposure of ADB.

ADB can either realize the loss or it could be restructured as an ADB country loan to the MOF with a longer maturity.

This risk sequence is presented in the following figure. It shows that the MOF pays fully in any event: either through the bulk water off-taker and water project company (WPC), or under the guarantee to the foreign lender, or under the counter guarantee to ADB. The only difference is how much it pays for this project: fully, 95%, or less by sovereign default.

Figure 33: Sequence of risk events determining the risk exposure

7.2.3.2 MOF risk exposure

7.2.3.2.1 Assumptions

If the WPC defaults on its project debt-service obligations, there are two possible reasons: either the revenues are at risk or the operating costs escalate. In this analysis, operational risks are neglected and only revenue risks analyzed. Also possible currency devaluation on the foreign loan repayment is neglected.

The revenue risk is not considered separately for tariff payments and water off-take risk. It is considered accumulated. The revenue risks are assessed through questionnaire survey. The risk identification is based on generic risk analysis.

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7.2.3.2.2 Risk identification

The risk factors that may cause default on the loan payment are identified by the principles of a PEST analysis. The political and social risks are aggregated as “Political risks” and categorized according to MIGA convention (MIGA 1985) into insurable political risks: currency convertibility, expropriation, breach of contract, and political violence. The economic and technical risks are aggregated as “commercial, technical, and economic risks” and assessed based on Porter’s five competitive forces analysis (Porter 1998): supply risk (raw water quality and quantity), customer risks (water demand quantity and payment collection), substitution risk (here, substitution risk is not relevant as water is not substitutable), new entrants (new/other water plants/producers), and competition (liberalization of water market).

ADB’s mediation power before project default will be specially assessed. ADB’s mediation may result that project will not fall into default either at all or at least, that the claim amount is reduced.

Figure 34 shows the influence of the risk factors on project default and the claim amount. ADB’s mediation acts as risk mitigant.

Figure 34: Risk factors affecting project default and value of guarantee

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The resultant probability distribution function is modeled on the annual total revenue over the loan life cycle.

7.2.3.2.3 Assessment

The assessment in Table 39 shows that before project default may occur, ADB’s mediation power is of great value. It lowers the perception on the total project risk exposure from “medium” to “extremely low” from ADB’s point of view. The MOF in return may perceive ADB’s mediation as threat as it would force the MOF to honor its debt service obligations from the WPC to the foreign lender. However, the total amount that the foreign lender may claim from the MOF if ADB mediates decreases.

Even though the perception on political risks worsens from “low” in 2006-2012 to “medium” in 2013-2020, the claim amounts decrease. This is due to better debt service capacity of the project. This observation is in line with the rule of thumb that the risk profile decreases over the project life cycle.

Following table (Table 39) shows the perceptions on the revenue risks as well as the perceived effect of on ADB’s mediation power.

Risk factor	2006-2012	2013-2020
	Perception	Perception
Commercial, technical, and economic risks	Medium	Medium
Political risks	Low	Medium
ADB's willingness and ability to mediate	High	High
A: if ADB mediates before default on loan occurs	Extremely Low	Extremely Low
B: if ADB does not mediate before default on loan occurs	Medium	Medium

Table 39: Perceptions on risk factors impacting the revenues and ADB’s mediation power

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Figure 35: Comparative analysis of impact of ADB mediation on revenue risk impact

The impact of ADB's mediation power is shown in Figure 35 as a comparative analysis of the probability density functions (PDFs) that were derived with the QQIR method and are shown in the following figure. The risk exposure is perceived much less with ADBs mediation.

7.2.3.2.4 Base case

In the base case, no revenue risks or mitigations are considered.

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
MOF risk exposure – Probable amount being called	12,033,250	23,129,610	3,821,924	5,321,478

Table 40: Risk exposure of MOF in base case [US\$]

The Table 40 shows the risk exposure of the MOF. This is that the project company cannot honor its debt service obligations and the MOF guarantee is being called. In the base case, the water project is economically not viable. It cannot service its debt obligations. In the period of 2006 to 2012, it falls short of repaying the local lenders partially and the foreign lender in full. In the beginning of the period 2013 to 2018, the project company also cannot service its debt service obligations.

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Even though the project is not economically viable in the base case, this case is still carried out to demonstrate the QQIR method and discussing its reasonable results.

7.2.3.2.5 Risk case

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
A: MOF risk exposure – with ADB mitigation	12,033,250	26,431,390	5,862,135	8,373,335
B: MOF risk exposure – without ADB mitigation	12,033,250	51,807,150	11,774,410	37,328,300

Table 41: Risk exposure of MOF in risk case [US\$]

In this risk case, WPC again cannot service at all the debt service obligations to the foreign lender in 2006 to 2012 and only partially to the local lenders. Even though ADB’s mediation may not help the foreign lender, it helps the local lenders. In 2013 to 2018, the risk exposure is less than before (Table 41).

7.2.3.2.6 Valuation of ADB mediation to MOF

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
Value of ADB’s mediation to MOF as reduced claim amount from the foreign lender	0	25,375,770	5,912,280	28,954,960

Table 42: Valuation of ADB mediation to MOF [US\$]

The ADB mediation creates value except for the period of 2006-2012 and the case that the foreign lender is junior. The risk exposure is reduced by zero with ADB’s mediation. Due to ADB’s mediation, the claim amount of the foreign lender against the MOF under the MOF guarantee can be reduced considerably. While ADB’s mediation may create value to the overall perception of contingent losses in this project, to the MOF, however, it creates no value. The MOF still needs to pay its debt service obligations either by indirect payments through WPC or payments under the guarantee or counter guarantee (Table 42).

7.2.3.3 The foreign lender risk exposure

7.2.3.3.1 Assumptions

In the second step, the risk exposure to the foreign lender is assessed. The risk exposure is determined by the amount by which the WPC falls short in debt service payments minus the amount the foreign lender can recover under the MOF guarantee. Of

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that difference only 5% is the risk exposure as the remaining 95% will be passed on and is covered under the ADB guarantee.

7.2.3.3.2 Risk identification

In determining the recovery rate under the MOF guarantee, the MOF’s ability and willingness to pay and to engage in mediation is critical.

Also, it will be assumed here, that ADB will definitely engage in mediation as the outcome will directly affect the claim amount of the foreign lender to ADB under the guarantee. At question is to what degree the ADB is able to mediate and willing to do so (Figure 36).

Figure 36: Risk factors affecting the government to indemnify ADB

7.2.3.3.3 Recovery rate assessment

The survey with the three ADB employees and the QQIR analysis yields following perceptions on the possible recovery:

	2006-2012	2013-2018
MOF's ability and willingness to honor the guarantee	high	high
Mediation effort from ADB and MOF	high	high
Total honoring of the guarantee	high	high

Table 43: Recovery perceptions

The MOF’s ability and willingness to honor its guarantee to the foreign lender is perceived as “high” and the successful engagement in mediation from both, ADB and the MOF is also regarded as “high”. Thus the overall chance that the MOF will honor its guarantee obligations to the foreign lender is perceived as “high”., i.e. the chance for

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the foreign lender to recover its outstanding debt service is “high”. However, a scalable chance remains that it does not recover fully under the MOF guarantee and needs to call ADB’s guarantee.

The recovery perceptions are represented by following probability distribution functions (PDF) in the Figure 37, which are derived with the QQIR method.

Figure 37: PDF on recovery rate

The mean value of the recovery rate is 65.4% for the period of 2006 to 2012 and 65.6% for the period of 2013 to 2018.

This PDF is then multiplied with the total claim amount, calculated in the previous section. This is the amount the foreign lender is likely to recover from the MOF directly under the MOF guarantee.

After MOF has paid to the foreign lender, ADB will need to pay 95% of the rest of the claim amount under the guarantee to the foreign lender. The foreign lender retains 5% of the risk under the ADB guarantee which is the foreign lender’s risk exposure.

7.2.3.3.4 Base case

In the base case, the following Table 44 shows the recoveries and risk exposure of the foreign lender.

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	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
Recovery amount under MOF guarantee	7,868,786	15,124,930	2,505,875	3,489,069
Unrecovered amount	4,164,461	8,004,687	1,316,049	1,832,408
The foreign lender risk exposure - 5% of unrecovered amount	208,223	400,234	65,802	91,620

Table 44: Recovery and risk exposure of the foreign lender in the base case [US\$]

7.2.3.3.5 Risk case

In the case of the previously outlined risk exposure of the revenues, the recovery and risk exposure amount are as follows (Table 45).

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
If A, recovery amount under MOF guarantee	7,868,795	17,284,160	3,843,240	5,489,324
If B, recovery amount under MOF guarantee	7,868,795	33,879,680	7,719,988	24,475,160
If A, unrecovered amount	4,164,452	9,147,227	2,018,895	2,884,011
If B, unrecovered amount	4,164,452	17,927,470	4,054,427	12,853,140
If A, The foreign lender risk exposure - 5% of unrecovered amount	208,223	457,361	100,945	144,201
If B, The foreign lender risk exposure - 5% of unrecovered amount	208,223	896,374	202,721	642,657

Table 45: Recovery and risk exposure of the foreign lender in the risk case [US\$]

Under the ADB guarantee, the foreign lender retains 5% of the total unrecovered claim. The foreign lender' risk exposure decreases over the loan life cycle. The risk exposure in a junior status is less if it is assumed that the other local lenders are "somehow" compensated (scenario 1). Therefore, the total risk exposure of all debt service obligations in a lump sum is higher (scenario 2).

7.2.3.3.6 Valuation of ADB mediation to the foreign lender

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
Value of ADB's mediation to The foreign lender	0	439,012	101,777	498,456

Table 46: Value of ADB's mediation to the foreign lender [US\$]

The difference in the risk exposures between the scenarios with ADB mediation before project default (A) and without mediation (B) is the value to the foreign lender of ADB's mediation before WPC defaults on the foreign lender's loan.

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7.2.3.4 ADB risk exposure

7.2.3.4.1 Assumptions

Under the guarantee to the foreign lender, ADB covers 95% of possible unrecovered amounts that the foreign lender cannot recover in the event that the MOF breaches contract and does not honor its guarantee to the foreign lender. The ADB will claim the same amount it pays to the foreign lender from the MOF under the counter guarantee agreement.

ADB's risk exposure under the guarantee is the difference between the amount it has to pay to the foreign lender and the amount it can recover under the counter guarantee.

7.2.3.4.2 Risk identification

The key question is the MOF's ability and willingness to indemnify ADB. The MOF might be motivated to indemnify ADB due to national and international legal requirements and obligations, for example the ADB charter or framework agreements and in particular to maintain its international reputation and attractiveness for foreign direct investments.

The following figure (Figure 38) shows the factors influencing MOF's decision to indemnify ADB which determines the recovery rate of ADB.

Figure 38: Risk factors affecting the MOF decision on indemnifying ADB

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7.2.3.4.3 Recovery rate assessment

The survey yields following perceptions on the possible recovery under the counter guarantee:

	2006-2012	2013-2018
MOF's ability and willingness to indemnify	high	medium
MOF's motivation due to national and international legal requirements and obligations	high	High
Total recovery potential	high	medium

Table 47: Perception on recovery potential under counter guarantee

The total chance to be indemnified is “high” in the period from 2006 to 2012 and “me-
dium” from 2013 to 2020. This perception may be due to the perception of MOF's abil-
ity and willingness to indemnify in the future as it may face many claims in case of gov-
ernment default (Table 47).

The mean value of the recovery rate is determined as 69.5% for the period from 2006
to 2012 and 58% for the period from 2013 to 2018.

The probability density function of the recovery rate is then multiplied with the claim
amount of ADB against the MOF which is the recovery amount (Figure 39).

Figure 39: PDF on recovery rate

ADB's risk exposure is determined as the difference between the amount paid to the
foreign lender and the recovery rate under the counter indemnity from the MOF.

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7.2.3.4.4 Base case

In the base case, ADB's risk exposure is as follows (Table 48):

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
ADB pays the foreign lender 95% of total risk exposure and claims same amount from MOF	3,956,238	7,604,452	1,250,247	1,740,788
ADB recovers from MOF under the counter guarantee	2,749,368	5,284,676	725,057	1,009,537
ADB risk exposure – ADB needs to mitigate	1,206,870	2,319,776	525,190	731,251

Table 48: Recovery and risk exposure of ADB in the base case [US\$]

7.2.3.4.5 Risk case

In the risk case, the recovery potential and risk exposure are as follows (Table 49):

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
If A, ADB pays the foreign lender 95% of total risk exposure and claims same amount from MOF	3,956,230	8,689,866	3,851,705	2,739,810
If B, ADB pays the foreign lender 95% of total risk exposure and claims same amount from MOF	3,956,230	17,031,100	1,112,777	12,210,480
If A, ADB recovers from MOF under the counter guarantee	2,749,913	6,039,947	2,234,494	1,589,329
If B, ADB recovers from MOF under the counter guarantee	2,749,913	11,837,830		
If A, ADB risk exposure - ADB needs to mitigate	1,206,317	2,649,919	805,173	1,150,481
If B, ADB risk exposure - ADB needs to mitigate	1,206,317	5,193,271	1,617,212	5,126,861

Table 49: Recovery and risk exposure of ADB in the risk case [US\$]

ADB needs to mitigate its risk exposure. A common way for ADB would be to extend a country loan to MOF on that amount with a longer repayment period. The other option is to write off the loss as unrecovered loss.

7.2.3.4.6 Valuation of ADB mediation to the foreign lender

ADB can engage in mediation before WPC defaults on the foreign lender's loan. The cost for that mediation should not exceed the value of that mediation. The value is de-

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terminated by the difference in risk exposure in the case of with (A) or without (B) ADB mediation.

	2006-2012		2013-2018	
	1: The foreign lender junior status	2: total debt obligations	1: The foreign lender junior status	2: total debt obligations
Value and marginal cost of ADB mediation	0	2,543,352	812,039	3,976,380

Table 50: Valuation of ADB’s mediation to ADB

ADB should not engage in mediation before WPC defaults on loan repayments to the foreign lender unless the costs of mediation are below the value it adds to ADB’s recovery potential or lowering of risk exposure.

It should be noted that this valuation of ADB’s mediation is an example that may apply to other entities, as ADB would engage in mediation regardless of the costs.

7.2.4 Conclusion and recommendation

The MOF, the foreign lender, and ADB are exposed to different amounts of risk under the guarantee and ADB’s involvement offers different values to the involved parties. Therefore, the incentive of choosing a guarantee from ADB may vary.

ADB’s role of mediation before WPC defaults on the debt service obligations to the foreign lender has a significant impact on the risk exposure of the MOF, the foreign lender, and ADB.

The risk exposures have been calculated for both cases that ADB engages in mediation and that ADB does not engage in mediation. The comparison of the risk exposures to MOF, the foreign lender, and ADB for the cases of with and without mediation allowed determining the value of that mediation to the different entities.

From the information available, it was not entirely clear if the foreign lender enjoys a senior or junior lender status. The risk exposure assessment was conducted for two scenarios. In the first scenario, it is assumed that the foreign lender is treated as junior, and in the second, all lenders are treated as equal.

Base case calculations show that the project has no sufficient debt service coverage capacity until 2016. Since the actual loan agreements are not available to the author, three mitigating measures are proposed:

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1. It is proposed to mitigate the annual revenue shortcomings with an additional liquidity facility which is repaid over a longer maturity and could be provided by ADB at low interest costs.
2. Another mitigating measure would be to propose either reducing the operational costs or increasing the tariff to generate higher revenues.
3. Thirdly, it is proposed that the project company requests the banks involved for longer loan repayment periods and lower loan repayments at the beginning of the project operation.

In reality, the MOF would probably pay fully for all political risks in any event: either through the off-taker and the WPC by subsidy, or under the guarantee to the foreign lender, or under the counter guarantee to the ADB. The only difference is how much the MOF pays for this project: fully, 95%, or even less in the event of sovereign default.

For ADB, it would ask the borrower to restructure the financing to ensure that the project was viable.

The QQIR Method was in particular useful to determine the risk exposure and recovery potential. Here, the QQIR method was not applied in the context of a financial model, but in the context of a risk scenario analysis. The contribution of the QQIR Method to this analysis is a) structuring the risk and recovery process and b) assessing the essential financial streams and knots within this analysis.

CHAPTER 8: CONCLUSION AND RECOMMENDATIONS

8.1 Conclusion

In this research, the method for quantifying qualitative information on risks (QQIR) has been applied to public-private partnership (PPP) schemes that represent one form of contractual arrangements in structured finance transactions.

The research objectives are to develop, validate, and apply a methodology for bridging the gap between qualitative and quantitative risk assessment methods.

The QQIR method is generic and can be applied to any problem set in which influences can be structured and the single influence factors can be assessed in terms of a weight and possible consequence with some expert opinion. The QQIR method has been thoroughly derived from theory and discussed with professionals.

It adds value to the due-diligence risk assessment process and designing of structured finance transactions. The QQIR method bridges the gap between qualitative and quantitative risk assessment methods.

The QQIR method adds value to investors, lenders, and governmental entities as it allows assessing the financial impact of project specific risk factors that lack historical or numerical records.

The contribution to science can be the consistent process of deriving customized probability density functions from expert opinions. Current scientific contributions using fuzzy sets in risk assessment mainly use fuzzy sets for analytical purposes such as ranking of parameters or determining linguistic values from aggregated factors. Actuarial works in risk assessment use statistical methods with their known limitations to analyze risks stochastically. This QQIR Method connects both fields of research. It bridges the gap between the two fields by allowing for conversion of results qualitative risk assessment being an input to quantitative risk analysis.

The QQIR method has been applied in two case studies. In the first case study, the impact of governmental actions on demand and pricing was assessed. The results were considered by the Japanese power developer to be "in line" with current project developments. The second case study assessed the risk exposure and recovery potential in a water project under an ADB guarantee. The results are in line with actual project viability assessments. Recommendations on the loan restructuring were provided.

Conclusion and recommendations

The QQIR method has been validated through an international survey on the impact of political risks on PPPs. In 77.5% of all observations, QQIR results fall within 0.85 standard deviations and including the other 22.5% of observations, QQIR results are within 1.6 standard deviations. This means that using a sample size of only 4 respondents, with a chance of 77.5% (3 out of 4), one can produce results with the QQIR method, that fall within 0.85 standard deviations and theoretically with "100%" certainty, results generated with the QQIR are within 1.6 standard deviations and one out of the four observations may be 4.2 standard deviations off.

8.2 Limitations

The QQIR method has been validated by survey. Not all survey responses were "correct" in terms of how respondents replied. However, no response was eliminated from evaluation which may be the reason that 22.5% of the results in comparing absolute and QQIR results were outside the range. Also, the response rate was rather low which is attributed to the specialty nature of the survey questions.

Also, the results from application in the case studies have not been validated with current financial project data. The "validation" in the case studies came from positive replies and comments on the project developments by senior staff of the companies and organizations.

The chosen validation method and applications do however suggest that the QQIR method produces reasonable results.

8.3 Recommendations for future research

For future research, there are two areas that could be investigated further.

First, the QQIR method can further be validated. Such validation can be either by survey or case study application. In a survey, keeping the current structure of collecting three data sets for triangulation and fitness for purpose test is recommended. However, the topic that data is collected on may be changed to make it easier to collect significantly more responses. Validation through case studies would require access to financial data and contracts. Here the quality of accessible data and documents as well as the comparability of QQIR assessment results with current project developments is the main concern.

Second, the QQIR method can be expanded. Currently, the QQIR method is an interface between information that the expert has collected to form his/her opinion, and the financial modeling and simulation. In future work, the QQIR method might be expanded in such a way so that market data rather than expert opinion can serve as in-

Conclusion and recommendations

put which can then be incorporated directly in a structured approach which may result in a rule-based expert system for country risk rating/ranking. Possible examples would be one that is based on financial ratios such as the interest cover ratio or other financial ratios of countries, the likelihood for currency inconvertibility and transfer restrictions as well as the assessment of the possible impact of such a shortcoming. Here, the rule-based expert system can be derived to tell the QQIR method at what coverage levels which likelihoods are to be chosen. By addressing the array of political risk categories (currency inconvertibility and transfer, political violence, breach of contract, and expropriation) such an approach may eventually be used for country risk assessment systems, underwriting pricing tools, or other risk related applications.

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Appendix 1

Survey questionnaire to construct the fuzzy sets

APPENDIX 1: SURVEY TO COLLECT OPINIONS FOR CONSTRUCTING THE SEVEN-GRADE FUZZY REPRESENTATIONS OF LINGUISTIC VALUES

A1.1 Instruction: Example on expert opinion

A1.2 Enter here your own perception

Linguistic terms	Fuzzy representation (Tr.F.N)			
	a	b	c	d
Extremely Low (EL)	0	0		
Very Low (VL)				
Low (L)				
Medium (M)				
High (H)				
Very High (VH)				
Extremely High (EH)			1	1

Instructions
Please fill in the blanks with numbers from 0 to 1.0. 0 is the lowest value, 1.0 the highest. Please follow the logic in the example. The numbers may have up to two decimals (e.g. 0.37). You may create triangular shaped fuzzy numbers by assigning the same value to "b" and "c" (see in the example "medium"). The choice between triangular or trapezoidal shapes is yours.

Appendix 1

Survey questionnaire to construct the fuzzy sets

Statistical Evaluation of the survey responses

Extremely Low (EL)					
Resp. No.	a	b	c	d	
1	0	0	0.15	0.25	
2	0	0	0	0.1	
3	0	0	0.15	0.2	
4	0	0	0.05	0.1	
5	0	0	0.1	0.2	
6	0	0	0.05	0.15	
7	0	0	0.05	0.1	
8	0	0	0.05	0.1	
9	0	0	0	0.1	
10	0	0	0.05	0.1	
11	0	0	0	0.1	
12	0	0	0	0.1	
13	0	0	0.1	0.15	
14	0	0	0.2	0.3	
15	0	0	0	0.1	
16	0	0	0.1	0.2	
17	0	0	0.05	0.1	
18	0	0	0.1	0.2	
19	0	0	0	0	
20	0	0	0.1	0.2	
21	0	0	0.1	0.2	
22	0	0	0.05	0.1	
23	0	0	0.05	0.1	
24	0	0	0.1	0.2	
25	0	0	0.1	0.2	
26	0	0	0.2	0.3	
27	0	0	0.1	0.1	
28	0	0	0.05	0.15	
29	0	0	0	0.1	
30	0	0	0.1	0.2	
31	0	0	0.1	0.1	
Average	0	0	0.073	0.148	
Stand. Dev.	0.00%	0.00%	5.60%	6.77%	

Table 51: Statistical determination of TrFN for “Extremely Low” (EL)

Appendix 1

Survey questionnaire to construct the fuzzy sets

Very Low (VL)					
Resp. No.	a	b	c	d	
1	0.1	0.15	0.3	0.35	
2	0.1	0.1	0.2	0.2	
3	0	0.1	0.3	0.4	
4	0.05	0.15	0.25	0.45	
5	0.1	0.1	0.1	0.2	
6	0	0.1	0.2	0.3	
7	0.1	0.15	0.2	0.25	
8	0.05	0.1	0.2	0.25	
9	0.1	0.2	0.2	0.3	
10	0.1	0.15	0.2	0.25	
11	0.05	0.15	0.2	0.3	
12	0.2	0.2	0.3	0.4	
13	0.1	0.15	0.15	0.2	
14	0.1	0.15	0.2	0.25	
15	0.1	0.1	0.2	0.2	
16	0.1	0.2	0.3	0.4	
17	0.1	0.15	0.25	0.3	
18	0.05	0.1	0.2	0.3	
19	0	0.1	0.2	0.3	
20	0.1	0.2	0.2	0.3	
21	0.1	0.15	0.25	0.35	
22	0.1	0.2	0.2	0.3	
23	0.1	0.3	0.3	0.5	
24	0.1	0.2	0.2	0.3	
25	0.1	0.25	0.25	0.4	
26	0.05	0.1	0.2	0.3	
27	0.1	0.2	0.2	0.3	
28	0.1	0.2	0.3	0.4	
29	0.1	0.2	0.3	0.4	
30	0.1	0.2	0.3	0.3	
31	0.1	0.1	0.2	0.2	
Average	0.085	0.158	0.227	0.311	
Stand. Dev.	3.85%	5.10%	5.05%	7.69%	

Table 52: Statistical determination of TrFN for “Very Low” (VL)

Appendix 1

Survey questionnaire to construct the fuzzy sets

Low (L)					
Reso. No.	a	b	c	d	
1	0.2	0.3	0.4	0.5	
2	0.2	0.25	0.3	0.4	
3	0.2	0.25	0.4	0.45	
4	0.3	0.4	0.4	0.5	
5	0.15	0.25	0.4	0.5	
6	0.25	0.3	0.35	0.4	
7	0.2	0.3	0.3	0.4	
8	0.1	0.25	0.4	0.5	
9	0.15	0.25	0.35	0.45	
10	0.2	0.3	0.3	0.4	
11	0.2	0.3	0.3	0.4	
12	0.15	0.25	0.35	0.5	
13	0.3	0.4	0.4	0.5	
14	0.2	0.2	0.3	0.35	
15	0.3	0.4	0.45	0.5	
16	0.2	0.3	0.4	0.5	
17	0.2	0.35	0.35	0.5	
18	0.1	0.4	0.4	0.5	
19	0.3	0.3	0.3	0.4	
20	0.2	0.3	0.4	0.5	
21	0.3	0.4	0.4	0.5	
22	0.2	0.3	0.3	0.4	
23	0.2	0.3	0.4	0.5	
24	0.2	0.35	0.35	0.5	
25	0.2	0.3	0.4	0.5	
26	0.2	0.4	0.5	0.7	
27	0.2	0.3	0.3	0.4	
28	0.2	0.25	0.35	0.45	
29	0.3	0.4	0.4	0.5	
30	0.1	0.2	0.3	0.4	
31	0.2	0.2	0.3	0.3	
Average	0.206	0.305	0.363	0.461	
Stand. Dev.	5.64%	6.27%	5.23%	7.04%	

Table 53: Statistical determination of TrFN for “Low” (L)

Appendix 1

Survey questionnaire to construct the fuzzy sets

Medium (M)					
Resp. No.	a	b	c	d	
1	0.45	0.5	0.7	0.75	
2	0.35	0.5	0.5	0.6	
3	0.4	0.5	0.5	0.6	
4	0.45	0.5	0.5	0.55	
5	0.4	0.5	0.5	0.5	
6	0.35	0.45	0.55	0.65	
7	0.45	0.5	0.55	0.6	
8	0.4	0.5	0.5	0.6	
9	0.4	0.45	0.5	0.6	
10	0.4	0.45	0.55	0.6	
11	0.35	0.45	0.55	0.65	
12	0.45	0.5	0.5	0.6	
13	0.45	0.5	0.5	0.55	
14	0.35	0.45	0.55	0.65	
15	0.4	0.5	0.5	0.6	
16	0.4	0.5	0.5	0.6	
17	0.3	0.45	0.55	0.7	
18	0.4	0.5	0.5	0.6	
19	0.3	0.4	0.6	0.7	
20	0.5	0.5	0.6	0.6	
21	0.4	0.45	0.55	0.6	
22	0.3	0.4	0.4	0.5	
23	0.4	0.6	0.6	0.8	
24	0.4	0.5	0.5	0.6	
25	0.4	0.5	0.5	0.6	
26	0.4	0.5	0.5	0.6	
27	0.4	0.45	0.55	0.6	
28	0.4	0.5	0.5	0.6	
29	0.3	0.4	0.5	0.6	
30	0.4	0.5	0.5	0.6	
31	0.3	0.5	0.5	0.6	
Average	0.389	0.481	0.526	0.613	
Stand Dev.	5.12%	4.02%	5.14%	6.05%	

Table 54: Statistical determination of TrFN for “Medium” (M)

Appendix 1

Survey questionnaire to construct the fuzzy sets

High (H)					
Resp. No.	a	b	c	d	
1	0.7	0.8	0.9	0.95	
2	0.6	0.6	0.7	0.7	
3	0.5	0.6	0.6	0.7	
4	0.5	0.62	0.72	0.85	
5	0.5	0.6	0.6	0.7	
6	0.6	0.7	0.7	0.8	
7	0.6	0.65	0.7	0.75	
8	0.5	0.6	0.75	0.9	
9	0.6	0.7	0.7	0.75	
10	0.55	0.6	0.7	0.75	
11	0.5	0.6	0.75	0.85	
12	0.6	0.7	0.7	0.8	
13	0.55	0.6	0.75	0.8	
14	0.6	0.65	0.75	0.8	
15	0.6	0.6	0.7	0.7	
16	0.5	0.6	0.7	0.8	
17	0.5	0.65	0.65	0.8	
18	0.6	0.7	0.7	0.8	
19	0.6	0.7	0.7	0.8	
20	0.5	0.6	0.7	0.8	
21	0.5	0.6	0.6	0.7	
22	0.6	0.7	0.7	0.8	
23	0.5	0.6	0.7	0.75	
24	0.5	0.65	0.65	0.8	
25	0.5	0.6	0.7	0.8	
26	0.5	0.7	0.8	0.9	
27	0.5	0.6	0.6	0.7	
28	0.55	0.65	0.75	0.85	
29	0.6	0.7	0.7	0.8	
30	0.6	0.7	0.8	0.9	
31	0.6	0.7	0.8	0.8	
Average	0.553	0.647	0.709	0.794	
Stand. Dev.	5.47%	5.27%	6.47%	6.55%	

Table 55: Statistical determination of TrFN for “High” (H)

Appendix 1

Survey questionnaire to construct the fuzzy sets

Very High (VH)					
Resp. No.	a	b	c	d	
1	0.7	0.8	0.8	0.8	0.9
2	0.75	0.8	0.85	0.85	0.9
3	0.8	0.85	0.85	0.85	0.9
4	0.7	0.7	0.8	0.8	0.8
5	0.7	0.8	0.85	0.85	0.95
6	0.7	0.75	0.85	0.85	0.9
7	0.7	0.8	0.9	0.9	0.95
8	0.75	0.8	0.9	0.9	0.95
9	0.75	0.8	0.85	0.85	0.9
10	0.7	0.8	0.9	0.9	1
11	0.7	0.8	0.8	0.8	0.9
12	0.55	0.65	0.8	0.8	0.9
13	0.6	0.7	0.8	0.8	0.9
14	0.7	0.7	0.8	0.8	0.8
15	0.9	0.9	0.95	0.95	0.99
16	0.6	0.7	0.8	0.8	0.9
17	0.8	0.85	0.95	0.95	1
18	0.7	0.8	0.9	0.9	0.95
19	0.7	0.8	0.9	0.9	1
20	0.8	0.8	0.9	0.9	0.9
21	0.65	0.75	0.85	0.85	0.95
22	0.7	0.8	0.8	0.8	0.9
23	0.7	0.8	0.8	0.8	0.9
24	0.7	0.8	0.8	0.8	0.9
25	0.6	0.75	0.75	0.75	0.9
26	0.7	0.75	0.8	0.8	0.9
27	0.7	0.8	0.8	0.8	0.9
28	0.6	0.7	0.8	0.8	0.9
29	0.6	0.7	0.8	0.8	0.9
30	0.7	0.8	0.8	0.8	0.9
31	0.8	0.8	0.9	0.9	0.9
Average	0.702	0.776	0.840	0.840	0.914
Stand. Dev.	7.36%	5.46%	5.23%	5.23%	4.63%

Table 56: Statistical determination of TrFN for “Very High” (VH)

Appendix 1

Survey questionnaire to construct the fuzzy sets

Extremely High (EH)					
Resp. No.	a	b	c	d	
1	0.95	0.97	1	1	1
2	0.85	0.9	1	1	1
3	0.8	0.9	1	1	1
4	0.85	0.9	1	1	1
5	0.9	1	1	1	1
6	0.9	1	1	1	1
7	0.9	0.95	1	1	1
8	0.9	1	1	1	1
9	0.8	0.9	1	1	1
10	0.85	0.9	1	1	1
11	0.85	0.9	1	1	1
12	0.8	0.9	1	1	1
13	0.9	0.95	1	1	1
14	0.85	0.9	1	1	1
15	0.9	1	1	1	1
16	0.8	0.9	1	1	1
17	0.9	0.95	1	1	1
18	0.9	0.95	1	1	1
19	0.8	1	1	1	1
20	0.7	0.8	1	1	1
21	0.8	0.9	1	1	1
22	0.9	0.95	1	1	1
23	0.8	0.9	1	1	1
24	0.8	0.95	1	1	1
25	0.8	0.9	1	1	1
26	0.8	0.9	1	1	1
27	0.8	0.9	1	1	1
28	0.85	0.9	1	1	1
29	0.9	1	1	1	1
30	0.8	0.9	1	1	1
31	0.9	0.9	1	1	1
Average	0.847	0.928	1.000	1.000	
Stand. Dev.	5.47%	4.67%	0.00%	0.00%	

Table 57: Statistical determination of TrFN for “Extremely High” (EH)