An Analytical Framework for Cost and Schedule Planning in the Construction of Hydropower Projects

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ABSTRACT

This dissertation is an aggregation of three major aspects of investment planning – cost projections, measurement of benefits and externalities, and risk quantification. In the first instance, the aim of the study was to assess the statistical significance of a common hypothesis that, cost and time overruns are particularly synonymous with hydropower dams. To demonstrate the magnitude and severity of overrun risks in hydropower planning, the study re-examines the cost issues associated with a portfolio of 58 dams that were financed by the World Bank from 1976 to 2005. Focusing on the technical parameters used in projecting the cost of these set of dams, there is sufficient evidence to show that errors in forecast follow a systematic pattern and cannot be solely attributed to randomness in input parameters such as inflation, exchange rate and demand forecasts.

Following the empirical evidence in support of the hypothesis that cost overruns is a commonality among hydropower dams, it was also necessary to investigate the benefit side of dams in order to ascertain if the justification to build these projects are actually invalidated after incorporating the errors in forecast. Hence, the second aspect of this thesis was aimed at estimating the ex-ante and ex-post economic rate of return for the individual hydropower projects as well as for the aggregated portfolio of dams studied. Using the avoided cost methodology for measuring the benefits of a hydropower project, there is substantial evidence to support that the rents generated by these dams has been positive in spite of the common experience with overruns. The ex-post real economic rate of return for the entire portfolio is estimated to be greater than 14 percent. This findings implies that, decision making on building dams must consider adequate margins of ex-ante benefits over costs to account for the risks of cost overruns.

Finally, the study provides a practical framework for addressing the issue of uncertainty in cost planning of hydropower dams. Using the reference class forecasting (RCF) technique, I construct a forecasting model that depicts what cost overruns can be expected (in probabilistic terms) for dams of different characteristics and locations. This technique is widely applied in the transportation sector, but here, I demonstrate how this methodology can be useful for improving the reliability of costs used for making decisions under uncertainty in power planning. The technique makes it possible to link contingency estimates closely to the likely incidence of uncertainty of construction costs for hydroelectric dams. A case study - the Bujagali dam in Uganda - is used to demonstrate how investment appraisal can be enhanced to better account for the risk of cost overruns. While the Bujagali project had suffered substantially from cost overruns, the expected net benefits of the dam are still expected to be adequate to cover for the actual cost of the dam.

The conclusion is that if the dams were not built, the alternative source of generating power could have been more costly. Consequently, this study recommends the use of the RCF as a support tool for prescribing a margin for error, in the CBA deterministic estimates, to account for the risk of overruns before making a decision to build.

Keywords: investment appraisal, hydropower, dams, cost overruns, reference class forecasting.

ÖZ

Bu tez yatırım planlamanın üç temel konseptinin toplamından oluşmaktadır. Bu konseptler sırasıyla maliyet projeksiyonları, fayda ve dışsallıkların ölçülmesi, ve risk sayısallaştırılması şeklindedir. Ilk tahlilde bu çalışmanın amacı hidroelektrik santral barajlarının maliyet ve zaman aşımlarıyla eşdeğer oldugu hipotezini istatistiki anlamda kanıtlamaktır. Hidroelektrik santrallerinin taşma risklerinin büyüklük ve önemini gostermek amacıyla calışmada Dünya Bankası tarafından 1976 ile 2005 arasında finanse edilen 58 barajın maliyet sorunları analiz edilmiştir. Barajların kurulması ile ilgili teknik parametrelerin maliyetine bakıldığı zaman da tahminle ilgili hataların sistematik bir örüntü sergilediği net bir şekilde ortaya cıkmıştır. Ek olarak bu sistematik örüntüye sahip hataların enflasyon, döviz kuru ve talep tahminleri gibi girdi parametrelerinin rastgeleliğine isnat edilemeyeceği karşımıza çıkmaktadır.

Maliyet fazlalıklarının hidroelektrik barajları ile ilgili olarak temel bir sorun olduğu hipotezinin ampirik bulgularla desteklenmesinin yanı sıra bu barajların ekonomik faydalarının da araştırılması bu projelerin hayata geçirilmesinin hatalarla birleşip geçersiz olup olmadığını gerekçelendirmek icin şart olarak karşımıza çıkmıştır. Bundan dolayı bu tezin ikinci amacı hidroelektrik barajlarının ex-ante ve ex-post ekonomik getiri oranlarını ölçmektir. Kaçınılmış maliyet methodolojisi kullanılarak hidroelektrik projelerinin faydaları ölçülmüş, sonuç olarak karşımıza bu projelerden elde edilen karların pozitif olduğuna dair önemli kanıtlar çıkmıştır. Ex-post reel ekonomik getirilerinin yüzde 14 ten fazla olduğu ispatlanmıştır. Bu bulgular, barajların yapılmasında karar üretirken ex-ante faydalarının maliyet aşımları risklerine karşılık yeterli düzeyde dikkate alınması gerektiğini ortaya koymuştur.

Son olarak bu çalışma barajlarla ilgili maliyet planlamadaki belirsizliklere dikkati çekmek icin pratik bir çerçeve sunmaktadır. Referans sınıf tahmini tekniği kullanılarak bir tahminleme modeli oluşturulmuş, hidroelektrik santralleri ile alakalı olarak ne tür maliyet aşımlarının karşımıza çıkabileceği farklı konumlardaki ve farklı özelliklerdeki barajlar icin araştırılmıştır. Bu teknik daha çok ulaşım sektöründe kullanılmasına rağmen burada bu methodolojinin hidroelektrik santrallerinin santral kurulmasının belirsizlikleri altinda karar üretirken ne kadar faydalı olacağı ispatlanmıştır. Bu teknik aynı zamanda hidroelektrik santrallerinin kurulum maliyetlerinin belirsizliklerini olasılık ölçümleriyle birbirine bağlamak icin de kullanılabilen bir yöntemdir. Bir örnek çalışmadan – Uganda'daki Bujagali barajı – yola çıkılarak yatırım danışmanlığının maliyet aşımlarının risklerini ortaya koymak için nasıl kullanılabileceği ortaya koyulmuştur. Bujagali projesi maliyet aşımlarından ciddi anlamda zarar etmesine rağmen, yapılan analizde, beklenen net faydaların barajın tüm maliyetlerini karşılayacak düzeyde olduğunu ortaya koymuştur.

Sonuç olarak barajlar inşa edilmez ise elektrik akımı üretmenin alternatif yollarla gerçekleştirilmesinin daha da maliyetli olabileceği karşımıza çıkmaktadır. Neticede bu çalışma, RCF modelinin destekleyici bir method olarak kullanılmasını CBA belirleyici ölçümlerinde hata payının ortaya koyulabilmesi için önermektedir. Bu methodlar aracılığıyla maliyet ve zaman aşımı risklerinin proje üretmeye karar vermeden önce ortaya koyulabileceği de aşikardır.

Anahtar Kelimeler: yatırım danışmanlığı, hidroelektrik, barajlar, maliyet aşımları, referans sınıf tahmin modeli.

To my beloved Ayomide
Your existence inspired me beyond imagination…

You will forever be in our hearts

- Omotola and Ijeoma

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Chapter 1

INTRODUCTION

1.1 Theme of the Study on Dams and Uncertainties

Hydropower source of energy has been the largest renewable energy source (IEA, 2013). It accounts for over 17 percent of global electricity output and more than 80 percent of the world’s total non-fossil fuel energy solution. Currently, there are more than 25 countries across the world having up to 90 percent of their electricity production sourced through hydropower. China, Brazil, and India are among the major countries where large sized and number of dams have been constructed over the years (IPCC, 2011). Hydroelectric dams/reservoirs provide soothing flexibility for power generation systems and is capable of adjusting to load fluctuations within very short time, supplying electricity as a base-load plant, storing energy over weeks, months, seasons or even years.

A fundamental advantage of hydroelectric source of energy is its incomparable flexibility and speed of adjustment to changes in load curve. Though, the conventional fossil fuel type of generating plants can also adequately respond to such changes in load, the speed of adjustment to such changes is not as quick and often not as flexible over their full output bound.

Emerging economies in Asia (led by China) and Latin America (led by Brazil) have become key markets for hydropower development. China added 16 GW during 2010 to reach an estimated 210 GW of total hydro capacity. Brazil brought around 5 GW on stream in 2010, bringing its existing capacity to 81 GW while a further 8.9 GW is under construction (IHA, 2012). In South America as a whole, 11 GW is planned and a further 16.3 GW is at the feasibility stage. In Western Asia, there is a total of 15.5 GW of capacity under construction with India accounting for 13.9 GW and Bhutan for 1.2 GW (IHA, 2012).

China as the leading country in the development of hydropower facilities is planning huge investments in hydroelectric systems in the upcoming years. Most of these projects would involve the construction of large dams. In collaboration with Iran, China also plans to build the world’s tallest dam, a 1.5 GW project in Iran’s Zagros Mountains. Brazil plans two major projects in the Amazon, including a 3.2 GW dam facility (Hydro World, 2011). Countries in South-East Asia, Africa, Eastern Europe including Turkey and Russia, have also pipelined various projects to harness their hydro resources for power generation. But then, this class of infrastructure projects can be costly to the system.

Investment decisions under a least-cost power system framework with alternative capital investment strategies when faced with uncertainties have often turn out to be bad decisions where the present value of the net benefits realized by the risky projects are negative at ex-post evaluation.

An ex-post study of previous experience in implementing this type of infrastructure projects shows that the projection of cost and schedule are unreliable in spite of the sophisticated models and the adoption of improvised data during appraisals in recent time. The modern practices in investment appraisal of infrastructure projects have been well proven to ignore the risk and uncertainty involved in dam construction (static approach).

An approach to minimizing the pre-investment induced cost biasedness is in the interest of government/utilities to thoroughly investigate the project-site before calling for bids. A properly investigated site would get competitively priced bids with less scope for subsequent contractual issues. In most cases, sponsors are too optimistic about the site worthiness and make design and cost estimates of the dams without having engaged in this form of examination. The huge up-front investment in hydro dams means that the potential overruns in sponsor's budget can be very substantial due to construction delays, to the extent that financing the completion of the dam may become bigger challenge that could cause further delays.

On a more progressive note, a new technique of forecasting, the Reference Class Forecasting technique (RCF) have been proven to be a useful tool in planning for contingencies of major infrastructure works. The RCF is advocated as a tool for accounting for the level of uncertainty by a way of learning from the outcomes of comparable projects that are already completed. The procedure provides dynamic approach to minimizing the risk of cost overruns that often results from optimism bias. The essence of this dissertation is streamed into 3 major investigations: what is the severity of the construction cost and schedule uncertainties in the dam industry? Are Dams really uneconomical investments? How can we apply the RCF methods to improve the deterministic outcome of CBAs used in supporting the decision process in the power planning?

1.2 Background to the Dissertation

Over the past few decades, countries around the world have witnessed various regimes of volatile electricity prices and fluctuating economic performance. Many developing economies have had an era of transition, having to adjust to the present reality of a blurry energy market. Power generation and demand patterns are now constrained by environmental regulations and global climate challenges. In what could perhaps be regarded as the most atypical problem with developing infrastructure facilities, uncertainty in power planning. The phenomenon of uncertainty in project planning became more pervasive towards the end of the 20th century- a period that witnessed a dramatic rise of the environmental economists. As a result of the growing evidence of the impacts of uncertainty on investment decision outcomes, project analysts and power planners are now even more aware about the reliability of cost and schedule estimates used in justifying the choice of project.

In planning for electricity system expansion, important investment choice are being made based on an ex-ante evaluation of the financial viability of various technologies available. This pre-investment analyses requires that planners/analyst make long-term projections of key project parameters like domestic and foreign inflation rates, exchange rate, market price of petroleum products, hydrological and climatic variations, among other inputs. Often times, these projections are based on incomplete information about future events, and in a few cases, they simply lack merit where information perceived to be unfavorable to projects are intentionally concealed by the project sponsors at the appraisal phase. Because of this, investment decisions are often exposed to adverse effects of selecting a questionable investment plan that fails to follow a least cost system expansion program (Crousillat, 1989).

Substantial body of literature have shown that in the last four decades, infrastructure projects have underperformed in terms of cost and project schedule projections. These mis-forecasts could be tragic to the societies where the structures are built, having substantial negative impacts on the stability of their economies. It could also have major effects on government current account as well as budgets for capital spending. Studies by Merrow and Shangraw (1990), Bacon et al. (1996) Head (2000) documents the severity of cost and time overruns in power projects approved for financing by the World Bank for periods before 1986, in developing countries. A common finding by these studies shows that the appraisal estimates of cost and schedule of major power projects implemented in more than 28 countries across the world, were systematically biased below their actual completion figures. A series of studies by Flyvbjerg on infrastructure projects have similar findings (Flyvbjerg, 2005, 2007; Ansar et al., 2014). The failure to make accurate projections about project parameters have severe implications for the economic and financial viability of an investment, as well as the long term strategic plans of most utilities. It could weaken the economic justification for implementing a particular type of power project where there actual outcome of the project if it had been properly appraised, would not have chosen the project as the least cost viable option.

Since the late 1970s, several moves have been made to curb the incidence of overruns in infrastructure projects. Development agencies are investing heavily in data accuracy and designing sophisticated models and software packages for risk analysis. Yet the deterministic approach to project appraisals have not improved the cost performance of majority of these projects, rather the complexity in the approach to resolving these issues have only created more avenues for hiding…. For instance, Merrow and Shagraw (1990) study of 45 hydropower projects found that, on an average, had misforecast project cost by about 21 percent of their original estimates, Bacon et al. found 27 percent for a set 66 hydropower projects, and a survey by the World Commission on Dams, in 2000, found about 29 percent real cost overruns. More recently, Ansar et al. (2014) and Sovacool et al. (2014) found 99 percent and 78 percent respectively in magnitude of cost misforecast for hydropower dams; Awojobi and Jenkins (2015) also found 27 percent overruns for an exclusive portfolio of World Bank financed dams.

This common findings suggest that the problems of uncertainty in power project implementation is an unavoidable risk that needs to be identified and adequately treated during the planning phase of an infrastructure project. More importantly, there is need to provide strategic plans for mitigating the adverse effects of uncertainty in planning so that investment decisions are not regrettable by their actual outcomes. The least cost system program can only yield fruitful outcome if the issues of uncertainty peculiar to each type of investment is well considered rather than just putting a focus on the deterministic indicators about project parameters. This could imply an additional cost to the process of planning but the justification for making an economic choice within a least cost system planning would utmost depend on how the possible additional cost of an uncertain event could impact on the viability of a particular choice of project.

The issue of uncertainty in project planning presents a major challenge to decision makers, especially, under a least cost investment program. To analyze this issue, an important aspect of this dissertation makes an attempt to discuss and differentiate between risk and uncertainty. Further, the work provides an insight on how to make contingency plans; what amount of investment reserve must be budgeted for avoiding and/or minimizing the effects of uncertainties in hydropower project planning. The outcome of this study is likewise applicable to similar infrastructure projects.

The goal of power utilities, saddled with the responsibility of providing electricity supply for public consumption, is to ensure that investments decisions for expansion of the system capacity for generating power are meant to minimize cost to the system, and that the choice of technology is able to secure a reliable supply of electricity. These goals are considered within the socio-economic objectives of the society, environmental policies and the resource capacity of the government. Hence, while the power planners are attempting to minimize the societal cost of a project, they also aim to achieve this with an acceptable level of reliability.

Generally, the complexity of the decision making framework in the power sector and the issues often associated with the outcome of decisions under uncertainty substantiates the need for a systems approach to project planning, especially where the cost of bad decisions are with great consequences. This method of planning is vital for assessing the viability of the investment plans as well as providing sufficient economic justification for the appraisal methods used for reaching a decision to build a facility.

1.3 Fallacies in Planning Infrastructure Projects

There is significant level of uncertainty that exist in making cost and time projections for power projects. Most studies on the issue of forecast errors have placed much emphasis on the construction risk which seem to put hydro power projects at odds because of the large civil works required. On another angle, there is quite substantial risk in operations for a conventional thermal plant that uses fossil fuel. Oil prices forecast have been highly inaccurate (see figure 1). Petroleum prices have shown high fluctuation over the past 3-4 decades. This implies that there exist a trade-off.

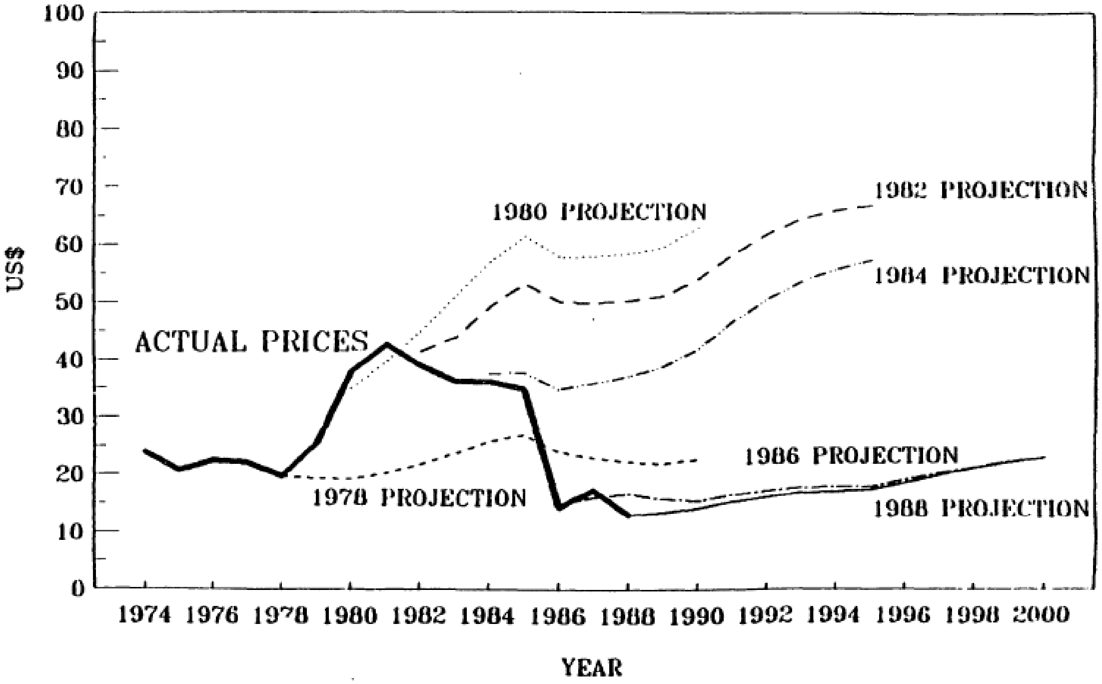

Figure 1. Oil price forecast, real 1987 USD/bbl
[Source: Crousillat, 1989]

Simply defined, *uncertainty* is the lack of adequate knowledge about future events. To this end, the components of uncertainty in project planning can be described as those upon which there are no adequate information at appraisal phase of the planning cycle, consequences of which could result in major interference with the objectives of the power utility. To diagnose the problems of uncertainty and bias in projections of cost and schedule of hydropower dams, it is good to identify the nature of uncertainties that are often encountered in power system planning, analyze the magnitude of damage and how such impact on project outcomes.

The magnitude of uncertainty can be reduced by a well-organized management system during the construction and operating phase of the project if the origin of concern are within the control of the planners. On the contrary, if the origin of uncertainty in future event is not within the control of the planners, then incorporating the cost of uncertainty into planning will be more appropriate approach to treating the unknown reflex. As in the case of the latter, incorporating the cost of uncertainty into the planning process does not guarantee any reduction in the magnitude of uncertainty, but the cost of exposure of an investment decision to adverse consequences will be minimal.

The focus of this study is on hydropower dam development in developing countries. The work is designed to initiate a framework that can improve the economic efficiency of decisions in the power system planning. Dams are very large civil structures with mechanical configurations used for energy storage. These superstructures are quite complex to design and usually would require a long term planning. They require large upfront capital outlay and so, if anything go wrong at the beginning, it can extend a permanent long term impact on the performance of the system. Dams are typically characterized with uncertainties, yet they are capable of generating energy at very low cost when compared to other power generation alternatives. It serves as a source of clean energy, provides flexibility to utility system planners, and has also been identified by the World Bank as an important aspect of its policy towards sustaining a stable agricultural commodities supply.

Despite the efforts at understanding the problems of cost projections and the rationale behind these superstructures, the controversies surrounding dam development remains an unresolved issue in energy policy debate. The magnitude of uncertainty in planning hydropower dams is illustrated by examining the problems of mis-forecast, placing the actual completion cost of hydropower dam projects against their appraisal cost estimates. The severity of the problem is explained by the historical pattern of the deviations from the expected average deviation for a portfolio of projects. This gives a perspective of risk when planning for large complex projects. The degree of uncertainty is empirically studied for both cost, benefit and schedule performance of hydropower projects.

Chapter three of this dissertation deals with issues of cost overruns and time overruns. The importance of forecasting inflation, input prices and implication of currency devaluation for project planning are all empirically studied. Uncertainty and mis-forecast are more likely for projects with long construction period. For example, the 1970s was a period of oil market crisis. A major study on World Bank financed electricity infrastructures revealed that projects implemented from 1967 to 1984 had incurred, on average, cost overruns of 19 percent but with individual cost escalation getting as high as 200 percent. The study further identified that there was a significant variance in the cost performance for projects approved before the 1973 oil market crisis and then completed after the crisis period. This means that the interaction of project-specific parameters with exogenous shocks play a role. Uncertainty in the oil market activities distorts both the benefits and costs side of a power system planning. World Bank record have shown evidence that projection of oil prices movements are often marred with inaccuracies (see Crousillat, 1989). Hence, the type of technology chosen as the least cost method for generating electricity should also consider the oil price dynamics and the cost implication of its volatility to the utility power system.

Lastly, in terms of forecasting the performance of hydropower dams, the problems identified as a driver for this dissertation follows the findings of many studies:

i. Many studies have successfully shown, with facts and figures, that the appraisal cost and schedule estimates of large hydropower dams have been systematically and severely biased below their actual cost.
ii. The indicators used for assessing the viability of power infrastructure projects have been overly optimistic, reflecting both over-estimated stream of benefits as well as underestimated cost of project.
iii. The distribution pattern of errors in forecast gives a notion that the discrepancies between the estimated project cost and actual project cost for hydropower dams are not as a result of random events alone. But they can be explained better as the joint consequences of strategic misrepresentation of project variables and the lack of information about some elements of planning that are not within the control of the project planners.

To answer the question of whether the issues highlighted above are enough evidence to halt further investments in construction of hydropower dams, it would be necessary to examine the economic value of dams, and study what alternative approach to planning under a least cost program can help resolve the highlighted issues, suppose that the net values of dams to the society is positive.

1.4 Significance of the Study

Developing economies are currently faced with the challenge of meeting the energy needs that is quintessential to a sustainable growth. The global green climate policy targets and scarcity of resources present power planners with major challenge, and unavoidable trade-offs in the process of making decisions on power expansion. Because most of the available power generation options are only marginally beneficial to these societies, there is need to ensure that the framework under which choice of investment are decided are consistent with the risk features of power projects pipelined, and the choice of technology is the most cost-effective among other available technologies.

Among other renewable source of energy such as solar and wind, hydropower, averagely has a capital cost advantage (Hydro World, 2011). Even when compared to fossil-fuel type of power generation, the unit cost of generating electricity through hydro means makes it a competitive choice.

This dissertation presents a strong basis for thorough risk analysis during appraisal of power projects to avoid implementing bad choice projects. The post evaluation of World Bank financed dams presents a standard analysis of the experience of dam construction in developing countries.

1.5 Research Objective and Motivations

This dissertation is particularly motivated by the growing concern about the economic justification for supporting hydropower projects that involve dams/reservoirs for financing by multilateral institutions due to the inaccuracies that have characterized the cost estimates used to justify the implementation of such power policies that sees hydro as the most cost effective type of power generation technology. One of the very recent controversies is the three Gorge dam built in China (insert case overruns). The environmental impact was criticized globally as not worthy of the benefits of the dam. Though the criticisms are mainly formed on environmental and social reconstruction ground (the Pareto principle), the economics of dam investment remains an open debate.

Under a least-cost energy development program, the bias in estimation of cost of dams at appraisal stage might result in a bad investment decision where the actual cost of the dam, in comparison with the cost of alternatives technologies, cannot guarantee that hydropower is actually the least-cost choice.

The scope of this dissertation is to give an insight, to a large extent, regarding the key objectives highlighted for this dissertation under the following topics:

- The effectiveness of the conventional Cost-Benefit Analysis approach to investment appraisal under uncertainty.
- The nature and origin of risk and uncertainty in construction of large infrastructure projects such as hydropower dams.
- The implication of risk and uncertainty for investment decisions and application of the state of the art risk analysis software to infrastructure projects with focus on risk identification and quantification.
- Prescribe measures for improving the outcome of decisions based on Cost-Benefit Analysis. In particular, the study considers the importance of looking at the dynamics of a risky project from an “outside view” outcome of previously completed similar projects, rather than concentrating on the internal judgment of experts.
- The effectiveness of the prescribed measures for improving cost estimates; I illustrate a practical application of the RCF technique with the Bujagali hydro power plant constructed in Uganda.

Within the scope listed above, this research aims to provide an answer to the following questions:

- Are cost and/or time overrun a commonality in electricity projects?
- What magnitude of overruns would make investment choice on hydropower irrational considering the existence of an alternative thermal facility under the "least cost power development program" ?
- To what extent can we rely on the use of NPVs and IRRs to reach a conclusion on the economic viability of a Hydropower project?
- How dynamic are the errors of cost projection in the past and what are the sources of these problems? Is cost underestimation caused by weak planning, poor project management, or strategic deception by promoters, a factor Flyvbjerg et al. (2005) refers to as "lies"?
- On the reliability issue, how reliable are the parameter indicators used in appraising construction projects?
- Assuming that the cost of dams were properly estimated and cost of uncertainty incorporated into the decision framework of the utility planner, are hydropower investments still a source of economic surplus to the society?

1.6 Data Collection and Methodological Approach

The study basically relies on an improvised CBA approach to study the actual cost and benefits of dams. The cost overruns and magnitude of time overruns in this class of infrastructure projects are estimated based on World Bank guidelines for economic appraisal of investments. On the cost performance, the accuracy of information on actual project-specific parameters used in forecasting the cost of the dam, like domestic and foreign inflation exchange, etc., are investigated. Benefits of dams are based on the amount of cost savings realized by avoiding a thermal plant investment as replacement plant for hydropower dams. This is plausible within the context of this study.

To test the relevance of 'outside views' style of overriding the common fallacies in planning for contingencies in hydropower investments, we follow the Reference Class Forecasting techniques that was developed for practical use in Flyvbjerg and COWI (2004). This technique requires the use of multilevel regressions, specifically, the Hierarchical Linear Modelling (HLM). Hence, in addition to the CBA methodology, (non-)parametric regression models are developed to provide policy recommendation in the chapter 5 of this dissertation.

1.6.1 Cost benefit analysis as an effective tool for planning

The CBA methodology is widely recognized as an important tool in making investment choice(s). Basically it measures the marginal implication of the choice of investment both financially and in economic terms. Modern CBA methods are refined for optimization of project objectives and they have the following features:

i. Investment actions are often irreversible such that, once the decision is made to build, and the capital expenditure has been made, projects cannot be abandoned. Otherwise the penalty will be very severe for the system.

ii. CBA models allows for interaction of project parameters within a framework of analysis. It simultaneously define the limits of individual project-specific parameters and the models can also be calibrated to capture the cross-effects of input variables on expected project outcomes.

iii. They are dynamic tools for showing the interaction between the current investment action and future expected outcome.

iv. Though they are flexible tools for modeling human behavior and interaction between economic agents, they are particularly constrained by basic theories and principles. For instance, logical statements can be built into models to make project parameters follow their apriori forms.

A combination of these features gives a sense that the modern CBA models for making decisions are quite complex, requiring many assumptions to be made about project parameters, yet subjected to basic theories.

While the CBA technique has been a very useful tool for making decision, its merit in addressing risk and uncertainty has been questioned. In the last decade, various supporting tools have been developed to address this concern. The ability to incorporate parameters for risk and uncertainty into the modern models can help improve the quality of project planning process and decision outcomes.

1.6.2 Source of data for an ex-post evaluation of hydropower dam projects

At the onset, the first challenge of this study was to create a portfolio of completed dams, large enough to be able to provide substantial empirical evidence for the issues peculiar to hydropower investment planning. In this regards, a major problem encountered in the process of collecting data was that information on the cost and schedule performance of hydropower dams are quite difficult to find. This is not surprising as information on public sector projects are often been classified to avoid public scrutiny and criticism. Apart from the political reasons, these type of projects are complex and it may be quite tasking to manage a database that keeps record of such information for future use, especially for projects that involve a long period of construction, recalculating the actual construction cost of the project can be tasking, requiring special accounting and auditing personnel. Unavailability of these type of data poses a major constraint for research into the process of utility planning and hinders the opportunity to develop better strategies for future planning.

Because of this, empirical analyses of infrastructure projects are not very common, and where they are performed, they are often presented as major case studies lacking strong statistical evidence of mis-forecast in power system planning. This makes it practically impossible to sufficiently account for the sources of uncertainty in project planning.

The analysis from this work is particularly focused on World Bank financed hydropower projects. Besides the fact that it provides a substantial sample to perform this study, it was very important that we establish a portfolio of projects for which the appraisal methods are similar. World Bank is the largest institution financing large infrastructure investments. Between 1976 and 2005, a total of 67 hydropower project was approved for financing, out of which 62 was successfully completed. Out of the 62 completed dams, minimum information required to complete the analysis for this study was available for 58 projects. In spite of all the challenges faced in the collection of data, it was possible to form a portfolio of 58 hydropower dams. This portfolio includes dams implemented in 32 countries across the 5 major regions. The sample represents a total of 34, 264 MW of installed capacity, worth USD 60 billion (2010 constant dollar) of capital investments in those developing countries.

For all the projects included in this study, project-specific information were retrieved from the Staff Appraisal Reports (SARs), Implementation and Completion Reports (ICRs), and country information were collected from the World Bank databank (databank.worldbank.org).

It is worth noting that half the sample in this work over-laps with those used in a major World Bank study of power projects cost performance by Bacon et al. (1996). By including this sub-set of hydropower projects, this study is able to examine how the experience has changed over time for the World Bank.

Further description of data and methods are presented in the empirical chapters of the dissertation, chapters 3 and 4.

1.7 Organizational Structure

The structure of this dissertation is presented in the chart below.

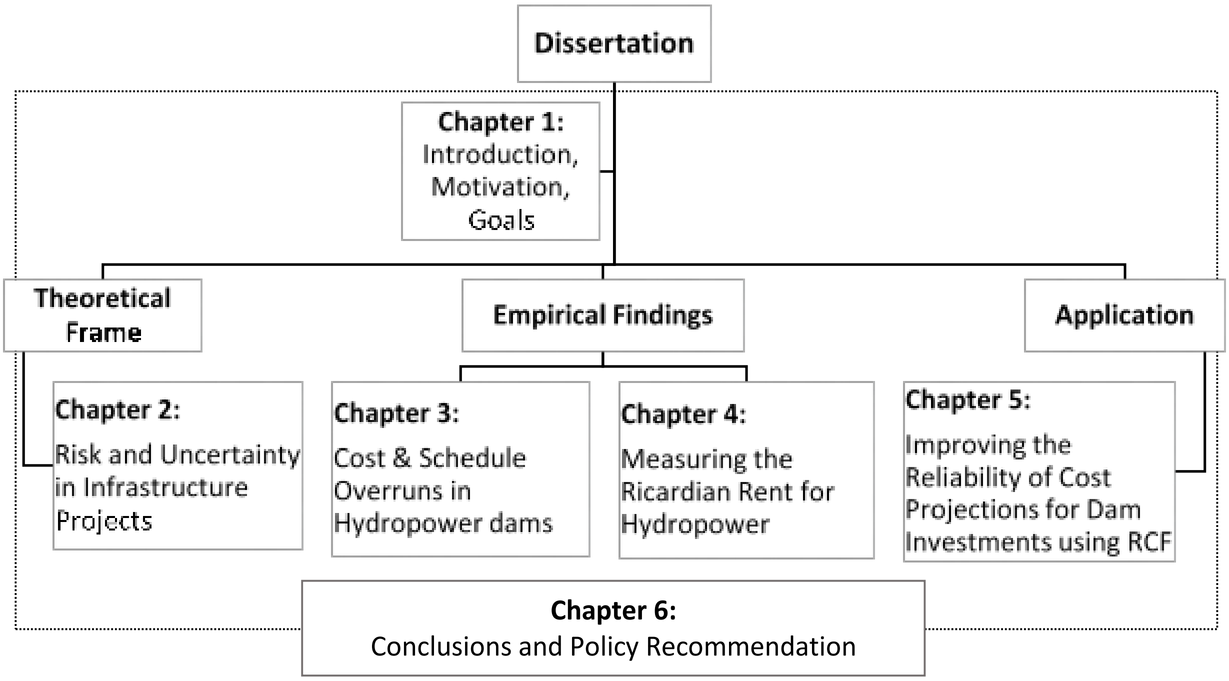

Figure 2. Schematic chart of the work structure.

Chapter 2: Risk and Uncertainty in Infrastructure Projects.

The chapter provides a theoretical framework for understanding the uniqueness of risk and uncertainty in planning large infrastructure projects. First, it describes the concept of risk and uncertainty and further compares and contrast the two concepts within the context of investment analysis. Also, the chapter discusses the usefulness of, and constraints to probabilistic modeling of risk/uncertainty when performing a viability study of hydropower power projects under a least cost system expansion framework.

Chapter 3: Cost and Schedule Overruns in Hydropower Dam.

In this chapter, the first empirical analysis of the dissertation is illustrated for cost and schedule overruns risk in hydropower dam investments. The section prescribes a methodology for diagnosing the pattern of errors in forecasting the construction cost and schedule for large hydropower dams. It also provides a unique method for estimating the cost of time overruns to the society where the expected output of the power project is unable to materialize due to delays in physical completion of the facility. Another significant contribution of this chapter is that, the effects on cost overruns of cost of currency devaluation, implied cost of inflation misforecast, and the cost of time overruns are disentangled systematical to show the possible sources through which uncertainty have manifested in the implementation of this portfolio of dams. The results from analysis of data on cost and schedule issues are presented according to size profile of the dams as well as the regional features of the data collected for this study.

Chapter 4: Estimating the Ricardian Rent for Hydro.

Rather than just focusing on the cost issues as discussed in the previous chapter, the chapter four of this work starts with a justification for measuring the actual benefits of hydroelectric dams. It provides a balanced view on the economics of building dams, and in broad terms it finds a conclusion as to whether building more dams is a pro- or anti- development campaign. Various techniques for estimating the economic rent of hydropower resources are identified from previous studies and discussed extensively within the context of this study. The methodological approach to this chapter, the avoided cost methods, helps to quantify the direct benefits and estimate the economic surplus generated by the portfolio of dams studied. Further, the chapter makes a comparison of the ex-ante and ex-post rate of returns, and then concludes with the policy implication of the empirical findings from both chapter 3 and chapter 4.

Chapter 5: Improving the Reliability of Cost Projections for Dam Investments Using the Reference Class Forecasting Techniques.

This chapter is a demonstration of an advanced quantitative technique for accounting for cost overrun risks. The section starts with a discussion of the theoretical foundation of the RCF technique and its relevance to utility scale power planning scheme. Using hierarchical regression modeling, in this chapter, we provide a predictive model that indicates the likely incidence of cost overruns for a proposed dam, based on a probability distribution of overruns in a reference group of previously completed projects. Also, the Bujagali hydropower dam is used as a case study to test the robustness of the RCF technique for this class of infrastructure projects.

Chapter 6: Summary, Conclusions and Policy Recommendation.

This is the final chapter. It highlights the research questions as provided in this introductory chapter, summarizes the findings from the study, and then provides a set of prescriptive measures for enhancing the efficiency of CBA in investment decision making under uncertainty

Chapter 2

A THEORETICAL VIEW OF RISK AND UNCERTAINTY IN INFRASTRUCTURE PROJECTS

2.1 Introduction

A theoretical understanding of risk and uncertainty in large infrastructure projects is presented here. There are various approach to assessing the risk of a project. As this study is focused on hydropower dams, it is very important that we describe risk in a broader term. In fact, here we differentiate between risk and uncertainty. As in the case of large infrastructure projects, as similar to dam investments, uncertainty is a very big issue and requires adequate attention at appraisal phase. Much of the information on project parameters needed for forecasting the cost and time for dam construction are not accurately available during the time the feasibility study is done.

In the subsequent sections we provide a brief definition of the risk assessment and methodologies often used in investment analysis, then the challenges of these approach to assessing the risk in infrastructure projects is diffused.

2.2 A Conceptual Framework for Assessing Risk and Uncertainty

This section presents two important terms that are commonly considered when performing risk analysis. The possibility to diversify risk provides an alternative way to confronting risk in project planning. In the next few paragraphs, we describe in details these terms. This section also distinguish between risk and uncertainty and discuss the relevance of separating the two components when assessing project exposures to some unwanted events.

2.2.1 Project risk

Various description of risk has been provided in literatures, depending on the context within which risk is applied. Risk can be defined as a source of unwanted negative impact of an action. Zou et al. (2007) describes rsisk as a combination of hazard and exposure; that is, a possibility that an event occurring will have either positive or negative effects on an expected outcome of a decision. Hillson and Murray-Webster (2007) simply relates risk to “uncertainty that matters.” This component of a project planning can lead to disturbances that could cause a system failure in infrastructure project development. To satisfy the purpose of this dissertation, risk is perceived as unknown project components that affect the costs, benefits, and the schedule of a project since they are associated with decision making under uncertainty or vagueness.

In planning for power investments, events/outcomes that could be unfavorable to the project are identified and mitigating measures are stated to avoid adverse effects of such events on the project. As normally practiced, the estimated cost of a project is to include an amount to cover for real contingencies and price escalation, in addition to the base cost engineering estimates. The real contingency is provided for in the cost estimates to incorporate slight changes in scope or events schedule of the projects while the provision for price escalation accounts for domestic and foreign inflation.

Risk assessment entails two major factors: (i) the probability that it occurs; and (ii) the cost of risk to the project. The quantification of risk in project planning is a product of these two factors which can be defined with a simplified equation as shown below:

$$R = \sum \pi_i P_i \qquad \text{Equation (1)}$$

Where R denotes the aggregated impact of risk on project cost, πi is the probability that an identified risk will occur during the implementation of the project, and Pi is the value of the component of project that is affected by risk.

The equation (1) above used to define the impact of risk lacks two important merits. First is that it does not capture the uncertainty in the πi, neither does it account for the uncertainty in Pi. Secondly, the equation fails to differentiate between the extreme unlikely and insignificant likely events. Dikmen et al. (2007) point out that the degree of risk exposure should be assessed, not just as a product of the probability of occurrence and the value of the project component exposed, but also it should consider the ability of the project planners to cope with such unwanted losses, or be able to adjust plans that would minimize the impact of risk on projected outcomes. Risk assessment aims to present the most reliable estimation of probability of occurrence, π, and the value of components exposed to risk. At this stage, the key elements and interdependence of risk items can be identified. In the case of large dams, this approach to measuring risk does not adequately capture the exposure of dam projects to uncertainties, but it is an important step to identifying the sources of uncertainty, at the feasibility stage of planning.

Risk assessment is very important for providing a best estimates of cost and schedule of projects in making a mutually exclusive choice of investment under a least-cost framework. It helps in providing alternative measures of mitigation against adverse effects of an event, and also, the degree of risk analysis of a project can raise the confidence of stakeholders in the project objectives.

In general, the cost estimate of a large infrastructure project according to the World Bank appraisal methods is defined with an aggregation of 3 main components - a base cost engineering estimates, the physical contingencies based on perceived level of risk, and then a component for price escalation. The provisions for price escalation is required to cover for changes in general price level and market exchange rate. A schematic representation of the appraisal cost estimates for a typical infrastructure project can then be described as follows:

$$Project\ cost = base\ cost + physical\ contingency + price\ contingency$$

For dam projects, project design is unique for each site and most times very complex. It also takes a long period of time to plan and implement. Because of the geological difficulties peculiar to this type of investments, the length period for completing the civil structures often extends beyond their planned schedule and the sequence of events may deviate from original plans.

The definition of project cost in equation above implies that a single estimate is assumed and used for making investment decision. However, the equation fails to account for actions with varying outcomes. When investment officers make attempts to incorporate this factor into the project cost estimates, the uncertainty in base cost and contingency budget becomes unclear and then uncertainty is treated the same way risk is treated. In most cases, project risks are managed with contractual terms under a project financing arrangement or Public-Private-Partnership (PPP) framework. Combining risk and uncertainty using simulation models can help determine, with respect to an acceptable level of confidence, what amount of contingency budget would be required as uplift on a base cost estimate, in order to overcome bias in cost estimates used for making decision to build economic projects.

In chapter 5 of this dissertation, a detailed approach to treating uncertainty when estimating project cost is discussed.

2.2.2 Uncertainty

This is a new paradigm in project appraisal and decision making. It reflects the lack of knowledge about certain events over the future of a project. Risk and uncertainty are complementary terms. Over the years, the perception on how to treat ambiguity in project planning and procedures has been intensified across major discipline such as in finance, economics, engineering and even psychology. The global drive towards improving the reliability of cost estimates in cases of unknown events is now instituting a sub-field of investment risk analysis, focused on constructing uncertainty models as an extension to risk assessment modeling. Examples of techniques developed for containing uncertainties in planning are the fuzzy logic modeling, Boolean algorithms – a rule based modeling of uncertainty, Bayesian simulation, etc. These type of model are not so common in investment appraisal because they are quite complex to handle and usually requires special mathematical software packages to design. Statistical models, in the past few decades, are now becoming the most applied. With the models being able to extract the lacking information at feasibility phase from similar past experience, and integrating these information into the proposed action plan, this approach draws a more reliable estimate of probability of an even occurring and also accounts for the inter-dependence of variables in planning.

Though risk and uncertainty are complementary terms, they differ technically. Integrating uncertainty into risk assessment, as practiced in probabilistic CBA for large infrastructure project provides a broader perspective of risk and helps the planners to be aware of the effects of uncertain events on project objectives, and possibly prepare mitigation plans in advance. Besides, this approach to treating risk in its broader perspective is becoming a necessary tool for decision making in modern day power planning.

Construction of dams and similar tunneling projects presents unique physical challenges. There is lack of information about the geological terrain of the proposed project-site; sometimes, geological and hydrological information are not properly processed. In civil construction, the site terrain contains a number of uncertain features like soil and rock materials. After taking some soil sample from the project-site for laboratory examination, the features of the soil material are disturbed and the conditions of the soil used in the lab examination may have changed from what was actually collected from the project-site. This type of laboratory tests are quite costly. Besides, the outcome from such test can vary significantly in comparative analysis of site investigation by different experts. (*see* Oberguggenberger and Fellin 2005, for the geo-mechanics of soil properties). Hence, the project planner is faced with a trade-off between making decision with inadequate information, and incurring additional cost to acquire more information on geological uncertainties.

For this study, the term uncertainty is used interchangeably with risk; though they differ technically. While risk can be controlled, uncertainties are events that are not within the control of the project planners. In particular, these type of events cannot be predicted with certainty since information about the planned action is not available in advance. But to some degree, these kind of information can be modeled with probabilistic assumptions if the action being studied have historical sample of completed similar events.

In hydropower investments with reservoirs, important information on the hydrological features and geological data can be collected from data can be acquired from existing sources if available. Due to unavailability of such vital information, project planners often rely on expert judgment which could be very inaccurate. To acquire more of these information through an on-site investigation, additional investment is required, making the project cost escalate and perhaps not worthy an exercise.

2.3 Probabilistic Modeling of Risk/Uncertainty

Both risk and uncertainty possess a paradox. On the one hand, revealing more underlying risks during planning reduces the risk of the whole undertaking. This fact not only highlights the importance of timely information, but also stresses the need for a rigorous risk analysis, especially when a considerable investment is at stake. On the other hand, uncertainty—even if partly viewed as ignorance— can be cognitively studied and efficiently used to supplement understanding on the processes of concern. Furthermore, uncertainty may increase with knowledge.

Basically, risk in power investments is common with attributes like power pricing, generation cost, financing/liquidity risk, and the regulatory barriers that could change too often due to political instability. Uncertainty goes beyond these attributes and has more to do with events of nature and complexity of human behavior in decision process. The problem of forecast gets compounded with the asymmetry of information usually common between the project sponsors and financiers.

The outcome of decisions made under uncertainty follows three main dimensions:

i. There is a probability that the decision made under uncertainty will be regrettable

ii. There is a degree to which such decisions are regrettable

iii. Regrettable decisions come with a cost

Hence, forecast models designed for complex projects with uncertain events need to be based on some logic, robustness of historical analysis done for a large set of reference projects to show the likelihood that a decision made under uncertainty will be regrettable, and how the degree of exposure to regrets could impact on the economic justification for choosing the project among available investment options. The cost of regrettable decision is the actual cost of a decision less the cost of an investment option that would have been a better choice assuming that the value of outputs from the projects are not distorted.

The reliability of the probabilistic models used in treating uncertainties in pre-feasibility study is a factor of how large the sample is, how similar the completed projects in the past are with the present one proposed, and how far into the future are we to forecast uncertain variables. If there are no such information to show for past experience, or if there is no adequate information to get a probability function for the proposed action, then uncertainty can be modeled at bounded range of outcomes as depicted on Figure 3 below.

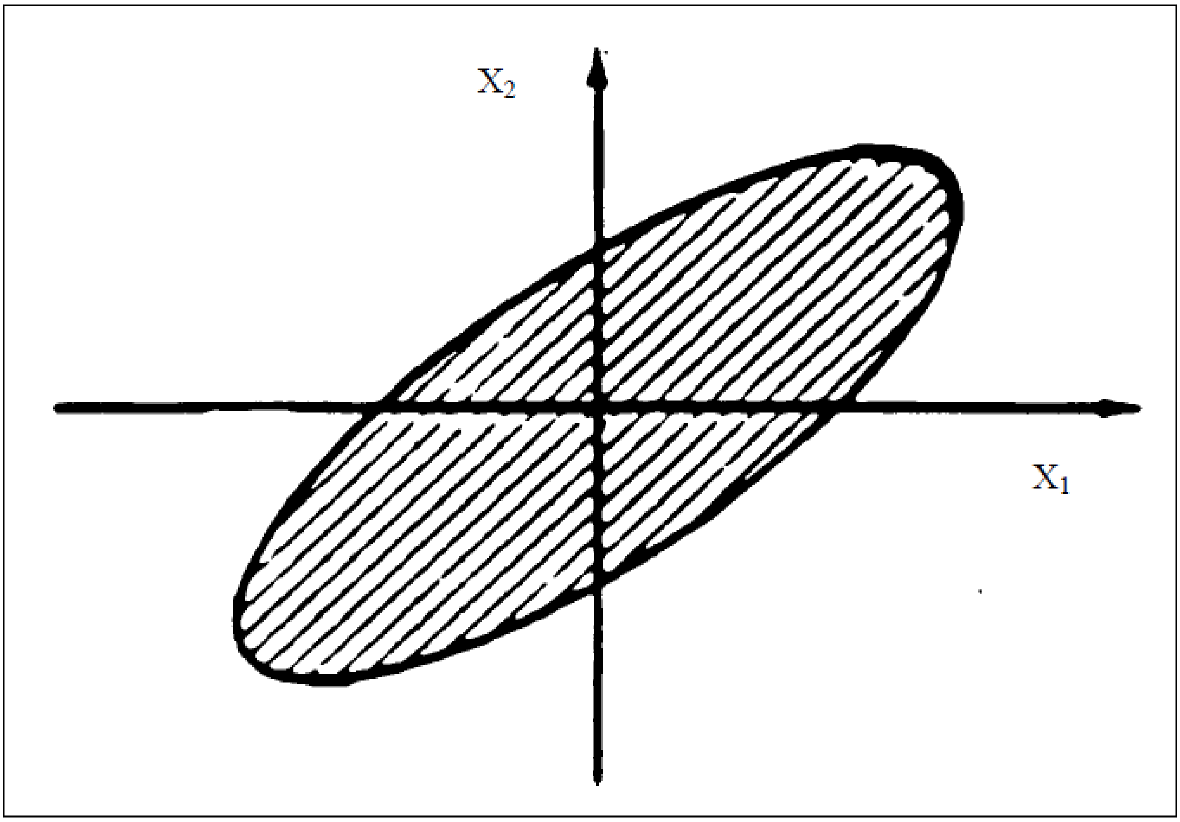

Figure 3. Graphical illustration of a bounded function for uncertainty
[Source: Dortolina et al. 2004]

This approach, however, is more exposed to forecast errors than the probabilistic modeling of uncertainty. Unfortunately, the bounded interval approach to assessing the impact of uncertainty on a project cost-effectiveness is the most common approach, where investment analyst sets limits for magnitude of uncertainties. The bounds may be closed within ‘pessimistic case’ and ‘optimistic case’, with the base case as the most likely outcome. Sometimes it is useful to use ellipsoidal bounds, as in Figure 3. This is a strong test for robustness but not for expected value (Dortolina, 2004).

The robustness of outcomes from historical distribution of uncertainty helps to describe the level of regrettable choice been made at the point of appraising the investment. If an event is certainly the best under a least-cost system, and also has no uncommon risk, then the level of regret from such a decision would be minimum. Hence, it will be well justified to go ahead and build the hydropower dam. This is illustrated in Figure 4 below.

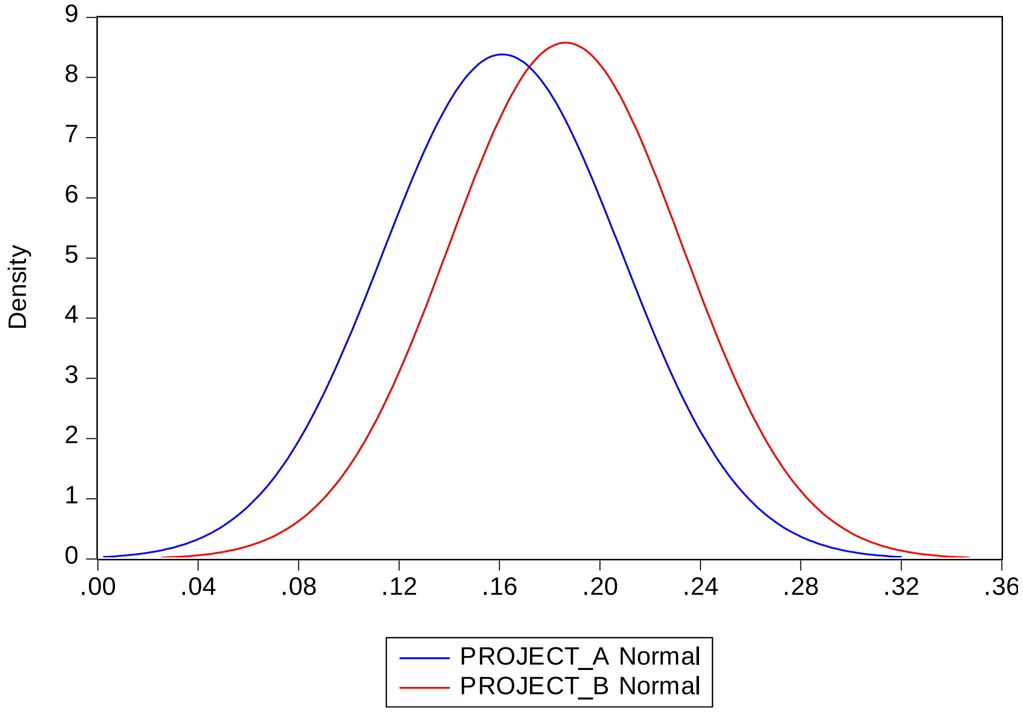

Figure 4. An illustration of minimum level of regrettable choice under a least-cost system

In the words of a Roman scholar, Pliny the Elder, “The only certainty is that nothing is certain.”

Figure 4 shows that both projects have similar probability distribution function - same level of variance – but Project B has higher expected value of outcome. Therefore, choosing project B is a rational decision. The problem arise when making a choice in a least-cost framework, where there is a trade-off between the expected outcomes of the projects identified and uncertain events that characterize the investment options based on past experience. For marginally economically justified investments, at appraisal phase, information about uncertain events are lacking and treated as best guesses. This could drag the outcomes significantly away from their expected values as depicted in Figure 5.

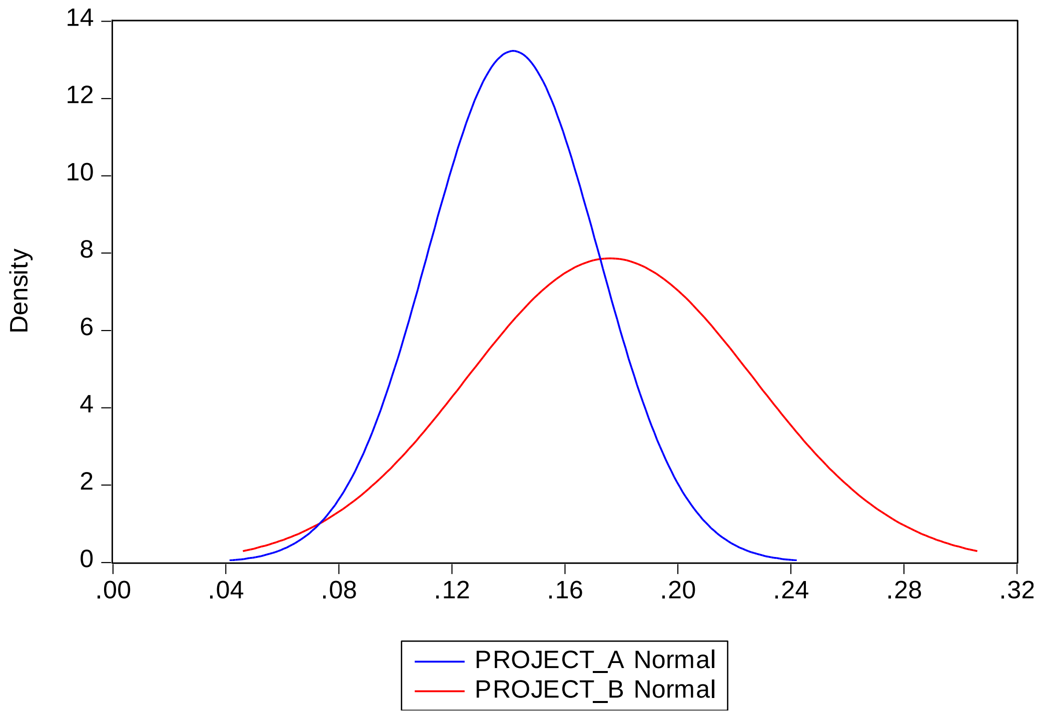

Figure 5. An illustration of high level of regrettable choice under a least-cost system

As shown in the Figure 5 above, the expected return on Project B is 18% with standard deviation of 0.05; while the Project A has an expected net return of 14% with standard deviation of 0.02. The returns from choice of Project B is more dispersed and uncertain when compared with those of Project A. However, decision to build Project B could amount to adverse selection and the cost of regrettable decision would be the difference in the value of forgone benefits from Project A, and the realized benefit from the implemented Project B, assuming Project B turns out to be a bad choice investment.

Zero degree of regrettable decision is very unlikely under the least-cost framework as that would require a probability distribution of possible outcomes where the minimum expected outcome of the advantaged project is greater than the maximum expected returns from the alternative investment option(s). Projects appraised in a least-cost system are often marginal projects.

The likelihood of a regrettable decision, and the degree of regret, may have little to do with the expectation or/and standard deviation of a particular event especially when the historical pattern of outcomes do not follow a normal distribution. Error in forecasts could rather be due to a combination of the various sets of project uncertainties confronting the decision makers at the time of project approval. These systematic type of errors have been described for infrastructure projects by Wachs (1989), Pickrell (1990), and Flyvbjerg et al. (2007) as strategic deception. Treatment of risk in project does not capture such errors.

2.4 Monte Carlo Risk Simulation

A modern method of probabilistic modeling for uncertainty is the Monte Carlo simulation (MC). MC technique belongs to a class of computational algorithms that assess the risk of a project by drawing an outcome from a series of repeated samples. It defines probabilistic assumptions for a set of risky input variables and make a probabilistic simulation of possible outcomes. This method is a surrogates for other attributes that are much more difficult to quantify. The probabilities applied in the MC, often are based on experts' best guess of future state of the world considered relevant to a planned action.

Whereas Monte Carlo risk simulation is an effective mechanism for dealing with complex and sizeable class of risk, it is restricted to the following:

i. The reliability of the probabilistic MC models depends, to a large extent, on how accurate are the sets of assumptions defined for the risk inputs. Decisions based on MC risk analysis can be prone to cognitive bias.

ii. It does not resolve the issue of uncertainty and flexibility in decision making framework as the defined assumption for the input parameters may change over time.

iii. It is not much an effective tool for contingency planning. No strategic rules on how the results of the distribution of expected project outcomes can be used to improve the accuracy of input parameters.

2.4.1 Flaw of averages

When constructing a table of parameters for appraising a project, input parameters are set, as in most cases, based on expected mean value of the individual parameter. This implies that the projected operations from the investment will yield an expected average outcome. In planning, the hypothesis of expected average as an indicator of project performance cannot be empirically supported. Savage (2000) posits that, plans that are based on such premises are usually flawed. The Jensen’s Inequality proposition also describe this condition mathematically as seen in equation below. The Jensen’s mathematical proposition follows that expected value of a particular function is not necessarily equal to a function of ‘expected values’.

$$E[f(x)] \neq f[E(x)]$$

The left hand-side of the equation denotes the expected value of a function; while the right hand-side is an expression for function of expected values.

Flaw of averages provides a strong ground for performing risk assessment to be able to ascertain the level of reliability of such indicators in making economic choices.

For technical parameters like inflation, exchange rate, wages, real price growth, etc., MC risk simulation can be used to bypass exposures that are due to "flaw of averages." It gives a distribution of outcomes that include the expected average and the tailed outcomes.

Later in chapter 5, this dissertation provides an advanced forecasting technique that does not only capture the technical errors in projections, but also accounts for cognitive bias in judgments about specific uncertain events – the so called "fallacies in planning" - following a Nobel prize winning innovation from Kahneman and Tversky study of decision making under uncertainty (see Kahneman and Tversky 1979, *The Prospect Theory*). The proposed model is developed within the context of common issues affecting the cost performance of hydropower dams.

2.5 Challenges in construction of hydropower dams

Dam is one of the major innovations of the 20th century. This very complex structures have been discovered to be a mechanism for controlling floods, providing potable water supply, supplying water for irrigation purposes, and for generating energy. Over the last century, hydro source of energy have contributed more than 30 percent of the total energy usage globally. Currently, hydropower dams generate about 20 percent of total electricity supply; about 90 percent of the power supplied by 18 countries across the globe, is generated from hydro source (Aylward et al. 2001).

After the World War I&II, the construction of large hydropower dams became synonymous with technological advancement, economic development, etc. Major dams got financing from international agencies like the World Bank/IFC, IADB,

ADB. Towards the end of that century, the actual impact of dams became a topic full surrounded with controversies. The financial, economics, and social impact, in addition to the environmental concerns of dam construction came under public scrutiny and financing institutions started prioritizing available remedial options to hydro dams because of the public criticism.

Stakeholders now express concerns about the environment damage and the economic hardship of the civil works on the upstream. While the proponents for more dams advocate the economic and social benefits, the opposing group dispute is against the adverse effects of cost overruns, schedule slippage, negative environmental externalities, and the displacement of the locals from the location of the dams.

To reduce the negative environmental impact of these super-structures, financing partners require that before any hydro dam facility would get approval for financing, a detailed Environmental and Socio-economic Impact Assessment (ESIA/EIA) and Environmental Mitigation Plan (EMP). The implied cost of the mitigation activities are to be incorporated into the investment budget of the dam. These costs are quite uncertain at the time of appraising the dam investment and often the cost of uncertain events are understated. Aylward et al. (2001) reports the performance of dams, showing that the majority of the hydropower projects implemented across the globe had incurred major financial losses due to the weak risk assessment and mitigation at the planning stage.

Typically, the financial misfortunes of such large infrastructure projects are due to sector-wide issues caused by poor projections, aggregation of risk, cognitive bias in decision making when faced with uncertainty, and generally poor management.

These issues are unavoidable sometimes and have no clear explanation because the designing of this class of projects are very complex and usually they require a lengthy period of planning (Awojobi and Jenkins, 2015).

A survey of related literatures show that the theme of many of the studies is on investigating the severity of mis-forecast and just a few like the study by Bacon et al. (1996), and Ansar et al. (2014) have tried diagnosing the origin of the problem. Three major factors critical to the feasibility analysis of a hydropower project are further discussed.

2.5.1 Technical feasibility

Large complex infrastructure investments require comprehensive design in order to guarantee that the proposed activities and investment are attainable within a specific technological framework. The design of a dam must cover all aspects of engineering processes and regulatory constraints, from the erection phase to operations, and decommissioning. Most of the difficulty of hydropower project occurs during the construction phase when the engineers are face with unexpectedly difficult geological terrain. Confronting these barrier often require multi-disciplinary expertise and scientific innovation.

2.5.1.1 Project-site geological features

To ensure that the physical risk imposed by the location of the dam is minimal, there is need to perform a thorough investigation of the topographic features of the site of a proposed dam and further review as much as available, all mapping information and inspections. The mapping information such as features of the river basin, seismicity, rock/soil type, water level of area, bedding of the site can be collected from local authority/ministry responsible for geography and culture. Where necessary, private investigation of the site may include a tachometric caption, aerial survey of the dam site. Information about the geological features are useful for evaluating the technical feasibility of the choice of site for the dam and it can also help identify missing information that may be necessary in preparation of the site for civil works.

2.5.1.2 Hydrological history

The hydrological features of the site basically provides information about water availability at the site for powering the plant at various seasons of the year. Hydrological feasibility of the site entails an assessment of the historical climate pattern of the region, the hydraulic height that describes water force to the turbines, river direction and origin, flood model, and reservoir/dam cascading on the up/downstream of the site the dam is proposed. The investigation of water availability at site of dam is to be based on a long period model of both river features and rainfall for sustainability of the streamflow to the power station. Since these kind of information are collected for forecasting the capacity of the dam, they are prone to uncertainties and so, the analysis usually will take a three-case scenarios; the base case, the best case, and the worst case scenarios for water availability.

In the case of cascading, it is necessary to examine how the proposed dam could be affected by dam(s) located on the upstream, and also, consider if the site of the dam is posing any threat to other dams that are located at the downstream. Understanding the cascading effect on hydrological features of the dam can provide suitable measures to mitigate against such effects.

2.5.2 Financial and economic feasibility

The financial viability of an investment is an indicator of profitability. It defines the limit of project returns to the extent that the benefits realizable throughout the life-cycle of the project are at least enough to cover for the construction and operation costs, maintenances, and repayment of debts and cost of debt. For an investment to be economically viable, the marginal benefits attributable to the investment, assumed as a stand-alone project, must exceed the total societal cost of the investment (Jenkins et al. 2013). In the case of mutually exclusive investment, an economically viable choice would be preconditioned on the fact that the choice of investment does not only guarantee a positive net benefits, but also, it is the least cost investment among available options. A reliable decision making framework needs to account for uncertainties and risk peculiar to each type of investment/technology.

There are various benchmarking techniques for evaluating the financial and economic feasibility of an infrastructure type project.

2.5.2.1 Net Present Value

This technique of evaluating projects is perhaps the best known criteria for making investment decisions. It measures the difference between the discounted total benefits and the discounted cost.

The NPV methods, sometimes referred to as the discounted cash flow (DCF) method, is computationally easy to practice and follows a general rule for determining the financial/economic viability of an investment. However, the simplicity of the method ignores vital information about the risk and uncertainty of an option by reducing the benchmark indicator to a single deterministic one. In other words, the NPV method fails to incorporate risk and uncertainty in assumptions about input parameters used in projecting the future cash flows.[1] Another difficulty

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[1] Using this technique for a comparative investment strategy should not be limited to purely technical structure or the monetary benefits of known capabilities, it is very necessary that we consider the social externalities and ambiguities such as human irrational behavior, environmental risks, etc.

of using this method is how to decide on what discount rate is appropriate for evaluating marginal investments such as power projects.[2] The discounting factor applied to NPV computation is a very critical factor for harmonizing the value of cash inflows and outflows which occur at different times, into a comparable base period. It also accounts for the time value of money used for intergenerational project (Howarth, 1998).

2.5.2.2 Internal Rate of Return

This technique for assessing the viability of a project is closely related to the NPV computation. The FIRR/EIRR as commonly used in investment appraisal is a rate of return that equates the discounted benefits from an investment option, to the discounted total cost of the project. The benchmarking rate, in this instance, is a weighted average cost of capital for financial analysis, and a prescribed social discount rate for economic analysis. The merit in this technique is that it permits the analyst to evaluate the viability of an investment with no constrain to choosing a particular discount rate for discounting the future cash flows.

Again, as similar to the NPV, this technique fails to adequately account for risk.

2.5.2.3 Life Cycle Costs

The life-cycle approach is commonly used for comparing investments with different cost structure spread over a defined lifetime. It incorporates all the relevant initial capital outlay required for constructing the facilities, the overall cost of operating the various comparable facilities and the salvage value or de-commissioning cost of a project within a system (Dursun and Alboyaci, 2010). Since the investment

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[2] Jenkins et al., 2013, provides detailed explanation on the NPV calculation and the merits of using this technique for making investment

outlay/construction period and operating life of the technologies varies, all the costs to be incurred throughout the life of each facility is summed up and discounted to a comparable base year for all the plants proposed for the utility. For instance the method of LCC can be very helpful in making a decision about whether to build a hydropower dam that would require substantial front-end capital investments and insignificant operating cost, or a thermal facility with relatively low front-end cost and high operation cost.

This technique is slightly different from the net present value technique. For example, assuming that the life-cycle of a typical hydroelectric facility is twice that of a thermal plant, then, there would be a trade-off such that the hydro facility may only become more attractive after a break-even point where, twice the cumulative life-cycle cost of a thermal plant is just equal to the total life-cycle cost of constructing the hydropower facility. The advantage of this method over the conventional NPV technique is that it considers the trade-offs that exist between alternative investments, throughout the life cycle of the projects; whereas the NPV analyses is focused on cash flows over a specific time period. An illustrative example: the project life of hydropower and thermal power generation technologies differs, hence it could takes a longer period of time to recover the huge capital cost for hydro project. Also, hydropower facilities usually do not have salvage value. In this instance, the NPV approach to evaluating the economic viability of an investment plan may not be fair to the hydropower if the time length of analysis is short framed.

2.5.2.4 CBA Methods with decision supporting tools

The traditional CBA methods of appraising electric power investments are based on deterministic outcomes and decisions made under this framework are static since it is practically impossible, or extremely expensive to reverse such process after the cycle of the project has been initiated. A major problem with the traditional methods of appraisal is that, when faced with uncertainties, metrics of uncertainties are usually averaged even though previous test have indicated the impacts of systematic bias and large variance in distribution of outcomes resulting from deviations in prior expectations about events and parameters used in designing the decision making framework.

There are many ways through which these unexpected variations in outcome of investments can be managed, including the real option analysis, engineering and procurement contracts, incentivized system that would encourage the sponsors/agents to reveal private information, and the reference class forecasting of cost and benefits to improve appraisal estimates for all power generating options available to the system/utility planner.

The real options is a tool for planning and managing risk similar to the options pricing methodology in finance theory. It measures the value at risk from the system dynamics and indicate what physical contingency planning would be required for a particular project that is characterized by uncertainties. It incorporates some form of flexibility into the decision making process of the system planners.

Another approach to evaluating the choice of investment is the contingent valuation methods which measures the integrability of the project into a community where the project is planned. The contingent valuation method can be a difficult exercise as it tries to gather information about people’s choice through their willingness to pay or accept the services to be provided from a proposed facility.

2.5.3 Ecological sustainability

Construction of large dams have major impact on the ecological features of an environment. Infrastructure projects inevitably disturb the flora and fauna of the nearby location and modify environmental aspects to some extent. Therefore, any relevant adverse environmental impact, resulting from the construction of dam, need to be studied and managed in advance. This requirement broadens the scope of the planned works, which can often exceed the technical ability of the project planner.

2.6 Conclusions

Despite the apparent reasons for carefully treating the issues of uncertainty and risk in energy investment planning, not much has been done to avert the implication of these unfavorable events, especially in the developing countries where the static CBA models still constitute the major benchmarking tool for making investment decisions under a least cost policy framework. The aim of the deterministic models centers on choosing the minimum cost techniques of expanding the utility system power output but all done under a basic assumption that events for all scenarios are equally predictable. The obvious-severity of uncertainty- is ignored. In most cases, the events/parameters associated with risk and uncertainty are simply subjected to a sensitivity analysis which often do not provide adequate indication of robustness for the financial and economic viability of a project under the least-cost power planning system.

While this dissertation is not aimed at changing the present approach of sensitivity analysis to investment appraisal, a more prescriptive approach is put forward as a remedy to the current practice where the fixed-margin of misforecast captured by the sensitivity and risk analysis at ex-ante, usually end up being much less than the actual error of misforecast at ex-post evaluation. These kind of shortcomings can deter the purpose of least-cost power scheme in utility policy where the ‘economical’ choice is not actually the least cost choice of meeting the system electricity demand if the events of uncertainty in cost forecasts had been adequately addressed at the point of decision making. The static CBA method applied to a least-cost power planning scheme fails to explicitly account for possible implications of investments decisions being sub-optimal in the instance of uncertainties. Though, the consequences of misforecast and unaccounted margin for errors in forecast parameters may not necessarily undermine the fundamental principles of a least cost long-term power expansion scheme, it often cast doubt over the reliability of the traditional CBA tool in decision making. As a result of the incidence of misforecast rampant in electricity investments, many advanced countries, including the USA, have stopped relying on the least-cost optimization models for utility power planning.

Chapter 3

ESTIMATING THE COST OF HYDROELECTRIC DAMS: A DIAGNOSTIC STUDY

3.1 Introduction

In this chapter, a comprehensive analysis of cost issues are made. Prior to our data analysis of the cost issues, a detailed literature survey is done to show the strength of the topic and importance of providing a diagnosis to the problem of cost overruns in the construction of hydropower dams. This chapter also provides a conceptual framework for understanding various cost concepts that are used for analysing the data collected for the dams. Further, it explains the methodological approach to diagnosing the pattern of errors in forecasting the cost and schedule of dam construction. Then, the results from data analysis are presented and findings from the sample of projects are examined. Policy implications of the findings from this study are considered thereafter.

Our analysis includes all the hydropower projects that were financed by the World Bank over the period 1976 – 2003, for which complete data are available. This comes to 58 projects that represents a total of 34,264 megawatts of installed capacity of hydroelectricity implemented across 32 countries.

3.1.1 Background

Uncertainty in the future price of petroleum products, and the growing concern about Green House Gas (GHG) emissions and its impact on climate change has seen a renewed interest of power utilities/system planners in the development of new hydroelectric dams. While dams have made possible large scale GHG reduction, the actual cost of building these dams have generated arguments among stakeholders within the industry as to whether these type of investments are worth undertaking.

There are diverging views on the role of dams in meeting the global energy demands and energy policy targets. Critics of investments in dams have argued that these type of projects are just too costly to the society. A major part of the growing concern is the past experience of poor cost projections for dam projects, the environmental damages and the social costs of resettlement incurred by the societies affected by these superstructures. Because these investments are challenging to plan and implement, and require substantial periods of time to build, they are particularly susceptible to cost and time overruns. Furthermore, for efficient expansion of an electricity system, planners must make projections of the cost of the design and construction of these unique sites in order to compare these costs with those of an alternative configuration of thermal plants that would produce an equivalent amount and configuration of energy over time. The reliability of the cost projections for these large construction projects are critical for making the correct choices. The methods used to construct these projections should take into consideration the characteristics and sources of errors that have been epidemic to this task.

This study investigates the issues surrounding the formulation of cost projections for the construction of hydropower dams. These include errors in projecting input quantities for a chosen design, the cost of change orders arising from non-standard project design, the cost of construction time slippage and the opportunity cost of the energy lost due to time overruns. Furthermore, movements in the real exchange rate that occur between the time project is initiated and its completion may have a huge impact on the future cost of financing the project. Finally there are errors in the projection of the general rate of inflation in the project country. The cost-effectiveness of a power generation project with alternative technologies can only give a true economic justification for such developments if the costs can be reliably estimated and compared to those of the alternatives.

A number of authors have investigated the problems with implementing hydropower dams and identified that cost overruns is a common problem of these projects. The reason for cost overruns is not just because of the difficulty in predicting random parameters like inflation, and exchange rate movements, etc.; Most of these studies have also attributed the failure of cost performance to strategic misrepresentation and delusion by sponsors (Flyvbjerg et al. 2002, 2009, Flyvbjerg 2007, Bacon et al. 1996, Sovacool and Bulan 2011; and Ansar et al. 2014). Cost overruns comes in two forms; the unreliable original estimates provided by sponsors, and the difficulty of managing unexpected events that come up after the decision has been made to build the dam. The incidence of unreliable estimates relates to strategic deception, on the other hand, the issue of managing contingencies is the main problem of hydropower projects where there are many uncertainties at the point in time when the project is initiated/appraised.

Common issues identified in the World Bank post evaluation reports points at environmental mitigation and changing resettlement plans, and labour disputes as major causes of cost and time overruns. For instance, in China, the Ertan hydropower project had budgeted USD 82m for resettlement plans, but by the time dam construction was completed, it had incurred a total cost of USD 228m on resettlements of the locals from project site (Ertan I&II, ICR). Furthermore, it is very common that at the announcement of dam construction, people from outside the project site migrate to the construction site of the dam in order to be in a position to claim resettlement benefits.

Other proximate issues affecting cost performance of dam projects include weak project planning and supervision, organizational and political pressure for approval of project financiers. Project sponsors are most optimistic about the success of the project, and in some cases, investment choice can be influenced when a political interest is involved. The promoters in trying to reduce pre-construction cost, to attract financing, end up avoiding key pre-appraisal preparations necessary to avoid major physical and geological disturbances during construction of the dam.

3.2 Methods

3.2.1 Literature survey on cost overruns in infrastructure projects

World Bank studies have revealed the severity and chronology of cost overrun problems for hydropower dams, which seems to have not improved even with the technological sophistication in the industry (Merrow and Shangraw 1990; Bacon et al. 1996; and Head, 2000). There are a number of studies by Bent Flyvberg that has helped produce some facts with figures to the controversies over the historical pattern of cost escalation of large construction projects (Flyvberg et al., 2002, 2009, 2012; and Flyvbjerg 2007). A recent study by Ansar and colleagues at Oxford has further popularized the debate on whether new dams should come on board given the historical evidence of cost overruns (Ansar, et al., 2014).

A commonality among these studies that have analysed the cost performance of dams is the findings that there is substantial bias in cost estimates of hydropower projects at the planning stage as compared with their actual costs upon completion. Construction delay is also identified as a major common problem among these class of projects (see Flyvberg et al. 2005, Flyvbjerg 2007, Wachs 1989, Merrow and Shangraw 1990; Bacon et al., 1996; McMillan, 1992, Ansar, et al., 2014; and Sovacool, et al., 2014; Sambasivan and Soon, 2011).

Following is a review of some of the relevant previous studies. Merrow and Shangraw (1990) in a path-breaking study addressed the ex-ante issues associated with cost and schedule projections. It identifies the unreliable predictions in World Bank financed hydroelectric projects as a major cause of overruns. He also attempted to develop quantitative models for predicting the cost of constructing hydro power schemes using a regression analysis.

Bacon et al. (1996), also using data from World Bank financed electricity projects completed between 1965 and 1986, employed a more detailed regression approach to show that cost overruns are a common experience in the power sector. A comparative study of cost and schedule projections across hydroelectric projects and thermal alternatives was evaluated for the World Bank financed projects. The results supported the hypothesis that project planning is the major cause of cost overruns. The incidence of underestimation of project cost, however, was more serious for hydroelectric projects than for the thermal systems, with the estimated average cost overrun in hydro projects triple that of thermal power projects.

In a study published in the Journal of the American Planning Association (2002), Flyvbjerg validated previous claims by Wachs (1989) and Pickrell (1990) regarding the causes of underestimation using a large sample of infrastructure projects. The outcome of the study supported the argument that cost underestimation is not totally explained by random errors but rather caused by intentional deception; this he termed “lies”. The study further traced the source of deception to project promoters. The validity of these findings, however, are limited to a degree by the sample pattern that concentrated on the US and other developed countries’ experience.

In what perhaps can be regarded as the most commendable effort in investigating the problems of building dams, Ansar, et al. (2014) using a reference class of projects for analyzing the performance of large dams, found that 9 out of 10 dams constructed had cost overruns. Their study shows that an average dam project had an actual cost that double their initial cost estimates. This raises questions about the worthiness of constructing new large dams. To make a rational decision about building any dam, they suggest an upward adjustment of the initial cost estimates by about the same margin.

Just after the Ansar study had started generating much comments among stakeholders in the industry and CBA professionals, Sovacool, et al. (2014) published another report on the construction nightmares of the power industry. The Sovacool study so far represents the largest dataset on power project evaluations of all types, with 66 hydropower dams covered. Sovacool, et al. (2014) provides a comprehensive study that describes the frequency and magnitude of construction cost overruns in electricity sector, taking an outside look at the unique sets of construction risk for various power technologies that involve large scale energy investment including Nuclear power, Solar technology, Wind farms, and hydropower dams. The study identified significant variations in the frequency and severity of cost ad time overruns in terms of size, location, and generation technology. Using a large dataset of 401 power projects, Sovacool reveals that about 75 percent of electricity projects had cost overruns. Out of the total sample of projects examined, hydropower exhibits, on average, the highest magnitude of cost overruns which was estimated to be 70.6 percent of estimated/quoted construction cost after adjusting for exchange rate and inflation (Sovacool et al., 2014). Except for the nuclear power projects, hydropower dams had the most frequent incidence of cost overrun. Surprisingly, they found that there was no significant difference in the incidence of cost overrun for hydropower dams and thermal plant projects, though the magnitude of overruns differ significantly.

While Flyvberg et al. (2002), Ansar, et al. (2014) and Bacon et al. (1996) describe a positive connection between time overruns and cost overruns, Sovacool, et al. (2014) dataset of power projects show the contrary. The high estimates of cost overrun in the Ansar and Sovacool study can be attributed to similar source of data, which also include government financed projects. It is becoming a norm that government projects suffer serious from planning and implementation. Also, a very large number of the projects in both studies include hydropower dams which were built in already developed areas of the USA, which cannot be compared reasonably with those projects financed by the World Bank in remote areas of the developing countries where most of the projects were implemented.

Due to concerns about the environmental and socio-economic hardship caused by dam construction to the upstream inhabitants, the World Commission on Dams was set up to review the operations, development cause and effects of dams. The World Commission on Dams (2000) had found that on average, large dams have been at best only marginally economically viable with an average cost overrun on dam construction at about 56 percent. This could be attributed to poor project appraisal and project management or even “lies” as Flyvbjerg puts it. Flyvbjerg et al. (2005) found that 86 percent of public infrastructure projects exceeded their budget plans, with actual costs on average 28 percent more than estimated. Bacon et al (1996) also estimated average cost overruns for hydropower projects to be 27 percent with standard deviation of 38 percent. This reveals that the problem of cost overrun or underestimation is a universal menace that has persisted for a long time and needs the attention of professionals in the field of investment appraisal and construction management.

In building a dam, Aylward (2001) roughly estimated preliminary and civil works to take about 60% of total capital expenditure, 35% for equipment and 5% for engineering. The huge share of cost to civil work makes prediction even more challenging. This, perhaps, is one of the reason why most hydropower dams suffer this menace. In developing countries, construction cost may be lower because of the availability of inexpensive labor, but there are greater risks associated with many other costs and institutional constraints on a timely completion of such projects.

Cost overruns are the consequences of the unreliable original cost estimates and difficulty in managing the uncertainties that spring up after decision to build the dams have been made. Aylward (2001) explains these problems as largely caused by non-standard construction design, poor project management, weak financing plans, complex bureaucratic process causing delays and indecision, political influence, and poor communication between project owners and EPC contractors. In India, 186 out of 290 public projects have exceeded their budget by 50 percent mainly due to delays in construction, with 25 percent of projects having huge cost overruns of about 95 percent of their base capital cost (Morris, 1990). The cost of building dams and renewable energy projects, generally, are so large that if something go wrong after making decision to build the project, the effect on the economy can be very severe.

Despite the gratifying efforts at understanding the problem of cost overrun and the rationality behind building dams, no study to the best of our knowledge, has put effort to consider the benefits side of hydropower dams.

3.2.2 Conceptual framework for studying cost and schedule performance of hydropower dams

For the analysis of cost overruns, basically, four cost concepts are used - estimated nominal cost, estimated real cost (base year price), actual nominal cost, and actual real cost. The estimated nominal cost as used in this study is the sum of base cost (using constant prices), plus an amount to reflect the provisions for physical contingency and an amount to cover price contingency. According to the World Bank methodology introduced since 1976, cost estimates at appraisal of projects should include a price contingency to account for expected changes in the price level of both imported and locally purchased inputs. Therefore, the estimates of real cost at appraisal is simply derived by deducting the price contingency from the estimated nominal project cost, but including physical contingencies. Projects appraised before 1976 are excluded from this analysis to maintain a consistent methodology for evaluating the cost performance of the selected projects for this study.

The change in the real cost schedule of a large project can be as a consequence of two factors. First, real cost changes can come about due to changes in input quantities and real price adjustment; second, change orders will alter the real cost as a project is redesigned. The change in real cost reported here is the difference in cost between the real estimate of cost (which include physical contingencies) at the time of appraisal – point of decision making, and the actual real completion cost. Real cost overrun as measured in this study exclude cost changes due to change orders.

The actual nominal costs (in current prices) is the completion cost of the project as reported on the Implementation and Completion Reports (ICRs), while the actual real cost is the deflated values of the actual nominal costs. The impact of general inflation on the cost of a project will usually be transferred eventually to the consumers of the output of project through the adjustments of electricity tariffs to reflect the movements in the general level of prices. Hence, a budget overrun caused by general inflation should not be counted as a real cost overrun.

Differential inflation rates, however, between the country where the dam is being built and the USA leads to movements in the nominal US dollar exchange rate. Such movements tend to be periodic rather than adjusting smoothly. The repayment of principal and interest on the debt financing of the project should usually be made in units of foreign exchange (commonly in USD) whereas income from electricity sales is in local currency. This means that the project will need to buy foreign exchange at the prevailing market price to service its debt. Overtime the real exchange rate may fluctuate, adding to the risk of the project. In terms of the exchange rate disturbances, the cost of hydro power projects are analysed using both the actual market exchange rate at the time of completion and the nominal exchange rate that reflects the purchasing power parity exchange rate that would exist if the market exchange rate were to adjust smoothly for the changes in the ratio of price indexes for the domestic and foreign countries.

3.2.3 Data and methodological approach

The data employed by this study are sourced from project reports on 58 World Bank-financed hydropower projects in developing countries, completed between 1976 and 2003. Information was collected from the World Bank's Implementation and Completion Reports (ICRs), and the Staff Appraisal Reports (SARs).

The table below shows a composition of the data used for this study. The cost per MW of an installed power station is also presented in 2010 constant USD prices. From the Table 1, the distribution of the 58 hydroelectric projects is concentrated in Africa (13), Latin America (15), and Asia (22). Of the remaining, 5 are in Europe and 3 in Oceania. The average size of the projects (in MWs) is much smaller in Africa and Oceania, than in Latin America and Asia. The average cost per MW of installed capacity of the project when fully implemented was significantly lower in Asia at US$ 1.39 million/MW as compared to US$ 2.38 million/MW in Africa, US$ 2.05 million/MW in Latin America, US$ 2.02 million/MW in Europe, and US$ 4.35 million/MW in Oceania (Table 1, col 6).

Table 1. Summary of data across regions and average real cost per MW (2010 USD 'Million)

Geographical Location	**Number of Projects [col 1]**	**Capacity (MWe) [col 2]**	**Real Capital Cost Estimated [col 3]**	**Real Capital Cost Actual [col 4]**	**Estimated Cost/MW [col 5]**	**Actual Cost/MW [col 6]**
Africa	13	1,388	2,698.6	3,307.9	1.945	2.384
Latin America	15	13,172	17,742.7	27,046.7	1.347	2.053
Asia	22	16,500	21,167.1	23,037.3	1.283	1.396
Europe	5	3,088	5,117.9	6,223.3	1.657	2.015
Oceania	3	116	389.3	506.1	3.348	4.352
Aggregate	**58**	**34,264**	**47,115.6**	**60,121.4**	**1.916**	**2.440**

Note: [col 4] is the undiscounted, but deflated sum of the annual costs incurred for all projects within each regional category.

Figure 6 below presents a graphical view of the deviation of actual cost of the hydro dams from their appraisal estimates. Evidently, this is a common problem for all the regions studied.

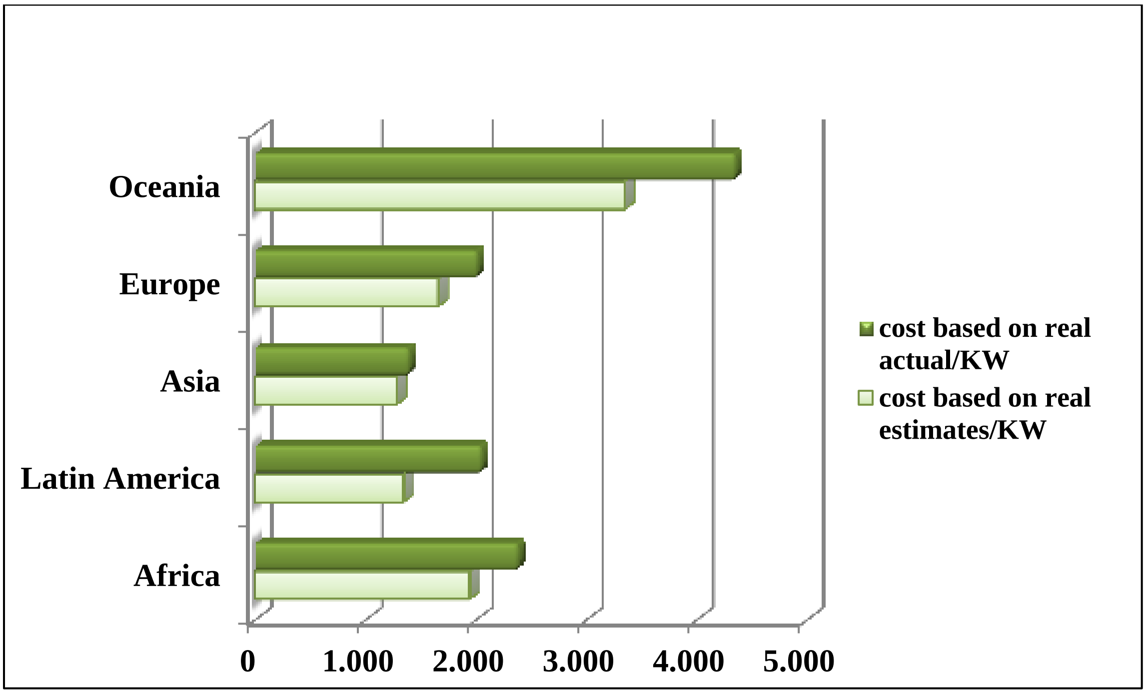

Figure 6. Evidence of cost escalation in hydropower projects by geographical regions [Source: Based on author's computation]

3.3 Measuring the Impacts of Cost and Time Overrun

3.3.1 Cost overrun computation

From the World Bank project implementation and completion reports, the cost of a project is given along with the percentages of the total that is foreign and local cost. The actual project cost, however, is expressed in nominal dollar terms. To compute the actual real cost ($C^{r\$}$), it is mandatory that actual nominal cost ($C^{n\$}$) be spread over the entire construction period. The approach used for the distribution of capital

Equation (2)

expenditure over the construction period of the projects in our sample is similar to that used by Bacon et al. (1996). This is expressed below by equation (2)[3].

$$Y_i = \frac{1}{2+p}\left[(s+1)\left(\frac{i}{I}\right)^s\left(p + \pi sin\left(\pi\left(\frac{i}{I}\right)^{s+1}\right)\right)\right]$$

Where Y_i is the share of total capital expenditures allocated to period *i* of the entire construction span that is *I years. S* represents the skewness of the cost lay-out curve assumed to be 0.2 for a positively skewed curve over the construction cycle; *p* is the flatness of the curve, and it varies according to the length of construction cycle.

Using our defined expenditure proportions Y_i for each construction year, the proportions Y_i are multiplied by the total project costs to get the nominal costs per period ($C_i^{n\$}$). These annual nominal costs are split into foreign and local components, and then deflated to the prices of the starting year. The domestic costs are first converted from nominal US \$ to nominal domestic currency units using the market exchange rate of each period. These nominal amounts of domestic costs are deflated with the domestic price index, and then converted back into US \$ of the starting year of project using the market exchange rate of that year.

The foreign costs are deflated with the manufacturing price index for the USA as shown by equation (4).

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[3] This equation is derived from the ‘S-curve’ mathematical formulation by John Drummond. Note was retrieved online [11/11/2013] http://www.businessfunctions.com/articles/The%20Origins%20of%20the%20S%20Curve%20in%20Business%20Functions.pdf

Equation (3)

Local cost real, US$ =

$$\frac{1}{E_0^m}\sum_{i=0}^{T}\frac{C_i^{n\$} * (1-FCX) * E_i^m}{I_{0,i}^D}$$

Foreign cost real, US$ =

$$\sum_{i=0}^{T}\frac{C_i^{n\$} * FCX}{I_{0,i}^F}$$

Equation (4)

Adding up equations (3) and (4) gives the actual real cost of the project expressed in dollar terms. So, we have

Equation (5)

$$(C^{r\$}) = \sum_{i=0}^{T}\frac{C_i^{n\$} * FCX}{I_{o,i}^F} + \frac{1}{E_0^m}\sum_{i=0}^{T}\frac{C_i^{n\$} * (1-FCX) * E_i^m}{I_{0,i}^D}$$

Note

$C_i^{n\$}$ is used to denote actual nominal cost for period i

$C^{r\$}$ is to denote actual real cost

FCX[4] is the share of foreign cost component in total project cost

$I_{0,i}^F$ & $I_{0,i}^D$ are the period i price index for foreign and domestic price levels respectively. Costs are deflated to first year of construction

This procedure is used to estimate the actual real costs of constructing the dams as presented in Table 1, col 4. The real cost overrun is then computed as the deviation

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[4] The foreign cost is the direct cost of all imported items and services used for constructing dam. This is an important concept introduced in Bacon et al. (1996) to distinguish between foreign and domestic impact of inflation. In most of the projects for this study, the foreign cost components are financed by World Bank. It is also a very useful tool in our analysis for showing the burden of dollar loans when real exchange rates are used instead of purchasing power parity exchange rates.

of the actual real cost from the estimated real cost, taken as a percentage of the estimated real cost; while we estimate the nominal cost overrun as the percentage deviation of the actual completion cost, from the estimated real cost of constructing the hydropower dam. It includes both the changes resulting from price escalation and real cost growth in excess of physical contingencies set aside during appraisal.

3.3.2 Cost of time overrun

Often, during the implementation of a hydro dam project, delays occur that extends the period of construction beyond its original schedule. Evidence from our sample of projects shows that more than 75 percent of the projects experience time overrun of more than 10 percent of the initial time estimated for completion. In planning for power project investments with alternative forms of energy generation, it is important to consider the fact that there are both economic costs and benefits from delaying the construction of these projects. When there is time overrun, there are benefits - in present value terms, which accrue from cost savings on postponed real investments. The actual project cost will be subjected to a longer period of discounting. These benefits however, may not be significant enough to clear the cost of supplying power with an alternative thermal plant.[5]

The cost of power generation through the best available alternative can be looked at from the perspective of economic cost of delay in the construction of hydropower facility. This cost varies according to fluctuations in oil price and capital cost of the

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[5] If the energy demanded goes unsupplied, the actual cost to the economy may be higher than the hypothetical thermal supply cost that is used in the estimation of the cost of delays.

alternative power generation technology. For countries with low cost of generating hydro energy, such delay would be more costly because of the unfavorable cost of generating power from the alternative sources. The difference between the cost of alternative power generation and the cost savings on postponed real investment is the net social cost of delay.

Given the responsibility of the electric utility to supply power to its customers, it is important that when making provisions for construction delays, a marginal evaluation of social cost of timing should be done to measure the extent to which this delay in construction would be harmful to the overall cost projections of the utility given the responsibility of supplying power to its customers. If the cost of alternative power supply would be higher than the cost savings from postponing the investments in hydropower that result from delay, then the project implementer should be more cautious of events that could delay completion.

Assuming that the next best alternative energy can be generated from a hypothetical thermal plant, then for the period during which the hydropower plant is not operational, we value electricity supply at cost/KWh that covers both the cost of capital and depreciation of the plant, in addition to the marginal running cost of the thermal plant.

Although, cost overrun and time overrun are not completely separable concepts in project appraisal, the cost implication of the latter is best explained with marginal evaluation of societal resource flows which may be beneficial to the society at the end.

For the calculation of cost of delay, Overnight Capital Cost/KW (OCC) for alternative electricity supply is deflated to the end of scheduled year of completion (T). Then, the cost of generating electricity from alternative thermal plant is the capital cost and fuel for an open cycle gas turbine plant which is estimated by equation 6.

$$\text{Opportunity cost of supply} = \sum_{j=1}^{Z}\sum_{k=1}^{Z-T}\left\{\left[\mathrm{OCC}_{T+1}\frac{r(1+r)^{N}}{(1+r)^{N}-1}\mathrm{IC}\right]+[\mathrm{f}_{k} * \mathrm{p}_{k}] * \mathrm{GC}_{k}\right\}(1+r)^{-j}$$

Equation (6)

Where *N* is the useful life of the alternative plant. *IC* denotes installed capacity in MW, and *GC* for generating capacity in GWh; j is the construction year during actual completion period *Z*, while k is periods after scheduled completion (i.e. delay periods). *f* is for fuel requirement litres/KWh, and *p* for price of fuel. The quantity of electricity to be replaced due to the delay is obtained from the ICRs for each hydropower project.

The other aspect of the cost of time overrun computation covers the savings from postponed real investments and this has been calculated using equation 7;

$$\text{Cost savings on delayed investment} = \sum_{i=1}^{T}[C_{i}^{r\$} * (1+r)^{-i}] - \sum_{j=1}^{Z}[C_{j}^{r\$} * (1+r)^{-j}]$$

Equation (7)

Where, i is the construction year within the scheduled period *T*, and j is the construction year within the actual completion period *Z*. $C^{r\$}$ is the real capital expenditure on hydro project during construction years.

For most of the World Bank-financed electricity projects in energy deficient LDCs, the utility is faced with a situation where the given demand forecast and the capital cost of the alternative thermal plant - in addition to its running costs, justifies the cost of building a new hydropower facility.

Most of the literature on this topic has attributed time overrun as a major cause of cost overrun. In present value terms, this is not obvious because we might as well say that the cost overrun is the cause of time overrun. When there is an increase in the cost of project beyond what was planned for, and project runs out of funds to finance the increase, it is often a time consuming task to raise additional funds during the construction stage to complete the dam. Usually the project sponsors are required, based on financing covenants, to seek approvals from existing lenders before embarking on such activity. This process of financing the greater cost could take substantial amount of time out of the scheduled construction period.

3.3.3 Exchange rate adjustment

Exchange rate risk is a country's specific risk. Depending on the type of foreign exchange rate regime in the country were the project is being implemented, the process of adjustment in real exchange rate is important. Hydro power project usually have large proportion of tradable components. Changes in the real exchange rate of a country reflects changes in the prices of these tradable goods relative to the prices of non-tradable goods. For countries that operate a flexible exchange rate regime, this changes tend to happen naturally through adjustment in the relative price index for US and the domestic country. If a country has a fixed exchange rate regime, then prices of tradable goods will need to be adjusted in the domestic market, otherwise, the real exchange rate will be distorted and the market exchange rate will not be the same as the PPP exchange rate.

The movement of the real exchange rate during the time of construction of a hydroelectric dam and the repayment period of loan used to finance the project is a source of risk that can create additional costs for the project. When the costs of a project are being projected, it is often assumed that the real exchange rate would remain constant and the market exchange rate adjusts over time with the movement of the ratio of domestic price index to the index of the foreign exchange country. This is commonly referred to as the Purchasing Power Parity (PPP) exchange rate. There is strong evidence that over a 25 year period of time the nominal exchange rates for most countries adjust almost completely to reflect the cumulative impacts of inflation experienced by the domestic and foreign exchange countries (see figure 7 below; extracted from Irwin, 2007).

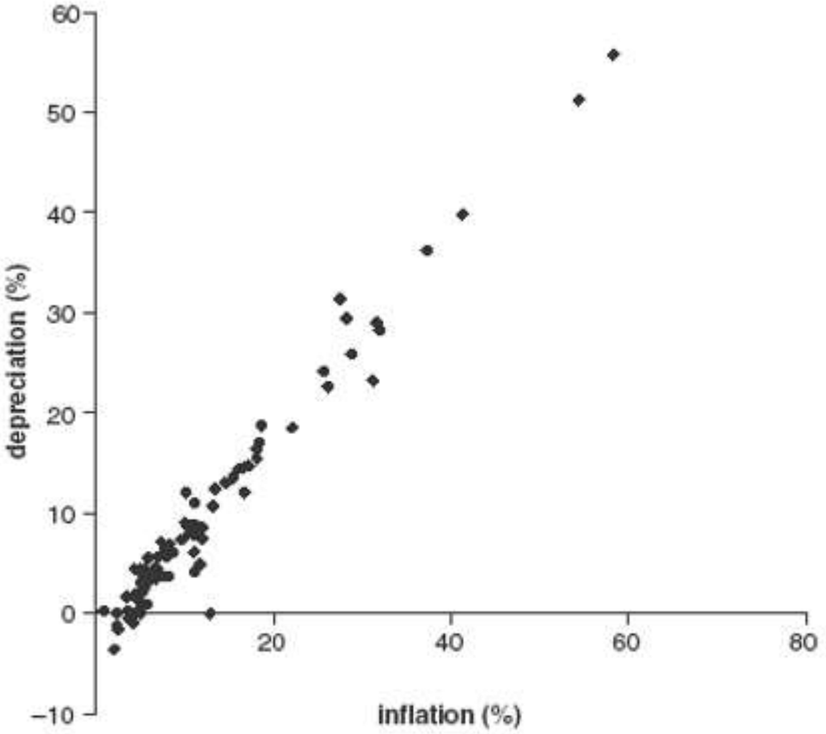

Figure 7. Annual average inflation and currency depreciation against the U.S. dollar in a sample of 89 countries, for 25yr period 1976-2001
[Source: Gray and Irwin, 2003]

In investment appraisal, a benchmarking assumption often made for exchange rate behavior is that, if averaged over the life of the project, purchasing power parity will hold between the amount of cumulated inflation (domestic and foreign) and the adjustment of nominal exchange rate. However, there will be major deviations from this in shorter time periods. Later in this chapter, we present empirical evidence to supports this notion.

A problem arises, however, when the nominal exchange rate moves significantly from the projected PPP exchange rate path; implying an increase or decrease in the real exchange rate, and hence a change in the real costs of the project.

Electricity sales are denominated in domestic currency while the loans that finance such investments are usually in foreign currency. Hence, a severe devaluation of the domestic currency is a fundamental adjustment towards a new equilibrium rate that will increase the real cost of the project. Conversely, an appreciation of the domestic currency will reduce the financial burden on electricity consumers who are ultimately the ones who will bear the burden of paying back the financing raised for the project. At the very least, the variability of the real exchange rate is a risk variable for large projects.

In this section, we investigate if there is any systematic bias in the adjustment of the market exchange rate during the period of construction. For example, currencies tend to become overvalued when foreign exchange is readily available. If this is only a short term phenomena, then the current availability of funds, combined with an appreciated currency, will make import intensive capital projects appear attractive to decision makers. In the longer term the market exchange rate move to what might be considered a long term equilibrium real exchange rate for the country, then the real cost of the project in local currency will increase because the foreign currency denominated loans will need to be repaid through revenues from electricity sales received in the relatively depreciated local currency. In this study we will evaluate the existence and size of such “real” exchange rate losses.

To measure the costs or benefits of the movement of the real exchange rate over a long construction period of the hydropower dams, we compound forward all the dollar denominated values of expenditures to the end period T using a real rate of discount. This gives us the total cost of financing including the amount of principal that would need to be paid back in units of foreign currency. We assume that loans are disbursed as the dam is being built and interest during construction will accumulate from the beginning year of construction till period project starts to generate financial cash flows and pay back the loans. Thereafter, the total cost of repayment is converted to local currency using the current exchange rate, and we compare that amount to the PPP exchange rate amount that would have been required assuming that the year 0 real exchange rate was an equilibrium exchange rate. The difference between these two values is the amount of the ultimate cost of the project borne by consumers which is changed due to the realignment of the exchange rate over the period of construction.

Equation (8)

$$\text{Cost of foreign component in domestic currency} = \left[\mathrm{E}_T^{\mathrm{M}} - \mathrm{E}_0^{\mathrm{M}} \frac{I_{0,T}^D}{I_{0,T}^F} \right] \sum_{i=1}^{T} C_i^{p\$} * FCX * (1+r)^{T-i}$$

Where $C^{p\$}$ is the projected cost; r is the real interest rate on loans, and since interest accumulates on principal and unpaid interest expense during construction, $(1+r)^{T-i}$ is used for cumulative interest expense till end period of construction.

3.4 Findings

The objective of this analysis is to determine the nature of the divergences between the actual completed cost of these projects and their planned costs at the point of appraisal. We wish to discover which aspects of these discrepancies follow a systematic pattern and what aspects are due to randomness. There is little doubt that the World Bank financed hydroelectric dams have undergone a more thorough process of project preparation, appraisals and an overall due diligence process than ones that are purely government financed. Furthermore, the methodology used by the

World Bank for the appraisal of hydroelectric power investments has been largely stable over the period of time under this study.

3.4.1 Findings on cost overruns

In Table 2, both the impacts of inflation as well as real cost overruns are reported. In column 2, one finds that the costs of these impacts have on average increased the nominal cost of these projects by 58.7 percent of the estimated real base cost. The estimated real base costs includes the non-price contingencies which are usually included at the time of appraisal. The range of total nominal escalation of costs ranges from 106.8% of base estimated costs in the Latin America, to 26.4% for Asia. In Africa, Europe and Oceania, the rates of cost escalation were 50.6, 30.6, and 44.9 percent, respectively.

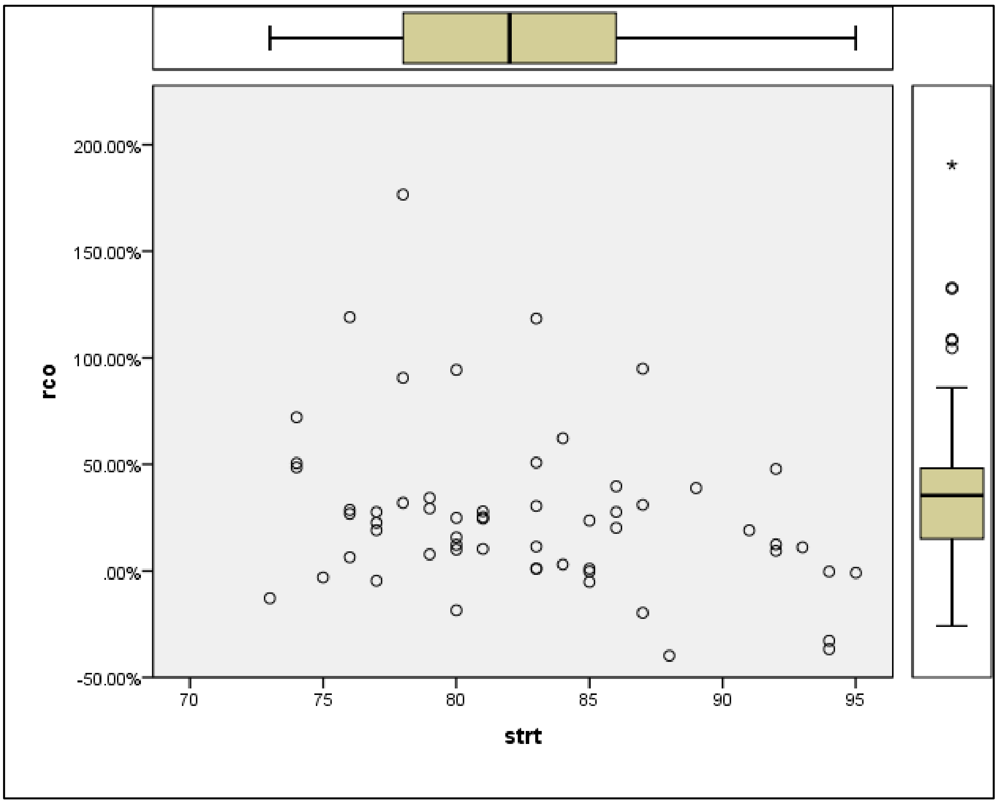

Figure 8. Cost overruns over the past three decades

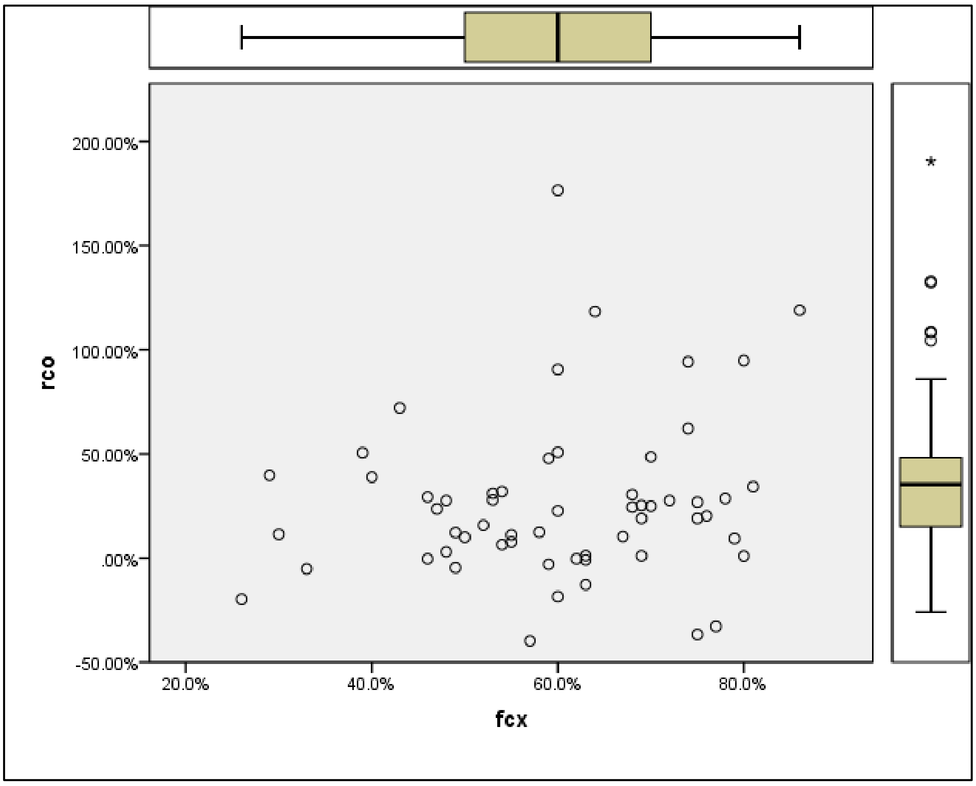

Figure 9. Relationship between cost overruns and share of foreign spending

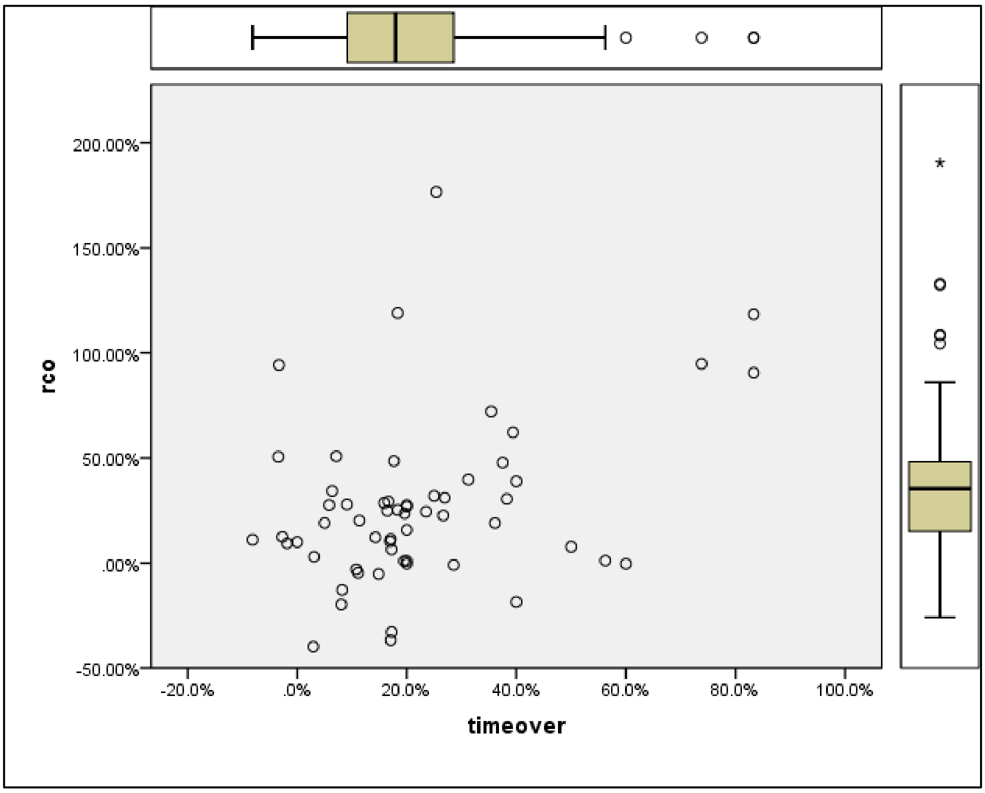

Figure 10. Relationship between cost overruns and time overruns

The values of the real cost overrun are measure as the excess of the change in actual real costs over what has been estimated as non-price contingencies, expressed as a percentage of estimated real cost. The averages are weighted averages of the various projects where the weights are the proportion of MWe capacity represented by each project in the total sample.

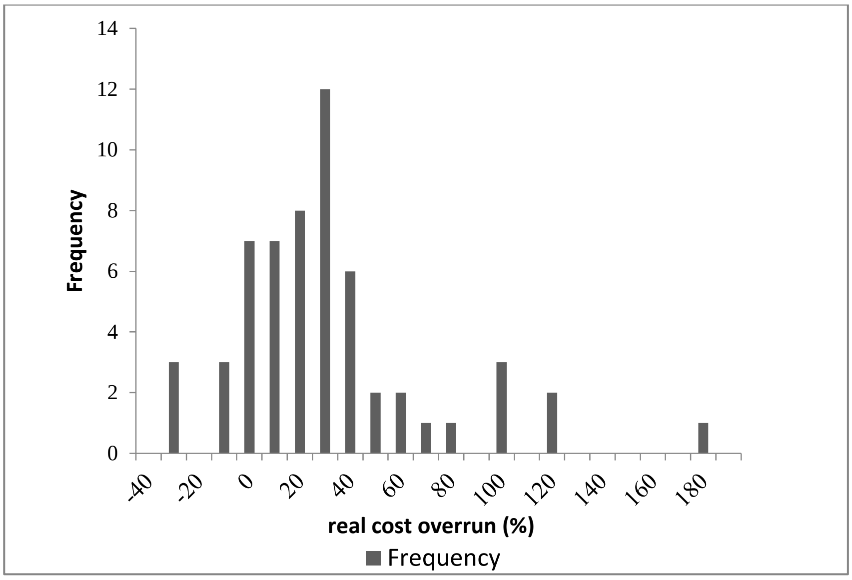

Figure 11. Cumulative distribution of real cost overruns

Based on our sample data and result presented in Figure 11, we observed that 78 percent of the projects incurred construction costs beyond what was planned for at appraisal stage. More than half of the projects had real cost overrun above 20 percent, with 20 percent of the projects having actual overruns above 50 percent of their estimated real cost. This implies that, even if sensitivity analysis had been performed at appraisal stage for a 20 percent increase in project cost - as commonly practiced, there would still have been substantial cost overruns for some of these projects. Overall, the average real cost overrun is 27 percent for the entire set of 58 projects (Table 2, col. 5), which is exactly the same average found by Bacon et al. (1996) for a much earlier study.

Table 2. Estimated average cost overruns across regions

	Number of Projects# [col 1]	**Nominal Cost Overrun as Percentage of Estimated Real Cost (%)** [col 2]	**Estimated Price Contingency as percentage of Estimated Real Cost (%)** [col 3]	**Actual Price Escalation as Percentage of Estimated Real Cost (%)** [col 4]	**Real Cost Overrun as Percentage of Estimated Real Cost (%)** [col 5]
Africa	13	50.6	21.7	25.5	25.1
Latin America	15	106.8	21.9	52.7	54.0
Asia	22	26.4	16.3	18.7	7.7
Europe	5	30.6	12.1	15.2	15.4
Oceania	3	44.9	18.9	18.6	26.2
Weighted mean	***58***	***58.7***	***17.3***	***31.7***	***27.0***

By region, the lowest of the real cost overruns are found for the 22 dams built in Asia, averaging only 7.7 percent over what was projected. The experience of Asia is to be contrasted with that of Latin America where the real cost were on average 54 percent greater than initial estimates, with a cost overrun which is 7 times that estimated for the Asian region. The average real cost overrun computed for the hydropower projects implemented in Africa was 25.1 percent of estimated cost, while for Oceania the error was 26.2 percent for a smaller sample of projects. For projects in Europe, the average error of real cost estimates was 15 percent.

In terms of the incidence of cost overrun, a somewhat similar pattern is observed across various regions as shown in Table 2. Except for Chile, every country in the Latin region witnessed very high real cost overruns.

In table 3 column (1) reports the weighted average physical contingencies made by the project planners at time of appraisal to be 9.8 percent of the estimated real cost as of that date. The minimum physical contingency made was 5.3 percent. The maximum was 18.6 percent with a standard deviation of 2.3 percent. The actual real cost growth (before deducting planned physical contingencies) is reported in column (2) and averages 36.8 percent. After deducting the amounts estimated for physical contingencies, the error in the estimate of cost overrun is the 27.0 percent real cost overrun as reported in Table 2 column (5). The range of outcomes spanned from an underrun of 39.8 percent, to a maximum cost overrun of 176.8 percent, with a standard deviation of 34.7 percent.

It is clear that the project managers and consultants associated with the planning of these projects have greatly underestimated over a period of 25 years both the average magnitude as well as the range of physical contingencies required by these dam projects. Clearly the uncertainty in the estimation of costs by engineers has led to a very significant downward bias in the estimated costs as compared to actual experience.

Table 3. Cost overrun

	Est. Physical Contingencies as Percentage of Estimated Real Cost (%) [col 1]	**Actual Real Cost Growth as Percentage of Estimated Real Cost (%) [col 2]**	**Estimated Price Contingency as percentage ot Estimated Real Cost (%) [col 3]**	**Actual Price Escalation as Percentage of Estimated Real Cost (%) [col 4]**	**Nominal Cost Overrun as Percentage of Estimated Real Cost (%) [col 5]**
Mean	9.8	36.8	17.3	31.7	58.7
Minimum	5.3	-39.8	3.4	-3.2	-35.8
Maximum	18.6	176.6	57.0	111.1	246.7
Std Dev.	2.3	34.7	11.3	33.4	56.2

In Table 3 column 3, at the appraisal stage, an average of 17.3 percent change in price level is projected for the 58 projects selected for this study. The actual result shows that there was a 31.7 percent change in nominal costs that is due to price escalation. Taking into account the error between the estimated price contingency and the actual price escalation - expressed as a percentage of estimated real cost, the cost overrun that is due to inflation is computed to have averaged 14.4 percent. This part of cost errors are taken as random errors since inflation is a random parameter. Table 2 shows that the projects implemented in the Latin America suffered more from inflation as compared to those of the other regions. When three extreme outliers[6] were excluded from the results, the average error due to inflation forecast was only 2 percent (with a standard deviation of 15.5 percent). This reveals that inflation forecast for cost projections in the World Bank projects have not in most cases being systematically biased. But errors in the forecast are a significant source of risk and the impact of inflation on project outcomes through exchange rate fluctuations cannot be ignored.

3.4.2 Findings on time overruns

In Africa, 9 out of the 13 projects implemented in the region had experienced significant time overrun. The average time overrun for this region is 16.4 percent of the estimated construction schedule at appraisal stage. Table 4, column 6 shows that the cost of time overrun to the society averaged 8.9 percent of the estimated real cost of project. This cost could have been avoided if there was no delay in construction. Latin America, projects had greater errors in time planning than any other region. Results for this region shows that there was time overruns in 11 projects out of the 15 projects covered by this analysis. The average estimate of scheduled construction of a dam in this region was 78 months, whereas, the average time slippage is estimated

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[6] All the outliers were identified for the Latin American region (Yacyreta Dam completed 1990 in Argentina, Paulo Afonso 1984 in Brazil, and La Fortuna HPP completed 1984 in Panama). Individually, these projects had nominal cost overrun above 120 percent and cumulative price escalation exceeding 70 percent of initial cost estimates.

to be 17 months - 23 percent of the estimated construction schedule. Cost of the time overruns considering all the projects for the region is estimated to be 7.4 percent of the estimated real cost of the projects.

Table 4. Incidence and cost of time overruns across various regions

Region	Number of Projects [1]	Number of Project with Time Overrun [2]	Average Capacity MW [3]	Scheduled Months [4]	Slippage Months [5]	Average Time Overrun [6]	Cost of Time Overrun [7]
Africa	13	9	113	62	10	16.4%	8.9%
Latin America	15	9	873	79	17	23.2%	7.4%
Asia	23	12	783	89	8	10.2%	4.1%
Europe	4	3	673	78	18	22.6%	13.0%
Oceania	3	1	39	57	7	14.4%	0.7%
Weighted mean	***58***	***34***	***610***	***83***	***12***	***16.3%***	***6.2%***

The cost of time overrun is measured for projects that had actual time of construction exceed their schedule by more than six months. Out of the total sample, 22 projects had no delay beyond six months, so we assumed that there is no cost of time overrun for this set of projects.

Table 4 shows that projects implemented in the Asia region had a better implementation performance as when compared to the other regions. The construction schedule estimates at appraisal were relatively more realistic. With an average construction schedule length of 89 months for hydropower projects in Asia, there is little bias with an average delay in completion of 8 months. Out of the 23 projects implemented in the Asia region, covered by this study, only 11 projects had significant time overruns. The overall cost of the time overruns for this region amounted to 4.1% of the estimated real cost of the projects.

For Europe, the analysis showed that the average time overrun is 20.5 percent of estimated construction time during planning, though for a small sample size of 4 projects. The net cost of not making electricity available to consumers according to project schedule (i.e. associated with the time overrun estimated above), is 13 percent of the estimated real cost. Out of the 3 projects constructed in the Oceania, only 1 had a substantial delay in construction time of 26.9 percent of time budgeted for its completion. When averaged for the region, time overrun was estimated to be 14.4 percent for the region and the associated cost to the society for this overrun is averaged 0.7 percent.

In addition to our findings on the severity of time overrun across regions, an investigation was made to determine if the bias in the estimated time for constructing these projects varies by sizes. Table 5 gives a summary of the variations between the scheduled length of construction and the actual completion period of projects, distributed according to size of the project.

Table 5. Distribution of the net social cost of time overrun by size

Size - Installed Capacity	**Number of Projects [1]**	**Scheduled Months [2]**	**Slippage Months [3]**	**Average Time Overrun [4]**	**Cost of Time Overrun [5]**
0 - 99	17	61	12	25.4%	1.0%
100 - 299	12	59	14	23.4%	7.6%
300 - 699	13	69	16	22.0%	5.0%
700 - 1499	8	84	19	25.3%	0.5%
1500 and above	8	92	8	8.7%	4.1%
Weighted average	***58***	***83***	***12***	***16.3%***	***3.5%***

Table 5, column 4 shows that there is high level of inaccuracies across various sizes of hydropower projects implemented. No particular pattern is identified in the distribution of time overrun by sizes, except that there is indication that the extremely large projects - on average, had relatively very little bias in their estimated construction schedule during appraisal when compared to their actual period of completion.

In terms of the net social cost of slippage for various sizes, results does not show a particular pattern that could relate the cost of time overrun to size. Results in column 5 shows, however, that the small size projects with installed capacity between 100 MW and 299 MW had an average of 13.8 percent of the estimated real cost of project as net social cost that is due to delayed completion. This cost comes about because they are relatively efficient sources of electricity generation, hence, the delays of these plants are costly relative to the other projects in the sample. Although, all the projects less than 1500 MW in capacity had about the same delay of between 22.0 and 25.4 percent of the time initially scheduled, the net loss is much greater for the projects between 100 and 299 MW. This can only arise because as a group they are lower cost sources of power than the average of the other plants in the other categories.

For the set of 58 projects analyzed, the results indicate that there is a substantial bias in the estimation of the time required to construct a majority of the hydropower projects. The average construction schedule for this sample is 83 months, whereas the average slippage from planned construction is estimated to be 16 percent of planned construction length.[7] If we take out the 8 extremely large projects that had very low time overrun but contributed large weights in our estimates of time overrun, the average time overrun for the remaining sample of 50 projects is 24 percent. A comparison of these findings to those of a much earlier study by Bacon (1998) which found the average slippage in the actual construction length of hydropower projects

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[7] This is weight-adjusted average of installed capacity for each project to the total installed capacity for all the projects in this sample.

to be 28 percent, there is evidence that time planning for construction of hydropower projects has improved significantly over the past two decades.

3.4.3 Findings on exchange rate disparity

The fluctuations in the exchange rate over time creates a disturbances to the cost performance of large projects. It is very unlikely that the projections of the nominal exchange rate that is made at the point of appraisal will match the actual market exchange rate by the end of construction period. The projected market exchange rate is usually projected on a purchasing power parity (PPP) basis that is constructed under the assumption that the nominal exchange rate, and hence the real exchange rate, are equilibrium exchange rates at the point of time of the appraisal.

This section presents the findings on the disparity of the PPP and market exchange rate for the project countries by the end of the period of construction for the set of projects covered in this study. Data used to analyze the exchange rate risk presented in this section are based on annual average market exchange rate, and wholesale price index of US and the respective currency country, as provided by the IFS.

For those countries whose currency is overvalued, at the time of project planning, relative to its longer term equilibrium exchange rate, it would make a project that is foreign exchange intensive look cheaper. After planning, if the real exchange rate adjusts (the domestic currency devalues) we would observe the market exchange rate will become greater than the PPP exchange rate by the end of construction. The implication is that the financial burden of the foreign cost component of the project in units of domestic currency would have increased by the end of construction over what was initially projected.

Table 6. Evidence of disparity[8] between the market exchange rate and the PPP exchange rate

Region	Mean Cost of Disparity (% of Real Cost) [1]	#Countries with Over-valued Currencies [2]	#Countries with Under-valued Currencies [3]	Minimum Cost of Disparity (% of Real Cost) [4]	Maximum Cost of Disparity (% of Real Cost) [5]
*Africa	0.7%	6	5	-23.0%	59.4%
Latin America	11.7%	4	11	-51.5%	67.6%
Asia	2.7%	8	15	-50.7%	41.2%
Europe	4.8%	3	1	-24.4%	9.9%
Oceania	-9.3%	2	1	-10.3%	5.1%
Weighted average	***6.3%***	***23***	***33***	***-51.5%***	***67.6%***

*The two projects constructed in Ghana between 1977 and 1982 are excluded from the estimation of exchange rate risk for regions. Both projects where developed solely to serve the purpose of VALCO (Volta Aluminum Company) and power sales were arranged in USD.

Table 6 summarizes the experience of exchange rate disparity across various regions and the cost of such disparity on the outcome of projects. The cost of disparity on this project depends on the proportion of the foreign cost components in the total. Out of the total sample of 58 projects, 2 projects are excluded. These 2 projects constructed in Ghana in 1977 were developed to largely supply an aluminum smelter. The sales of power to these companies was priced in terms of US$, hence, eliminating this exchange rate risk. In Africa, out of the 11 projects analyzed for the exchange rate risk, 6 projects experienced overvalued currency situation within the period the projects were constructed. The mean cost of disparity between the market exchange rate and the PPP exchange rate averaged 0.7 percent of the estimated real cost in this region. The cost of disparity on a project by project bases in exchange rate for the region ranged between -23 percent and 59.4 percent.

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[8] The exchange rate disparity is measured as the market currency rate less the PPP exchange rate, expressed as percentage of the PPP exchange rate. Negative indicator implies that the currency is over-valued and vice versa.

Out of the 23 projects in Asia where hydropower dams were constructed, 15 projects were affected by currency depreciation. The cost of disparity in exchange rate varied across projects in different countries between -50.7 percent and 41.2 percent. The average cost of disparity for this set of projects is estimated to be 2.7 percent.

A great majority of the countries in the Latin America experienced currency depreciation during the period of the 1970s and 1980s. Most of the hydropower projects constructed in this region happen to have taken place during this period. A total of 11 projects out of the 15 projects analysed in this study were affected by currency depreciation. The cost of disparity in exchange rate on the projects expressed as percentage of estimated real cost per project ranges between -51.5 percent and 67.6 percent. On an average, the projects in this region had actually experienced an additional cost of 12.1 percent which was as a result of the market exchange rate staying above the PPP exchange rate.

Table 6, column 2 and 3 shows that only 1 country each in Europe and Oceania had currency depreciation – Turkey during early 1980s and Western Samoa in the late 1980s. Projects in Europe had cost of disparity between -24.4 percent and 9.9 percent, while those in the Oceania had cost of disparity fall between -10.3 percent and 5.1 percent for the sets of projects in each category. On average, the disparity in exchange rate did not result in any additional cost to the project in Europe, whereas in Oceania, it turned out that the disparity had benefited projects with the actual cost of project getting cheaper by 9.3 percent. This does not mean that this project were free from the incidence of cost overrun. Rather, it reveals that the actual cost of the project would have been higher if the parity in exchange rate took place during the length of construction.

Table 7. Comparison of PPP exchange rate and market exchange rates for financing purpose

	Cost of Exchange Rate Disparity	**Number of Projects**
Projects that experienced market exchange rate falling below PPP exchange rate	-19.17%	25
Projects that experienced market exchange rate falling above PPP exchange rate	10.33%	33
Overall, mean cost of exchange rate disparity	3.07%	58
Std. Dev	26%	
Minimum	-53%	
Maximum	56%	

Percentage Change in Cost Due to Exchange Rate Adjustment is the amount of divergence between the PPP exchange rate and the market rate, measured over the PPP exchange rate and then multiplied by the proportion of foreign cost in total cost of project.

Following the result from the sample of projects used for analyzing the exchange rate risk in the construction of large projects that has substantial share as tradable goods, there is evidence that most countries actually experienced depreciation in real exchange rate.

3.5 Conclusions

When planning for electricity projects, power pricing are often based on the expectation about the generation cost of electricity among other factors. The analysis in this chapter have shown that the deviation of the expectations from realities are quite significant. The high level of uncertainty in the case of hydropower dams have great implication for consumers and producers of the power. Table 8 shows the overall impact of overruns from various sources, and aggregated for the portfolio of dams studied, on economic cost of the dam.

Table 8. Overall impact of forecast errors

Cost Escalation Averages	**Percentage of Estimated Real Cost**
Real Cost Overrun	27.01
Cost Overrun due to Exchange Rate Disparity	3.07
Cost Escalation Due to Time Overruns	6.20
Average Total Real Cost Escalation (economic point of view)	36.28
Error on Price Escalation	14.40
Average Forecast Errors of Estimated Cost (in percentage)	***50.68***

Given the outcome of analysis of the dam projects covered by this study, there is much evidence to show that, at appraisal, the construction cost and scheduling of dam projects are commonly estimated below their actual values. This is either due to strategic deception by the sponsors, or because of the inherent difficulty in predicting long term events with various components of uncertainties. We found that about 80 percent of the dams had incurred construction cost above their initial estimates. Averagely, we estimate the real cost overruns for this portfolio of dams to be 27 percent. In addition, the incidence of time overrun, on an average, had increased the real cost of the dam to the society by 6.2 percent of planned investment. The cost to the society, due to time overrun, was as high as 59 percent as in the case of the Kerala Hydro Scheme that was developed in India. While the contingent investments that results from these erroneous forecasts are often transferred to consumers of electricity output through electricity pricing, the implication of these overruns on the electric utility planning the system expansion can be more severe as regards the economic choice of investment for electricity which must be generated somehow. Biased projections severely affect the expected economic returns from a project.

While hydropower dams can generate substantial surplus for the society, the utility planners need to be aware of the pertinent risks/uncertainties involved in the construction of dams and provide contingency plans that follow a reference class of projects previously implemented. The hydropower dams appraised and financed by the World Bank in the China region performed well both in terms of cost projections and projected rate of returns, though not as much in the projection of time for construction. The delays in the completion of the dams in China were as a result of various environmental issues. For the set of dams constructed in the Latin American region, projection of cost and time were much deceptive at appraisal stage. There is need for more thorough investigation of cost projections and reliability of estimates provided by sponsors of projects at the appraisal phase. High priority should be given to dams that the ex-ante analysis indicates that they are very low cost or marginal benefits are very high.

Finally, in estimating the cost of hydropower constructions, a base-cost estimation should split the project to as many components as possible to assess the risk involved in each component. The weakness of commonly practiced estimation is the aggregation of risks when estimating a base-cost for power projects. Such practice prevents analyst from getting a clearer picture of bias in the project cost estimates.

Chapter 4

ESTIMATION OF THE VALUE OF RICARDIAN RENT FOR HYDROPOWER AND BENEFITS OF DAMS

4.1 Introduction

Hydropower is disadvantaged by the high capital upfront investment cost and uncertainties especially during the construction period, the geological information lacking at time of appraisal. During operation, it could also be plagued by hydrological factors. Nonetheless, hydropower is low cost operational system of generating electricity. Construction of dams minimizes the risk of hydrological uncertainty common with the run-of-the-river and also provides additional externalities such as supply of potable water, irrigation facility, flood control, etc. More important, hydropower is a clean source of energy and is widely seen as the least source of renewable energy. Furthermore, the IEA (2005) have stated that hydropower today is the main source of large scale electricity storage. Also the IEA (2012) states that dams are now safe. In this regards, it is a source of substantial economic returns in public investment.

While the controversies surrounding building dams remains, it is very important to measure the actual volume of benefit from hydropower dams. The addition of hydropower to the existing power system has been in most cases a source of economic surplus to the society where power is deficient or the current system is generating electricity through an alternative with a higher cost.

The construction of dams has made it possible for hydropower facilities to serve as baseload plant, replacing the fossil fuel plants in many countries, for this purpose. It provides reliable, flexible system of supplying electricity and can operate at a very high load factor. This has been the main technical obstacle associated with renewable energy systems such as solar and wind.

Besides, the IEA (2005) have acknowledged the fact that hydropower plants can supply both baseload and peak-load electricity demand since the water storage capability is an advantage of having dams. Also, Egre and Milewski (2002) focusing on the diversity of hydropower projects, argue that, depending on the plant design, dams allow technical flexibility by making it possible to supply electricity at all periods, and it is most efficient energy storage system.

4.1.1 Objective of this Chapter

The previous chapter has focused on the controversies surrounding hydropower dams. It discussed the framework for measuring cost overruns and schedule slippage in construction of dams. A novelty of the chapter is the methodology used in measuring the cost of time delay and the ability to measure the additional cost of dams that results for exchange rate short term disequilibrium, as a reflection of foreign currency financing of dams.

This chapter is focused on the benefit side of hydropower dams. While the common theme in literature as regards this aspect of energy investments has focused on cost issues, making dams look like anti-development instrument, here I aim to provide a balanced view on dams and their impact to the society where they are structured, and on a broader terms, the contribution to the global campaign against greenhouse gas emissions. The approach to this chapter is to estimate the economic surplus derived from the portfolio of dams collected for my study. The amount of cost-savings from hydropower dams is estimated, somewhat, a measure of the economic rent of hydropower generated from each dam site. A slight slip away of my study from the theoretical measurement of economic rent is that my analysis is focused on the supply angle of power generation and it is believe that if the hydro dam was not built, an alternative thermal system would have been built in these societies where the dams were constructed. Also, this study assumes that the choice for the hydropower facility is based on World Bank least-cost framework that sees hydro as the most economical choice of investment.

4.2 Methods

In this study, I describe the benefits of dams in terms of the Ricardian rent and economic surplus. The economic rent of a natural resource such as hydro is the surplus return over and above the value of factor inputs used in exploiting the resource (Rontham, 2002). Zuker and Jenkins (1984) measure the hydroelectric rents in Canada and they argue that hydro rents are site dependent and the ability of hydroelectric sites to generate economic rent is due and only possible if the hydroelectric facility can generate power at least cost when compared to the available alternative power generating technologies.

A common method of measuring hydro rent is by taking the difference between market price of electricity and the long run marginal cost of generating additional kWh unit of electricity from hydro source. This method is a bit cruel because the demand for electricity overtime fluctuates. As a result, the Ricardian economic rent for hydropower dams as measured to fulfill the purpose of this dissertation is by measuring and comparing the cost of hydropower generation with the cost of generating electricity through the thermal fossil fuel alternative. Implication of additional investment in transmission and distribution.

Since the data used for this research is focused on World Bank experience with hydropower dams, a mix of both the single cycle and combine cycle thermal plant would be appropriate for measuring the cost of producing an equivalent amount of electricity that the hydropower dam is designed to generate. It is worth noting that the economic surplus from hydro resource is unique for each dam site and power capacity size and load factor. While the per unit cost of capital savings on the alternative thermal plant can be same for all the projects in this sample of hydro dams, the marginal running cost-cost of fuel-varies by country through proximity to sea ports, ownership of fuel/gas resources, and trade barriers peculiar to each country.

4.2.1 Literature survey on estimation of hydro rent

This section is focused on three main approaches to measuring the economic rent of hydropower. The first approach is described in Zuker and Jenkins (1984); and applied to the power system in Canada; the secong approach is based on Banfi, et al. (2005) study on Swiss hydropower sector, and the third method is developed by Shresta and Abeygunawardana (2009).

The Zuker and Jenkins study argue that economic rent on a hydroelectricity only exist if the hydropower system of generating electricity is the least cost method of power generation. They apply an electricity expansion model to measure the value of hydro rent from four provinces in Canada-Ontario, Quebec, Manitoba and BC. Zuker and Jenkins (1984), in the estimation of the value of the power system without hydro. They assumed that the most efficient combination of alternative power generation technologies will be used in generating electricity to meet the observed load curve for the electricity system. As such, the hydropower is a comparable alternative to the “least-cost” combination of thermal power generation technology. In other words, the model for estimating hydro rent is based on optimal stacking for an observable annual duration load curve.

Hence, the economic rent from hydro can be measured by deducting the total economic cost of an existing system with the dam from the total cost of a system that replaces the hydro facility with an alternative low cost thermal facility. This method is similar to the approach used by Bernard et al. (1982), though with outcomes slightly different.

Banfi, et al. (2005) approach follows a pattern of market price of electricity to estimate the economic rent of hydropower for Switzerland. Their method of estimating economic rent for hydro computes the difference between the projected total revenue generated by the hydropower facilities, and the actual cost of generating and supplying the hydropower. The Banfi, et al. (2005) assumes that the market price of electricity are centrally determined based on the load period ad seasons, and the system capacity will be the same through their period of analysis. This type of assumption is unlikely and a change in demand and supply can significantly alter the expected price of electricity in a deregulated electricity market.

A mathematical expression for the model is given as follows:

$$rent = \sum p_t q_{tl} - c_t q_{tk} \qquad \text{Equation (9)}$$

Where,

q_{tl} = is the amount of electricity generated for meeting various periods of the load curve,

p_t = is the market price used for measuring the expected total revenue from power to generated through hydro sources

q_{tk} = is the production from each hydro site; and

c_t = is the cost of hydropower generation.

The results from Banfi et al. study for the Switzerland hydropower sector shows that hydro stations with storage and those with storage and pumped, generated on average, about twice as much rent when compared to the run-of-the-rivers station.

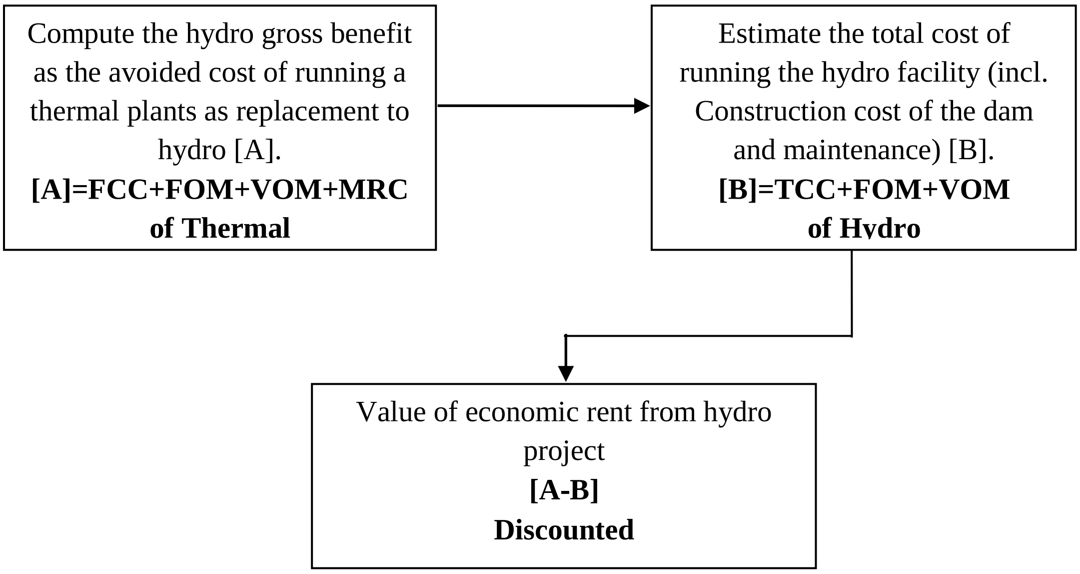
The third approach to measuring the economic rent of hydropower follows the discussion by Shrestha and Abeygunawardana (2009) for the water resource system in Nepal. They presented a “with” and “without” case scenario where the system could embark on power sales across border, to India electricity market. This approach simply measures the rent as the difference between the total cost of power generation in the system without hydro, and total cost of generation for a system with hydro. This is a very similar approach to the one developed in Zuker and Jenkins (1984). The Shrestha study assumes that without hydro, the system will have to rely more on coal and gas which seem to be the alternative least cost (next best) source of generating electricity in Nepal. The finding form their analysis using this method shows that the economic rent from trade (to India) hydropower generated in Nepal could increase by about 4 times the value if supplied to domestic electricity markets.

While the approach by Shrestha and Abeygunawardana (2009) is similar to Zuker and Jenkins (1984), the Banfi et al. (2005), good as it is, the Shrestha approach is less plausible considering the competitiveness of electricity markets in recent times. However, if the prices forecast by their model is accurate, the model captures the economic rent of hydropower better than the other models discussed above.

Following the Zuker and Jenkins model for estimating hydro rent, taking into perspective the hydro as an alternative to thermal in a least-cost power framework, there is a trade-off between capital cost and the marginal running cost of the two technologies. Whereas, the hydro requires a high capital investment, its running cost is very insignificant. This is the opposite for a low cost thermal system. Also, while the hydro carries huge uncertainty in construction cost because of the dam, thermal fossil fuel plant are susceptible to risk of fuel market price volatility.

Hence, in this study, we build our framework for measuring the economic rent of the World Bank financed hydro dams as the cost savings from implementing the dam projects, as against building an alternative thermal configuration. This is a better approach to hydro rent than using profit measures where the market price of hydro power supplied cannot be substantial guaranteed as the economic value of hydro.

In the next section, we present a conceptual framework for measuring the Ricardian rent on a portfolio of hydropower dams



FCC – Annual Fixed Capital Cost, estimated using the annuity formula in excel, “-PMT(*r*, 25y, *fv*)
FOM – Fixed Operating & Maintenance Cost, available in EIA (2013)
VOM – Variable Operating & Maintenance Cost, available in EIA (2013)
TCC – Total Capital Cost of Hydropower, taken from individual project completion reports.

Figure 12. Methodology for calculating hydro rent

4.2.2 Methodology for measuring the benefits of dams

The economic benefit of hydro dams is estimated by taking into consideration, what would have been a replacement for the current hydro project. The believe here is that the dams constructed for generating electric power are based on decisions that see hydro technology as an alternative to the expansion of the system by conventional thermal technologies. One way to measure the benefits of a hydropower dam is to find the value of the avoided generation cost of the fossil fuel powered plants that would be required to be built and operated to supply the same volume of electricity as would be supplied by the hydro dam (Zuker and Jenkins, 1984). In this case, we hold every other operation in the system, prior to building the hydro project, constant and the estimated generation cost which is now avoided from the alternative technology can be used as a measure of economic benefits of hydro dam.

Thus, the benefit of hydro dam, excluding the positive externalities, is measured in two parts: i) the cost savings on the fixed annual capital cost; and ii) the marginal running cost of the alternative plant. Fixed O and M is assumed similar for both the hydropower facility and the oil fired plant (EIA, 2013). Hence, we do not include Fixed O and M in the formula for estimating the hydro benefit. Equation 10 below shows a mathematical formulation used for estimating the hydro benefits;

$$Benefit\ of\ hydro\ dam = \sum_{t=0}^{T} \left\{ \left[K \frac{r(1+r)^N}{(1+r)^N - 1} IC \right] + \mathrm{VOM} + (f_t p_t) G_t \right\} (1+r)^{-t}$$

Equation (10)

Where K represents the capital cost and N is the economic life of the alternative plant. IC denotes the installed capacity in MW, and G for equivalent electricity output expected to be generated from hydropower facility in period t; f stands for fuel requirement litre/kWh, and p for price of fuel at period t.

4.2.3 Data on capital cost from World Bank and EIA

Data on the capital cost of single cycle and combined cycle of power generation plants are collected from World Bank database of implemented projects. The annuity formula is used to estimate the annual capital cost/KW which includes both depreciation and social opportunity cost of capital investment, where the economic life (N) of the alternative plant is assumed to be 25 years. The calculated annual capital cost/KW, is then multiplied by the installed capacity size of the hydro to get the total fixed annual capital cost.

High capacity factor would indicate that the hydro is planned to run as a baseload type plant and for plants that have big installed capacity of over 200MW, we assumed the Combined Cycle Thermal plant would have been the alternative replacement for the current hydro. For hydro projects with less than 0.50 capacity factor and capacity size below 200MW, it would indicate that the project is likely planned to be a peaking solution; hence, we use an Single Cycle conventional technology as a candidate for hydro replacement. The efficiency rate of these two proximate technologies vary and so, the fuel requirement for the two types of plant is defined accordingly. A 52 percent rating is used for a CC, while we use 33 percent for the OC. In general, there are no significant changes in fuel usage per unit of electricity (ltr/MWh) produced by the alternative thermal plant over time. Historical CapEx data is sourced for thermal plant projects financed by WB, through WB/IPP, at various periods.

In the context of this analysis, the MRC is taken as the value of fuel that would be necessary to operate the alternative plant if the hydro had not been implemented. This value of fuel is a function of fuel price9 (pt) and fuel requirement per unit of electricity generated (ft). The fuel price is adjusted upward by a markup of 20 percent when calculating the fuel cost for all the regions except for China where 10 percent margin is applied because of the relatively low cost of transaction. This margin/markup on price is to cover for handling fees, transportation cost, insurance, further refinering, and distribution cost (IEA, 2014: 19-20).

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[9] Fuel price is based on historical HFO spot price for years plants have operated up to this current period. For subsequent years for which data are yet unknown, we assumed a fixed real price (2014 HFO price) and integrated a sensitivity mechanism for possible volatile price after 2014 period. The spot price of HFO is the world price which is exclusive of taxes. HFO spot price, end user price (electricity), and price markups, data were sourced from various volumes of IEA, energy prices and taxes yearbook.

Fuel requirement per kWh varies across the projects, depending on the capacity factor and net capacity size of the hydro power generating system. For projects with capacity size > 200MW and projected load factor > 50 percent, we suppose the alternative choice would have been a combined cycle configuration, otherwise, a single cycle plant would have been a more likely economical choice.[10] This assumption is plausible in the context of this study. Assuming a 33 percent efficiency rating for the single cycle plant and 52 percent for the combined cycle, the fuel requirement is calculated to be 0.240 liter/KWh and 0.152 liter/KWh for the single and combined cycle respectively. Data for net electricity generation is available from the World Bank post evaluation reports for various projects.

A discount rate of 10 percent is used to adjust both benefits and costs to take into account the opportunity cost of holding such economic asset. Since these type of projects produce benefits on a margin, results are expected to be sensitive to choice of discount rate. Therefore, a range of discount rates are considered in a sensitivity analysis to provide a strong support for the outcome of our analysis.

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[10] 11 out of the 59 projects covered in this study fall under the category of combined cycle.

Table 9. Parameters for estimating the economic benefits of hydro dams

General Parameters:	Unit	Applied	Source
Energy conversion	MJ/KWh	3.6	BP conversion factors (info at www.bp.com)
Efficiency rating, SC plant	%	30%	http://www.industrialinfo.com/gas_turbine_world/
Efficiency rating, CC plant	%	54%	http://www.industrialinfo.com/gas_turbine_world/
Heating value	MJ/litre	45.5	EIA, 2013
Fuel requirement, SC	litre/KWh	0.264	Computed by author based on efficiency rating and energy conversion.
Fuel requirement, CC	litre/KWh	0.147	Same as above
Fuel price, yr2010	USD/barrel	79.5	IEA, 2014
>>>margin for processing	%	20%	Assumed
Adjusted fuel price, yr2010	USD/barrel	95.40	Adjusted for fuel processing margin
Unit conversion for fuel	barrel/ltr	159	www.bp.com
Carbon emission from fuel	kg/litre	2.671	U.S. EPA, 2013
CapEx Thermal SC, 2010	USD/KW	900	Weighted average for WB financed thermal plants
CapEx Thermal CC, 2010	USD/KW	1260	Same as above
Discount rate, real	% p.a.	10%	Assumed and tested for sensitivity range 8 -12%
Rental cost of plant	% p.a.	10%	Assumed
Economic life of plant	#years	25 year(s)	Assumed
Fuel price sensitivity	%	100%	±25%
Power generation sensitivity	%	100%	±20%
Control for SC Installed Capacity	MW	200 MW	Assumed
Control for SC Load Factor	%	40%	Assumed

Many studies on the issue of social discounting have shown the significance of using an appropriate rate for discounting project future cost and benefits in economic evaluation of major infrastructure investments. Aylward et al. (2000), in particular, summarised the various approaches to social discounting. The World Commission on Dams also, have emphasised that there questioning on decisions that follow strictly the summation of cost and benefits of different plants in a least cost framework overtime without a consideration of the intertemporal effects of a choice of investment. It is also quite important to express the net benefits of projects with different construction and operation time profile to a similar base year before making an economic choice. International financial institutions/organisation often apply a benchmark rate of 10 percent for project to be implemented in developing countries. Whether the 10 percent rate is too high or low for long cycle projects is outside the scope of this study. However, applying a low social discount factor may lead to over-investment in questionable social policies with very low returns. This is not unlike the argument that low discount rates may "induce a capital intensive pattern of development and promote investments with high upfront costs, such as dams, that could be harmful to the environment" (Birdsall and Steer, 1993).

Once the benefits (cost savings) of the hydropower projects are estimated, the net value of the dams are derived by subtracting the actual cost of the dam projects from their estimated benefits and then expressed in real present value terms, with year 2014 as base. The value of electricity that is estimated in this study includes all generation costs but do not include transmission and distribution costs.

Detailed procedure used for estimating the cost and time inaccuracies, and the real benefits of dams are presented in Appendix 1.

4.3 Findings and Discussion on Net Benefits of Hydropower Dams

The discrepancy between the appraisal and the actual rate of returns on the sets of dams under this study has been analyzed based on the ‘avoided cost’ methodology. Here, the economic benefits of the hydro-dams are measured as the savings in cost that would have been incurred to generate an equivalent amount of electricity with a similar load factor of a configuration of single cycle and combined cycle thermal technologies. The rates of return of this portfolio of electricity dams are estimated twice. First, we estimate the ex-ante rates of return which is based on the estimated construction cost of the dams at the time of appraisal. Second, the rates of return are calculated based on the actual construction costs of the dams. The results are presented below by the region in which the dam is located, and also by the installed capacity (MW).

No additional benefits are included due to alleviation form of unplanned outages or increase of new connections since those benefits will be realized from the additional electricity generated by either the dam facility or the thermal plants. In the context of this study, the internal rates of return are the discount rates at which the benefits estimated for the dams over the operating life of the projects, are equal to the initial cost of the dams. The difference between the estimated ex-ante and ex-poste rates of return is directly associated with the magnitude of cost overruns which are included in the estimated ex-poste rate of returns. Intuitively, the systematic pattern of errors in cost projections identified in the study would suggests that the ex-poste rates of returns are more likely to deviate significantly below their estimated ex-ante values.

The quantities and load factor of the electricity generated by each hydro dam are those projected at the appraisal stage.[11] Any loss of output that is due to delays in the dam completion is accounted for in the analysis. When the dam is delayed, the benefit projected profile is shifted to the period when the dam actually starts operation. Hence, the benefits of the dam will have a lower present value. To better understand the impact of possible shortfalls in actual power generation on the outcome of our analysis, we perform a sensitivity analysis for the level of energy

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[11] Evidence from WCD Case Studies have shown that the power output of dams have performed reasonably well for stations where the designed plant capacity is not altered at completion, and in some cases, the annual power generated surpassed expectations (see Aylward, B., et al., Financial, Economic and Distributional Analysis, Thematic Review III.1 prepared as an input to the World Commission on Dams, p31).

output. The marginal benefit of the individual dams - that is, the cost savings from not employing the replacement plant, are estimated using actual data for HFO price that correspond to each of the years the hydro power plants have been operating to date. For periods beyond 2014, to the end of the hydro dams' life cycle (40 years), the HFO price is assumed to be fixed in real terms at USD 89 per barrel, and then results are simulated for different future fuel price scenarios.[12]

The marginal effects of the environmental externalities such as carbon emission control, flood control, disruption of upstream activities, etc., which may show up on both sides of the equation are not considered here. A detail of the results on net benefits of the individual dams are presented in the Appendix C.[13]

For the range of dams examined under this study, the rate of return at the time of appraisal varies between 3.1 percent, for the Nyaunggyat dam project implemented in Myanmar, and 54.4 percent for Tianhuangping project in China. The average ex-ante rate of return estimated for the whole portfolio of 58 dams over their expected lifetime is 20.1 percent, while the ex-poste average rate of return for this portfolio is 14.3 percent. Using a 10 percent rate of discount, the present value of the portfolio of

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[12] The results of sensitivity analysis for future fuel price is not included in this paper because the findings from this study is not particularly affected by the volatile fuel price since most of the benefits that are affected come at very late periods of the operating cycle of the dams, which when discounted become quite insignificant. For instance, at worst case fuel price scenario of 66usd/bbl (25% less 2014 price of 89usd/bbl), the actual EIRR is only reduced to 14.21 from 14.28% estimated for the base case. The best case future price of fuel is set at 110usd/bbl (25% above base price), and result for actual EIRR increased to 14.34%.

[13] While the ex-ante and ex-post EIRR estimated in this study follow similar methodology used by the World Bank in calculating EIRR, the approach differ technically in terms of the type and source of data used for the evaluation. Data in this analysis is mainly actual historical data.

dams as of 2014 and expressed in terms of 2014 price level, amounts to USD 505 billion. This value is net of the actual costs of construction which is also cumulated at an annual rate of 10 percent to 2014. The net benefits of USD 505 billion for the World Bank's portfolio of hydro dam projects represents a very substantial contribution to the wellbeing of these developing countries.

Table 10. Estimated vs. actual EIRR according to region, million USD

	Total Capacity Installed (MW)	**PV of Est. Costs (2014)**	**PV of Actual Cost (2014)**	**PV of Benefits (2014)**	**Net PV of Hydro (2014)**	**ex-ante EIRR**	**ex-poste EIRR**	**#project with actual negative NPVs**	**#project with projected negative NPVs**
Africa (13)	1,468	91,594	115,365	126,881	11,516	14.40%	11.08%	3	7
L. America (15)	13,092	351,804	578,200	832,454	254,253	24.30%	14.39%	5	1
Asia (22)	16,500	228,245	258,907	441,715	182,808	16.70%	14.95%	2	6
Europe (5)	3,088	83,343	93,186	152,220	59,034	17.72%	16.26%	1	0
Oceania (3)	116	7,878	9,828	8,053	-1,775	10.26%	7.86%	1	2
Total	34,264	762,865	1,055,486	1,561,323	505,837				

Table 11. Estimated vs. actual EIRR according to size of installed capacity (MW), million USD

	Total capacity installed (MW)	**PV of est. costs (2014)**	**PV of actual cost (2014)**	**PV of benefits (2014)**	**Net PV hydro (2014)**	**ex-ante EIRR**	**ex-post EIRR**	**#project with actual negative NPVs**	**#project with projected negative NPVs**
0 - 99 (17)	926	76,263	96,430	61,301	-35,129	7.9%	6.24%	5	12
100 - 299 (12)	2,231	107,587	128,920	151,746	22,826	14.2%	11.80%	2	3
300 - 699 (14)	5,914	177,414	232,120	278,238	46,118	15.9%	12.04%	4	1
700 - 1499 (8)	8,850	124,632	175,441	290,269	114,829	20.3%	15.62%	1	0
1500 & more (7)	16,342	276,969	422,575	779,768	357,193	25.2%	17.68%	0	0
Total	34,264	762,865	1,055,486	1,561,323	505,837				

A distribution of the results by regional classification as shown in Table 10 reveals that the thirteen dams constructed in Africa, representing about 1.5 GW of installed capacity, have generated an economic net benefit of about USD 11.5 billion for the region, in present value terms at 2014 prices. Though the ex-poste EIRR for the subgroup is 11.1 percent, falling slightly below the appraisal rate of return which is estimated to be 14.4 percent, there is significant marginal gains from the dams constructed. For the Oceania, none of the dam projects seem economically justified after incorporating the cost errors into the project cost.[14]

For other regions, fifteen out of the collection of dams examined were built in the Latin America representing about 13 GW of installed capacity. For this sub-sample, the ex-ante EIRR was estimated at 24.3 percent, but the ex-poste results shows that the actual EIRR generated by the projects is 14.4 percent on average. One simple explanation for the large deviation between the ex-ante and ex-poste EIRR for the region can be explained by the high magnitude of real cost overrun which this study have estimated to be 54 percent on average. This region had the highest frequency and magnitude of cost overruns which mainly was due to volatile exchange rates during the 1980s and about the early 90s when most of the projects were developed. Notwithstanding the high level of overruns, overall, the dam investments had contributed a net economic gain of USD 254 billion to the region. The deviation of the

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[14] For some of the countries, like the Oceania and some landlocked African countries, the margin on imported fuel above the international spot prices are likely to be far more than the 20 percent used for the estimation of the benefits. For instance, the refining and transportation margins for imported fuel in Cape Verde has been estimated to be about 50 percent above the price of crude oil (Salci and Jenkins, 2012)

ex-ante and the ex-poste IRR were moderate for the Asian and European regions. The 16.7 percent ex-ante EIRR estimated for Asia region turned out to be 15 percent at ex-poste and a total of USD 183 billion worth of net gains would have been realized in the region by the end of the expected operating lifecycle of the dams.

One interesting observation in the results of this study is that 8 out of the 22 hydropower dams financed in the Asia region by the World Bank over the period of this study, which were developed in China (forming about 68 percent of the total installed capacity for the region), will have contributed, by the end of their economic life, up to USD 160 billion of net surplus to the economy of China (in 2014 present value terms). Most of these dams constructed in China faced major resettlement challenges and the cost overruns were mainly due to overrun in resettlement budget plans. The magnitude of the overall cost overruns were reduced substantially by cost underruns in other components of the construction cost estimates. The portfolio of dams implemented in China seem to have passed through an effective appraisal exercise as the results show that they performed well both in terms of cost and net benefits. The average rate of return at appraisal estimated to be 24 percent had an actual rate of return of 22.7 percent.

Table 11 presents a distribution of net benefits according to the size of installed capacity. The results show that the net benefits of dams significantly varies by size of generating plant installed. Larger dams generate relatively higher marginal benefits and higher rate of returns.[15] This study also finds that the economic justification for investment in large hydropower dams is relatively less affected by events of cost overruns when compared with the smaller dams. The argument by some studies that propose the small hydropower scheme as an alternative way to make use of water resources potential in meeting the energy needs without having to face the major challenges of constructing large dams is weakened by the findings of this study.

4.3.1 Sensitivity of NPV of the portfolio of dams to choice of discount rates

Given that hydro dams are capital intensive and usually have the major part of its cost as up-front capital outlays, with most of the benefits expected at later periods of the project life cycle, the net benefits are quite sensitive to choice of discount rates. Table 12 below shows that the cumulated net benefits of the dams financed by the World Bank within the period covered by this study increases from USD 505 billion to USD 535 billion when 8 percent rate of discount is applied, and significantly falls to USD 386 billion when 12 percent rate is applied. Higher discount rates have greater effects on the estimated benefits, but even at the 12 percent rate of discount, a value of USD 386 billion is still a substantial net gain from this portfolio of dams.

Table 12. Sensitivity of net benefits to choice of discount rates, Million USD

Discount rate	**PV of est. costs (2014)**	**PV of actual costs (2014)**	**PV of benefits (2014)**	**Net PV of hydro (2014)**
8%	437,812	599,927	1,135,644	535,716
*10%	762,865	1,055,486	1,561,323	505,837
12%	1,330,683	1,856,622	2,243,257	386,635

*Base rate discount factor

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[15] It is important to note that the cross-effect of regional distribution and size of dams in our dataset is not considered in the distribution of the net benefits calculated in this study. The process of World Bank evaluation of power projects is more likely to be same for all regions.

4.4 Conclusions and Policy Implications

In this study the cost of time overruns is estimated in terms of the alternative generation costs of the electricity not supplied by the project owing to the delay in completion of the dams. Although these costs are positive, at 3.5 percent of the initial real estimated cost of the dams, they are not nearly as significant as the underestimation of the real costs of construction. In fact, there were no time overruns in 41 percent of the dams, while 78 percent of the projects had real cost overruns.

Nevertheless, the magnitude of failure in cost projections has not prevented these dams, in the vast majority of cases, from being economically beneficial investments. Aggregated over the portfolio of 58 dams, the economic NPV of the set is at least US$ 505 billion.

If the dams had not been constructed, the economic cost of generating and supplying an equivalent amount of electricity to these societies would have been much greater than the actual cost of the hydropower dam projects. Thus, the notion put forward in the literature that hydro dams should not be built because they suffer from cost overruns (Ansar et al., 2014; Sovacool et al., 2014) does not necessarily hold when the benefits of the dams are also brought into the assessment. For example, the Itumbiara Power Project in Brazil had an actual cost that was almost double the estimated cost at the time of appraisal. The estimated benefit for this project turned out to be twice as much as the actual cost, and four times that of its biased cost estimate. Even if the actual project cost had been estimated correctly at the time of appraisal, it would still have been the preferred choice over an alternative thermal technology.

Enhanced professionalism at the appraisal phase may reduce the errors in projection that are caused by strategic deception (Ansar et al., 2014), but the reduction of technical difficulties caused by geological and environmental mitigation uncertainties is likely to involve a trade-off between the extra front-end investments that would be required to obtain more accurate information and the possible overruns that will show up during the construction of the dam. Eliminating the artificial bias caused by political interest/strategic deception may not eliminate the inaccuracies in the projected cost of dams.

4.4.1 Policy implications

The high degree of variability and uncertainty of costs in dam construction raises the question of what improvements in the appraisal and project selection methodology would contribute to better investment decision making. The proposal made by Ansar et al. (2014) using reference class forecasting (RCF) is certainly a promising methodological advancement. The probabilities and magnitude of the cost overruns that are likely to arise with dams of specific types in particular countries should become a central part of a modern project appraisal in such investments. While in most cases there may not to be sufficient information available during the time of appraisal to link the provision for contingencies closely to the likely incidence of real cost and time overruns, the RCF models are one way of providing some of this information.

At the same time, the analyst should also take into consideration the nature of the benefits that a particular dam site is likely to produce. Considering this set of 58 dams as a portfolio, the ex-ante benefit–cost ratio was about 2, but ex post ended up at about 1.5. One could question whether the solar and wind projects that the World Bank has been financing over the past 15 years will, even without cost overruns, prove on an ex-post basis to have as good a track record.

Because the benefits and the costs of every dam differ, and many dams are far from being marginal investments, the analysts and decision makers should also consider what the risks are, on the side of both benefits and costs, before coming to a decision on whether a particular dam is an investment that should be supported. One obvious recourse is to carry out a rigorous and impartial sensitivity analysis that recognizes the uncertainty in estimating the major evaluation variables (project cost and time, power demand forecast, fuel price, hydrology, etc.), and to use this analysis to stress test the robustness of the project economic justification (such as by assessing the probability that the project NPV is less than zero). Under this approach, uncertainty about cost and time estimates is treated in a larger framework than when it is treated alone.

The few exceptional high-NPV hydro dam projects should not deter investment analysts and decision makers from remaining vigilant in conducting the most realistic assessment of costs and from trying to quantify the risks of both the costs and the benefits. Again following the recommendation of Ansar et al. (2014), small countries can be fiscally destroyed by unexpected cost overruns of large hydro dams unless the expected benefits of the project are so large that they can absorb significant cost overruns. Alternatively, as in the case of Bhutan and Ghana, countries may be able to spread their risks through joint-venture relationships with either neighboring governments or strong commercial partners.

The policy recommendation to be drawn from this analysis is that one should not view all hydro dams as being too risky to undertake. A critical variable is the value of the benefits they will produce, and at what range of costs. If the benefits are large enough relative to the expected costs, such investments can very well be worth the risk. In the case of hydro dams, in addition to the problems of delusion and deception common to many public sector investments, there is the very real technical uncertainty associated with the geophysical nature of the sites. Hence, a realistic assessment of the future benefits of a project is critical in order to assess the magnitude of construction cost risks that can be accommodated.

Chapter 5

MANAGING THE COST OVERRUN RISKS OF HYDROELECTRIC DAMS

5.1 Introduction

This study illustrates a practical application of Reference Class Forecasting techniques in planning hydropower dam investments. Based on World Bank data, we explore the experience of forecast error in cost planning of dam investments to derive a probabilistic distribution of cost uncertainty, and then use a case study – the Bujagali hydropower project in Uganda – to test the robustness of the RCF technique as a prescriptive tool for enhancing cost benefit analysis (CBA).

Hydropower dams involve complex planning and often take a long time to design and construct. Because of these unique features of dams, coupled with lack of adequate vital information at time of appraisal, hydropower investments are usually exposed to construction cost and time overrun risk. Many studies have documented the severity of overrun in power projects. (Merrow and Shangraw, 1990; Bacon et al., 1996; Ansar et al., 2014; Sovacool et al., 2014; and Awojobi and Jenkins, 2015). Ansar et al. (2014) found that 9 out of 10 dams suffered from cost overruns. Yet hydropower is economically justified as a low cost and clean source of energy generation (IHA, 2011).

The explanations for cost overruns are diverse and there is a large number of theories that have been used to discuss these phenomenon. Based on findings from previous studies on the cost planning of large construction projects, technical factors seem not to be the major cause for overruns but rather, experts' optimistic perception about future events and political influence have been identified as the major reasons of overruns (Wachs, 1989, Pickrell, 1990, Flyvbjerg and Holm, 2005; Flyvbjerg, 2008). The theoretical underpinnings of Reference Class Forecasting (RCF) technique was inspired by Kahneman and Tversky (1979), in an attempt to provide a fundamental explanation for cost overruns and incidence of delays in project implementation. This technique was fully developed to its first practical form by Flyvberg (2004) and applied in Flyvbjerg and COWI (2004) study for a set of transportation projects in UK. Subsequent studies have applied this technique to different types of infrastructure project (Makovšek, 2012; Ansar et al., 2014).

Kahneman and Tversky (1979) identified cognitive bias in planning and decision making under uncertainty. This fallacy in planning, as so called, explains why cost and schedule, including risk of projects, are often underestimated. Their argument centers on the fact that planners' decisions are particularly based on "inside view" which are usually focused on specific planned action rather than the outcome(s) of previously implemented projects with similar features. More recent studies by Bordat et al. (2004), Flyvberg (2008), Flyvbjerg and Holm (2005) Ansaret al. (2014), Sovacool et al. (2014), Cantarelli et al. (2012) and others are now focusing on strategic misrepresentation, a reflection of deceit due to political influence and human factors in decision process, to explain the origin of cost overruns in capital projects. When political interest is involved in project planning, project costs are strategically underestimated to attract financing and avoid public criticism of high cost projects (Bacon et al., 1996).

As a recommendation to correct this fallacy in planning under uncertainty, Kahneman and Tversky (1979) suggest that decisions be supported with information available from previously completed reference class of projects, taking an “outside view” of a planned actions. The information usually in form of data /parameters can be analyzed to draw a likelihood of expected outcomes and possible variations in project cost and schedule from a sample of completed projects comparable with the planned new investment. Basically, the RCF method is focused on understanding the strategic (mis-)behavior of project sponsors, but it can as well be applied when planning contingencies for market-wide events. This method of enhancing the decision making process when faced with uncertainty has proven to be an effective tool for reducing the incidence of overruns in large infrastructure projects. In 2005, the American Planner’s Association endorsed this technique for decision making under uncertainty (Flyvbjerg, 2006).

While the traditional Cost Benefit Analysis (CBA) remains a useful policy instrument for making investment decisions, the reliability question on performance indicators from such analysis for electricity investments is posing a threat to the CBA, especially in the case of mutually exclusive power projects. The traditional CBA are usually based on some deterministic input parameters, outcomes of which are irreversible and can be very costly to the society where these structures are planted (Merrow and Shangraw, 1990). One major limitation of the traditional CBA approach is that the cost estimates and projected outcomes are based on expected values from expert judgment rather than on experimental distribution of outcomes from a sample of previously completed similar projects. This single estimates creates an avenue for bias. They take less account of the uncertainties surrounding project input parameters and components. In particular, it does not account for the irrationality in human behavior, as well as the asymmetries of information between project sponsors and financiers/regulatory partners, a situation that can lead to adverse selection where the alternative technology is actually more economical investment after taking into consideration the risk level of projects under a least-cost framework. In most cases, information about the geological state of the proposed location of the dam, for instance, is unavailable during the appraisal phase and where fundamental views are used to provide such data, they are lacking with high degree of uncertainty. As a result of these flaws, decisions based on such estimates often turn out to be bad choice investment where the actual project net benefits eventually turn out to be negative.

The reference class forecasting is not a new tool within the decision making framework for large infrastructure investments. However, its application to energy projects is scanty (Sovacool et al., 2014; Ansar et al., 2014.). Sovacool et al. (2014) used the reference class techniques as a diagnostic tool to illustrate that construction cost overruns in electricity infrastructures are unavoidable plethora of risk in planning. Ansar et al. (2014) provide a more prescriptive application of RCF to managing the risk preference of power investment that has hydropower as part of the least-cost framework. This study illustrates how the RCF methodology can be used to provide a system dynamics for utility planners and project analysts, a vital step that may be required to improve the outcomes of CBA for energy investments and a useful tool for defining the risk preferences of power projects in the case of mutually exclusive selection process.

An important question this study attempts to answer is - “Can we improve the contingency planning for hydropower projects to enhance the quality of investment decisions in development of power systems?” A study by Sovacool et al. (2014) provides a distribution of cost overrun in power projects by technology type, and their findings show that typical hydropower investments are more prone to overruns when compared to other power generation technologies. In a study by Awojobi and Jenkins (2015), the average real cost overruns for a portfolio of World Bank financed hydro dams was found to be 27 percent, with a standard deviation of 38 percent. This shows that the uncertainty in hydro power investment estimates at appraisal stage are quite substantial. The study also provides a distribution of errors in estimates which varies by size and location.

Based on the findings from the Awojobi and Jenkins study on hydropower dams, there is substantial empirical evidence to show that the actual cost of hydro-dams have been systematically biased below their appraisal estimates, and delays in the completion of the facility can create a social cost in cases where the project output is not made available according to planned schedule. Further, while able to show that size is important in cost planning of dams, they failed to identify any concrete evidence that supports the notion that small hydropower projects (MW) have performed better than the big ones in terms of cost planning, a claim put forward in Ansar et al. (2014). The fact is that a trade-off exists because big dams come with large economic benefits, but the construction cost risk of small dams is easier to manage.

In terms of the economic net gains of hydropower projects, the divergence in actual project outcomes and projected net benefits varies significantly according to region. Latin America had more severe cases of forecast error but also had the highest average actual EIRR of the regions studied. For the portfolio of 58 World Bank financed hydropower investments, the net benefit of dams are quite significant with an economic real rate of return in excess of 14 percent. The study concluded that hydro-dams are economically feasible, but there is room for improvements in cost estimates. Similar to the Ansar et al. (2014) study, Awojobi and Jenkins (2015) recommended using the RCF to improve the performance of cost estimates at appraisal phase, particularly to provide some additional information that can link the contingency provisions more closely to the likely incidence of construction cost and time overruns.

Employing the data derived from Awojobi and Jenkins (2015) and using the outside view approach, we demonstrate the relevance of RCF to hydropower investments planning. To test the robustness of the RCF technique for investment decision making in power projects, the model is applied to the Bujagali hydropower project in Uganda. For the case, we compare the deterministic cost estimates from the appraisal with the adjusted cost estimates that are derived from our reference class.

The main logic in the RCF technique is not to aim at predicting uncertain events, but rather, it is a technique that helps build robustness around parameters that are affected by these events. Hydropower projects are vulnerable to uncertain future events like geological and hydrological conditions, environmental restraints, etc., and often can be exposed to penalties beyond what the deterministic models are able to predict.

5.2 Method of Approach to the Application of RCF Techniques

First, this study provides a statistical view of the severity of cost and time overruns[16] in the construction of hydropower dams. A distribution of the inaccuracies in costs as

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[16] Overruns are simply taken as deviation of Actual from Estimated, expressed as percentage of Estimated [(Actual-Estimated)/Estimated]. For all cost, real constant dollar is used. The values for ‘Estimated’ are based on information documented at approval stage of the projects, most of which can

well as the economic net gains from hydropower are provided for a set of World Bank financed hydropower projects. The results reflect how the issue varies across regions. Further, a simple univariate analysis is performed to identify the relationship between cost performance and project-specific characteristics such as time, size, etc.

Secondly, we describe the basic procedures for constructing a reference class and its applicability to hydropower investments. Our approach follows the ‘outside view’, as proposed by Lovallo and Kahneman (2003), to derive benchmarks and logical intuitions for analysing the statistical validity of each reference class identified from our data, a somewhat similar procedure was used by Bacon et al. (1996) and Ansar, et al. (2014) for power projects; Flyvbjerg (2008) and Makovšek (2014) for transportation projects.

The ability of the RCF to provide more accurate information for decision making, however, will depend on a number of factors such as the sample size of the reference group, the relevance of the projects in the reference group to the proposed hydro-dam. It is very important that the features of the appraised dam be very identical to those of the reference group[17]. Policy changes within the period of data analysis also should be considered (see Bacon et al. 1996 for impact of World Bank policy changes on performance of cost); and finally, longer length of construction period may weaken the degree of accuracy of the RCF.

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be found in the Staff Appraisal Reports (SARs) from the World Bank; while the values for ‘Actual’ are determined by information at end of construction, following the Implementation and Completion Reports (ICRs) of the Bank.

[17] The outcome of RCF process may not be confounding to possible cases of outliers. However, such events of outliers are rare.

Prior to making a reference class for the case studies, we provide multi-level form regressions to identify the key determinants for cost and time overruns. The results from the regressions are subjected to thorough statistical diagnostic checks to show the robustness of the regression outcomes.

Further, a probability distribution function of results of cost and time overruns are established from historical information to help incorporate the level of uncertainty particular to a similar reference class of projects, into projections and exploit the dynamics of implementing hydro dam projects. The reference class forecast takes an “outside view” on a project expected outcome based on information available from the actual performance of comparable projects previously implemented. Regression models are vital tool in deriving the probability distribution function that describes the uncertainty and possible bias common to a particular reference group of dams. While these models can help reduce, significantly, the errors in projections due to bias in assumptions about input parameters, they do not eliminate forecast errors completely (Merrow and Shangraw, 1990; Ansar, et al. 2014).

To discuss the steps for the application of RCF to dam projects, first we present the theoretical and methodological foundation underpinning this approach to decision making under uncertainty (see details in Kahneman and Tversky, 1979b; Lovallo and Kahneman 2003; and Flyvberg 2006). The RCF method is more useful in cases where errors are due to non-random events such as cognitive bias in decision making with uncertain future events[18]; or due to deception in project planning referred by Flyvberg (2007), as strategic misrepresentation in planning.

The reference class forecasting method basically attempts to fit a particular action into a probability distribution of a comparable class of completed events/projects, with range of expected outcome of the planned action corresponding to an interval derived from the formulated reference group used in predicting the outcome of the proposed action. This procedure provides an outside view of a proposed investment and decisions based on this approach accounts for, to some extent, the magnitude of unknown risk peculiar to such investment.[19] The RCF method makes possible for systematic adjustments to estimates from cost-benefit analysis, to include a margin for errors that are likely to be due to optimistic projections and strategic misrepresentation.

5.2.1 Dams and the common planning fallacies

Hydropower dams are marginally economical investments and usually very capital intensive. They require lengthy planning and construction period, with the benefits taking time before they start to accrue. Because of the complexity and risk involved in planning large hydropower projects, they are becoming synonymous with construction cost overruns. Under the least-cost framework, decision outcome that favors hydropower have been widely criticized for lack of merit in the benchmarking

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[18] Cognitive bias is a situation of unguided decision making under uncertainty. Decision are not based on realities from the past but rather on overly optimistic perception of an action. This has been a source of errors in predicting the cost and time of dam project.

[19] For a comparison of the inside view and outside view, see Buehler et al. (1994), Gilovich et al. (2002); also see Lovallo and Kahneman (2003).

estimates as they have been historically documented to be based on misleading forecasts in the cost and schedule of constructing the dams.

Flyvbjerg (2007) discusses how optimism bias and strategic misrepresentation can contribute to inaccuracies in cost of construction projects.

In addition, multilateral institutions that finance the construction of dams now require that project planners provide environmental, and socio-economic impact assessments with mitigation plans for the adverse effect of the dams on the people where the dam is to be located, before financing arrangements can be approved. The estimate of resettlement cost is uncertain as people tend to migrate and lay claims to resettlement benefits once the construction of dam commences. For instance, in China, the Ertan hydropower project had budgeted USD 82m for resettlement plans, but by the time the dam construction was completed, it had incurred a total cost of USD 228m on resettlements of the locals from project site (Ertan I&II, ICR). Also, the geological and hydrological constraints are major sources of uncertainty in the expected cost of building a dam.

5.2.2 Procedures for Reference Class Forecasting

To apply this methodology for the hydro dam case studies, we follow the 3 steps described by Flyvberg and COWI (2004): (i) identify a reference class of comparable projects, (ii) draw a prior probability distribution for each of the reference class identified; and (iii) fit the planned project into a prior probability distribution function which is derived from a suitable reference class and establish reliable estimate of expected outcome and credible interval. In addition to the three steps above, based on the degree of tolerance for risk of the organization financing the project, we can then decide what magnitude of uplift would be required in contingency budget to account for bias in cost estimates.

5.2.3 Choosing a reference class for hydropower dams

To make a meaningful classification of projects into various reference groups, it is worthwhile investigating in more detail the determinants that are known to have a great influence on the magnitude of cost overruns. To set a reference class for hydro dams under this study, we describe a function for the performance of project cost as follows:

$$\text{Cost} = f\,(\text{size, time, price-inputs})$$

$$y = \mu + X'\beta + u \qquad \text{Equation (11)}$$

Other proximate factors such as competitiveness of the bidding process, the structure of electricity market etc., are not included since they are less critical to the physical performance of the dam projects. However, the scheduled length for constructing of a project is affected by resettlement plans as historical records have shown that resettlement action plans carry high degree of uncertainty. This could also have impact on the actual cost of a dam.

The relationship described above can be estimated at individual levels and at a corresponding group level using regression models. While we would expect that the projects selected for each reference group have similar characteristics, and the relationship expressed in equation (11) do not yield significant difference for the individual projects within the same subgroup[20], the relationship can differ significantly across major groups (Wooldridge, 2009) For instance, macroeconomic parameters are more likely to be volatile in Africa when compared with those for Asia or Europe. For countries in the reference group (subgroup) Africa, we may expect somewhat similar

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[20] This assumption is very important for validating the collectiveness of projects in a reference group.

trend in macroeconomic indices. This assumption for defining our reference group sounds a bit crude but statistically proven to be correct for the set of data used for this study. In this instance, using the Ordinary Least Square (OLS) regression to identify key determinants of cost overruns can generate spurious regression results.

Therefore, to capture the cross-sectional random effects in the data collected for this study, hierarchical linear regression will be most appropriate for estimating the relationship in equation (11)[21] now expressed as:

$$y_{ij} = \beta_{0j} + \sum_{q=1}^{Q} \beta_{qj} X_{ij} + u_{ij} \qquad \text{Equation (12)}$$

Where y_{ij} is the dependent variable (actual project cost), with Q number of explanatory variables X_{ij} for each individual project 'i', nested within the reference group 'j'. β_{0j} and β_{qj} are the level 1 form unique parameters of X, for $\beta_{0j}=E(y_{ij}|X_{ij}=0)$. u_{ij} is the disturbance term.

Equation (12) is the level 1 form regression model for which the actual project cost is at the lowest level of the nested hierarchical structure. The level 2 form regression describes the variability in parameter estimates, βq, across the regional groups. We consider a simple case of level 2 form predictors, modeled using the equation below:

$$\beta_{0j} = \gamma_{00} + \sum_{s=1}^{S} \gamma_{0s} R_j + v_{0j} \qquad \text{Equation (13)}$$

$$\beta_{qj} = \gamma_{q0} + \sum_{s=1}^{S} \gamma_{qs} R_j + v_{qj} \qquad \text{Equation (14)}$$

Where, β_{0j}, β_{qj} are the parameter estimates from level 1 model, now expressed as dependent variable on level 2 form predictors, regional binary variables. The

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[21] See details of HLM in Hofmann (1997), and more complex form of HLM in Raudenbush et al. (2011)

parameter estimates for level 2 form predictors are represented with γ_{00}, γ_{0s}, γ_{q0}, γ_{qs}. R_j is the non-parametric value assigned to the level 2 form predictors, the regional identity; v_{0j} and v_{qj} are the group random effects.

In terms of the HLM, a combined form of the multi-level equations is then derived by substituting equations (13) and (14) into equation (12).

$$y_{ij} = \gamma_{00} + \sum_{q=1}^{Q} \gamma_{q0} X_{ij} + \sum_{q=1}^{Q} \sum_{s=1}^{S} \gamma_{qs} R_s X_{ij} + \left[v_0 + \sum_{q=1}^{Q} v_{qj} X_{ij} + u_{ij} \right] \quad \text{Equation (15)}$$

Equation (15) above incorporates the parameter estimate from level 2 form predictors, a cross-term component, and also a composite disturbance factor.

Whereas equation (12), (13) and (14) can be estimated using the standard OLS regression techniques, the mixed model, equation (15) cannot be appropriately estimated using same method since the disturbance term are no longer independent across the dependent variable units. The multi-level regression method permits correlation between forecast errors within each subgroup. For instance, if the cross-section of data collected have a significant amount of projects from the same country, it is very likely that the cause of cost overruns will be similar, making the errors across this subgroup of projects correlate (explain the implication of heteroscedasticity and the weakness of standard regression model for cross-sectional series… a flaw in models described by Bacon et al. 1996, and Merrow and Shangraw, 1990). The model as specified under this study allows for unequal variance across the subgroups. Estimating the HLM with unequal variance across groups requires an iterative process, usually using the Maximum Likelihood Estimation (MLE)[22] rather than the standard OLS technique (Hofmann, 1997).

For the analysis of hydropower dams, actual project cost is the level 1 form dependent variable (output variable) with *q* number of predictors modeled as the input parameters.

Table 13. Classification of variables according to hierarchical structure

A. First Level (project specific variables):

A.1 Cost variables

Estimated project cost, 2010 USD
Actual project cost, 2010 USD
Value of foreign component as percentage of total cost

A.2 Size

Dam height, in metres
Installed capacity (MW)
Generation capacity (GWh)
Number of installed turbines

A.3 Time

Year construction starts
Year construction ends (assumes operation starts immediately construction ends)
Estimated length of construction, in months
Actual length of construction, in months

A.4 Input price parameters

Cumulative foreign inflation (MUV index is used for foreign price index)
Cumulative domestic inflation
Currency depreciation, percentage of PPP exchange rate at end of construction period

B. Second Level (regional dummies variables):

Africa
Latin America
Asia

Table 13 above shows the variable classification according to their hierarchical structure. The reference group chosen for this process is the regional dummies with

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[22] In this case, the start values of the parameter for iteration are chosen from the first level form model. Then the best parameter is chosen from the sequence of iterations process. Hence, the expected variance in project cost can be expressed as: var (y_{ij}) = var ($v_0+\Sigma v_{qj}X_{ij}+u_{ij}$).

other projects outside these three regions taken as the base group. The regional classification provides better reference class than size (MW) classification in the estimation of parameter for evaluating the performance of cost for hydropower dams. Hence the level 2 form equation (13) and (14) describes the variability of parameter estimates across the regions. This process gives a robust standard error for drawing a reliable probability distribution function. In the next step, we derive a probability distribution of errors in cost estimates for the portfolio of 58 completed dams according to the reference class identified.

5.2.4 Hierarchical Model specification

Following the relationship described with equation 11, the HLM model is specified as follows:

Level-1 project-specific equation,

$$RCO_{ij} = \beta_{0j} + \beta_{1j}*(DAMHEIGH_{ij}) + \beta_{2j}*(MW_{ij}) + \beta_{3j}*(TIMEOVER_{ij}) + \beta_{4j}*(FCX_{ij}) + r_{ij}$$

Level-2 equations for regional non-parametric variations in project parameters,

$$\begin{aligned}
\beta_{0j} &= \gamma_{00} + \gamma_{01}*(D\_AFRICA_{j}) + \gamma_{02}*(D\_AMERIC_{j}) + \gamma_{03}*(D\_ASIA_{j}) + u_{0j} \\
\beta_{1j} &= \gamma_{10} + \gamma_{11}*(D\_AFRICA_{j}) + \gamma_{12}*(D\_AMERIC_{j}) + \gamma_{13}*(D\_ASIA_{j}) \\
\beta_{2j} &= \gamma_{20} + \gamma_{21}*(D\_AFRICA_{j}) + \gamma_{22}*(D\_AMERIC_{j}) + \gamma_{23}*(D\_ASIA_{j}) \\
\beta_{3j} &= \gamma_{30} + \gamma_{31}*(D\_AFRICA_{j}) + \gamma_{32}*(D\_AMERIC_{j}) + \gamma_{33}*(D\_ASIA_{j}) \\
\beta_{4j} &= \gamma_{40} + \gamma_{41}*(D\_AFRICA_{j}) + \gamma_{42}*(D\_AMERIC_{j}) + \gamma_{43}*(D\_ASIA_{j})
\end{aligned}$$

The regression model specified above directly takes the errors in cost projection as the dependent/output variable for the lowest hierarchy, a similar approach to Ansar et al.

(2014). However, this approach is quite different from the Bacon et al. (1996) approach to measuring the cost performance of power projects.[23]

The model for project cost overruns is made parsimonious using the stepwise variable selection procedures and then estimated with the HLM (7) software.

5.2.5 Data Origin

The database of hydropower projects collected for this study follows the same data used for a previous empirical study of cost overruns by Awojobi and Jenkins (2015). It consists of a total of 58 hydropower dam projects located in 33 developing countries that were financed by the World Bank/International Financial Corporation and completed between 1976 and 2005. Useful information to serve the purpose of this analysis were extracted from the Staff Appraisal Reports (SARs) and appropriate Implementation and Completion Reports (ICRs) for each project in this portfolio of dams. This portfolio of dams includes virtually all the hydropower projects with major storage facility that were constructed during the study period and for which complete information are publicly available. Besides the fact that the World Bank collection provides a substantial sample of reliable data for carrying out this study, it was also very important that we establish a portfolio of projects for which the appraisal methods are consistent. Hence, the findings from this study, in particular, the application of the RCF techniques to project appraisal would depend, to a very large extent, on how closely related are the methods used for appraising a dam, are to the method being applied by the World Bank.

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[23] The Bacon study used the log of actual cost as regressand on estimated cost to derive the cost overruns. The aim of this analysis, differs significantly from those of the analysis carried out in the Bacon study

5.3 Findings and Interpretation of the HLM Output

Table 14 below provides a descriptive statistics of the performance indicators of projects by their region.

Table 14. Descriptive statistics for some key project parameters

		Africa	America	Asia	Europe	Oceania	All Projects
Total Installed Capacity (MW)		1468	13092	16500	3088	116	34264
Average Installed Capacity (MW)		113	873	783	673	39	610
Construction Schedule, Months		62	79	89	78	57	83
Slippage Months		10	17	8	18	7	12
Number of Projects		13	15	22	5	3	58
Projects with Cost Overrun		13	13	13	4	3	46
Projects with Time Overrun		9	9	12	3	1	34
Projects with negative ex-post NPV		10	6	8	1	3	28
Real cost overrun	Mean	25.5	54.0	7.7	15.4	26.2	27.0
	Minimum	1.0	-39.8	-36.7	-12.8	19.0	
	Maximum	62.2	176.6	119.0	23.6	94.9	
	Std. dev.	18.0	52.5	31.7	12.7	33.3	
Time Overrun	Mean	18.3	23.2	10.2	22.6	14.4	16.3
	Minimum	-1.9	-3.4	-8.1	8.2	5.0	
	Maximum	39.4	83.3	40.0	36.1	73.8	
	Std. dev.	10.4	28.5	12.3	11.5	35.2	
Cost of Time Overrun	Mean	8.4	4.4	1.9	7.3	0.3	3.5
	Minimum	-4.4	-12.1	-6.3	-0.6	0.0	
	Maximum	42.2	22.5	26.6	14.2	1.2	
	Std. dev.	12.5	9.1	6.3	7.4	0.7	
Ex-ante Economic IRR (%)		14.40	24.30	16.70	17.72	10.26	20.11
Ex-post Economic IRR (%)		11.08	14.39	14.95	16.26	7.86	14.28
Actual Economic NPV, 2014 USD[a]		11,516	254,253	182,808	59,034	-1,775	505,836

[a] Expressed in millions.

Prior to estimating the parameters for the multilevel regression model, a univariate analysis is undertaken to identify the relevant determinants of cost and time overruns in the portfolio of completed hydropower dams. To do this, all the project-specific variables presented in Table 13 are tested for correlation with the cost performance variables. We decided to exclude all variables that were found to be statistically uncorrelated with the cost performance of the dams.

In terms of the signs for the correlation coefficients, taking the performance variable as cost overruns rather than the actual completion cost – a performance variable used in Bacon et al. (1996), it is possible that the sign for the relationship between cost overruns and any observable predictor would differ from the correlation sign of same predictor with the actual completion costs.[24]

Results for the correlation test in Table 15, shows that delays in construction and the foreign component of total capital expenditure have positive linear relationship with real cost overruns. Ex-post EIRR has negative relationship with both cost and time overruns. If project encounters cost and time overruns, expected economic rents from project is reduced based on empirical findings. It is quite interesting that size of dam is not correlated with cost overruns; but MW correlates negatively with time overruns. This does not necessarily mean that more complex designs that take longer time to

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[24] To illustrate this, assume that:

Errors in cost projection = log (A/E).

With "*A*" as the actual cost and "*E*" as the estimated cost of dam project. Whereas the variables A and E from the above are both derived with similar observable predictors, X, A is only observable at end period of construction but predictable as E at beginning of construction. Therefore,

$$A = a + bX + u$$
$$E = c + dX$$

Then, errors in cost projection can be expressed as:

$$\log\left({}^{A}\!/_{E}\right) = log\left(\frac{a}{c}\right) + (b - d)logX + u$$

Hence, the direction of the relationship between errors in projections, log(A/E), and the observable predictors, X, will be determined by "(b-d)" which depends on the sign of b and the level of precision of E as a surrogate for A.

build have less incidence of time overrun. Rather, it reflects a relative length of delay as a proportion of the long period of construction estimated for large projects.[25]

Table 15. Pearson's correlation coefficients and descriptive statistics of project specific variables

	Mean	Std. dev.	Real Cost Overrun	Time Overrun	Cost of Delay	EX_ANTE _ERR	EX_POST_ ERR
Real Cost Overrun	26.2%	0.39					
Time Overrun	22.2%	0.20	0.351***				
Cost of delay	3.6%	0.09	-0.021	-0.064			
Ex-ante ERR	16.3%	0.10	-0.04	-0.24*	0.298**		
Ex-post ERR	14.2%	0.10	-0.405***	-0.321**	0.235*	0.896***	
Dam height (m)	88	56	0.087	-0.167	0.11	0.333**	0.285**
Installed capacity (mw)	591	770	-0.072	-0.236*	0.075	0.671***	0.589***
Estimated cost			-0.1	-0.197	-0.062	0.394***	0.348***
Actual cost			0.182	-0.098	-0.066	0.37***	0.211
Estimated length	68.2	18.3	-0.264*	0.384***	-0.064	0.336***	0.333**
Actual length	81.9	20.9	0.019	0.159	-0.086	0.175	0.137
No. of turbine units	3.9	2.7	0.052	-0.107	0.001	0.357***	0.241*
Currency deprec.	11%	0.32	-0.03	0.152	-0.026	0.024	0.041
Generation capacity	2224	3429	0.032	-0.171	-0.048	0.436***	0.349***
Load factor	43%	0.15	0.082	0.144	0.114	-0.073	-0.064
FCX	60%	0.14	0.161*	0.087	0.107	-0.242*	-0.213
Cumulative local inf.	144%	2.51	0.074	-0.115	-0.021	0.066	-0.01
Cumulative foreign inf.	25%	0.111	0.335***	-0.027	0.295**	-0.015	-0.223*

***1%, **5%, and *10% levels of significance

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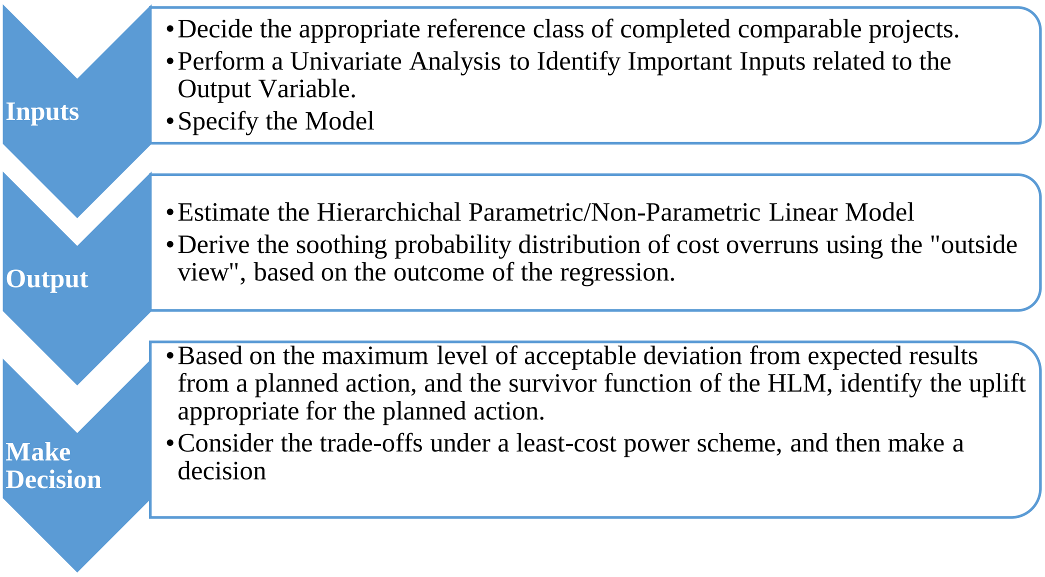
[25] For example, a small dam that is estimated to take 5 years to construct may encounter construction difficulties that extend the completion by 12 calendar months. This means a time overrun of 20 percent. Whereas, a large dam that is estimated to take 12 years to construct and had 2 years actual delay would have 16 percent time overruns. This does not mean the small project had longer delay. In fact, project appraisal use number of delay months for planning rather than the percentage time of delay.



Inputs

- Decide the appropriate reference class of completed comparable projects.
- Perform a Univariate Analysis to Identify Important Inputs related to the Output Variable.
- Specify the Model

Output

- Estimate the Hierarchichal Parametric/Non-Parametric Linear Model
- Derive the soothing probability distribution of cost overruns using the "outside view", based on the outcome of the regression.

Make Decision

- Based on the maximum level of acceptable deviation from expected results from a planned action, and the survivor function of the HLM, identify the uplift appropriate for the planned action.
- Consider the trade-offs under a least-cost power scheme, and then make a decision

Figure 13. Decision making framework with the RCF technique

Figure 13 shows the framework for decision making with the RCF technique. This framework is followed in the subsequent parts of our analysis.

Table 16 below is the outcome of the HLM regression model with mixed effects to capture both the global mean of cost overruns and the regional deviations of key parameters from the global mean. Technically, the parameter estimates in the Table 16 cannot be literarily interpreted in the same way been done for a standard single-level regression model (Recchia, 2010). However, the results from the regression are particularly useful for deriving the probability distribution function and the accumulated descending function of cost overruns based on the outside views.[26]

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[26] The application of the reference class follows two major statistical procedures to forecasting. First it identifies the statistical significance of the relationships between the dependent variable and sets of independent variables so that we do not include dormant variables that reduces the degree of freedom of the model. Second, given that the real estimates of cost overruns is not normally distributed statistically, the HLM regression helps normalize the distribution and it is the normalized distribution that is used to

The model assumes time overrun to be indirectly observable at ex-ante. Practically, this variable cannot be observed in advance, but for the purpose of this research, including this variable in a predictive form is justified in our attempt to disentangle the effect of misforecast in construction schedule from the other effects that are directly associated with the cost performance of the dam project. Also, including the time overrun variable in the model helps the planner to have an idea of what magnitude of overruns in construction time would be the maximum the project can afford in order to keep to its objective.

Table 16. HLM-MLE output (with robust standard errors, number of iteration = 100)

Effects	Coefficient	Standard error	*t*-ratio	*p*-value
For INTRCPT1, β_0				
INTRCPT2, γ_{00}	142.223739	30.285124	4.696	<0.001
D_AFRICA, γ_{01}	-228.538014	50.449274	-4.530	<0.001
D_AMERIC, γ_{02}	-215.186741	73.557997	-2.925	0.005
D_ASIA, γ_{03}	-170.376412	73.162365	-2.329	0.024
For DAMHEIGH slope, β_1				
INTRCPT2, γ_{10}	-26.611394	8.637027	-3.081	0.004
D_AFRICA, γ_{11}	28.856486	10.125900	2.850	0.007
D_AMERIC, γ_{12}	35.529204	12.264688	2.897	0.006
D_ASIA, γ_{13}	44.687756	17.511642	2.552	0.014
For MW slope, β_2				
INTRCPT2, γ_{20}	7.438621	3.722037	1.999	0.052
D_AFRICA, γ_{21}	-1.251633	6.473741	-0.193	0.848
D_AMERIC, γ_{22}	-0.732029	8.788288	-0.083	0.934
D_ASIA, γ_{23}	-15.507580	7.068968	-2.194	0.034
For TIMEOVER slope, β_3				
INTRCPT2, γ_{30}	2.030833	0.239346	8.485	<0.001
D_AFRICA, γ_{31}	-1.164286	0.429147	-2.713	0.010

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derive the uplift curve. Normalizing the distribution of cost overruns helps minimize the potential consequence of using an inflated measure of inaccuracy as a benchmarking for an individual dam.

D_AMERIC, γ_{32}	-1.595488	0.511885	-3.117	0.003
D_ASIA, γ_{33}	-1.606945	0.565741	-2.840	0.007
For FCX slope, β_4				
INTRCPT2, γ_{40}	-1.528780	0.344380	-4.439	<0.001
D_AFRICA, γ_{41}	2.358306	0.449338	5.248	<0.001
D_AMERIC, γ_{42}	2.014212	0.820056	2.456	0.018
D_ASIA, γ_{43}	1.582863	0.611755	2.587	0.013

As shown on Table 16, dam height, time overruns and the share of imports in total project cost, are all statistically significant variables for describing the source of uncertainty in the projection of the cost of a dam. The results also show that, except for the projects implemented in the Asia region, there is no significant difference in parameter for size of installed generator across the regions. However, size is a globally significant variable for explaining cost overruns (p=0.052). Dams with relatively large installed capacity are more likely to have cost overruns in all regions, but for Asia, size is expected to have a negative relationship with cost overruns.[27] In terms of the impact of time overruns and share of imported inputs in the construction of dams, there is positive implications for cost overruns for all the three reference groups (all levels, p<0.01). However, the degree of responsiveness varies significantly by region where dam is constructed. In general, this implies that the planners need to be vigilant of unknown events that could slow the physical completion of the dam project. Delays have double impacts: (i) the implicit cost to the society, of not supplying power as

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[27] A simple way of interpreting the HLM parameters is by substituting for the level-2 form variables in equations (7) to (11), and then compute the appropriate coefficient to ascertain the sign of the parameter. For instance, the global mean of the parameter for size, MW, is γ_{20} = 7.438621. The adjusted parameter (β_{2j}) for Africa = 7.438621 + (-1.251633)*(1) + (-0.732029)*(0) + (-15.507580)*(0) = 6.186988. This implies a positive effect of size on cost overruns in Africa.

scheduled; and (ii) the financial implications for project cost. Results in Table 16 also shows that dams with extensive height are more prone to uncertainty in cost projections.

5.3.1 Probability distribution of forecast errors in construction cost of hydropower dams

This section shows the magnitude of errors in cost projections for hydropower dams. For the subgroups of hydropower projects, classified according to regional similarity in terms of uncertainty and historical records of overruns, a probability distribution of project cost performance is derived. Figure 14 shows that, for the projects in Africa, 35 percent of the dams completed in the region had a maximum cost overrun of 18 percent, 50 percent of the projects witnessed a maximum cost overrun of 22 percent. This implies that taking a 50-50 chance, the incidence of uncertainty in cost projections for hydropower dams in the African region could cost a typical hydro dam project up to an additional 22 percent of the original cost estimate of the project. For the other regions, the distribution of cost overruns is depicted on the Figure 14 below. From the cumulative distribution charts, there is clear evidence of substantial error in cost projections for dams in all the regions, with the Latin America having the widest range for cost overruns.

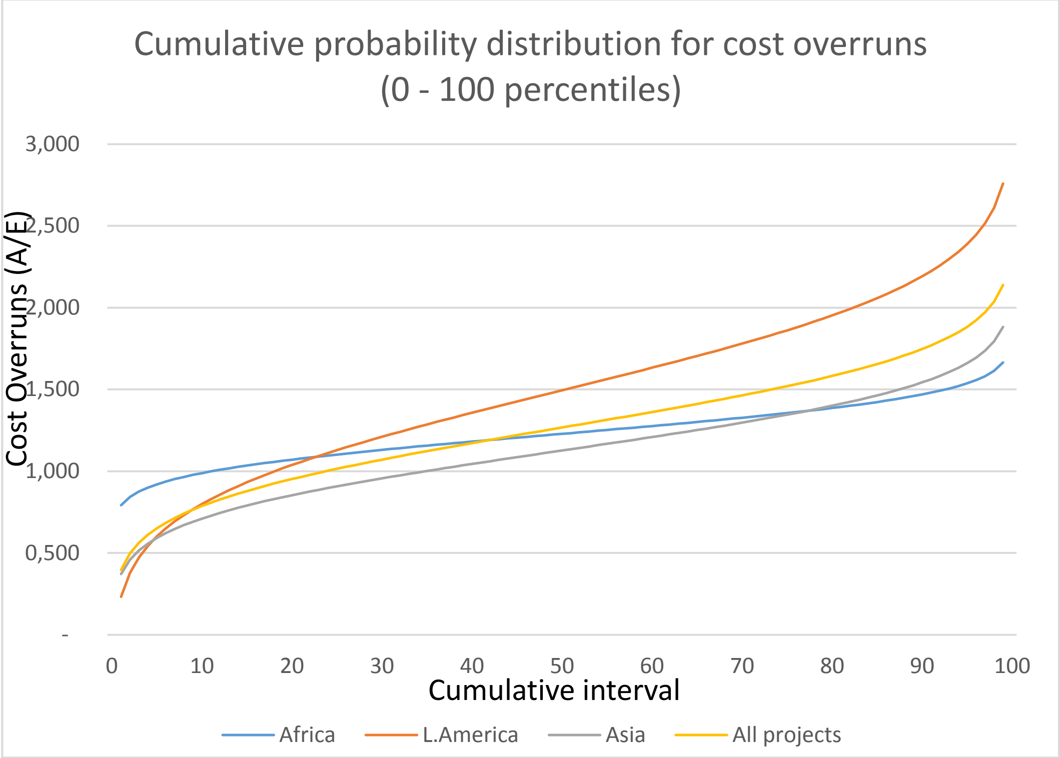

Figure 14. Cumulative probability distribution for cost overruns

Having shown the magnitude of cost overruns, Table 17 below describes the prevalence of the issue of misforecast in cost planning for dams. In Africa, 69 percent of the dams constructed had an error in cost projection of more than 10 percent, while in the Latin America and Asia, about 80 percent and 77 percent of the projects had error in forecast of more than 10 percent respectively. Giving an outside view to a proposed investment in the Latin American region, the investment analyst would need to be more sensitive to the sources of misforecast as the region also shows that 47 percent of comparable dams completed in the region had error in appraisal estimates of over 50 percent.

Table 17. Relative frequency distribution of forecast errors

Margin of forecast errors	Reference Class						All Projects	
	Africa		Latin America		Asia			
	Freq.	Rel. freq.	Freq.	Rel. freq.	Freq.	Rel. freq.	Freq.	Rel. freq.
More than 10%	9	69%	12	80%	17	77%	46	79%

More than 20%	7	54%	12	80%	11	50%	36	62%
More than 50%	2	15%	7	47%	1	4%	11	19%

5.4 Discussion

For the portfolio of 58 dams covered by this study, classified by regional features, there is sufficient evidence of misforecast in project cost. More complex projects in terms of size of plant installed and physical height of the dams are some of the origin for optimism bias and strategic parameters used to underestimate the cost of the projects. Table 14 have also shown that dams are economical choice of power investments with substantial net gains accruable to the societies where such structures are built. These two findings about the cost and benefits of dams points to the fact that the net economic gains from hydropower investments can increase if the forecast performance for cost of a dam is enhanced. It follows that if the cost performance of dams can be improved, the quality of decisions made under a least-cost power expansion scheme will as much be better.

The notion put forward in Ansar et al. (2014) that the alternative ‘import and install’ renewable technologies can replace investment in dams lack merits as these technologies are very expensive. To date, these technologies in the developing countries can only be financially viable if the capital costs are subsidized by the advanced countries. If viewed from a country’s perspective, the economic net present values of such renewable energy technologies are even more problematic.

5.4.1 Using the RCF technique to improve the quality of investment decision on dams

Following the steps outlined in Flyvbjerg (2006) study, as applied by Ansar et al. (2014) for forecasting the actual cost of dams, the derived probability distribution of cost overruns across the reference groups identified are used to determine the level of uplift that would be required at appraisal point, to account for uncertainty in the cost projections for dams. Table 18 shows that to take an outside view in planning for a typical dam to be built in Africa, if the level of risk tolerance for the decision maker is set at most 10 percent deviation of actual cost of dam from its appraisal estimates, 47 percent of the projected cost estimate would be required as uplift to neutralize the possible effect of uncertainty/bias on project cost. If the decision makers are neutral to risk and would take a 50-50 chance on the accuracy of cost estimates to be used in justifying the economics of investments in a dam project, 23 percent uplift may be adequate. Figure 15 illustrates the appropriate uplift that would be required on sponsor's estimates of cost for dams in Africa.

Table 18. Required uplift according to minimum acceptable level of regrettable choice

Reference Class	Level of Tolerance for Risk	Uplift Required
Africa	10%	47%
	20%	39%
	50%	23%
Latin America	10%	117%
	20%	95%
	50%	48%
Asia	10%	54%
	20%	40%
	50%	13%

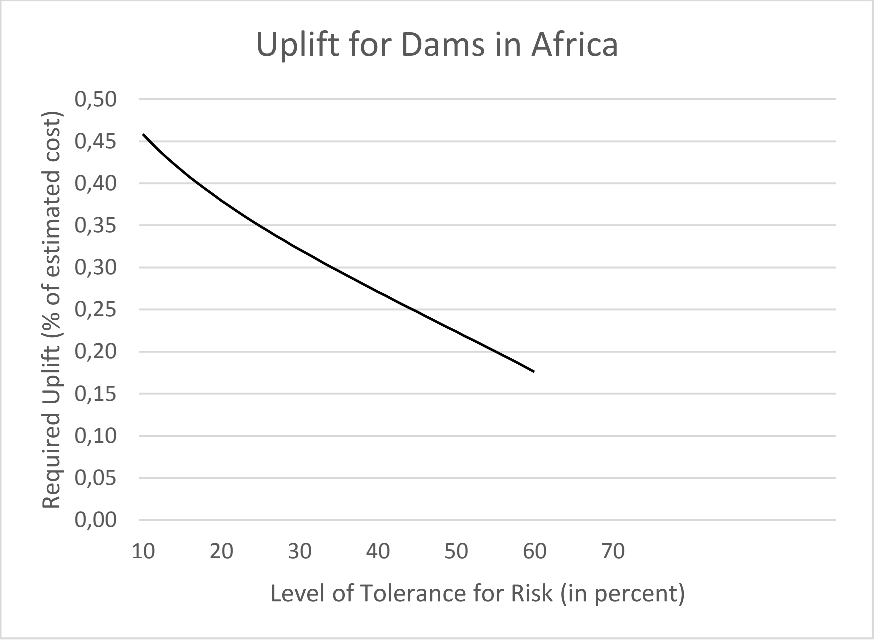

Figure 15. Required uplift in project cost proposed for dams in Africa

For a dam that is proposed by a country in the Latin America, project planners and decision makers would need to be more careful of sources of exposures to both random events and optimistic parameters used for estimating project cost. Following the probability distribution of errors in forecast for the region, Figure 16 shows that a hydropower project appraised with 10 percent tolerance for forecast error would need an uplift of 116 percent of the sponsor's estimate, and 90 percent uplift for 20 percent level of tolerance for risk in order to minimize the adverse effect of uncertainty and bias in the construction cost of the dam. Figure 17 shows the required uplift for various level of tolerance for risk in embarking on large hydropower projects.

The experience of dam investment in the Latin America supports the fact that hydroelectric source of power is very economical and sustainable, as the region shows the highest ex-post economic rate of return, average at 24.3 percent.

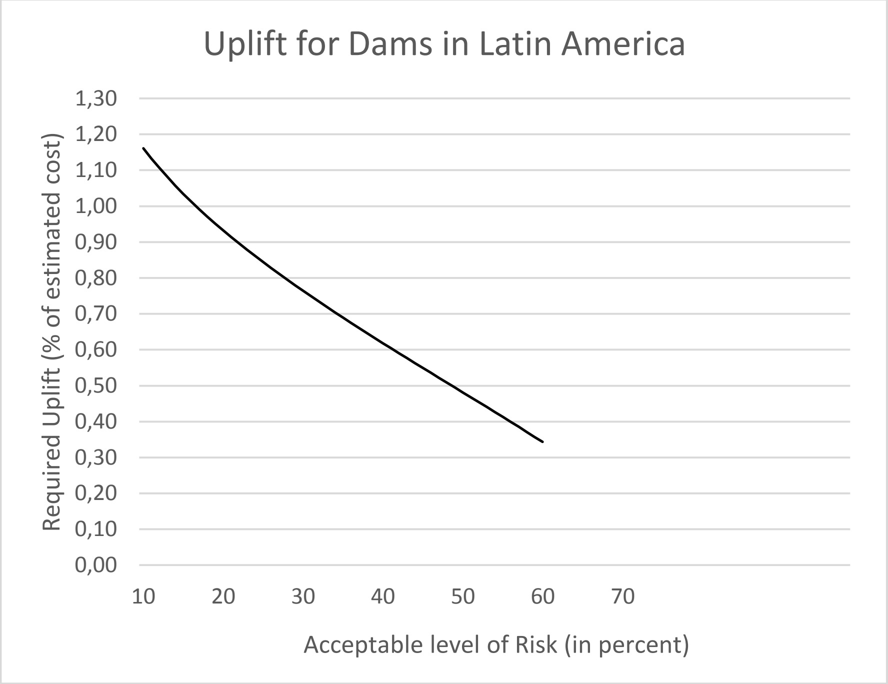

Figure 16. Required uplift in project cost proposed for dams in Latin America

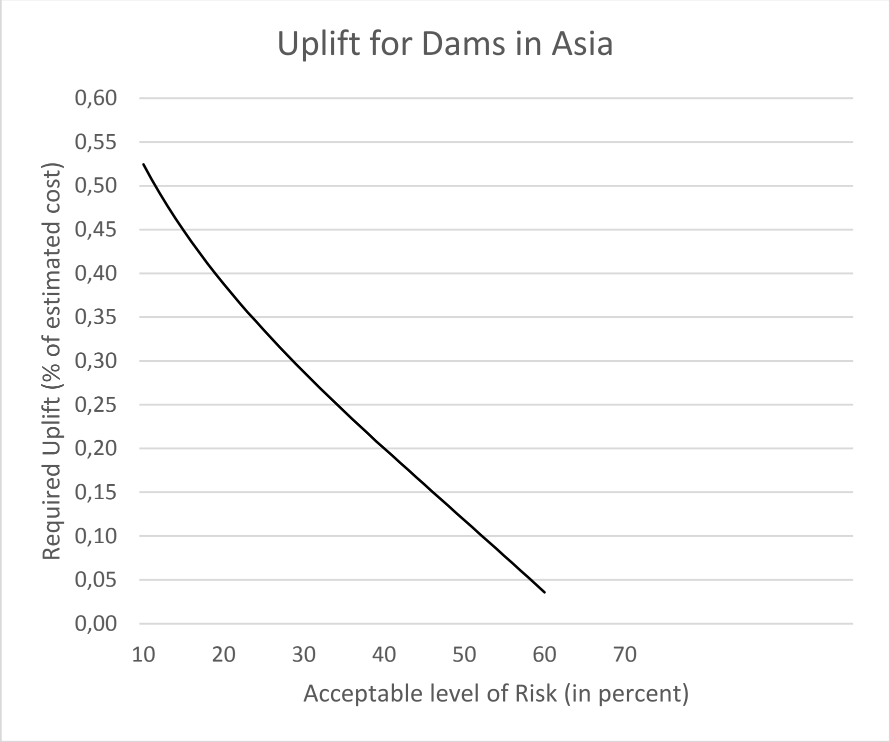

Figure 17. Required uplift in project cost proposed for dams in Asia

5.4.2 Limitations to the use of RCF Technique in dam investment

The information provided by the reference groups may likely not give a perfect indication of future events since they are just samples collected for representing previously completed projects. Moreover, whether the reference groups are samples or population of a complete set of information from past projects, there is a probability that outliers exist in the distribution of forecast errors. Fundamentally, the level of significance for outliers in a statistical sample approximates zero-percent. Hence, if a proposed dam investment eventually fall within the insignificant region where outliers exist, the adjustments made by the RCF methods may show very weak predictive powers.

Lastly, while the reference class forecasting technique is capable of capturing the dynamics of a system that is used to make projections at appraisal stage, the dynamics of the system might have changed over time. For instance, most of the Latin America projects covered by this study were completed around the 1980s to early 1990s, period of hyper-inflation and currency devaluation and foreign debt sanctions in the region. This have changed for the region is now well stabilized. If a proposed dam for the Latin American region is appraised based on a reference class of data that falls within that troubled era, the uplift for that period may be excessive penalty on the proposed dam. Bacon et al. (1996) was able to identify this factor as a key element in estimating the cost of power projects.

5.5 The Bujagali Hydropower Dam

In this section, we make a practical illustration of the usefulness of the RCF in investment appraisal for large hydroelectric projects. The case study selected is one of the controversial dams financed by World Bank after WCD in 2000 published their findings on dams and development. The controversy over the Bujagali dam was mainly based on environmental and social grounds, and also the high cost of the dam. The hydropower facility was successfully completed in 2012 at an extra cost of 50 percent, in constant prices, over what was initially budgeted for the project.

5.5.1 Background of the Bujagali Dam Project

Owing to the energy crisis that confronted Uganda during 1990s, a number of electricity projects, including the Bujagali hydropower, were conceived (Gore, 2012). The Bujagali Hydroelectric project is a private power generation, run of the river scheme, developed to increase the energy supply through the national grid of Uganda. It has a rock-filled dam of about 30m height with the powerhouse complex located along the Nile river basin. In the 1999, an American power company, AES, signed an agreement with the Ugandan authority to construct the storage dam and a powerhouse. At the initial phase of the planning of the investment, the World Bank had agreed to support the implementation of the project financially. In the process of preparing the project, however, there were major issues raised by opposing parties, ranging from high power pricing agreement, to bribery allegations. There were also opposition from various environmental and social groups regarding the social impact of the project, especially the poor populace that would be directly affected by the dam. Due to the opposition from the environmental groups, the AES was pressured to withdraw from participating in the largest single private infrastructure investment in Uganda.

Subsequently, the Ugandan authority initiated a re-bidding process which later saw the Bujagali Energy Limited as a preferred sponsor for the hydropower generation facility. The Bujagali Energy Limited is a Special Purpose Vehicle (SPV) established as an overseeing company, a collaboration between the Sithe Global Power Company and Industrial Promotional Services (IPS), to build and operate the hydropower facility throughout the contractual life of the project. The construction of the dam and power house at Bujagali eventually started in June 2007 (AfDB, 2010). The project was mainly financed by loan, 79 percent of total investment cost. The loan financing were partly supported by the World Bank/IFC, the African Development Bank, and the European Investment Bank (Bujagali SAR, 2007).

The dam which is located at Dumbbell Island has 5 x 50MW generator installed, amounting to a gross capacity of 250MW of electricity system (Bujagali SAR, 2007). At the conception of the project, the objective is to utilize the water resource endowment of Uganda to provide electricity at a low cost relative to the generation cost of USc 25 per KWh which was attainable from the emergency thermal plants by that time.[28] The dam was to double the total power generation through the utility grid and replace as much as possible, the most expensive running thermal plants.

5.5.2 The problems in forecasting the cost of Bujagali Dam

The Bujagali Hydropower plant was proposed at a period when the controversies on dam was at the peak, just before the setting up of the WCD in 2000. The proposal to construct the hydroelectric facility commenced in 1999 (NAPE Uganda, 2012). By the time the project pre-feasibility studies was completed in November 1999, the cost of

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[28] As a result of delay in the Bujagali dam project and the continuous effort by the Ugandan authority to meet the growing demand for power, several emergency thermal generators were launched to supply electricity to the national grid. Because of the reliance on diesel fuel to generate electricity, the generation cost of electricity by the utility, UETCL, was very high, averaged 25 USc/KWh (Gore, 2012).

the project was estimated at USD 450m, later revised upward to USD 530m by the contractor.

In November 2001, the World Bank appraised the project to require a total investment cost of USD 582m (Bujagali SAR, 2001). By 2002, the contractor was locked in financial crisis and withdrew from the arrangement amidst a lot of controversies in the environmental assessment and corruption charges against some of the key officials. As a result of the long period suspension of the project, the World Bank reappraised the project in April 2007 to an investment cost of USD 799m (estimated USD 735m without financing) - a cost escalation of about 37 percent even before commencing the construction of the dam. The construction of the dam fully commenced in 2007 and the project was completed in August 2012 at a total value of USD 902m (USD 858m when deflated to 2007 real prices). By completion the Bujagali hydro-dam investment had incurred a total real cost overrun of 50 percent on the original appraisal estimate, and about 19 percent overruns on the re-appraisal value. One likely cause of the significant difference between the cost estimate at initial appraisal and reappraisal is the boom in commodity market that saw the international price of metal increase by up to 90 percent from 2000 to 2007 period when the reappraisal was carried out. This had major impact on the cost of equipment and construction materials.

In this case study, three main problems can be identified as the origin of the cost overruns experienced by the project. First, there was strategic misrepresentation of the cost of the project due to political interest of the Ugandan government at the feasibility phase (Bosshard, 2002)[29]. Second, the planning of the construction of the dam was poor and unduly prolonged. This obviously had unfavorable impact on the cost of the dam. The major part of the exposure of the project to uncertainty was in the civil works which took about 65 percent of the total cost of the project (Bujagali SAR 2007). The civil works and engineering cost of the dam had risen from USD 315m estimated in 2001, to USD 511m reappraisal estimate in 2006.[30] Lastly, the budget for the social and environmental mitigation plan was a source of cognitive bias. Without adequate consultation with the locals on site where the dam was planned to be located, a budget was prepared for resettlement. The original project plan had prepared an optimistic budget of USD 12m for resettlement, but after much pressure from the environmentalist, the cost of resettlement and mitigation against negative environmental impacts of the dam was revised to USD 25m (IFC/PPA 2007)[31].

While the IFC independent project consultant had professed the possible impact of uncertainty on the total project cost of the Bujagali to be bounded within 10% range from the projected cost, the actual deviation at completion had crossed 50%.[32] With a 10 percent bound on cost of uncertainty, we would have expected that the decision to build the Bujagali dam be based on an expected investment cost of USD 640m. The 10% provisions for uncertainty, about USD 58m, then would have covered for possible optimism in parameters and the unknowns. Assuming that we follow the

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[29] http://www.internationalrivers.org/resources/irn-comments-on-bujagali-large-hydro-project-uganda-3280

[30] Expression in current market price as stated in the appraisal report.

[31] International Finance Corporation (2007). Bujagali II: Economic and Financial Evaluation Study, Final Report. Prepared by Power Planning Associates Ltd.

[32] See the IFC/PPA 2007, p74.

prescriptions for required uplift for projects implemented in Africa, as depicted on Figure 15, the rightful adjustment to the projected cost for a 10% tolerance for risk, would have been 46%. With the 46% uplift, the de-biased cost of the Bujagali dam is estimated to be USD 849m. Even, if the decision makers had taken a neutral position on risk and decide to build the dam based on a 50-50 chance that the cost of the hydropower project used in the planning would exceed the appraisal budget, a logical uplift to cover for uncertainties would have been 23% of the USD 582m estimated during appraisal.

Table 19. Project Indicators, pre- vs. post-construction period.

Bujagali Project Parameter	**Appraisal 2001**	**Re-appraisal 2007**	**Actual 2012**
EIRR	23.7% (90% interval at 18.4-27.8%; hydrologic uncertainty could take down to 14.7%) SAR 2001	22% (90% interval at 11.3-26.4%; hydrologic uncertainty and fuel price risk identified could further change ERR) SAR 2007	Computed as 18.2% based on current electricity market scenario
Dam height (m)	30m	30m	30m
Project cost (2008 real USD)	USD 582 million	USD 735 million, excluding financing charges	USD 902 million
Length of construction/CoD	44months from sept.2005	44months	54 months
No. of turbine units	5 x 50 MW	5 x 50 MW	5 x 50 MW
Installed capacity (MWe)	250 MW	250 MW	250 MW
Generation capacity (MWh)	1.615 million	1.822 million	1.385 million (ramp-up), worse case forecast 1.198
Share of foreign input in project cost, in percent	87%	66% (IFC/PPA 2007, p105)	unknown
Contingencies USD	Physical (9.7), Price (9.0)	Physical (18), Price (23)	Real overrun (USD 272 million), Actual price escalation (USD 47 million)
Resettlement cost	USD 11.9 million Include compensation to 1288 Households to be displaced by project.	USD 25 million Include financial compensation to 1288 households directly affected by the dam	Yet unknown
Tariff, real USc	0.09 USc/kwh (cost reflective, fixed capacity payment and usage), if unserved, 38cents/kwh	Average 12 USc/kwh and expected to further decline 13 years into operation	Bulk price 12-16cents/kwh. Thermal plants 24-36cents/kwh

A comparison was made of the results of the reference class for large dams as used by Ansar et al. (2014), with the regional reference classes used in this study, also assuming that the risk tolerance of the institution is 20%. While the Ansar study would have required an uplift of 99% on the appraisal estimates to account for bias the outcome of our analysis would suggest an uplift of 39%. For the Bujagali case study, the regional experience seems to provide better view of uncertainty since the 39% uplift suggested by this study is closer to the actual real cost overrun of 50% than the 99% suggested by the Ansar study. It is however very likely that the source of disparity in the findings be traced to the source of data as these study focus only on World Bank data and the case study is also an out-of-sample project which was co-financed by the World Bank.

5.6 Conclusions and Policy Implications

This study have shown that errors in forecast are eminent in hydropower construction and can be further driven by complexity due to size of the generating facility. Delays in completing the physical structure of this set of infrastructure project and the commitment to using foreign inputs in the construction of the dam also contributes to the problems of mis-forecast. Further analysis suggests that the extent to which size of project impact on cost overruns differs significantly across the regions. While cost uncertainties is an unavoidable risk in hydropower planning, there are incentives to ensuring that the cost estimates used for reaching decision to build a dam are reliable and have substantially accounted for uncertainty in planning. It creates a framework for efficient allocation of scarce economic resources. The improvements in forecasting the cost of a hydropower project, perhaps, will be more justified in cases where the expected benefits from the hydro dam are obvious.

The application of the RCF technique to power planning is no doubt a promising methodology in solving the issue of bias in cost projections. Our analysis shows that if a planned investment in hydropower fits reasonably well into one of the reference class formed for this study, provided that the dynamics of the system during the period covered by this study are still reliable in the current period, then the prescribed uplift from the RCF illustration will provide a more reliable estimates of the cost of a dam that would be used in justifying the decision to build the dam.

Under this framework, decision makers are more informed about the likelihood of overruns in the cost estimates for hydropower projects and if the expert opinions - the inside views – used for appraisals will be guided by the benchmarking provided by the ‘outside views’, the cost overruns due to strategic misrepresentation and/or cognitive bias may be reduced. The Bujagali hydropower showcases the relevance of the technique to modern day CBA.

5.6.1 Policy Implications

With the substantial evidence of the difficulty in forecasting the cost of a dam, there is need to address the issue of bias/uncertainty by performing a rigorous quantitative risk assessment for any planned investment in hydro dam. The decision making framework need to consider adequate margin on ex-ante cost to account for uncertainty. To this end, the policy implication of this study is that, the bias in cost estimates of hydropower projects can be significantly reduced using the process of adjustments that follows from the RCF model.

Two practical ways of integrating the RCF methodology into investment appraisal of hydropower projects can be through setting up a reserve account to the amount of uplift required on cost estimates, based on the probability distribution of an appropriate reference group of projects. This account would cover for mishaps during the implementation of the project. For instance, the Bujagali dam that was built in Uganda follows the reference class of projects implemented in Africa and would have required up to 46 percent of the appraisal estimates in a reserve account for contingency capital expenditure if a risk tolerance of 10% was acceptable to the World Bank. The project actually ended up with a cost overrun of 50%, an indication that the reserve account of 46% would have covered substantially the rising price of the project.

Given that the establishment of a reserve account could put the hydropower project at a disadvantage in a least cost power system, an alternative way of applying the RCF method is by permitting an impartial sensitivity analysis for cost overruns that recognizes the empirical probability distribution derived from the RCF exercise as the likely magnitude of error in cost estimates. The standard ±10 or ±20 percent often applied by financing agencies for project appraisal may not be logical for evaluation of hydropower investments as the results in this study shows that about 60% of the projects implemented had incurred cost overruns exceeding 20% of the estimated real cost.

The information expressed by this analysis are particularly in the perspective of the financier as the decision maker and can be used for utility system planning that considers wide range of uncertainties/risks as part of decision framework under a least-cost power scheme. It could also be of use to government agencies appraising hydropower investments. The probability distribution of errors in forecast provided by the reference class of projects can give an indication of what limit of overruns the policy makers are able to contain and ensure that project managers are well informed of the consequences of cost overruns to the sustainability of the project. If the expected benefits from the hydropower dam is not very substantial, or the likely incidence of uncertainty are large enough to cause financial problems for the project, then it will be important that the decision maker take a very low level of tolerance for risk or consider an alternative investment plan.

It is important to note that relying on this technique of forecasting can also be misleading. The constructiveness of the technique depends to a large extent on the professional instinct of the analyst/planner in identifying the source of risk and whether the reference class selected provides a logical frame that conforms to the realities with the proposed dam investment. Deciding the level of tolerance at this stage is not standardized as it depends on the institution’s perception of the project. For instance, a relatively low tolerance for risk/uncertainty may be justified for a new dam proposed in a country without any prior experience with dam construction. Also, the contractor given the responsibility of implementing the project may be considered as a factor in deciding the degree of tolerance for forecast error.

Finally, while this study illustrates the RCF technique as a prescriptive tool for improving the credibility of decisions under uncertainty as peculiar to investments in hydropower dams, the due diligence during implementation would still be necessary to ensure that the project managers are not incentivized to be reckless.

Chapter 6

SUMMARY, CONCLUSIONS, AND POLICY RECOMMENDATION

6.1 Introduction

This dissertation has focused on investigating the key issues associated with the construction of dams. Both theoretical and empirical framework were developed to analyze the topic and a unique methodology is put forward as a mechanism for addressing the various issues identified by the research. In this concluding chapter, I briefly re-address the research questions imposed on the theme of this study based on the empirical findings from the study, and then provide some policy perspectives to the study.

The history of cost and time overruns in dam investments are among the common factors that are often cited by opponents to the construction of dams. In particular, biased cost estimates used in justifying the economics of building these structures, in recent times, has been put at the forefront of the argument against dams. The implication of this bias in cost estimates of the dam is that the decision to build lacks merit. Nevertheless, whether or not the decision to build are justified is not just a matter of looking at the poor performance of the cost estimates used for decision but also, we should consider the benefits side. While the former has been the theme in major studies, this dissertation balances the views by providing an empirical indication of the actual benefits of the dams financed by the World Bank. By so doing, I substantiate with evidence the worthiness of building more dams.

6.2 Summary of Major Findings

To address some of the research questions developed for this study, I summarize the key content of the questions as follows:

i. Are cost and/or time overrun a commonality in hydroelectric projects?
ii. How dynamic are the errors of cost projection in the past and what are the sources of these problems? Is cost underestimation caused by weak planning, poor project management, or strategic deception by promoters, a factor Flyvbjerg (2002) refers to as “lies”?
iii. What magnitude of overruns would make investment choice on hydropower irrational considering the existence of an alternative thermal facility under the “least alternative cost” principle?
iv. Are dams actually worth it as a mechanism for economic development?

Prior to investigating the problems with dams, the chapter 2 gives a theoretical perspective of risk and uncertainty and why this may be unavoidable in large infrastructure projects such as hydropower dams. The fact that a large portion of capital expenditure is on civil works which usually entails a complex designing and a long term implementation, this type of projects will be exposed to uncertainty. While the common risk such as pricing, market demand, etc., can be mitigated through contractual agreements between the sponsor/government authorities and contractors, the uncertainty involved in construction of dams are quite difficult to model and can be very costly for a single party to carry. Apparently, the decision to build becomes irreversible once construction is initiated. As a result, there is an incentive to ensuring that adequate preparation has been made to cover for the cost of uncertainty.

Are cost and/or time overrun a commonality in hydroelectric projects?

In response to the first research question above, the empirical findings from this analysis is straight forward. Cost and time overruns are common experience in implementing hydropower dams. The severity of the cost issue is diffused into two major cases: the regional characterization and the complexity in terms of size of the generating plants installed on-site of the dam. The findings for cost overruns shows that projects in the Latin America are more prone to cost overruns than projects in the other regions. More than 80% of the dams implemented in the Latin America region had a cost overrun of over 20%. When comparing the results for Latin America to those of the other regions like Asia, Africa, etc, just about 50% of projects had their actual cost exceed the estimated cost by 20% and above. On an average, weighted to the installed capacity of the individual projects in the region, Latin America had real cost overrun of 54% for the subset of projects analyzed for the region, compared to 23% average in Africa, and 19% in Asia.

In addition to the regional manifestation of overruns, complexity in terms of the size of installed capacity, has also been identified as a factor that exacerbate cost overruns. This study makes two interesting findings in this direction. First, results from chapter 3 failed to show that larger dams are more likely to have cost overruns. The chapter 5 of this work, however, reveals the contrary, that is, cost overruns is positively linked to size of plant on dam site. The conflicts in the findings from the two chapters was resolved with the multilevel regression model used in the chapter 5 as it shows that cost overrun is positively linked to size for most of the regions except for Asia where size had a negative relation with cost overruns. This finding suggests that larger dams are more carefully planned in Asia. The dams constructed in the Asian region had more experience with time overruns when compared to the other regions. This might as well indicate that the credibility of the process of planning a dam is not compromised in the region as more time than expected is put into preparation of the project.

> How dynamic are the errors of cost projection in the past and what are the sources of these problems? Is cost underestimation caused by weak planning, poor project management, or strategic deception by promoters, a factor Flyvbjerg (2002) refers to as “lies”?

Whilst cost overruns could be logically attributed to randomness in parameter values, the results from this analysis of 58 dams financed by the World Bank points to the fact that the errors in projecting the cost of a dam follows a systematic pattern rather than a random process, and the estimated cost of these projects have been systematically biased below the actual completion cost of most of the projects. This findings adds to the body of evidence that cost used in making decision to build, at the appraisal phase, often lack merit and so there is support for the Flyvbjerg (2002) findings that cost overruns can be attributed to strategic deception by the project promoters or perhaps the sponsors are just deluded in their expectations. The perspective of strategic deception is that when political authorities are involved in planning or are interested in a project, they tend to influence the process of decision making sometimes by misrepresenting the cost of the dam to make it attractive for financing approvals. This is a common principal-agent problem in planning.

Considering the pattern of cost overruns, another possible explanation for the significant positive bias in cost estimates can be attributed to the psychological/human factor. Since there is no clear involvement of government in all projects, the errors might be genuinely attributed to cognitive bias in judgment about uncertain events. This explanation for overruns was discussed by Kahnemann and Tversky (1979) in their famous ‘Nobel prize’ winning study – the Prospect Theory. A major problem in hydropower planning arise when certain assumptions about an uncertain event must be made in order to proceed to the decision stage of the project cycle. The notion here is that experts opinion are based on a best guess and so, the assumptions made about risk parameters do not adequately feed-in information about uncertainty. The experts tend to be overly optimistic in their assumptions about some parameters.

What magnitude of overruns would make investment choice on hydropower irrational considering the existence of an alternative thermal facility under the “least alternative cost” principle?

The findings from the chapter 4 of this study helps provide a response to this question. The economic justification for building the dams is that economic rents exist for such investments. The problem identified in this research is that there is a significant deviation of the actual net gains from these dams from the ex-ante net gains estimated for the individual projects. On an average, the ex-ante benefit/cost ratio for the portfolio of 58 dams estimated by this study is 2.0x; whereas, the actual benefit/cost ratio from these dams is 1.5x. For the portfolio, if the incidence of cost overruns had taken the ratio below 1.0x, then the economic justification for building dams would have been invalidated. However, the question of what magnitude of overruns renders a dam unviable will depend on individual case since each dam has a unique feature.

Are dams actually worth it as a mechanism for economic development?

Even though this portfolio of dams suffered substantially from cost overruns, the net contribution of these dams has been positive and substantial. The ex-post real economic rate of return for the entire portfolio is estimated to be greater than 14 percent. Therefore, the magnitude of failure in cost projections has not prevented these dams, in the vast majority of cases, from being economically beneficial investments. Aggregated over the portfolio of 58 dams, the economic NPV of the set is at least US$ 505 billion. This is an evidence of the contribution of dams to the economic development of the countries where the dams where constructed. In fact, if the dams had not been constructed, the economic cost of generating and supplying an equivalent amount of electricity to these societies would have been much greater than the actual cost of the hydropower dam projects. Thus, the notion put forward in the literature that hydro dams should not be built because they suffer from cost overruns (Ansar et al., 2014; Sovacool et al., 2014) does not necessarily hold based on the findings from this research.

Highlights of major findings:

- Average real cost overruns were 27% (σ=0.38), cost of currency devaluation, 3% (σ=0.021); and the cost of time overruns computed as 3.5% (σ=0.032) of ex-ante costs.
- Complexity in planning dams makes it prone to forecast error. Therefore large dams need to be carefully planned to reap the benefits of economies of scale
- The PV of benefits produced by this portfolio of 58 dam was 1.5 times the PV of the costs. The ex-ante BCR was 2.0x.
- Dams are economically marginal projects and so, the risks of cost overruns must be evaluated in relation to projected benefits of hydropower project.

These findings seem to suggest that power planners/decision makers need to widen their scope on risk/uncertainty assessment of dams and provide a framework that adequately treats the issue of the unknowns in relation to the potential benefits expected from the proposed dam.

6.3 Using the RCF Technique to Improve Cost Projections for Dams

The common experience with cost overruns shows that predicting the cost of dams is quite difficult. Also, the systematic pattern of the distribution of cost overruns suggest that the method of forecasting the cost of a dam can be improved by incorporating an adjustment mechanism that would de-bias the biased cost estimates provided by sponsors. Using a standard scalar with a fixed margin for bias in cost estimates can make the cost estimates used for decision more credible and unbiased. The choice of margin, however need to be consistent for projects that share similar features.

The reference class forecasting technique has been developed in this study within the framework of power investments taking a perspective of the financier/utility planner as the decision maker.[33] There could be a strain to the system if this type of rigorous risk analysis is not performed for the hydropower project, the investment strategy for power expansion may not be optimal. In other words, the consequential cost of uncertainty might invalidate the economic justification of hydropower as the choice for expanding the system where an alternative strategy could have yielded better outcomes.

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[33] *see* chapter 5

Using the reference class technique, the likely magnitude of cost overruns can be predicted with credible intervals, for a proposed dam. This method of quantifying cost overrun risk is illustrated in the chapter 5 of this dissertation with the Bujagali dam as a case study.

Three key questions posed for the Bujagali study are as follows:

i. Is the Bujagali project different from other dams in terms of cost misforecast?
ii. Are the benefits real?
iii. Is RCF relevant?

In terms of cost misforecast, the Bujagali project had incurred an extra budget of 50% of the initial estimates by the time the project was completed. Is this project different from other "controversial" dams? Not exactly. The findings from this study further investigates the benefit side. Using the current market scenario, a downtime in the oil market, the economic rate of return on the actual investment is estimated at 18%. This does not include any of the externalities associated with a dam. The results shows that hydro benefits are real for this case.

The Bujagali hydropower project had initially been projected to cost USD 582m in 2001, but the project was eventually completed in 2012 at an actual value of USD 902m (USD 858m in real prices). The application of reference class forecasting technique to this case suggests that an upward adjustment of 46% of the estimated cost would have been hypothetically required to de-bias the estimated cost that was used in making decision to build. With an actual real cost overrun of 50%, there is little doubt that the RCF technique will be a successful tool for managing the risk of cost overruns in hydropower planning. The RCF framework is constructed to provide robustness to the outcome of CBA models. Following the indications from the outside views, the decision makers can be guided on how much to rely on the estimates obtained through expert opinion. The framework does not ignore the importance of expert opinion in investment analysis, rather, it attempts to support the decision making framework by providing more accurate information about uncertainty and possible bias in human judgment.

The use of Multi-level regressions in deriving the empirical distribution of errors in forecast makes it possible to stream project features into a hierarchical structure. For instance, in this study individual projects have been nested into regional subgroups. The regional referencing of the projects in this case assumes that cost performance and project characteristics are quite similar for projects from the same region. Ansar et al. (2014) applied the technique to a reference of large dams. The distribution of error in forecasts for the various reference group provides an indication of the likely magnitude of cost overruns, which is a very useful benchmark for testing the sensitivity of estimated project outcomes to cost overruns. It is also a useful tool for contingency planning.

> "The mistake is thinking that there can be an antidote to the uncertainty."
> ― David Levithan

6.4 Recommendation

The high degree of variability and uncertainty of costs in dam construction raises the question of what improvements in the appraisal and project selection methodology would help improve the quality of decisions in power planning. Before making a decision to build a dam, the decision maker need to perform a thorough investigation of cost projections and reliability of estimates provided by sponsors of projects at the appraisal phase and high priority should be given to dams that the ex-ante analysis indicates that they are very low cost or marginal benefits are very high. One way to perform such thorough investigation is by carrying out an impartial sensitivity analysis that recognizes the uncertainty in estimating the construction cost and time for the dam, and to use this analysis to stress test the robustness of the project economic justification. Under this approach, uncertainty about cost and time estimates is treated in a larger framework than when it is treated alone.

Finally, this analysis has shown that each hydropower project presents its unique features in terms of benefits, costs, and risk/uncertainty. Therefore, one should not view all hydro dams as being too risky to undertake. A critical variable is the value of the benefits they will produce, and at what range of costs. If the benefits are large enough to cover for the expected costs, including the margin for cost overrun risk, such investments can very well be worth undertaking.

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APPENDICES

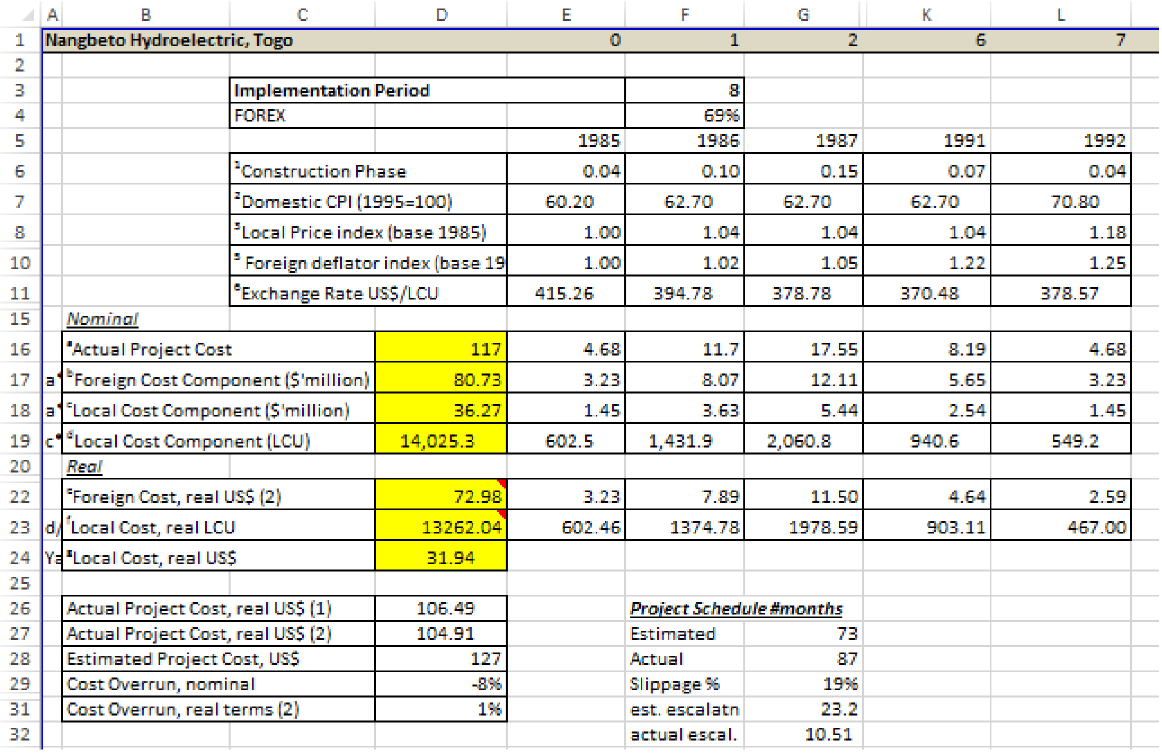
Appendix A: Step-by-Step Procedure for Deriving the Real Cost and Benefits

A. Estimating the real cost overruns for hydropower dams

World Bank ICRs provide actual cost and estimated cost of the dam in nominal USD. The estimated nominal cost include both provisions for price escalation and physical contingencies. Also, there is a projection of what portion of project spending will be in foreign currency.

A. Estimated Real Cost: real estimate is simply the estimated nominal less provisions for price escalation (we include physical contingencies as part of the real cost estimates.

B. Actual Real Cost: given the picture below, the procedure follows.



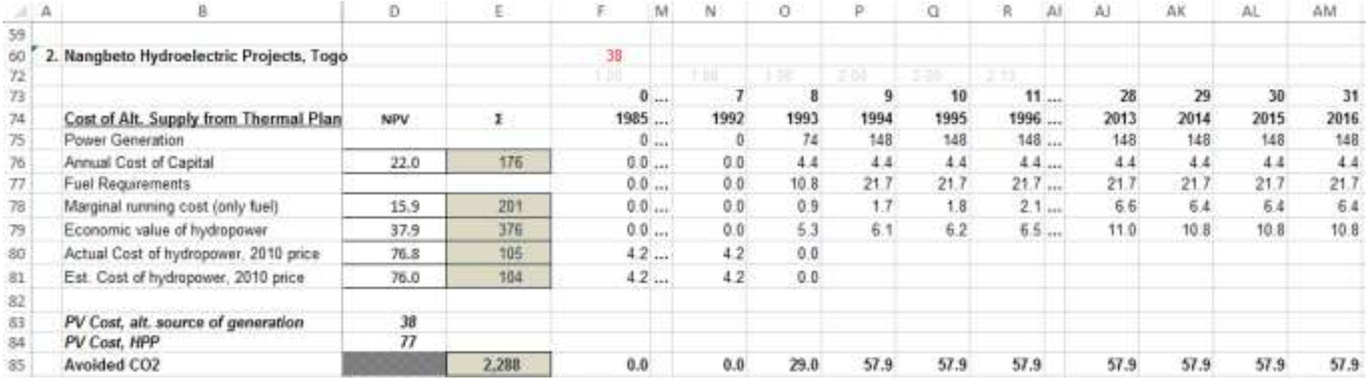
	A	B	C	D	E	F	G	K	L
1	**Nangbeto Hydroelectric, Togo**				0	1	2	6	7
2									
3			**Implementation Period**			8			
4			FOREX			69%			
5					1985	1986	1987	1991	1992
6			[1]Construction Phase		0.04	0.10	0.15	0.07	0.04
7			[2]Domestic CPI (1995=100)		60.20	62.70	62.70	62.70	70.80
8			[3]Local Price index (base 1985)		1.00	1.04	1.04	1.04	1.18
10			[5] Foreign deflator index (base 19		1.00	1.02	1.05	1.22	1.25
11			[6]Exchange Rate US$/LCU		415.26	394.78	378.78	370.48	378.57
15		*Nominal*							
16		[a]Actual Project Cost		117	4.68	11.7	17.55	8.19	4.68
17	a	[b]Foreign Cost Component ($'million)		80.73	3.23	8.07	12.11	5.65	3.23
18	a	[c]Local Cost Component ($'million)		36.27	1.45	3.63	5.44	2.54	1.45
19	c	[d]Local Cost Component (LCU)		14,025.3	602.5	1,431.9	2,060.8	940.6	549.2
20		*Real*							
22		[e]Foreign Cost, real US$ (2)		72.98	3.23	7.89	11.50	4.64	2.59
23	d/	[f]Local Cost, real LCU		13262.04	602.46	1374.78	1978.59	903.11	467.00
24	Ya	[g]Local Cost, real US$		31.94					
25									
26		Actual Project Cost, real US$ (1)		106.49		***Project Schedule #months***			
27		Actual Project Cost, real US$ (2)		104.91		Estimated	73		
28		Estimated Project Cost, US$		127		Actual	87		
29		Cost Overrun, nominal		-8%		Slippage %	19%		
31		Cost Overrun, real terms (2)		1%		est. escalatn	23.2		
32						actual escal.	10.51		

1. Given the actual completion cost cell D16, extracted from the ICRs (nominal USD), I spread cell D16 over the actual construction period.
2. I separated the annual construction spending (row 16) into foreign (row 17) and local cost (row 18) components to be able to deflate with appropriate price

index. The share of foreign component is available in the SARs (cell F4), and so for instance, the actual foreign cost is simply derived by multiplying the annual construction spending (nominal USD), by the forex share percentage.

3. Since we got foreign cost and local cost separated, to get the actual real foreign cost (row 22), we deflate the foreign cost (row 17) to year zero- the start of construction- by diving with US deflator (row 10).
4. The local cost component (row 18) is stated in USD nominal and so, we adjust to nominal local price (row19) by multiplying row 18 by corresponding market exchange rate (row 11) for each period. Then the real local cost in local currency units (row 23) is derived by dividing row 19 with domestic price index (row 8) using start of construction as base year.
5. The end of step 4 gives real local cost in local currency unit. Therefore, the real local cost in USD (cell D24) is derived by taking the total sum of real local cost (cell D23), which is estimated in LCU, and then divide by year zero exchange rate (cell E11).
6. Actual real cost in USD (cell D27), is a sum of D22 and D24.

B. Derivation of the Economic Net Benefits of Hydropower Dams



	A	B	D	E	F	M	N	O	P	Q	R	AI	AJ	AK	AL	AM
59																
60	2. Nangbeto Hydroelectric Projects, Togo				38											
72																
73					0	...	7	8	9	10	11	...	28	29	30	31
74		Cost of Alt. Supply from Thermal Plan	NPV	Σ	1985	...	1992	1993	1994	1995	1996	...	2013	2014	2015	2016
75		Power Generation			0	...	0	74	148	148	148	...	148	148	148	148
76		Annual Cost of Capital	22.0	176	0.0	...	0.0	4.4	4.4	4.4	4.4	...	4.4	4.4	4.4	4.4
77		Fuel Requirements			0.0	...	0.0	10.8	21.7	21.7	21.7	...	21.7	21.7	21.7	21.7
78		Marginal running cost (only fuel)	15.9	201	0.0	...	0.0	0.9	1.7	1.8	2.1	...	6.6	6.4	6.4	6.4
79		Economic value of hydropower	37.9	376	0.0	...	0.0	5.3	6.1	6.2	6.5	...	11.0	10.8	10.8	10.8
80		Actual Cost of hydropower, 2010 price	76.8	105	4.2	...	4.2	0.0								
81		Est. Cost of hydropower, 2010 price	76.0	104	4.2	...	4.2	0.0								
82																
83		*PV Cost, alt. source of generation*	38													
84		*PV Cost, HPP*	77													
85		Avoided CO2		2,288	0.0		0.0	29.0	57.9	57.9	57.9		57.9	57.9	57.9	57.9

Discounted Cost of Hydro.

1. Using the outcome from 6 in section above, I spread the actual real cost (cell D27 of worksheet above) over a construction profile as seen in row 80 & 81 of the worksheet above, then calculated the PV (cell D80 and D81 for discounted actual real cost and estimated real cost, with base year as start of construction. For discounted estimated cost of hydro, I spread the estimated real cost

(without price contingencies), over the actual construction period and take the PV at year zero.

<u>Discounted Benefit of Hydro (Benefits: capex cc thermal, fuel savings)</u>

2. Real Price Capex. Capex is taking from Bahman’s paper. The average CAPEX for the projects (CC) is in 2010 USD price. Therefore, the real CAPEX for combined cycle plant at start of construction period is the 2010 CAPEX multiplied by deflator for year construction starts (base year indexing is 2010).
3. The outcome from 2 is used to calculate the annualized capital cost per KW using the PMT formula, 25 years operating life for thermal plant, and 10% discount factor.
4. The annual capital cost savings is derived by multiplying the annualized capital cost per KW, by using the installed capacity of hydro plant.
5. The fuel cost savings. Fuel requirement is estimated using 56% CC plant efficiency rating, and, given the projected output in GWh extracted from the SARs, multiply by the fuel litre/KWh to get total fuel requirement.
6. Fuel price data is annual series collected from IEA (1999, 2014), nominal USD per barrel. Price is then converted to nominal USD per litre
7. The price of fuel is adjusted to start of construction real price per litre by dividing the nominal price with US deflator (base year is start of construction period).

Sum-up 4 and 7, then discount to the start of construction year to get the discounted benefit.

Appendix B: Data log for projects used for the empirical analysis and the multilevel regression model

	Project name	Start of construction (a)	Dam height (in meters) (a)	Installed capacity (in MW) (a)	Time overrun (b)	Foreign share of total expenditure (b)	Real cost overruns (b)
1	Nangbeto Hydroelectric Projects, Togo	1985	40	63	20.0%	69.0%	1.1%
2	Gitaru HPP, Kenya	1974	136	145	17.6%	70.0%	48.6%
3	Kapichira Hydroelectric, Malawi	1992	54	64	-1.9%	79.0%	9.4%
4	Ruzizi Hydroelectric, Rwanda	1983	28.5	29.6	19.5%	80.0%	1.0%
5	Kiambere Hydroelectric, Kenya	1984	110	150	3.1%	48.0%	3.0%
6	Andekaleka Power Madagascar	1979	10	56	6.4%	81.0%	34.3%
7	Nkula II Project, Malawi	1976	51	56	20.0%	75.0%	26.9%
8	Mtera Hydroelectric, Tanzania	1984	59	80	39.4%	74.0%	62.2%
9	Kidatu Hydropower Plant, Tanzania	1976	172	200	15.9%	78.0%	28.6%
10	Sıdı Chero-Al Massıra Project, Morocco	1976	82	120	17.2%	54.0%	6.5%
11	Lupohlo 3rd Power Project, Swaziland	1981	29	20	18.3%	69.0%	25.3%
12	Volta River Hydroelectric Project, Ghana	1977	37	324	26.7%	60.0%	22.7%
13	Kpong Hydroelectric, VRA, Ghana	1977	20	160	20.0%	72.0%	27.6%
14	San Carlos I&II, Colombia	1980	75	1,240	16.5%	70.0%	24.9%
15	Fourth Guadalupe, Colombia	1981	125	213	23.5%	68.0%	24.5%
16	Playas Hydropower Project, Colombia	1983	65	200	56.3%	63.0%	1.2%
17	Rio Grande Hydroelectric Project, Colombia	1985	65	324	60.0%	62.0%	-0.3%
18	Itumbiara Dam, Brazil	1974	106	2,080	-3.4%	39.0%	50.5%
19	Pehuenche Hydroelectric Dam, Chile	1988	90	500	2.9%	57.0%	-39.8%
20	Yacyreta Dam, Argentina/Paraguay	1983	83	3,100	7.1%	60.0%	50.8%
21	Nispero Power Project, Honduras	1979	5	22.5	50.0%	55.0%	7.8%
22	Guavio Hydro Power Project, Colombia	1983	250	1,000	83.3%	64.0%	118.4%
23	Paulo Afonso IV Complex, Brazil	1974	35	2,462.4	35.4%	43.0%	72.1%
24	Aguacapa Power Project, Guatemala	1978	58	90	83.3%	60.0%	90.5%
25	La Fortuna, Panama	1978	60	300	25.4%	60.0%	176.6%
26	Chixoy Hydro-power, Guatemala	1978	108	300	25.0%	54.0%	31.9%
27	El Cajon Hydropower Dam, Honduras	1980	187	300	-3.3%	74.0%	94.3%
28	Aguamilpa & Zimapan power dam, Mexico	1989	203	960	40.0%	40.0%	38.9%
29	GaziBarotha Hydropower, Pakistan	1995	44	1,450	28.6%	63.0%	-0.9%
30	Cirata Hydroelectric Site, Indonesia	1994	125	500	17.2%	77.0%	-32.8%
31	Second Xiaolangdi Multipurpose Dam, China	1994	154	1,800	20.0%	46.0%	-0.3%
32	Kulekhani HPP, Nepal	1976	114	60	18.3%	86.0%	119.0%
33	Lam Takhong Hydroelectric, Thailand	1994	40.3	500	17.1%	75.0%	-36.7%
34	Yixing Pumped Storage, China	1983	47.2	1,000	17.1%	30.0%	11.5%
35	Saguling Dam Indonesia	1981	99	700	9.1%	53.0%	27.9%
36	Chungju Multipurpose Dam, Korea	1979	98	400	16.7%	46.0%	29.3%
37	Malaysia 9th Power	1980	33	72	40.0%	60.0%	-18.5%
38	Ban Chao HPP, Thailand	1975	140	360	10.8%	59.0%	-3.0%
39	Pattani Hydroelectric Project, Thailand	1977	47	72	11.1%	49.0%	-4.6%
40	Khao Laem HPP, Thailand	1980	90	241	14.3%	49.0%	12.3%

41	Yantan Hydroelectric Project, China	1987	110	1,100	8.0%	26.0%	-19.7%
42	Tianhuangping Hydroelectric Project, China	1993	72	1,800	-8.1%	55.0%	11.1%
43	Kerala Power Project, India	1986	32	180	31.3%	29.0%	39.7%
44	Shuikou I&II Hydroelectric Project, China	1986	101	1,400	5.8%	48.0%	27.6%
45	Daguangba Multipurpose Project, China	1992	52	240	37.5%	59.0%	47.8%
46	Marsyangdi Hydroelectric, Nepal	1986	108	69	11.4%	76.0%	20.3%
47	Nyaunggyat Dam, Myanmar	1981	73	56	17.0%	67.0%	10.3%
48	Lubuge Hydroelectric, China	1985	103	600	14.9%	33.0%	-5.2%
49	Upper Indravati Hydro Project, India	1983	73	600	38.3%	68.0%	30.5%
50	Ertan I, Sichuan, China	1992	240	3,300	-2.7%	58.0%	12.4%
51	Karakaya Hydropower, Turkey	1980	173	1,800	20.0%	52.0%	15.8%
52	Middle Neretva Hydro Project, Yugoslavia	1980	70	396	0.0%	50.0%	10.0%
53	Turkey - Sir Hydropower Project	1985	116	282	19.6%	47.0%	23.6%
54	Sigalda HPP, Iceland	1973	44	100	8.2%	63.0%	-12.8%
55	Berke Hydropower, Turkey	1991	201	510	36.1%	69.0%	19.1%
56	Yonki Dam, Papua New Guinea	1987	60	30	26.9%	53.0%	31.1%
57	Afulilo Hydropower project, Western Samoa	1987	29	6	73.8%	80.0%	94.8%
58	Wailoa Hydroelectric, Fiji	1977	60	80	5.0%	75.0%	19.1%

(a)Sourced from the World Bank SARs, ICRs

(b)Computed by author based on information extracted from World Bank documents

Appendix C: NPV for individual project

(in million USD, k = 8%)

Region	Project_id	Project start	Capacity (MW)	PV of Est. Cost (2014)	PV of Actual Cost (2014)	PV of Benefits (2014)	Net PV of Hydro (2014)	ex-post BCR
Africa	Nangbeto Hydroelectric Projects, Togo	1985	63	1466	1482	1377	-105	0.93
Africa	Gitaru HPP, Kenya	1974	145	7362	10937	13558	2621	1.24
Africa	Kapichira Hydroelectric, Malawi	1992	64	743	813	864	51	1.06
Africa	Ruzizi Hydroelectric, Burundi-Rwanda-CDR	1983	30	1220	1232	934	-297	0.76
Africa	Kiambere Hydroelectric, Kenya	1984	150	3769	3883	4604	721	1.19
Africa	Andekaleka Power Madagascar	1979	56	3367	4522	3271	-1252	0.72
Africa	Nkula II Project, Malawi	1976	56	3142	3986	4627	641	1.16
Africa	Mtera Hydroelectric, Tanzania	1984	80	1381	2241	2794	554	1.25
Africa	Kidatu Hydropower Plant, Tanzania	1976	200	3801	4889	11319	6430	2.32
Africa	Sıdı Chero-Al Massıra Hydro Project, Morocco	1976	120	5603	5965	6331	367	1.06
Africa	Lupohlo 3rd Power Project, Swaziland	1981	20	1072	1343	668	-675	0.5
Africa	Volta River Hydroelectric Project, Ghana	1977	324	7502	9202	21440	12237	2.33
Africa	Kpong Hydroelectric, VRA, Ghana	1977	160	8652	11044	11426	383	1.03
America	San Carlos I&II, Colombia	1980	1240	11223	14019	50502	36482	3.6
America	Fourth Guadalupe, Colombia	1981	213	3900	4855	9786	4930	2.02
America	Playas Hydropower Project, Colombia	1983	200	4032	4079	9467	5388	2.32
America	Rio Grande Hydroelectric Project, Colombia	1985	324	5068	5051	8637	3586	1.71
America	Itumbiara Dam, Brazil	1974	2080	34725	52278	132053	79775	2.53
America	Pehuenche Hydroelectric Dam, Chile	1988	500	5981	3603	15891	12288	4.41
America	Yacyreta Dam,	1983	3100	37093	55943	119983	64040	2.14

	Argentina/Paraguay							
America	Nispero Power Project, Honduras	1979	22.5	1690	1821	1001	-820	0.55
America	Guavio Hydro Power Project, Colombia	1983	1000	15805	34515	32754	-1761	0.95
America	Paulo Afonso IV Complex, Brazil	1974	2462	35057	71792	123559	51766	1.72
America	Aguacapa Power Project, Guatemala	1978	90	3235	6979	6772	-208	0.97
America	La Fortuna, Panama	1978	300	5759	15928	16495	566	1.04
America	Chixoy Hydro-power, Guatemala	1978	300	14014	18491	19012	521	1.03
America	El Cajon Hydropower Dam, Honduras	1980	300	10024	19473	13322	-6151	0.68
America	Aguamilpa & Zimapan power dam, Mexico	1989	960	9381	13030	20339	7310	1.56
Asia	GaziBarotha Hydropower, Pakistan	1995	1450	7885	7814	24970	17156	3.2
Asia	Cirata Hydroelectric Site, Indonesia	1994	500	1683	1131	7258	6127	6.42
Asia	Second Xiaolangdi Multipurpose Dam, China	1994	1800	11171	11132	25791	14659	2.32
Asia	Kulekhani HPP, Nepal	1976	60	2468	5406	3505	-1901	0.65
Asia	Lam Takhong Hydroelectric, Thailand	1994	500	2318	1468	4387	2919	2.99
Asia	Yixing Pumped Storage, China	1983	1000	7988	8904	19528	10624	2.19
Asia	Saguling Dam Indonesia	1981	700	12697	16240	24039	7799	1.48
Asia	Chungju Multipurpose Dam, Korea	1979	400	12925	17544	13062	-4482	0.74
Asia	Malaysia 9th Power	1980	72	5407	4407	2472	-1935	0.56
Asia	Ban Chao HPP, Thailand	1975	360	8488	8233	24783	16550	3.01
Asia	PATTANI HYDROELECTRIC PROJECT, Thailand	1977	72	5729	5464	4432	-1032	0.81
Asia	Khao Laem HPP, Thailand	1980	241	8675	9738	9297	-441	0.95
Asia	Yantan Hydroelectric Project, China	1987	1100	3918	3145	29725	26580	9.45
Asia	Tianhuangping Hydroelectric Project, China	1993	1800	3222	3580	18826	15246	5.26
Asia	Kerala Power Project, India	1986	180	3577	4998	4971	-27	0.99

Asia	Shuikou I&II Hydroelectric Project, China	1986	1400	8435	10766	29011	18244	2.69
Asia	Daguangba Multipurpose Project, China	1992	240	1184	1750	3107	1357	1.78
Asia	Marsyangdi Hydroelectric, Nepal	1986	69	2909	3498	2271	-1227	0.65
Asia	Nyaunggyat Dam, Myanmar	1981	56	4230	4668	1676	-2992	0.36
Asia	Lubuge Hydroelectric, China	1985	600	8043	7627	17433	9806	2.29
Asia	Upper Indravati Hydro Project, India	1983	600	6081	7936	15304	7368	1.93
Asia	Ertan I, Sichuan, China	1992	3300	10406	11702	71301	59599	6.09
Europe	Karakaya Hydropower, Turkey	1980	1800	26065	30175	70135	39960	2.32
Europe	Middle Neretva Hydro Project, Yugoslavia	1980	396	9343	10276	12601	2325	1.23
Europe	Turkey - Sir Hydropower Project	1985	282	3112	3846	6664	2817	1.73
Europe	Sigalda HPP, Iceland	1973	100	5061	4415	12251	7836	2.78
Europe	Berke Hydropower, Turkey	1991	510	4389	5226	8698	3472	1.66
Oceania	Yonki Dam, Papua New Guinea	1987	30	1069	1401	952	-449	0.68
Oceania	Afulilo Hydropower project, Western Samoa	1987	6.3	202	394	202	-193	0.51
Oceania	Wailoa Hydroelectric, Fiji	1977	80	3061	3646	4209	563	1.15

Rate of return 14.27%

(in million USD, k = 8%)

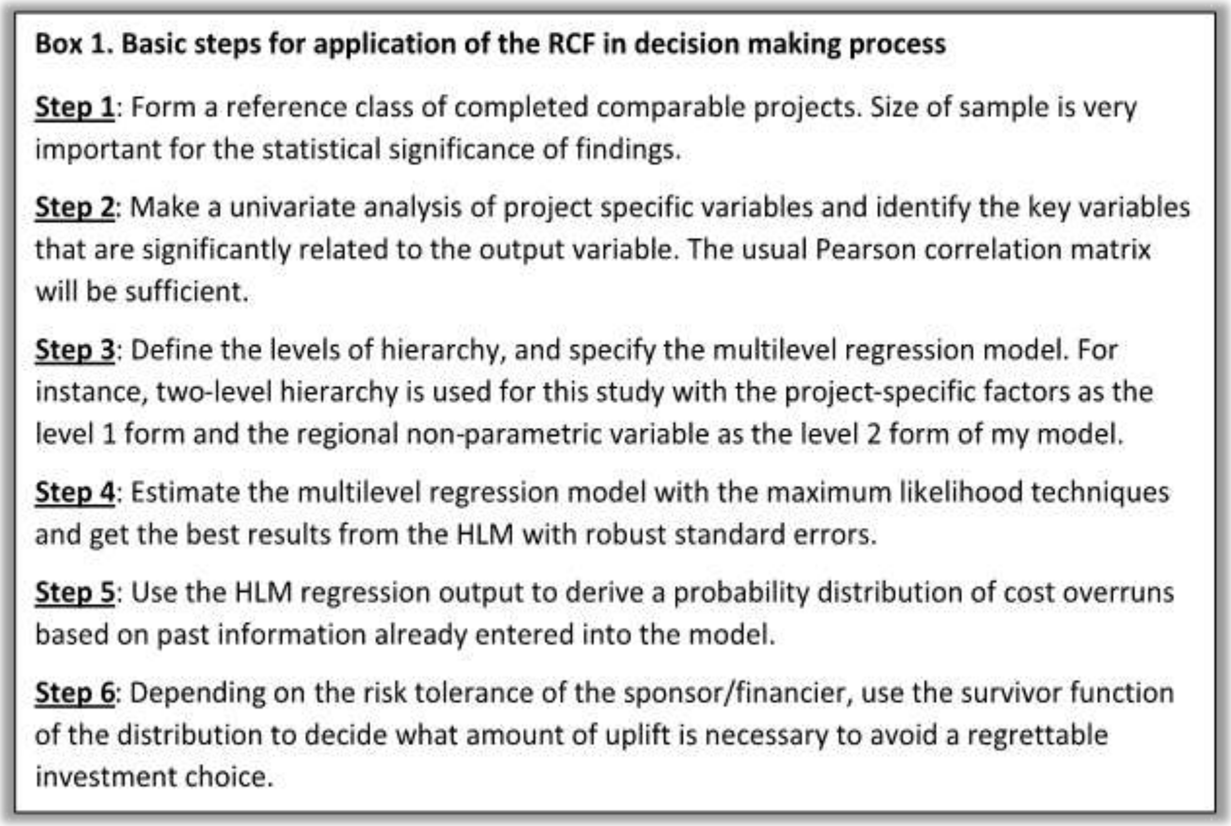
Region	**Project_id**	**Capacity_MW**	**PV of Est. Cost (2014)**	**PV of Actual Cost (2014)**	**PV of Benefits (2014)**	**Net PV of Hydro (2014)**	**ex-post BCR**
Africa	Nangbeto Hydroelectric Projects, Togo	63	2356	2381	1698	-683	0.71
Africa	Gitaru HPP, Kenya	145	14881	22107	22598	491	1.02
Africa	Kapichira Hydroelectric, Malawi	64	1039	1136	925	-211	0.81
Africa	Ruzizi Hydroelectric, Burundi-Rwanda-CDR	30	2033	2053	1183	-870	0.58
Africa	Kiambere Hydroelectric, Kenya	150	6100	6283	5573	-710	0.89
Africa	Andekaleka Power Madagascar	56	6246	8389	4955	-3433	0.59
Africa	Nkula II Project, Malawi	56	6122	7767	7344	-423	0.95
Africa	Mtera Hydroelectric, Tanzania	80	2260	3666	3400	-266	0.93
Africa	Kidatu Hydropower Plant, Tanzania	200	7339	9439	17886	8447	1.89
Africa	Sıdı Chero-Al Massıra Hydro Project, Morocco	120	10707	11398	9800	-1599	0.86
Africa	Lupohlo 3rd Power Project, Swaziland	20	1889	2366	926	-1440	0.39
Africa	Volta River Hydroelectric Project, Ghana	324	14221	17445	33318	15873	1.91
Africa	Kpong Hydroelectric, VRA, Ghana	160	16402	20935	17275	-3660	0.83
America	San Carlos I&II, Colombia	1240	19764	24689	70136	45447	2.84
America	Fourth Guadalupe, Colombia	213	6870	8552	13654	5102	1.6
America	Playas Hydropower Project, Colombia	200	6847	6926	12215	5289	1.76
America	Rio Grande Hydroelectric Project, Colombia	324	8052	8024	10611	2587	1.32
America	Itumbiara Dam, Brazil	2080	68269	102779	213933	111153	2.08
America	Pehuenche Hydroelectric Dam, Chile	500	9266	5582	19071	13489	3.42
America	Yacyreta Dam, Argentina/Paraguay	3100	61824	93241	153353	60112	1.64
America	Nispero Power	22.5	3088	3328	1448	-1880	0.44

	Project, Honduras						
America	Guavio Hydro Power Project, Colombia	1000	25626	55962	39728	-16234	0.71
America	Paulo Afonso IV Complex, Brazil	2462	67047	137304	190587	53282	1.39
America	Aguacapa Power Project, Guatemala	90	6113	13186	10432	-2755	0.79
America	La Fortuna, Panama	300	10610	29343	24460	-4883	0.83
America	Chixoy Hydro-power, Guatemala	300	26322	34730	29518	-5212	0.85
America	El Cajon Hydropower Dam, Honduras	300	17984	34937	19263	-15673	0.55
America	Aguamilpa & Zimapan power dam, Mexico	960	14123	19616	24044	4429	1.23
Asia	GaziBarotha Hydropower, Pakistan	1450	10428	10334	25538	15204	2.47
Asia	Cirata Hydroelectric Site, Indonesia	500	2335	1570	8060	6490	5.13
Asia	Second Xiaolangdi Multipurpose Dam, China	1800	15343	15290	28121	12831	1.84
Asia	Kulekhani HPP, Nepal	60	4766	10438	5525	-4912	0.53
Asia	Lam Takhong Hydroelectric, Thailand	500	3157	1999	4904	2904	2.45
Asia	Yixing Pumped Storage, China	1000	13314	14840	26940	12099	1.82
Asia	Saguling Dam Indonesia	700	22366	28608	34509	5901	1.21
Asia	Chungju Multipurpose Dam, Korea	400	23377	31732	19779	-11952	0.62
Asia	Malaysia 9th Power	72	9602	7826	3444	-4382	0.44
Asia	Ban Chao HPP, Thailand	360	16691	16190	40726	24536	2.52
Asia	PATTANI HYDROELECTRIC PROJECT, Thailand	72	10959	10452	6924	-3528	0.66
Asia	Khao Laem HPP, Thailand	241	15564	17471	13639	-3832	0.78
Asia	Yantan Hydroelectric Project, China	1100	6068	4871	35425	30554	7.27
Asia	Tianhuangping Hydroelectric Project, China	1800	4554	5060	22137	17078	4.38
Asia	Kerala Power Project, India	180	5690	7950	5997	-1953	0.75
Asia	Shuikou I&II Hydroelectric	1400	12944	16521	33950	17429	2.05

	Project, China						
Asia	Daguangba Multipurpose Project, China	240	1673	2473	3503	1030	1.42
Asia	Marsyangdi Hydroelectric, Nepal	69	4745	5707	2907	-2800	0.51
Asia	Nyaunggyat Dam, Myanmar	56	7166	7908	2137	-5771	0.27
Asia	Lubuge Hydroelectric, China	600	13031	12357	22200	9843	1.8
Asia	Upper Indravati Hydro Project, India	600	9931	12960	19410	6450	1.5
Asia	Ertan I, Sichuan, China	3300	14541	16351	75941	59590	4.64
Europe	Karakaya Hydropower, Turkey	1800	45391	52550	95697	43147	1.82
Europe	Middle Neretva Hydro Project, Yugoslavia	396	16121	17731	17143	-588	0.97
Europe	Turkey - Sir Hydropower Project	282	5094	6296	8898	2602	1.41
Europe	Sigalda HPP, Iceland	100	10420	9088	20707	11619	2.28
Europe	Berke Hydropower, Turkey	510	6317	7521	9776	2255	1.3
Oceania	Yonki Dam, Papua New Guinea	30	1703	2231	1166	-1065	0.52
Oceania	Afulilo Hydropower project, Western Samoa	6.3	319	622	241	-381	0.39
Oceania	Wailoa Hydroelectric, Fiji	80	5856	6974	6645	-329	0.95
			762,865	1,055,486	1,561,323	505,837	1.4792

Rate of return 14.27%

Appendix D: Steps for reference class forecasting technique.



Box 1. Basic steps for application of the RCF in decision making process

Step 1: Form a reference class of completed comparable projects. Size of sample is very important for the statistical significance of findings.

Step 2: Make a univariate analysis of project specific variables and identify the key variables that are significantly related to the output variable. The usual Pearson correlation matrix will be sufficient.

Step 3: Define the levels of hierarchy, and specify the multilevel regression model. For instance, two-level hierarchy is used for this study with the project-specific factors as the level 1 form and the regional non-parametric variable as the level 2 form of my model.

Step 4: Estimate the multilevel regression model with the maximum likelihood techniques and get the best results from the HLM with robust standard errors.

Step 5: Use the HLM regression output to derive a probability distribution of cost overruns based on past information already entered into the model.

Step 6: Depending on the risk tolerance of the sponsor/financier, use the survivor function of the distribution to decide what amount of uplift is necessary to avoid a regrettable investment choice.