A HIERARCHICAL MULTI-STAKEHOLDER PRINCIPAL-AGENT MODEL FOR (ANTI-) CORRUPTION IN PUBLIC INFRASTRUCTURE PROCUREMENT

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Bingyan Huang

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Bingyan Huang, Ph.D.

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Infrastructure system is the backbone of the economy. However, large gap between demand and supply is observed in both developed and under-developed countries. Such gap is induced by two reasons, lack of fund invested in infrastructure procurement and low procurement efficiency due to corruption. Closing this gap can improve the economy of a country, help business to thrive and make citizens better off. This dissertation focuses on dealing with the low procurement efficiency in the context of private participation in infrastructure procurement. Based on literature review, stakeholder management, decentralization and agency problem is identified as three key fields in tackling corruption problem. Therefore, a framework incorporating these three fields is built. Based on hierarchical principal-agent model and highway pricing model, such a framework also bridges the engineering and economic models. Several vital problems in post-tender phase of infrastructure procurement are studied. Cost overrun is a problem plaguing all the infrastructure projects and using the framework, a model is established to distinguish the unintentional cost overrun due to technical uncertainty and intentional one induced by selfish motivation of official. The corruption in renegotiation of PPP projects is also investigated. Different scenarios based on the institutional monitoring and anti-corruption governmental contract are studied. This dissertation's contribution is three-

fold: Firstly, a framework connecting two dimensions, that is, horizontally the stakeholder management, decentralization and agency problems and vertically the engineering and economic models, is established. Secondly, the corruption problems in post-tender phase of infrastructure project are addressed, given that previous research in such field is limited. Thirdly, Several important policy insights are provided in this dissertation.

BIOGRAPHICAL SKETCH

Bingyan Huang graduated from Tsinghua University in 2011 with a Bachelor of Engineering in Automation. In the same year, he joined the MS/PhD program in School of Civil and Environmental Engineering at Cornell University.

While pursuing his degree, Bingyan has finished multiple papers in his research. Bingyan worked as research assistant (RA) and teaching assistant (TA) in school of civil and environmental engineering. He was TA of CEE 3610 and CEE 5930. He also participated in PPS and CMP projects in cooperation with NYMTC and NYDEC.

Bingyan's dissertation was supervised by Prof. Oliver H. Gao.

This thesis is dedicated to Yifan and Zhiping for giving me life, raising me up, and loving me unconditionally,

and to Meng for her love, support and encouragement.

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CHAPTER 1

INTRODUCTION

1.1 Preliminary remarks

Infrastructure encompasses roads and bridges connecting cities, water-main delivering to households, hospitals and schools supporting communities, and all other similar systems serving as backbones of the society. As pointed out by American Society of Civil Engineering (ASCE) in their annual *Infrastructure Report Card* "Every family, every community and every business needs infrastructure to thrive".

Despite its importance, there is still a huge deficit in infrastructure supply. Taking U.S. road system as an example. In 2013, 32% of US major roads are in poor or mediocre condition and 42% of US major highways are congested. Similar examples can be found in under-developed countries (ASCE, *Infrastructure Report Card*). For example, World Bank reports that only one-third of sub-Saharan African people living within two kilometers of all-season roads, compared to two-thirds in other developing regions.

Infrastructure deficit indicates demand of infrastructure exceeding its supply. To deal with such deficit, however, the government can do little to restrain the demand but can only focus on the supply side.[1] The supply side is the level of infrastructure, which consists of fund invested into the infrastructure and the procurement efficiency of the fund, as shown in 1.1.

[1]Although there are evidences that the demand of toll free highway may be irrational to some extent, such demand is only small fraction in total demand [63].

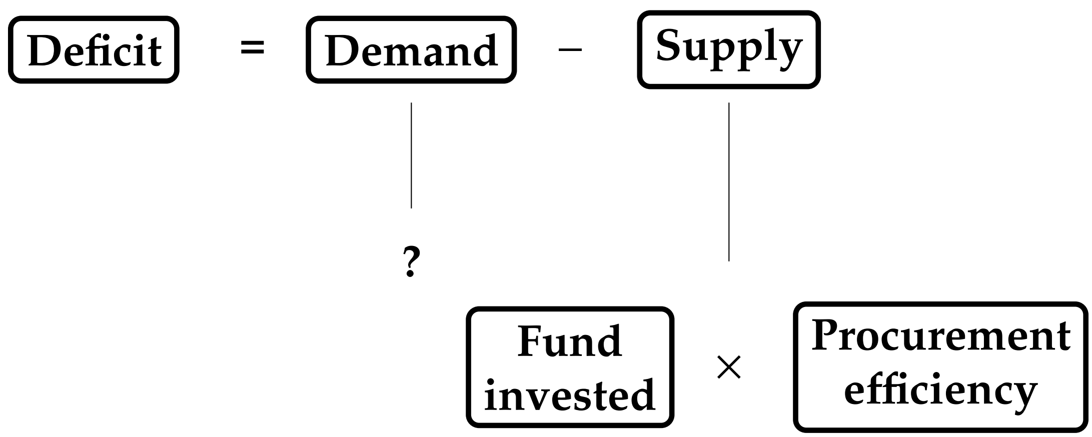

Figure 1.1: Infrastructure deficit

On one hand, the fund invested into the infrastructure system is also experiencing huge deficit. According to the estimation of Federal Highway Administration, between 2008 and 2028, annual investment into the US road system should be at least $170 billion, however, the real investment is only $91 billion. Some solutions, such as private participation, are introduced.

On the other hand, the procurement efficiency is never satisfying. Corruption, regarded as biggest problem, consumes a large part of fund invested into the system. According to [46], 10 – 30% total investment into public infrastructure may have been lost through corruption. Annual loss in global construction industry through problems such as inefficiency and corruption could reach $2.5 trillion by 2020. However, there is no straight-forward solution to corruption problems.

Delivering infrastructure remains one of the biggest challenges in public procurement as it usually involves economic, political, social and technical considerations. Contracts are complex and prone to changes and renegotiations. The design is usually highly localized and therefore requires decentralized procurement. Therefore, infrastructure procurement is regarded as one of the area that easily breeds corruption related problems, especially in developing countries.

This dissertation establishes approaches to model the formation of corruption in infrastructure procurement and provides several possible solutions for the community. This chapter serves as the introduction. In the following sections, I first explore the corruption problem currently lying in infrastructure procurement process. Then discuss how to capture different features of infrastructure procurement in a model. Based on the features I discussed, principal-agent model is identified as the best model to be used. Therefore, in the following section, the concepts of principal-agent model are introduced. Finally, I briefly introduce the organization of this dissertation.

1.2 Corruption in infrastructure procurement

Corruption, defined as "the abuse of entrusted power for private gain" (Transparency International), is one of the major problems associated with infrastructure projects. Corruption induces inefficient political institutions, neutralizes economic gain, destroys social trust or even destruct the environment ([72], [47]). Therefore, fighting against corruption in infrastructure projects is essential to secure the public interest and well functioning of this advanced form of public procurement.

Corruption can happen in all stages of life cycle of an infrastructure project which can be divided into pre-tender (decision making), tender and post-tender (contract execution) phases (shown in Figure 1.2). A more detailed five-stage model ([29]) is also given in the same figure for comparison. Pre-tender phase consists of designing market and making financing decisions. In tender phase, the governments hold auctions to decide who will be awarded with the contract. In post-tender phase, the infrastructure is constructed and services are delivered. Pre-tender and tender phases corruptions are both well studied and comprehensively regulated ([48]). In pre-tender phase, the corruption may influence the choice of projects ([27]). Hence the research and regulation regarding pre-tender phase corruption focus on these issues. The tender phase is also prone to corruption. Topics of studies include the form of tendering, contract awarding criteria and also how corruption undermines the efficiency of the infrastructure project ([2], [28], [17]).

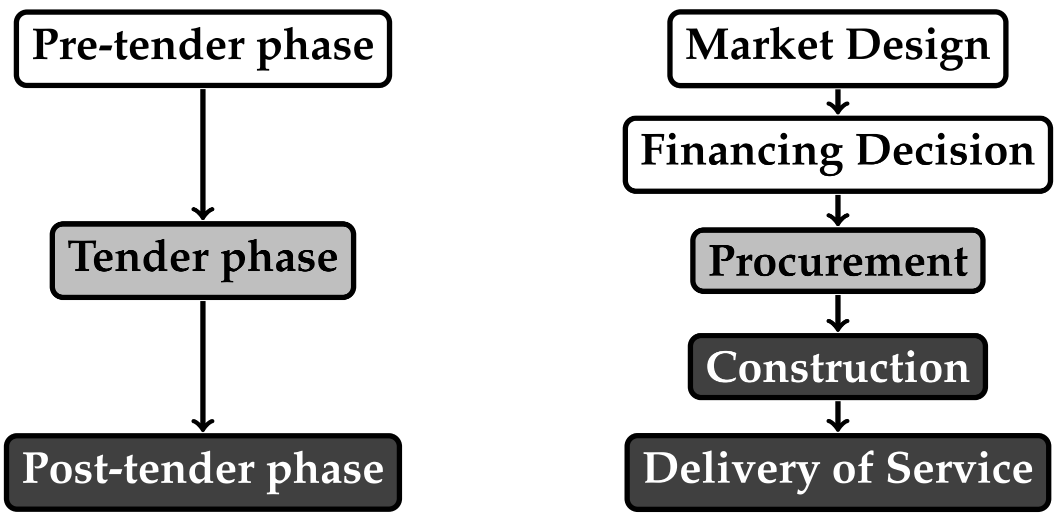

Figure 1.2: Stages of infrastructure procurement

In contrast to the massive effort invested in the study and regulation of pre-tender and tender phases corruption, misdeeds in post-tender session receive insufficient attention from both academia and governments. However, past research (for example, [48] and references therein) showed that corruption in contract execution stage is more severe than that in the pre-tender and tender phases. Despite of this, knowledge about post-tender phase corruption is still limited. To our best knowledge, the only detailed discussion under the context is [48]. They discuss how to alter the payment scheme and risk allocation in projects with contingent contract to reduce corruption after the contract being awarded. In their model, a contractor is selected to procure the infrastructure for a central government, who delegates the administration to an local official. The project's revenue is influenced by both the effort of the contractor and the exogenous shock which is a private information of the contractor. The local official may have knowledge on the exogenous shock with some possibility and whether she possesses such information is privately known by herself. With the presence of asymmetric information, the official is able to collude with the contractor. Based on these settings, the authors discuss an anti-corruption program that awarding the official for providing informative report.

One of the major sources of corruption in infrastructure projects, as pointed out in [40] and [53], is the renegotiation of the initial contract, which usually takes place in contract execution phase. There are two types of renegotiation, operator-led renegotiation and government-led renegotiation. Operator-led renegotiation usually happens after economic shock hitting the operator of the project who thereafter initiate renegotiation for possible relief. Government-led renegotiation, on the other hand, reflects change in the priority or economic environment. In either form of renegotiation, the official can collude with the other parties to solicit bribery or other personal benefit. For example, although government-led renegotiation is claimed to be Pareto improving, it is sometimes featured with opportunism in the sense that the officials leading the renegotiation seek to please their voters during or after elections.

Several papers explore outcomes of renegotiation with or without the presence of selfish official. Nevertheless, the research about collusion in the renegotiation game is absent. In [26], the authors discuss the officials using contract and renegotiation as an approach to circumvent the budget constraint during their terms of office. They report that the firms will low-ball their offer during the tender phase and additional work will be added through renegotiation at the start of contract execution phase. By this way, part of the cost is transferred to future officials and not borne by incumbent. Although in their paper, the official is not benevolent, they do not consider the situation when officials collude with the contractor. Another paper covering the behavior of officials during renegotiation game is [43]. The author considers a operator-led renegotiation where the official is benevolent. In his model, the operator could ask the government to bail him out from an economic shock. The author examines the effectiveness of different government procurement policies.

In summary, although the post-tender phase is regarded as at least, if not more, important as pre-tender and tender phases in preventing corruption in infrastructure projects, the study of collusion and corruption is limited and, what is worse, the study of collusion in renegotiation is absent. This fact seems to be more surprising if one also notices that literature of collusion in renegotiation-process-alike games is actually abundant.

1.3 Research of corruption in general

Corruption happens when private and public interests overlap. There are two levels of corruption: petty and grand corruption ([62]). Petty corruption is low-level corruption happens where basic law and regulations are in place. The officials in a petty corruption seize chances to benefit themselves. Petty corruption may happen when the resource is scarce, the discretion power to select qualified or unqualified agents is held by officials, or the agents hope to get better service. On the other hand, the grand corruption, sharing some common properties with petty corruption, is featured with corrupting the how public sector, government or system. For example, the public sector can be designed to be a rent-extraction machine through high-level corruption, the electoral system's outcome is determined by money, or the assets are transferred and projects engaged by government have significant effect on the wealth of business. Petty and grand corruption are of equal importance. In this dissertation, I will focus on discussion of petty corruption.

The literature on corruption in general focuses on the debate of relationship between corruption and economic growth [62]. This includes discussion in two dimensions: whether corruption induces low growth rate and whether economic growth can cure corruption problem. To answer these two questions, two branches of studies are conducted. Empirical study, on one hand, try to identify the linkage between economic growth and corruption in real world countries. However, for illegal activities such as bribe, it is difficult to directly collect data or evidence. Therefore, indirect measures ([50]) or field experiments([60]) are widely adapted in research. However, as pointed by [36], forensic economic methodologies can hardly investigate into the corruption problem because it is impossible to establish the intentions of the actor involved.

On the other hand, theoretical research focus on testing the black box between institutional measures and economic outcome. Literature of this class studies the interaction between public official and private agent ([32], [68], [49]), interaction between public official and voters ([51], [21], [42], [67], [67]), decentralization ([7], [8], [6], [22], [65]) and agent problems ([55], [19], [10], [3], [4]).

1.4 Research of corruption in infrastructure procurement

Corruption in infrastructure procurement is also widely studied. As infrastructure is identified to be important to economic growth ([1]), study of corruption in infrastructure narrow down the debate around corruption and growth to corruption and infrastructure level. Similar to study of corruption in general sense, the literature in infrastructure scope can also be divided into empirical and theoretical branches. On the theoretical side, the research focus can be divided into three fields.

Stakeholder management. Stakeholders of infrastructure projects can be divided into by two dimensions: public vs. private, and internal vs. external, as shown in Figure 1.3. Among them, researchers usually play an indirect and long term role in the projects and therefore we don't consider them in this dissertation. Government, contractor and residents, however, are all incorporated into the framework of this dissertation. Previous studies in stakeholder management discover that failure of public infrastructure projects are always subjected to opposition from various stakeholders ([76]). Major stakeholders include government official, procurer, the residents (public) and also researchers in this area. Stakeholders may have informal power to influence the decision on the infrastructure, for example the public can put pressure on other stakeholders to change their position in the infrastructure project ([59]).

Decentralization. Another stream of research falls in decentralized procurement. In public infrastructure procurement, two distinct types of institutional organization are relied on: decentralized and centralized procurement. In decentralized procurement, decisions are delegated such that selection, financ-

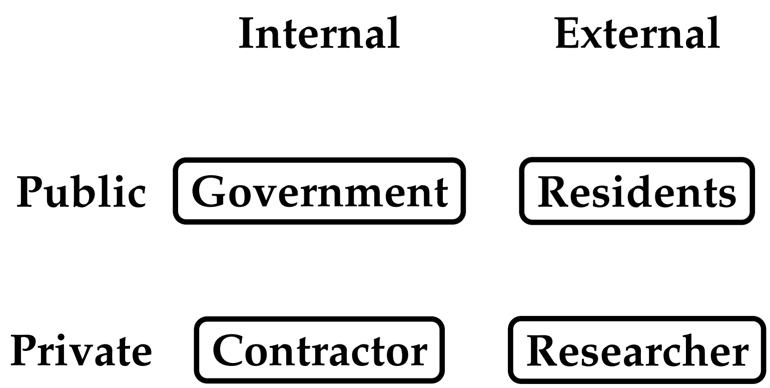

Figure 1.3: Classification of stakeholders

ing and implementation are responsibility of subnational governments or departments. On the contrary, centralized procurement is featured with central government completely control the decision rights([38], Chapter 1.). Infrastructure projects with private participation usually are implemented distributively in subnational governments. Despite the possible benefits of decentralization, it is well-accepted that, corruption is more prominent in decentralized public infrastructure procurement compared to centralized counterparts. Decentralized procurement breeds corruption due to several reasons ([38], Chapter 14.). Firstly, decentralization may induce personalism and interest group capture. As localization brings official closer to citizens and hence reduces professionalism. The official may pay attention to the need of individuals or a group of citizens and ignore the local residents as a whole. Secondly, decentralized procurement decision weakens the central government monitor and control. The effectiveness of central government auditing decreases as the decisions are distributed and bureaucrats can collude to achieve self-interest. Lastly, political decentralization can also facilitate corruption, especially when the local government does not play a supportive role in the enterprise.

Agency problem. Agency problem arises in infrastructure procurement when the interests of different stakeholders are conflicting and information asymmetry exists. Therefore, literature in this field focuses on how a benevolent government can overcome the information asymmetry and align the interest of different parties to deliver a social optimal projects. The study in this field is pioneered by [71], which introduces the collusion between agents or between agent and supervisor in a hierarchical organization (for a complete review in this field, we refer to [56]). The models in this field usually consider different players including principal, supervisor and agent (One typical model is discussed in Section 1.5). The colluding agents and supervisors can sign side contract with each other and realize hidden transfer to take advantage of the private information they possess. [48] is the first paper applying such framework to corruption in post-tender phase of projects to our best knowledge. In their paper, they build a central government - local official - contractor model to reflect the decentralized procurement and study how the central government can prevent collusion between local official and contractor with the presence of both adverse selection and moral hazard problems.

Based on the literature review, we can classify the existing literature into the following matrix in Figure 1.4 (For simplicity, only a fraction of highly cited papers is shown). From this matrix, several interesting observations are easily made:

- There is no uniform framework addressing all three fields
- A big gap exists between stakeholder management and other two field
- less attention is paid to post-tender phase corruption
- There is weak connection between engineering and economic models

	Pre-tender	Tender	Post-tender
Stakeholder management	Ng et al. (2007) Ng et al. (2012)	Flyvbjerg et al. (1999) Flyvbjerg et al. (2002) Flyvbjerg et al. (2003) Hu et al. (2015)	El-Gohary et al. (2006)
Decentra-lization	Shah (1999, 2005) Andrew et al. (2005) Arikan (2004) Waller et al. (2002) Shah (2006)	Batley (1999) Von Maravic (2003)	Scharpf (1997)
Agency problem	Hart (2003) Bennett et al. (2006) Martimort et al. (2008) Engel (2011)	Bajari et al. (2010) Yescombe(2007) Auriol(2006) Burguet et al. (2005) Estache et al. (2009)	Iossa et al (2011)

Figure 1.4: Existing Literature

This dissertation focuses on solving these problems in existing literature. To overcome these obstacles, principal-agent model is used. In the following section, I will briefly review the existing literature in principal-agent model.

1.5 Principal-agent model in dealing with corruption and collusion

Principal-agent model is the mostly adopted model in research of corruption in public infrastructure procurement or even corruption in general. The basic assumption in this model is that government, referred as 'principal' in the model, is benevolent and resourceful and aims on achieving maximal social welfare, the sum of utilities of the society. On the other hand, however, agents are self-motivated and seek to increase own benefit (See [11], [13], and [12]). The literature suggests that corruption can be curbed by increasing the expected penalty for misconduct.

In the literature of corruption, there is a stream of research focusing on modeling the decentralization using hierarchical principal-agent model. [71] establishes a classic three-tier principal-supervisor-agent model to analyze the impact of decentralization and information asymmetry on corruption behavior. The extensions, including four-tier hierarchical model by [19], multiple agents model by [56], different information condition by [20] and [30], illustrates its usefulness. Such models help us understand how different conditions will affect the outcome of collusion and corruption which is unavailable to researchers and government in the real world.

A majority of such studies in collusion compares two different organization forms, centralization and delegation, when collusion presents.[2] [3] In centralization, the principal directly offer contract to the productive agents while in delegation, the principal interacts only with some supervisor who thereafter contract with other agents. In such environment, collusion is inevitable if we assume that the supervisor is motivated by personal gain. The supervisor can side contract with the agents for misreporting their private information and ask for bribes. Scholars report that under different assumption of information structures, delegation can achieve same outcome as ([30]), or strictly worse than ([20]), centralization. Cases of multiple agents are also discussed. In [56], the authors consider the principal hires a supervisor to monitor two productive agents. The principal then consider whether he should directly contract with the two agents or delegate the right to the supervisor. In their paper, the au-

[2]In a larger scope of literature, the centralization and delegation is compared without the strategic behavior. For a good literature review in this area, refer to [56].

[3]Also, there is plenty of literature assuming soft information and/or breachable side contract, which is different from Tirole's framework. Introduction part of [31] provides a comprehensive review.

thors identify the condition when delegation to an informed supervisor would be superior to direct contract even with the risk of collusion.

One typical model is shown in Figure 1.5. The following numerical examples are used to illustrate the basic idea of the models in this chapter.

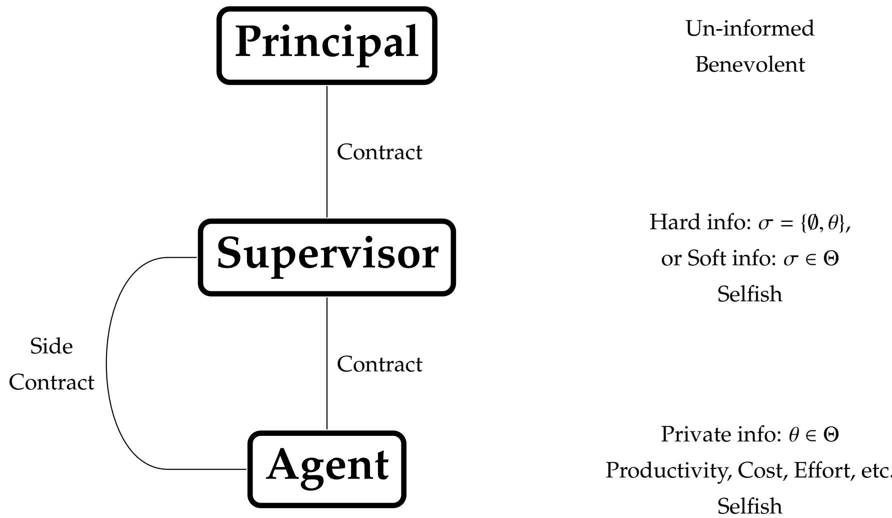

Figure 1.5: A typical principal-supervisor-agent model

Example 1. *Assume that in Figure 1.6, there is no supervisor, that is the agent directly contract with principal. The private information of agent is his procurement cost per unit output,* $\Theta = \{0.1,\ 0.2\}$. *Given output* x*, the cost is* $C = \theta x$. *Also, assume that the utility given the output is* $\sqrt{x}$. *The social welfare is therefore* $U = \sqrt{x} - \theta x$. *If principal possesses full information, the optimal output is (subscripts* 0.1 *and* 0.2 *denote the corresponding cost)* $x^*_{0.1} = 25$ *and* $x^*_{0.2} = 6.25$. *This gives that the social welfare being* $U^*_{0.1} = 2.5$ *and* $U^*_{0.2} = 1.25$. *If principal does not know the exact cost, she can only let the agent to report. However, the agent, being selfish, will not necessarily report true information. For example, he can report* $\tilde{\theta} = 0.2$ *when his real cost is* $\theta = 0.1$. *Given this wrong information, the principal will implement* $x^*_{0.2} = 6.25$ *and the agent will get a payment of* 1.25 *while he only spends* 0.625 *in production, which means that he makes a profit of* 0.625.

Therefore, principal can only sign an incentive contract with the agent. The contract stipulate the output $x = x(\tilde{\theta})$ and monetary transfer $t(\tilde{\theta})$ given the report from the agent $\tilde{\theta}$. Such a contract should at least satisfy the following two properties: Under any circumstances, the agent will 1. be willing to participate and 2. get higher or same utility for truth-telling than lying. Given these two requirements, the optimal solution now becomes $x^s_{0.1} = 25$ and $x^s_{0.2} = 2.8$. The social welfare decreases to $U^s_{0.1} = 2.22$ and $U^s_{0.2} = 0.55$. This indicates that the optimal output for efficient type ($\theta = 0.1$) remains the same but is lower for inefficient type. Social welfare under both condition decreases, however due to different reasons. When agent is efficient, the social welfare decreases because monetary transfer. On the other hand, the social welfare decreases due to suboptimal output compared to optimal case.

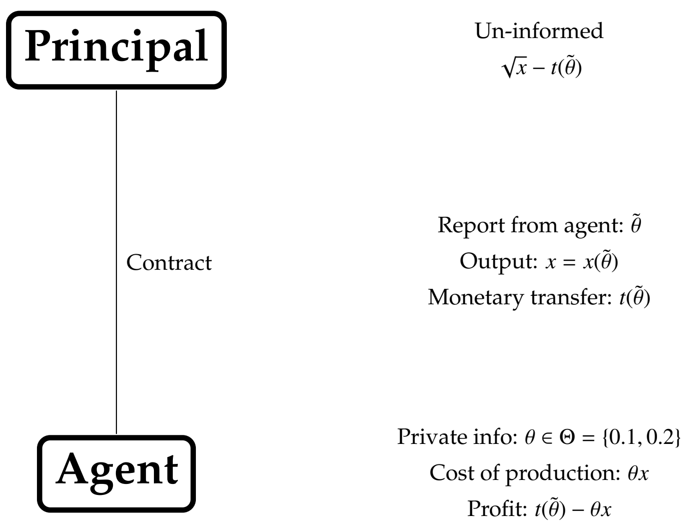

Figure 1.6: Model of Example 1

The above example illustrates how information asymmetry will affect the social welfare and optimal output. The requirements 1 and 2 in the example are called individual rationality and incentive compatibility, respectively, in literature of mechanism design. For a comprehensive introduction of mechanism design, please refer to [74].

One possible solution to the asymmetric information problem is introducing the supervisor, as in Figure 1.5, who is informed on the agents efficiency but is still rational. Therefore, similar to previous case, principal has to provide the supervisor with incentive to tell the truth. Although this seems to be a promising way to solve the problem, surprisingly, previous literature has proven that under most of the circumstances, it performs no better than the organization in Figure 1.6 ([20], [30], [56]). We will discuss a more complex case of Figure 1.5 in Chapter 3.

1.6 Organization of this dissertation

This dissertation is organized as follows:

Chapter 2 builds a model to analyze the cost overrun problem in public procurement. Cost overrun problem was, is and will be plaguing public infrastructure projects. It could be induced by technical uncertainty or political and economic drivers. To determine the root cause of cost overrun, We build a two-stage model to evaluate the impact of these drivers under user heterogeneity context where decisions are made by benevolent or selfish officers. We identify that there are two distinct types of cost overrun: ex-ante and ex-post cost overrun. Although cost overrun is widely regarded as unavoidable with the presence of technical inaccuracy, the problem induced by purely unselfish drivers, such as technical imperfectness consists of both types of cost overrun with same significance and minimal negative impact. On the contrary, the cost overrun induced by selfishness, such as economic motivation or political imperfectness is biased towards one side and the extent of cost overrun is larger. We also investigate the effectiveness of audit to address imperfectness within decision process and the requirement for the central government to effectively regulate both types of cost overrun. Although we mainly focus on transportation infrastructure project in this chapter, our modeling framework can comprehensively account the cost overrun problem in a wide variety of public infrastructure projects.

Chapter 3 discusses the post-tender phase renegotiation in Public-Private Partnership(PPP). Corruption is widely accepted as a major problem plaguing PPP projects and annihilating most of their potential benefits. It is believed that the corruption in post-tender phase of PPP is more severe than other phases in the life cycle of the projects. In this chapter we study corruption in government-led renegotiation process in the post-tender phase of PPP. A highway serving heterogeneous residents is built by central government through PPP with a contractor in an uncertain environment. After the resolution of uncertainty, a change in design of the highway can be made through renegotiation process in post-tender phase to make all parties, i.e. central government, residents and contractor, to be better-off. The central or state governments cannot interact with each contractor or residents group within their jurisdiction on account of administration cost. Therefore, such decision is delegated to a local official, which leaves the official the opportunity to collude with the other two parties and seek for possible personal gain. We derive a general social optimal design of highway under user heterogeneity is derived with the presence of asymmetric information. Based on the results, outcomes of different renegotiation games with various types of local officials are provided. Our derivation and results provide several important policy implications and regulatory guidelines, including that the official will be more likely to renegotiate the contract if she can collude with both parties than only one party, restricting official's colluding ability to only part of residents group will reduce social welfare loss, and corruption can be detected through whether renegotiation is declined by the residents group or contractor. Beyond its contribution to PPP literature, this chapter enriches the mechanism design and collusion theories with a model containing both consumer and producer. Also, our model links existing economic and engineering models in PPP literature and provides a uniform and useful framework for future discussion.

Chapter 4 establishes a comprehensive framework taking stakeholder management, decentralization and agency problem into consideration. Private participation is increasingly important in public infrastructure procurement. Despite various benefit it contributes to the society, corruption, which is one of the most prominent problems, neutralizes its advantages. We identify that to fight the corruption, stakeholder management, decentralization and agency problem are key components of the research. Infrastructure projects naturally have huge impact on majority of stakeholders, who in turn would find influencing the decision to favor themselves. Also, decisions are usually delegated to subnational governments, which is widely regarded as potential source of misconduct. Moreover, the agency problem is featured as asymmetric information where officials deliberately hide private information of other agents from the central government to seek bribe in return. Therefore, in this chapter, a framework that addresses these issues are built and applied to the post-tender phase renegotiation of PPP, where corruption is as severe as tender and pre-tender phase but has drawn insufficient attention. Through the lens of our model, we discover that that lower private side bargain power, lower estimated cost in design phase, and possibility of colluding with free riders will facilitate corruption. Also, we discover that governmental incentive contract can not fully prevent corruption behavior and therefore auditing and monitoring agents should be relied upon to curb misconduct of officials.

Chapter 5 serves as conclusion and points out possible future research direction.

The full framework of this chapter is given in Figure 1.7.

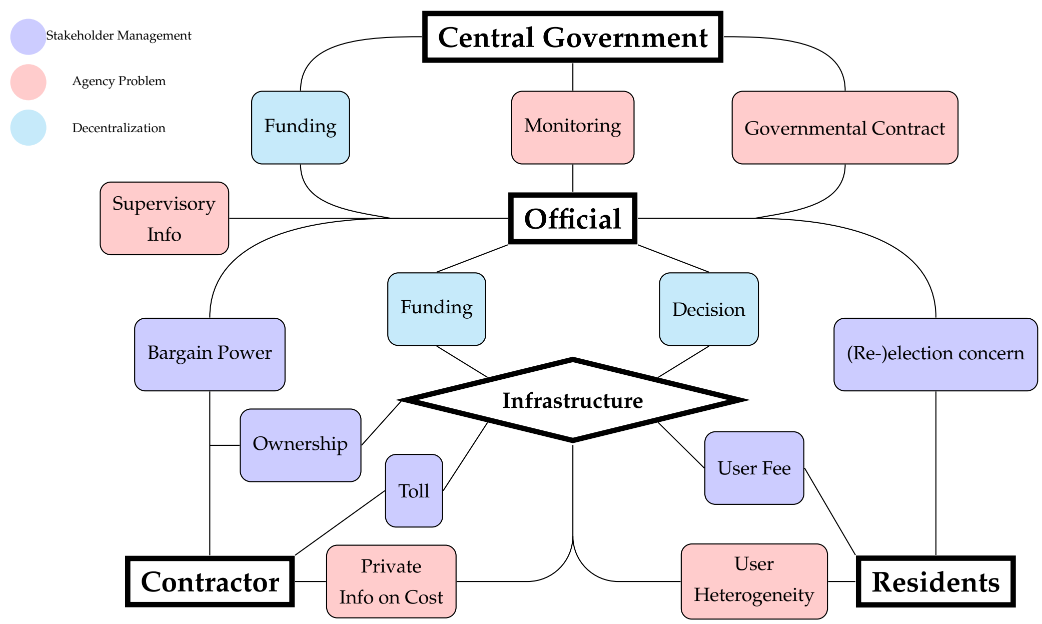

Figure 1.7: Research Framework

CHAPTER 2

SELFISH OFFICIAL AND COST OVERRUN IN INFRASTRUCTURE INVESTMENT

2.1 Introduction

Cost overrun is prevailing in public infrastructure projects and it was already widely studied since 1970 (for example, [54]). [35] report that 9 out of every 10 mega projects suffered from cost overrun. Existing literature attempted to identify different causal factors of the problem. There are mainly two categories of factors: a. political and economic drivers, and, b. technical uncertainty. Discussion about technical uncertainty applying forecast theory, planning theory and decision-making theory to study how uncertainty in future situation, improper or poor design and inappropriate institutional organization fail in controlling the spending of an infrastructure project [35]. That is being said, the excess of spending is due to 'honest mistake' rather than an intent to cheat. Many studies explore the impact of technical uncertainty on cost overruns. For example, [57] conclude that inadequate project preparation, planning and implementation is the main factor of cost inducing cost overrun. [75] consider lack of experience and techniques in forecasting future as a main source of cost overrun.

On the other hand, political and economic drivers originate from selfish motivation. For example, as lower cost estimation translates to higher likelihood of project implementation, agencies who benefit from the project's life cycle would have incentives to intentionally provide lower forecasts [35]. Another example would be cost estimation being intentionally costumed by politically driven reasons [33]. To get a questioned project started, the public exposure of cost escalation resulting from possible delays, accidents, project changes, etc is minimized. Such motivation may exist among third-party consultants, construction firms, other project promoters and forecasters, or even the government officers. The latter one may be inclined to build her own political capital through the infrastructure project and thus will be motivated to promote the project by hiding its cost. More surprisingly, although cost overrun is usually viewed as a harm to public interest, it may also be driven by public interest - project with lower cost estimation is more attractive and will be more likely to win access to public fund provided by federal governments, which is referred as pork-barrel politics [66].

Despite the intensive study on this topic, lessons are not sufficiently learned. According to [35], cost underestimation problem is not effectively improved over time. On one hand, with the advance in technology, there is a trend that cost estimation is improved along the time. However, there is no evidence that problems driven by selfish motivation are alleviated [41]. This is because, in contrast to technical uncertainty, directly uncovering political and economic drivers behind projects with cost overrun through empirical approaches is difficult, if not impossible. Public infrastructure projects are not transparent in the sense that contract and other information are not readily available to the public [73]. Furthermore, direct interview to decision makers on cost overrun topics is also infeasible because exposing political and economic drivers will put the decision makers' interests (such as reputation and political life) at risk. Therefore, indirect indicator and explanation should be relied upon to reveal potential drivers.

Theoretical modeling is necessary in locating these indicators. However, there is limited number of studies focusing on theoretical explanation of the motivation. [39] used a two-stage model with multiple agents to show that underinvestment may be beneficial to the sponsor because it increases the competition in the environment. [70] considered a dynamic multi-stage model where costs of the project are incurred over time during the construction and lead to an uncertain stream of payoff upon completion of the construction. All the studies mentioned above assume a benevolent decision maker which is insufficient in the exploration of indirect indicator on selfish drivers. Selfish decision maker should be incorporate in the model to locate possible indirect thread of cost overrun.

2.2 The model

In this section, we will first introduce the modeling framework for cost overrun analysis. Then we apply this framework to transportation infrastructure management problem and discuss the underlying models we use. Although in this chapter we only talk about transportation infrastructure project, this framework could be applied to various categories of infrastructure projects.

2.2.1 Modeling framework

In general, the infrastructure is directly procured by government who will construct, maintain and operate it for the whole life-cycle. The main funding source to cover costs incurred during the procurement is government's tax revenue. Then upon completion of construction the infrastructure will be available for public use for free. Public users (commuters, professional drivers etc.) is better off by having access to new infrastructure.

In this chapter, we establish a three-factor-two-stage model to describe this procurement process and attempt to provide insights through this model.

Three factors: Government agent, public and infrastructure

In infrastructure procurement, the decision made during building and operating phase would influence the local residents' attitude toward the administration. There are many factors that could influence such attitude, e.g. spending, user experience, environment friendliness, etc. Among them, spending is an important one. As part of the funding source of highway comes from the tax of local residents, heavy infrastructure spending is usually seen as a sign of tax rate hiking in future. Thus, lavish infrastructure spending is usually unfavorable from the perspective of households who are not directly benefited from.

User experience, on the other hand, will also influence local residents, especially users, i.e. who are directly benefited from the project. Although infrastructure almost always makes the whole system more accessible, sometimes bad user experience will negatively affect the satisfactory of travelers. Poorly constructed or maintained road, insufficient safety measures, or even unexpected or unreasonable tolls are all possible factors influence the user experience.

Therefore, both spending and experience on infrastructure would alter the public perception of government's competence and performance and hence affect the acceptance, support or satisfactory rates of incumbent officers. Therefore, it will inturn influence the behavior of the officer who makes the decision.

The impact of voting mechanism on infrastructure decisions is widely studied in political economics ([24]) but is not emphasized in study of cost overrun.

The interactions, i.e. procurement, tax, voting, utilization, between government, public and infrastructure is shown in Figure 2.1.

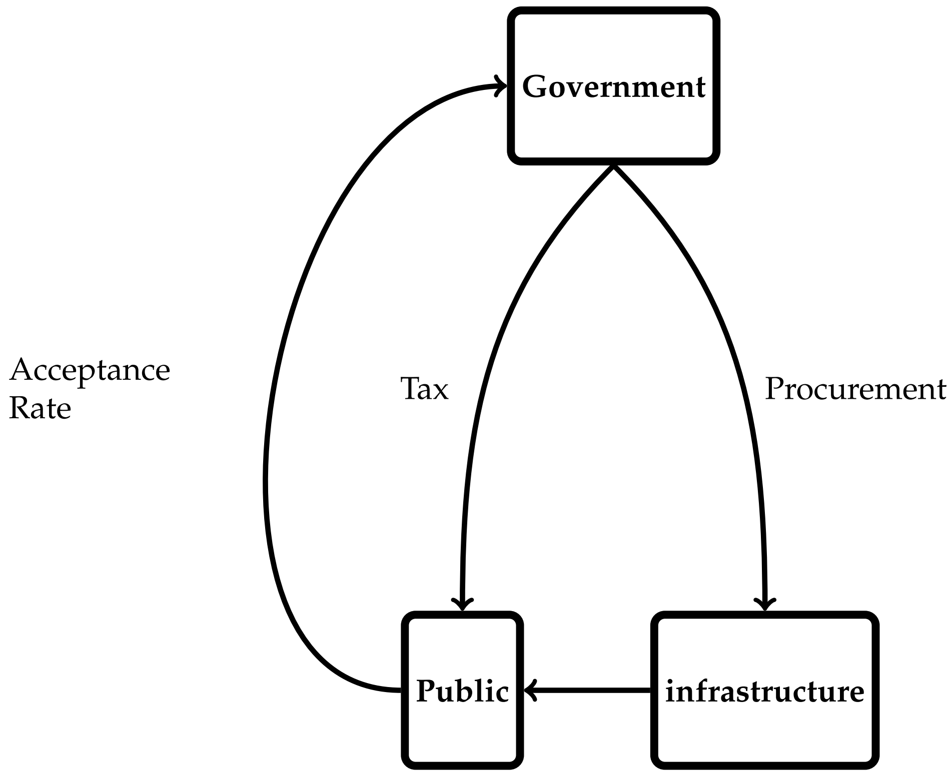

Figure 2.1: Modeling framework

As we emphasize in 2.1, existing literature in this field tries to dissect the whole problem and disentangle the interaction between government, the public and infrastructure. At best, only part of them are considered under the same context. Nevertheless, incorporating all the factors and the interactions in one single model would facilitate the researchers, practitioners and policy makers to achieve the following advantages:

1. Broader vision: As the factors that would cause cost overrun include

technical issue, economic motivation, political and institutional imperfection and psychological opportunism and optimism, the analysis of cost overrun should incorporate everything under one framework rather than study them individually.

2. More concrete result: Even with the descriptive and qualitative model, identifying the role played by each factor in inducing cost overrun is still impossible. Building a comprehensive model enables us to overcome this obstacle by quantitatively analyzing the effects and identifying the priority in tackling cost overrun problems.

3. More systematic policy: Based on 1. and 2., the framework provides a systematic solution to cost overrun to best address all aspects of issues. This could only be realized through counting the motivation of all players and effects of all interactions.

Two stages: decision and realization stage

In public infrastructure procurement involving uncertainties, there are two stages: decision stage and realization stage. In decision stage, the information about the uncertainty, for example the distribution of the construction and maintenance cost, is revealed to the decision maker(government agent). Notice that such information is usually not available to public and the federal government. Then the government agent works out plan and design on the infrastructure. Such design have to be forged with the existence of uncertainty. Possessing the ability to perfectly manage risk, (for example, better prediction of cost, fast reaction to volatility of commodity market, etc.) decision maker ideally can make contingent plans on different scenarios. Nevertheless, such assumption is over simplified that usually do not exist in real world projects. Decision maker without the ability of immediate reaction would rather make a compromising decision to be applied to all scenarios. The result of the compromising decision is loss of social welfare, but such trade-off is reasonable and common measures in risk management.

After the decision being made and the building work starting, the uncertainties are resolved. The real value of uncertainty could be either larger or smaller than the estimated one. Also, as the design decision was made based on estimation ex ante, the best decision ex post could be different from the ex ante one. Therefore, there will be extra unused capacity due to optimistic ex ante design, or under-served demand because of conservative decision. As all the investment in infrastructure is sunk, scale back capacity is usually not a possible choice, but scale up capacity, i.e. make additional construction is still feasible. Figure 2.2 shows the structure of this two-stage model.

The modeling framework introduced above is applicable to various types of infrastructure management projects. Transportation infrastructure, specifically highway infrastructure project is used as an example. In the following section, the network, transportation, agent and voting models are introduced.

2.2.2 Underlying models

A transportation infrastructure could be a highway, railroad, tunnel or bridge. Therefore, plenty of models could be involved in the decision process of infrastructure projects, such as facility/network design, building/maintenance cost evaluation, route choice/traffic assignment, highway pricing, environmen-

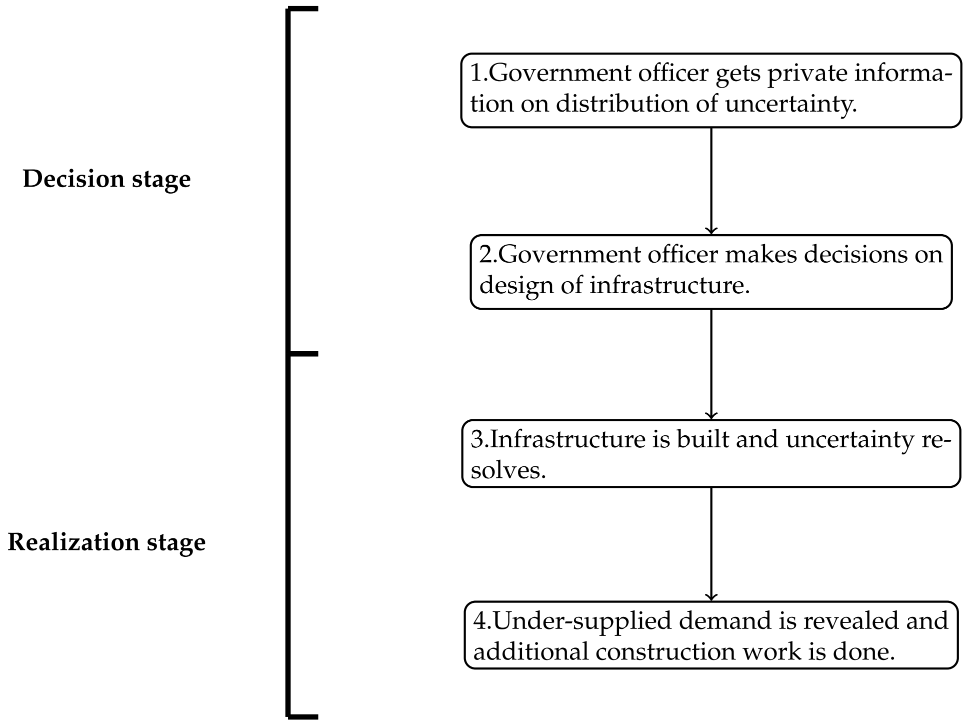

Figure 2.2: Two-stage model

tal impact, multi-modal traffic, etc. Each of them is intensively studied in a wide range of literature and the theories are backed up by models with different complexity and accuracy. As we are considering a theoretical framework and trying to shed lights on infrastructure management in a general manor, we try to achieve an optimal trade-off between complexity and accuracy to reveal essence of the problem with least complexity in structure and solution and cover as many aspects of the problem as possible.

Network

A network with a newly constructed highway could be represented by a 3-zone network, which is shown in Figure 2.3. There is a highway connecting city S and B. Also, two local roads which are supposed to have less capacity and lower speed limit are connecting I-S and I-B. Without loss of generality, assume that the officer of this jurisdiction is considering building a highway (larger capacity and higher speed limit compared to local road) connecting I to B.

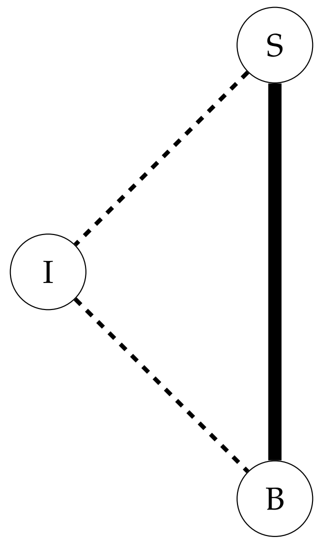

Figure 2.3: 3-node-3-link network

Let d denotes the design of the new highway. d could be either a scalar or a vector containing several decision factors, such as route, length, number of lanes, demand (traffic flow), etc. Also, there will be demand between each origin-destination (O-D) pair.

Besides demand, let q denote the flow on the link, q^0_{IS}, q^0_{IB} and q^0_{SB} denote the original flow between I-S, I-B and S-B, respectively and similar for ex post flows q_{IS}, q_{IB} and q_{SB}. The flow in the opposite direction is defined similarly. User equilibrium assumes that all the users on the network could not improve there utility, that is, travel cost of an individual is not decreasing by changing different route.

The travel time is determined by Bureau of Public Roads(BPR) model which is

$$\tau = \lambda_0 \left[1 + \beta_1 \left(\frac{q(d)}{Cap(d)} \right)^{\beta_2} \right]$$

where λ_0 is the designed free flow travel time on the highway, β_1 and β_2 are parameters determined by the highway character, $Cap(d)$ is the capacity of the link. Assume that

$$Cap_i(d) = \begin{cases} d, & i \in \{IB\} \\ Cap_i, & i \in \{IS, SB\}. \end{cases}$$

Thus the existing traffic flow on the highway could be determined by traffic assignment algorithm.

Social benefit and cost

The cost of building and maintaining the infrastructure is uncertain from government officer's perspective. This could due to lack of expertise of managing inventory, hedging risk, etc. Thus the cost could be denoted as c_ξ, where ξ is a random variable with density function $f_c(\cdot)$ and cumulative distribution function $F_c(\cdot)$. We assume that the distribution of such uncertainty is only known to the government officer, but realization can be observed by everybody (government officer, public or central government).

Benefit of building a highway between I and B comes from the improvement of travel time on the network. The improvement of travel time on link l is calculated as

$$\Delta U_l(d) = q_l^0 \tau_l^0 - q_l(d)\tau_l(d) \tag{2.1}$$

where d is the design decision variable, q_l^0 and q_l denote the flow before and after highway construction, respectively, and τ_l^0 and τ_l denote the travel time before and after highway construction, respectively

Heterogeneity

As we discussed, factors such as spending (cost) and improvement of traffic (benefit) in highway projects will have uneven impact on local residents. Furthermore, indirect utility will also influence the public perception of the government. Indirect utility may include all kinds of spill-over effect brought by the new infrastructure. For example, new highway would help growth of local economy, but would also have negative effects such as noise and air pollution.

Let σ denote the net indirect utility of each household or individual. Then the government officer's decision brings indirect benefit to the household or individual if $\sigma > 0$, and cost if $\sigma < 0$. Furthermore, assume that the indirect utilities of residents is randomly distributed according to cumulative distribution function $F(\sigma)$ (and corresponding density function is $f(\sigma)$). Without loss of generality, we assume that the expectation of x is zero. Thus, the number of people with utility larger than σ_0 is $1 - F(\sigma_0)$.

Decision making

Given a network and a link connecting two points to be built, decision variable d is decided given various constraints. Then the formulation is:

$$\max_{d} \quad \text{BENEFIT}(d, c) - \text{COST}(d, c) \tag{2.2}$$

$$s.t. \quad \text{CONSTRAINTS}(d, c) \leqslant 0, \tag{2.3}$$

(2.2) and (2.3) indicates that the decision maker's objective is to maximizes the benefit from the design and minimizes the cost by choosing d satisfying all the given constraints. Notice that the BENEFIT(d, c) and COST(d, c) are not necessarily the social benefit or cost, but could be the benefit and cost to the decision maker.

2.3 Cost overrun

In this section we will discuss the formation of cost overrun and the root driving cause. We confine our discussion scope in the situation where uncertainties are involved in projects' decision processes and government officer has information advantage compared with the public and central government. The advantage comes from the officers possessing the knowledge about the distribution of the random variable. The public, third party or central government only knows the possible range of the value of the uncertainty. Therefore it is difficult to assert ex ante whether a decision about the infrastructure is proper or not. Even there is ex post cost overrun, it is impossible to simply conclude that the decision is originally biased.

With uncertainty in building and operating cost, cost overrun is inevitable. Therefore cost overrun could be classified in two categories by the pattern of how real cost exceeding estimated cost. In one way, the estimated cost is smaller than the real cost. This could due to higher-than-expected material, financing or management costs, delay due to natural or political issues, etc. After the project is completed, the infrastructure is built, operated and maintained according to original design. We refer to this type of cost overrun as *ex-ante cost overrun*

Another form of cost overrun goes into entirely opposite way and is even ignored by literature in cost overrun literature ([18]). In this category, the estimated cost is higher than the real one. Although such conservative estimation could avoid ex-ante cost overrun, interestingly, there will be extra demand discovered ex post. For example, the real cost of building an extra exit on a highway is much lower than the estimated cost, which makes the addition of a new exit become economical, or after a deadly derailing accident occurs, installing speed control system on railroad is urgent while such demand is not address ex ante due to high installation fee of such system ([52]). Given the extra demand, the contract scope will be changed and new work will be done. Although the ex ante cost estimation is higher than the ex post one (which seems to be cost 'underrun'), after additional work, the design is changed and the final cost will still exceeds the estimated one. This type of cost overrun is referred as *ex-post cost overrun*.

In this section, we first review how ex-ante and ex-post cost overrun is derived from government's decision making process. Then we will compare the results and explain the root cause of cost overrun problem.

2.3.1 Benevolent government officer with expertise

We first consider when the government officer possesses all kinds of technical know-hows and makes decision to maximize the total social welfare. The result in this section will serve as a benchmark in the following analysis.

Let ξ denotes the uncertainties in cost. Then the objective function of the decision maker thus becomes:

$$S_\xi^0(d) = \sum_i \Delta U_i(d) - \Gamma(d, c_\xi),\ \forall \xi \tag{2.4}$$

The benevolent government officer will maximize the total social welfare. Also, with expertise in managing the uncertainty in cost, she could maximize this under any circumstances. Under this condition, she actually maximizes (2.4), which is,

$$(P_0) \qquad \max_d S_\xi^0(d)\ \forall \xi \tag{2.5}$$

To solve problem (2.5), we could get the first order condition of it:

$$\sum_i \frac{\partial \Delta U^i(d)}{\partial d} - \frac{\partial \Gamma(d, c_\xi)}{\partial d} = 0 \tag{2.6}$$

The root of equation (2.6), $d_\xi^0\ \forall \xi$, will serve as the benchmark in the following analysis. Notice that the subscript ξ indicates that the design is always optimal regardless of the realization of the randomness.

Therefore, in this case, the government officer can offer a 'menu' of decision contingent on possible costs and the infrastructure will be optimally built given the realization of uncertainty.

2.3.2 Benevolent government officer without expertise

Although the social welfare will be maximized in each scenario if the government officer has the ability to manage uncertainty, it is almost always the case that she is unable to effectively deal with the uncertainty, and only second-best outcome is available.

The objective function of government officer becomes,

$$S^1(d) = \mathbb{E}_\xi \left[\sum_i \Delta U_i(d) - \Gamma(d, c_\xi) \right] \tag{2.7}$$

Notice that in (2.4), for each scenario, i.e. possible realization of ξ, there is one objective function. On contrary, in (2.7), there is only one objective function specifying solution to all scenarios. This makes that decision coarser and less socially favorable than the one in (2.4).

The optimization problem and its first order condition becomes:

$$(P_1) \qquad \max_d S^1(d)$$

$$\mathbb{E}_\xi \left[\sum_i \frac{\partial \Delta U^i(d)}{\partial d} - \frac{\partial \Gamma(d, c_\xi)}{\partial d} \right] = 0 \tag{2.8}$$

Let d^1 denote the root of (2.8). Notice that this decision comes from the expectation of uncertainty. Define $c^0(d)$ as

$$d = \operatorname*{argmax}_d \sum_i \Delta U_i(d) \; - \; \Gamma(d, c^0(d))$$

That is $c(d)$ is the cost that makes decision variable d become optimal in 2.5. Accordingly, define $d^0(c) = (c^0)^{-1}(c)$, that is, the optimal design in 2.5 when cost is c. Therefore, after the uncertainty being resolved in the future, e.g. the cost is c_{ξ_0}, we will have $d^1 > d(c_{\xi_0})$ if $c^0(d^1) < c_{\xi_0}$ and $d^1 < d(c_{\xi_0})$ if $c^0(d^1) > c_{\xi_0}$, that is, if the real cost is higher than the estimated one, the design will be larger than the optimal one and vice versa.

From the analysis above and (2.8) we know that

$$S^1(d^1) = E_\xi S^0_\xi(d^1) < S^0_\xi(d^0) \tag{2.9}$$

Inequality (2.9) indicates that under the condition that the uncertainty could not be well-managed, the final decision will get lower social welfare than the ideal case. Moreover, the final design d^1 won't be optimal in most scenarios. Such sub-optimality comes from that the government officer could not optimally forecast the future uncertainty. Thus under some realization of uncertainty, the final design will be less than the optimal one and for other scenarios, the final design will be larger than the optimal one.

In this case, the government officer should announce an estimated cost $c^0(d^1)$ which based on the optimal solution, d^1, of the optimization problem (P1). The infrastructure is built based on this second-best decision, d^1, and there will be social welfare loss.

2.3.3 Selfish government officer without expertise

In 2.3.1 and 2.3.2, we assume that the government officer is benevolent, that is, she will always maximize the social welfare. However, it is widely accepted that in the infrastructure project decision process, political issues have a greater influence on the proposal.([33]) A government officer with objective other than social welfare is referred as selfish and the decision from her may not be socially optimal.

There are several motivations for government agent to be selfish: Firstly, with more people support the proposal, the more likely the project will be implemented. Studies in transportation infrastructure management have pointed out the significance of such incentive ([23]). The second motivation is reelection. Transportation projects are usually regarded as a positive mark of good performance of government officers. Thus incumbent officers usually use highway projects as political capital to gain more intermediate voters in future election, or as a way to directly 'buy votes'.[1] Thus, the objective function of officer's is different from (2.5) or (2.3.2) in the way that, the officer is not pursuing total social benefit, but the total *weighted* social benefit by popularity.

After the highway being built, each household or individual's utility function will be changed by three factors we mentioned in 2.2: spending, change in traveling utility and indirect utility from the highway. Therefore the utility function of a household or individual in group i could be expressed as,

[1]One prominent case is pork-barrel politics in infrastructure investment.[66]

$$S_i^2(d,\alpha) = \mathbb{E}_\xi \left[\frac{1}{\delta^i} \Delta U^i(d) - \frac{\alpha}{\sum_{k\in A} \delta^k} \Gamma(d, c_\xi) + \sigma^i \right], \qquad i \in A \tag{2.10}$$

where $\Delta U^i(\cdot)$ is the travel cost improvement of group i, $\Gamma(d,c)$ is the spending on the infrastructure including building, operating and maintaining cost, and σ^i is a random parameter of externality, that is the utility gain or loss beyond the spending and travel time improvement, such as expansion of local business, increasing of job market, or deteriorating of air/noise condition. The coefficient α denotes the local awareness of the possible future tax increase. If the local residents is totally aware and concerned on the spending, $\alpha = 1$ and if the local residents treats the highway as free, then $\alpha = 0$.

Thus, the utility of each group residents is the gain or loss from the sum of travel time improvement, cost per capita through taxation and the externality brought by the infrastructure. The cumulative distribution function (CDF) of σ^i is $F(\sigma^i)$ and probability distribution function (PDF) is $f(\sigma^i)$, which means that the number of people with random externality σ^i in group i is $F(\sigma^i)$. Without loss of generality, we assume that $\mathbb{E}\sigma^i = 0$, that is the indirect effect on local residential group is zero. This simplification does not influence our conclusion and will come back to this point later. Then the portion of people in group i having positive utility after the infrastructure project is built becomes

$$\delta^i \left(1 - F\left(S_i^{fix}(d,\alpha)\right)\right),\ S_i^{fix}(d,\alpha) = \frac{\alpha}{\sum_{k\in A} \delta^k} \Gamma(d, c_{\mathbb{E}\xi}) - \frac{1}{\delta^i} \Delta U^i(d)\ ,\ i \in A \tag{2.11}$$

All $S_i^{fix}(d,\alpha)$ are the fixed (dis)utility functions of group i and we have

$-\sum_i \delta^i S_i^{fix}(d,\alpha)$ is actually the total net social benefit of the infrastructure project.

The officer is trying to maximize the total number of people having positive utility after implementation, that is:

$$(P2) \qquad \max_d S^2(d,\alpha) = \max_d \sum_{i\in A} \delta^i \left(1 - F\left(\frac{\alpha}{\sum_{k\in A}\delta^k}\Gamma(d, c_{\mathbb{E}\xi}) - \frac{1}{\delta^i}\Delta U^i(d)\right)\right) \tag{2.12}$$

The first-order condition of (2.12) is

$$-\sum_i \delta^i f(S_i^{fix}(d,\alpha)) \frac{\partial S_i^{fix}(d,\alpha)}{\partial d} = 0 \tag{2.13}$$

The first-order condition (2.13) resembles its counterpart in previous sections 2.3.1 and 2.3.2 in the way that, it is actually a weighted average of the derivative of benefit and cost. The weights are determined by $f(S_i^{fix}(d,\alpha))$, the density of indifferent population of group i.

As $S_i^{fix}(d,\alpha)$ denotes the disutility of group i and $f(\cdot)$ is a probability distribution function (pdf), the term $f(S_i^{fix}(d,\alpha))$ then becomes the density of households or individual who are indifferent in building the highway. In other word, it is the fraction of people who will vote for (against) the project in group i if the mean disutility decreases (increases) by one unit. Then the product $\delta^i f(S^i_{fix}(d,x))$ is the number of people who are current indifferent on the project's implementation.

If first-order condition holds, the government officer would not be willing to change the design, and hence change the disutility function of each group when the change in total number of indifferent population is not positive, that is, she will lose support.

If the indirect utility of household is uniformly distributed, which is defined as follows:

$$f(x) = \frac{1}{S_H - S_L} = Const \qquad x \in [S_L, S_H]$$

Then we have the density of indifferent population remains the same in the interval $[S_L, S_H]$. The first-order condition (2.13) becomes

$$\sum_i \delta^i (Const) \frac{\partial S_i^{fix}(d,\alpha)}{\partial d} = 0 \tag{2.14}$$

Therefore, the solution to equation (2.14) is identical to the solution of (2.8), that is, when the government officer is benevolent. Thus, when the utility of residents in each group is uniformly distributed or at least the selfish agent believes so, the final decision made by her should be same as the the benevolent officer. In this case the weighted sum of derivatives coincides the first-order condition of social welfare.

When the distribution f is not uniform, we should expect that different utility function of individuals will induce different decision outcome. As we are interested in the final decision d^2's relationship with the second-best decision d^1, we can examine the value of left-hand side (LHS) of first-order condition, (2.13), at the point d^1. If for (2.13), $LHS > 0$ at d^1, we know that $d^2 > d^1$ and vice versa. Therefore we discuss the effect of different degree of awareness of spending, α on the LHS of (2.13). We refer to the case when $d^2 > d^1$ as *under-estimated decision* because the cost is under-estimated ex ante ($c^0(d^2) < c^0(d^1)$) and the case $d^2 < d^1$ as *under-designed decision* as the design decision d^2 is smaller than the benevolent one.

Residents have no awareness of spending, $\alpha = 0$

$\alpha = 0$ indicates that local residents treat the newly built infrastructure as total 'free'. This could due to that the government officer intentionally hide the spending information of highway from the public or the major or entire spending is covered by federal fund outside jurisdiction. In such situation, the utility function of each individual in region i, equation (2.10), becomes

$$S_i^2(d,0) = \mathbb{E}_\xi\left[\frac{1}{\delta^i}\Delta U^i(d) + \sigma^i\right], \qquad i \in A$$

and the disutility of each individual in group i becomes,

$$S_i^{fix}(d,0) = -\frac{1}{\delta^i}\Delta U^i(d)\,,\ i \in A$$

Therefore, the first order condition, (2.13), becomes

$$-\sum_{i\in A} f\left(-\frac{1}{\delta^i}\Delta U^i(d)\right)\left(-\frac{\partial \Delta U^i(d)}{\partial d}\right) = 0 \tag{2.15}$$

As $f(\cdot)$ is density function, $f(\cdot) > 0$. Then we can divide (2.15) by $\sum_{i\in A} f\left(-\frac{1}{\delta^i}\Delta U^i(d)\right)$ and get

$$\sum_{i\in A} f_0^i \frac{\partial \Delta U^i(d)}{\partial d} = 0 \tag{2.16}$$

where

$$f_0^i = \frac{f\left(-\frac{1}{\delta^i}\Delta U^i(d)\right)}{\sum_{i\in A} f\left(-\frac{1}{\delta^i}\Delta U^i(d)\right)}, \ i \in A$$

f_0^i is actually a coefficient that $\sum_{i\in A} f_0^i = 1$. One immediate observation is that, smaller $\Delta U^i(d)$ or larger δ^i produce larger f_0^i and the final decision d^2 will have more weight on group i.

After the highway being built, as there is no extra demand in the network and the travel time of link I-S and S-B are fixed, there are two different scenarios: The travelers between I-S choose only link I-S or choose the links I-B-S[2], as shown in Figure 2.4. Then the groups that are affected by the newly built highway are $i \in \{IB, IS\}$. Hence, (2.16) becomes

$$\sum_{i\in A} f_0^i \frac{\partial \Delta U^i(d)}{\partial d} = 0, \qquad , i \in \{IB, IS\} \tag{2.17}$$

As $\frac{\partial \Delta U^i(d)}{\partial d} > 0$ for all d (otherwise the newly built highway is not socially beneficial), we know that $LHS > 0$ for (2.17) at d^1 and $d^2 > d^1$. Actually, we could further get $d^2 \to \infty$. Therefore, in this case, when local residents are not concern with spending ($\alpha = 0$) and the newly built highway does not have externailities on people other than travelers between I-B, the government officer will claim low cost $c^0(d^2)$ and make high decision d^2 based on this low cost. There will be no change of scope ex post. In other words, there will be cost overrun entirely induced by under-estimated decisions.

From the above analysis, if the newly built highway does not have visible

[2]If the travel time on link I-S and S-B are not fixed, there will be a third scenario where travelers between I-S will choose I-S and I-B-S simultaneously. This is a case that the newly built link generate negative externality on other groups of residents, which is a case falls in the discussion of later sections.

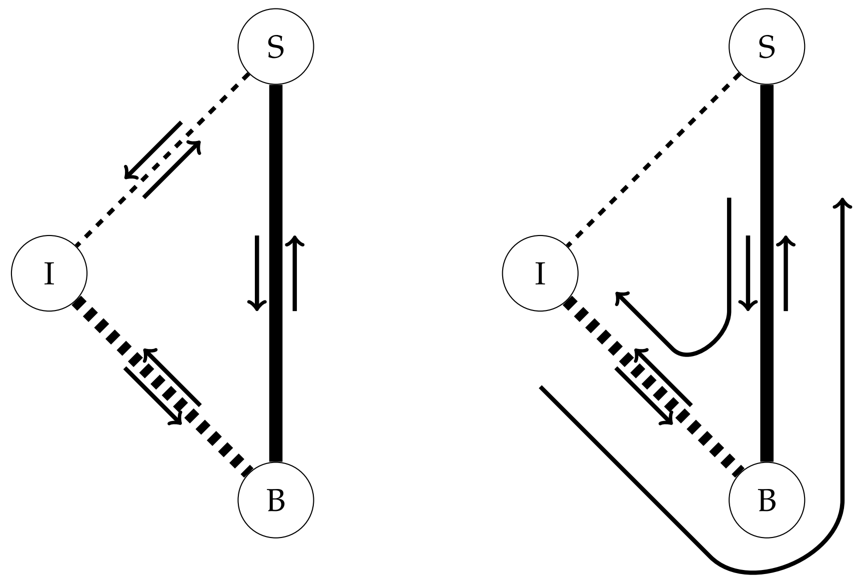

Figure 2.4: Left: Travelers between I-S use link I-S. Right: Newly built highway I-B does not change route choices

negative externality on other group (in our example, it is group of travelers between S-B), the government officer will report an lower cost $c(d^2) < c(d^1)$ than benevolent case and we will get under-estimated decisions.

Residents have full awareness of spending, $\alpha = 1$

When $\alpha = 1$, the residents are fully aware of the spending on the new highway. As the fund on transportation infrastructure usually comes from local gas tax, building a new highway could be treated as a negative externality to people who are not direct benefit from it but still need to pay tax on it. Therefore, when $\alpha = 1$, the government officer is making decision under the situation that there are negative externality on part of local residents.

Therefore, we have the first-order condition (2.13) becomes

$$\sum_{i \in A} f_1^i \left[\frac{\partial \Delta U^i(d)}{\partial d} - \frac{\delta^i}{\sum_{k \in A} \delta^k} \frac{\partial \Gamma(d, c_{\mathbb{E}\xi})}{\partial d} \right] = 0 \tag{2.18}$$

where

$$f_1^i = \frac{f\left(-\frac{1}{\delta^i} \Delta U^i(d) + \frac{1}{\sum_{k \in A} \delta^k} \Gamma(d, c_{\mathbb{E}\xi}) \right)}{\sum_{i \in A} f\left(-\frac{1}{\delta^i} \Delta U^i(d) + \frac{1}{\sum_{k \in A} \delta^k} \Gamma(d, c_{\mathbb{E}\xi}) \right)}.$$

f_1^i is equivalent to the 'weight' of the items in the first order condition. Same to previous section, we will examine the value of LHS of 2.18 at d_1.

Notice that the first-order condition for the case benevolent officer without expertise, 2.8, is a special case of 2.18 when $f_1^i = f_1^j, \forall\, i, j \in A$. Therefore, if the net benefit of each individual in the jurisdiction is the same, the decision made by selfish officer is coincident with the decision made by benevolent officer.

However, this is usually not the case given that the newly built highway is socially beneficial. Without loss of generality, we assume that the group of travelers between $I - S$ using only the link $I - S$, that is there is no positive utility change from the highway. Recall that the average utility of individual in each group i is ${S^i}_{fix}$. As the social welfare is the sum of utility of each group of people, i.e.

$$\text{Social welfare} = \delta^{IB} S^{IB}_{fix} + \delta^{IS} S^{IS}_{fix} + \delta^{SB} S^{SB}_{fix} > 0,$$

utility of group IB is positive, $S^{IB}_{fix} > 0$, and utilities of groups SB and IS are negative $S^{SB}_{fix}, S^{IS}_{fix} < 0$, we have $\delta^{IB} S^{IB}_{fix} + \delta^{IS} S^{IS}_{fix} > 0$ and $\delta^{IB} S^{IB}_{fix} + \delta^{SB} S^{SB}_{fix} > 0$. When

$$S^{IB}_{fix} > f^{-1}\left(\frac{1}{2}[f(S^{IS}_{fix}) + f(S^{SB}_{f} ix)]\right), \tag{2.19}$$

we have the decision from selfish government officer, d^2 is less than the benevolent decision d^1. (2.19) indicates that if the utility of individuals who directly benefit from the highway is large, the selfish decision will fall short of the social optimal one as it tries to mitigate the negative externality to groups I-S and S-B.

2.3.4 Summary

From the above analysis, when government agent is selfish, the perception of spending (negative externality) plays a key role in the final decisions. If the public only focuses on the utility they can get from the highway, the final decision d^2 will be entirely under-estimated, that is the government agent will report low cost and propose high design. On the other hand, if the public focuses both on utility and cost of the highway, the result will most likely to be under-designed. The different values of α will induce various degree of under-estimated decision and under-designed decision.

It is interesting that for the benevolent officer without expertise, the decision d^1 will also induce cost overrun. When the estimated cost $c^0(d^1)$ is less than the real cost c_ξ, d^1 is larger than the socially optimal design d^0_ξ and the estimated cost will exceed real cost (ex ante cost overrun). It is also possible that $c^0(d^1) > c_\xi$, that is, the design is less than the optimal design d^0_ξ. This indicates that the design is not sufficient ex ante and extra work will be done ex post to serve extra demand (ex post cost overrun).

Although d^1 will also cause cost overrun problem, there are two differences between d^1 and d^2. Firstly, from the definition of (2.7), although d^1 is not socially optimal, it actually minimizes the expected cost overrun. However, there is no guarantee that d^2 has the same effect (although some d^2 will coincidentally same as d^1). Secondly, in the cost overrun problem induced by d^1, two categories of cost overrun, ex ante cost overrun and ex post cost overrun, happen with same significance. However in the possible outcomes induced by d^2, there will be either more ex ante cost overrun caused by under-estimated decision or ex post overrun by under-designed problem.

Given that decision d^2 is not socially favorable, it is attractive for federal government and the public to regulate the government officer from making such decision. However, as such decision is enabled by the private information possessed by the officer, it is not trivial to prevent the unfavorable results. In the following section, we investigate the possibility to extract officer's private information on cost using auditing.

2.4 Auditing project costs

If there is a benevolent federal government who desires socially optimal decision d^1 and can exert influence on local residents within the selfish government officer's jurisdiction, the federal government can design an auditing mechanism that given the selfish government officer's decision d and corresponding cost estimation $c = c^0(d)$,

- The federal government audits the jurisdiction with probability $p(c)$,
- due to technical issue, the audit will successfully reveal real cost estimation $\bar{c}$ with only probability θ,
- if government officer does not honestly report the estimated cost $\bar{c}$, she will be punished by $\pi M(c, \bar{c})$, where $M(c, \bar{c})$ is the measure of difference between real cost and reported cost,
- cost of auditing is k, which is fixed,
- assume that the central government will always commit to the mechanism.

Auditing is considered as an solution to cost overrun problem ([34]). However, existing literature on audit ([61]) only consider the situation when project cost is paid by the agent subjected to auditing and the punishment for being dishonest is a monetary transfer. In the context of our model, it is the public who pays for the infrastructure and the government agent's utility is population of supporters of infrastructure. Therefore, we would expect two changes in our model. Firstly, the punishment is not a direct monetary transfer. Secondly, the available punishment may not be strong enough to make government officer truth-telling.

Therefore, the auditing problem is:

$$
(A) \quad \begin{aligned} \max_{p(c^*)} \quad & \mathbb{E}_{c^*}\left[\sum_i \Delta U_i(c^{-1}(c^*)) - \Gamma(c^{-1}(c^*), c^*) - kp(c^*)\right] \\ s.t. \quad & c^* = \text{argmax}_c\, S^2(c^{-1}(c), \alpha) - p(c)\theta\pi M(c, \bar{c}) \end{aligned} \tag{2.20}
$$

where S^2 is objective function of selfish officer,

$$
S^2(d, \alpha) = \sum_{i \in A} \delta^i \left(1 - F\left(\frac{\alpha}{\sum_{k \in A} \delta^k} \Gamma(d, c_{\mathbb{E}\xi}) - \frac{1}{\delta^i} \Delta U^i(d)\right)\right).
$$

We first consider that situation when the central government can exert arbitrary influence on government officer, i.e. $\pi \in [0, \infty)$. Then we have

$$
M(c, \bar{c}) = \frac{1}{m} S^1(c^{-1}(c)) - S^2(c^{-1}(c), \alpha^*), \tag{2.21}
$$

where $c^{-1}(c)$, which yields the corresponding design variable of cost level c, is the inverse function of $c(d)$, α^* makes $c^{-1}(c)$ the optimal solution of $S^2(d, \alpha^*)$ and m is the monetary value of one voter to the selfish government officer. The first term in equation (2.21) is the equivalent utility for government officer if she is maximizing social welfare and the second term is the real utility of the officer. Then the measurement is the difference between utility of benevolent officer (translated into voting number) and selfish officer. Therefore, we achieve that the optimal auditing policy is (for proof, refer to [64])

$$
p(c) = \frac{1}{\theta\pi} \in (0, 1) \tag{2.22}
$$

In summary, the central government should select a punishment $\pi M(c, \bar{c})$, such that $\frac{1}{\theta\pi} \in (0, 1)$ and can achieve second-best decision outcome d^1.

When the central government's ability is limited, e.g. the central government can only affect part of the population δ after revealing the biased design of selfish government officer, that is $\pi M(c, \bar{c}) \leqslant \delta$. From the above result, when $\frac{1}{\theta\pi} > 1$, even auditing can not guarantee the desired decision d^1. Then we have

$$M(c, \bar{c}) > \theta\delta \tag{2.23}$$

This indicates that, when the central government could not influence more local residents than the officer could gain by making selfish decision, the optimal audit mechanism could not ensure best outcome d^1.

2.5 Generalization to cost overrun in all infrastructure system

In this chapter, although our study focuses on a 3-node transportation network, the result could be easily generalized to the study of cost overrun in all infrastructure system with possibility of spatial externality. Let ΔU^i denote the positive utility group i get from the infrastructure and Γ^i denote the negative utility group i get (Notice that ΔU^i and Γ^i in previous sections are travel time improvement and spending respectively). In the system, there are multiple groups of residents, users, etc., $i \in A$. We also use S^0_ξ, S^1, and S^2 to denote the objective function of benevolent government officer with expertise, benevolent government officer without expertise, and selfish government officer without expertise, respectively and d^0_ξ, d^1 and d^2 are corresponding final decision.

Therefore from the result in previous sections, when the distribution of utility of different group is identical normal distribution, the decision d^1 and d^2 are the same. When there are no negative externalities, i.e. $\Gamma^i = 0, \forall\, i \in A$, we have $d^2 > d^1$. In this case, there will be mainly under-estimated decisions.

In section 2.3.3, we assume that $\Delta U^{SB} \geqslant 0$ simplified the discussion. This assumption can be claimed as 'without loss of generality' because when $\Delta U^{SB} < 0$, we can define

$$\bar{\Gamma}^{SB} = -\Delta U^{SB}$$
$$\Delta \bar{U}^{SB} = 0$$

this is equivalent to that the group S-B has an extra spending on the highway and the change of traveling utility is 0.

On the other hand, when $\Gamma^i > 0$, i.e. there is negative externality from the infrastructure, the final decision d^2 depends on average utility S^i_{fix} of each group i. If the groups gaining utilities has less population or more utility increase, the final decision $d^2 < d^1$ and vice versa.

Therefore, in cost overrun problem, the scenarios that decision is under-estimated dominates. This explain the the cost overrun is usually discovered as estimated cost exceeding real cost, that is ex-ante cost overrun. The ex-post cost overrun, caused by under-designed decision, usually requires change of contract scope.

The model could also provide deeper insights in infrastructure project. For example, it is sometimes appealing that bundling a group of infrastructure projects in one jurisdiction to ensure each group benefit from the bundling of projects and negative externalities are compensated. However, from our analysis, in this way, the cost overrun is still not mitigated because all the groups have positive utility and there will be under-estimated decision and hence ex-ante cost overrun.

2.6 Main Findings

In this chapter, we model the cost overrun problem under an infrastructure network context and identify the quantitative and qualitative signs of political and economic drivers. We consider a local government building an infrastructure within an existing infrastructure system with heterogeneous users and different groups enjoy different benefits from the newly built infrastructure. The cost of the infrastructure is uncertain. The government officer, who is decision maker, knows the distribution of such uncertainty privately but could not predict the exact realization. Therefore, she can only make a 'rough' decision given the distribution and cost overrun is a possible outcome. We assume that there are two types of officers, benevolent and selfish ones, where benevolent government officer will make decision to maximize the social welfare while the selfish one will maximize her own benefit. As the public and higher level government don't know the distribution ex ante, it is impossible to tell the government officer's type purely from the decision she made and the corresponding result (whether or not cost overrun).

In line with other literature in infrastructure management such as [5], the infrastructure project consists of two stages: decision stage and realization stage.

In the decision stage, the distribution of the uncertainty is revealed to government officer who will estimate cost and make decision. In the realization stage, infrastructure is built and the uncertainty will be resolved. The cost immediately following resolution of uncertainty is referred as intermediate cost, while the cost following completion of the whole project is called real cost.

We classify the cost overrun into ex-ante cost overrun and ex-post cost overrun. Ex-ante cost overrun is induced by optimistic cost estimation where, the estimated cost is lower than the intermediate cost immediately after the resolution of uncertainty. In the contrast, ex-post cost overrun is mainly caused by change of scope where the estimated cost is higher than the intermediate cost but lower than the real cost because of extra work after the resolution of uncertainty. We identify that the decision made by benevolent officer will induce both cost overrun with same significance. However, decision from selfish officer will favor one kind of cost overrun.

The main finding of this chapter is, in real world project, in examination of causes of cost overrun, the cost overrun induced by optimistic forecast of cost should be distinguished from change of scope. If the ex-ante or ex-post cost overrun dominates, it is a strong sign of existence of selfish driver behind the cost overrun. Among existing empirical studies, in [58], the authors' findings suggest that for a single transportation project, the cost overrun is either purely induced by poor estimation or by extension and [57] reported that major reason for time and cost overruns is inadequate funding of project. These findings are signs indicating that cost overruns are not purely driven by technical uncertainty.

Through this model, we explain the prevalence of cost overrun discovered in empirical study such as [35]. Although statistical data depicts cost overrun as dominating, our model indicates that this is reasonable according to the definition and irreversible investment. Irreversible investment prevents scaling-down ex post but permits scaling-up. Therefore there will be a tendency to have more cost overruns.

As it is suggested by [16], auditing could be an effective measure to prevent cost overrun. We also study the effectiveness of auditing mechanism of a benevolent central or federal government to randomly audit the real cost of project and punish the lying government officer. We discover that the effectiveness of auditing largely depends on the ability of central government to conduct successful audit and exert enough influence on local taxpayers and voters. With only limited ability in influencing residents, auditing is ineffective in correcting cost overrun. [61] introduced an auditing mechanism for cost overrun claims. The government will always audit the claim above a cut-off value and never for the one below the threshold. Their model discovered that most firms will claim cost overrun for the value precisely below threshold, which is supported by empirical observation. This chapter takes one step further to discuss the effectiveness of auditing mechanism to prevent the selfish government officer from making biased decision.

CHAPTER 3

CORRUPTION AND POST-TENDER PHASE RENEGOTIATION

3.1 Introduction

Public-Private Partnership, where governments and private companies collaborate to provide public infrastructure or service and share revenue, cost and risk, is widely applied in all spheres of economic activities such as transport, power grid, water supply, waste, IT, etc.[1] PPP may exist in different forms, such as "Build-Operate-Transfer" (BOT) and "Build-Own-Operate" (BOO). The advantages of PPP in procuring public infrastructure and service include better economic indicator, technological innovation, proper risk sharing and less constrained government budget.

In this chapter, we discuss the corruption in post-tender phase renegotiation of a PPP project. In our model, a new highway is built as an alternative of an existing local road. After the contract is awarded, uncertain factors realize and a potential government-led renegotiation could be Pareto-improving for the society. However, due to administration cost, the central or local government can not directly renegotiate the contract and therefore delegate the decision to a local official. The official can be selfish, which means that she can collude with either the local residents group or the contractor of the project, or both, in the process of renegotiation to seek illicit personal benefit.[2] The official can decide whether to initiate the renegotiation or not based on her information and then the residents group and the contractor can either accept or decline the offer. If

[1]For a complete review of PPP performance, refer to [44]

[2]To avoid confusion, we refer to the official with feminine form (she), local residents and contractor with masculine form (he) and the central government with plural form (they).

the offer is decline by either of the party, the original design is implemented otherwise, the new design is developed based on central government's rule.

3.2 The model

In this chapter we consider the renegotiation game in post-tender session in a highway project. The central or state government is building a new highway between point A and B where there is already an existing highway with a constant travel time t_A. The design of the new highway is a pair (p, C) with p denoting the toll price and C the capacity. Let the travel time of newly built highway being $t(q, C)$ where q denotes the traffic flow using the highway. Based on user equilibrium, we must have

$$t_A = t(q, C) - \frac{p}{\beta}$$

where β denotes the smallest value of time (VOT) of travelers on the newly built highway. Furthermore, the cost of building the highway is kC, where k is the cost of one unit of capacity.

The group of residents currently traveling between A and B is denoted as R. we assume that the total demand between A and B does not change after the new highway being built. The residents have heterogeneous VOTs which distribute according to a cumulative density function (CDF) $F(\beta, \theta)$, where θ is the parameter of the distribution.

Following the definition and derivation in [69], let $\gamma = \dfrac{q}{C}$ denote the volume-to-capacity (v/c) ratio. According to Tan and Yang (2012), the decision problem of (p, C) is equivalent to a decision problem of (β, γ) with $p = (t_A - t(\gamma))\beta$ and $C = Q\bar{F}(\beta, \theta)/\gamma$, where $\bar{F}(\cdot) = 1 - F(\cdot)$. [69] derives the social optimal design under similar settings. To keep this chapter succinct, we only refer to their results when needed and avoid reinvent the wheel.

3.2.1 Stakeholders

Although infrastructure projects are under the regulation of central or state governments, the decision is most likely delegated to local officials as discussed in ([48]). Then, the officials coordinate with contractors selected through tendering process to work out the design of the highway. The interactions between these two parties in pre-tender and tender phases are usually regulated by laws and closely monitored by government or third party agents. However, in the post-tender phase, as mentioned in Section 3.1, the local official and contractor have more freedom in renegotiation. Therefore, the post-tender phase of infrastructure projects is prone to corruption and collusion ([48]).

The contractors, as private companies, will attempt to maximize their own profit by increasing revenue or saving cost through contract renegotiation. To achieve this, they will be willing to share the extra profit with the official who facilitates this. On the other hand, the officials would be interested in both the bribe, which is in the form of personal benefit, political donation, or political capital provided by local residents such as the chances of being reelected. The local residents could also participate in the collusion to minimize their payment (toll and tax) and/or maximize the transportation benefit from the highway.

Although the local official, the contractor and the residents group are self interested, the central (or state) government is regarded as benevolent here in this framework. When information is symmetric, the central government can implement social optimal design without any loss. However, under asymmetric information, the local official, contractor and/or residents group can deliberately hide the true information from the central government and induce the outcome unfairly favoring their own benefits.

3.2.2 Information structure

In this model, all the three self-interested parties possess private information. The parameter of the distribution of VOT, $\theta \in [\underline{\theta}, \bar{\theta}]$ is privately held by residents group, the unit cost of building highway, $k \in [\underline{k}, \bar{k}]$ is privately known to the contractor and the local official possesses the information on whether she knows the private information held by residents group and the contractor, $\sigma \in \{(\theta, k), \emptyset\}$. Let $G_\theta(\cdot)$ and $G_k(\cdot)$ denote the cumulative distribution function of θ and k, respectively and $g_\theta(\cdot) = G'_\theta(\cdot)$, $g_k(\cdot) = G'_k(\cdot)$. The support and distributions of θ and k are public information. During the pre-tender and tender phases, θ and k are not realized and the decision of highway is made based on fair estimation θ_e and k_e which are completely audited and free of manipulation by any party. After the contract is awarded and signed, the θ, k and σ are realized and privately known to residents group, contractor and official, respectively. If the design of the highway is renegotiated, the local official must report her information about residents group and contractor' types, $\sigma = \emptyset$ or $\sigma = (\theta, k)$ to the central government. If the report is no information, $\sigma = \emptyset$, the central government will let the residents group and contractor to announce their type, $\hat{\theta}$ and $\hat{k}$, respectively. The design thereafter is determined by rule $\beta^F(\theta, k)$ and $\gamma^F(\theta, k)$

if local official reports $\sigma = (\theta, k)$ or $\beta^N(\hat{\theta}, \hat{k})$ and $\gamma^N(\hat{\theta}, \hat{k})$ otherwise. Notice that neither of the reports is necessarily truthful.

Given the decision rule β and γ, the utility functions of different interest parties are [3]

- Residents group R as a whole is maximizing the sum of the net benefit from the highway, $u_R(\cdot)$ and the subsidies from the government, $X_R(\cdot)$, with the expectation on contractor's type, k:

$$U_R(\theta, \hat{\theta}) = u_R(\theta, \hat{\theta}) + X_R(\hat{\theta})$$

  where $u_R(\theta, \hat{\theta}) = \mathbb{E}_k \left[Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta) m(\beta(\hat{\theta}, \hat{k}), \theta)(t_A - t(\gamma(\hat{\theta}, \hat{k}))) \right]$ denotes monetized value of travel time saving from the newly built highway minus the cost of toll.

- The utility function of contractor is the profit from the newly built highway, $u_c(\cdot)$ plus the possible subsidies, $X_c(\cdot)$ given the expectation of the resident's group type θ:

$$U_c(k, \hat{k}) = u_c(k, \hat{k}) + X_c(\hat{k}) \tag{3.1}$$

  where $u_c(k, \hat{k}) = \mathbb{E}_\theta \left[Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta)\beta(\hat{\theta}, \hat{k})(t_A - t(\gamma(\hat{\theta}, \hat{k}))) - Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta)\frac{k}{\gamma(\hat{\theta}, \hat{k})} \right]$ is the toll revenue from the highway subtracted by the cost of building and operating the highway.

- Central government: Assume that the central government is benevolent and maximizing the expected social welfare minus the out-of-pocket payment to both the residents group and the local contractor.

[3] The decision rules β and γ will take various forms under different conditions. We will discuss the optimal decision rule β^N, γ^N, β^F and γ^F short after.

$$U_g(\theta, k, \hat{\theta}, \hat{k}) = \mathbb{E}_\theta \left[u_R(\theta, k, \hat{\theta}, \hat{k}) - X_R(\hat{\theta}, \hat{k}) \right] + \mathbb{E}_k \left[u_c(\theta, k, \hat{\theta}, \hat{k}) - X_c(\hat{\theta}, \hat{k}) \right] \quad (3.2)$$

3.2.3 Optimal design under different information conditions

Given the information structure and the utility functions, we could derive the optimal design functions when official is absent and central government possesses full or no information.

Central government possesses full information

Based on results in mechanism design and information theory (such as [9]), if the government possesses full information, she does not need to provide monetary transfer and therefore $X_c(\hat{k}) = X_R(\hat{\theta}) = 0$, $\forall \hat{\theta}, \hat{k}$. Under this condition, the design of the highway under full information (β^F, γ^F) is determined by the following equations given in Tan and Yang (2012)

$$\begin{aligned} \beta^F &= \frac{k}{\gamma^F \left[t_A - t(\gamma^F) \right]} \\ m(\beta^F, \theta) + \beta^F &= \frac{k}{(\gamma^F)^2 t'(\gamma^F)} \end{aligned} \quad (3.3)$$

To simplify the analysis in the rest of this chapter, we make the following assumption:

Assumption 1. *The residual VOT $m(\beta, \theta)$ is independent of the design variable β and decreasing in θ.*

Therefore, we rewrite the function as $m(\theta)$. Notice that Assumption 1 holds when, for example, the distribution of VOT is exponential and if θ is the rate parameter of the distribution, where $f(\beta) = \theta e^{-\theta\beta}$, then $m(\beta, \theta) = m(\theta) = \frac{1}{\theta}$.

Following Assumption 1, we have the following lemma.

Lemma 1. *The social optimal design under full information* (β^F, γ^F) *in (3.3) satisfies the following relationship*

$$\gamma^F = \frac{1}{\beta^F} e^{-\frac{\beta^F}{m(\theta)}}, \tag{3.4}$$

for all $\gamma^F = \gamma^F(\theta, k)$ *and* $\beta^F = \beta^F(\theta, k)$.

Proof. In this proof, the superscription F is omitted for β^F and γ^F.

From the optimal solution 3.3, we know that

$$t(\gamma) = t_A - \frac{k}{\gamma\beta} \tag{3.5}$$

Then take derivative of γ on the both sides of Equation (3.5) and we get

$$t'(\gamma) = \frac{k}{(\gamma\beta)^2}\left[\beta + \gamma\frac{\partial\beta}{\partial\gamma}\right] \tag{3.6}$$

Substitute $t'(\gamma)$ in second equation of (3.3) by (3.6) and then we can get

$$m(\theta) + \beta = \frac{k}{\gamma^2 \frac{k}{(\gamma\beta)^2}\left[\beta + \gamma\frac{\partial\beta}{\partial\gamma}\right]}$$

$$\Rightarrow \qquad m(\theta) + \beta = \frac{\beta^2}{\beta + \gamma\frac{\partial\beta}{\partial\gamma}}$$

$$\Rightarrow \qquad \frac{\partial\beta}{\partial\gamma} = -\left(\frac{1}{m(\theta)} + \frac{1}{\beta}\right)\frac{1}{\gamma} \tag{3.7}$$

From (3.7) we know that

$$\gamma = exp\left(-\left(\frac{\beta}{m(\theta)} + ln\beta\right)\right) + \mathbf{C} \tag{3.8}$$

For (3.8) we can use the extreme value when $\gamma \to +\infty$ to get $\mathbf{C} = 0$.

□

Lemma 1 indicates that when central government is provided with full information, one design variable v/c ratio, γ, can be determined by another variable, the threshold value of time (VOT), β. Therefore, in the following sections, we can focus on single variable when we discuss the renegotiation outcome with fully informed official. Further, we have the following Corollary.

Corollary 2. *Given Assumption 1, $\beta^F(\theta, k)$ is monotonously decreasing in θ and k. $\gamma^F(\theta, k)$ is monotonously increasing in θ and k.*

Proof. Given the result in (3.3), substitute β in the first equation into second one, we have:

$$\begin{aligned} & m(\theta) + \frac{k}{\gamma^F\left[t_A - t(\gamma^F)\right]} = \frac{k}{(\gamma^F)^2 t'(\gamma^F)} \\ \Rightarrow \qquad & m(\theta) = \frac{k}{\gamma^F}\left(\frac{1}{\gamma^F t'(\gamma^F)} - \frac{1}{t_A - t(\gamma^F)}\right) \end{aligned} \tag{3.9}$$

As $t(\gamma)$ and $\gamma t'(\gamma)$ are increasing in γ for commonly used travel time - v/c ratio model, such as Bureau Public Road (BPR) model, the right-hand-side (RHS) of (3.9) is decreasing in γ. Also the left-hand-side (LHS) is monotonously decreasing in θ, we know that γ^F is monotonously increasing in θ. Then using (3.4), it is easy to check that β is decreasing in θ.

On the other hand, fixing θ on the LHS of (3.9), we can see that γ is increasing in k. Therefore, β is decreasing in k from (3.4).

□

Central government possesses no information

If the central government does not possess information about the types of the residents group and contractor, these two parties can misreport their type and profit from such behavior. Thus, the central government should provide them with proper incentive to prevent this. Such incentive is called information rent in Mechanism Design literature. With a little bit abuse of notation, let $U_R(\theta) = U_R(\theta, \theta)$ and $U_c(k) = U_c(k, k)$. The following lemma provides the minimum utility level the central government should provide the residents group and contractor to induce truth-telling (superscript 'N' denotes local official has no information).

Lemma 3. *To ensure both residents group and contractor to be truth-telling when government official has no information, the utility function $U_R^N(\theta, \hat{\theta})$ and $U_c^N(k, \hat{k})$ should satisfy the following conditions:*

$$U_R^N(\theta, k) = \mathbb{E}_k\left[U_R^N(\bar{\theta}, k)\right] - \int_{\theta}^{\bar{\theta}} \mathbb{E}_k\left[Q[t_A - t(\gamma(\theta, k))]\frac{\partial\{\bar{F}(\beta, \tilde{\theta})m(\tilde{\theta})\}}{\partial\theta}\right]d\tilde{\theta} \tag{3.10}$$

$$U_c^N(\theta, k) = \mathbb{E}_\theta\left[U_c^N(\theta, \bar{k})\right] - \int_{k}^{\bar{k}} \mathbb{E}_\theta\left[Q\bar{F}(\beta(\theta, \tilde{k}), \theta)\frac{1}{\gamma(\theta, k)}\right]d\tilde{k} \tag{3.11}$$

where $U_R^N(\bar{\theta})$ and $U_c^N(\bar{k})$ is the minimal utility the residents group and contractor can obtain, respectively, when their types are the highest.

Proof. The utility function of resident is

$$U_R^N(\theta, \hat{\theta}) = \mathbb{E}_k\left[Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta)m(\theta)[t_A - t(\gamma(\hat{\theta}, \hat{k}))] + b_r(\hat{\theta}, \hat{k})\right],$$

and the utility function of contractor is

$$U_c^N(k, \hat{k}) = \mathbb{E}_\theta\left[-Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta)\frac{k}{\gamma(\hat{\theta}, \hat{k})} + b_c(\hat{\theta}, \hat{k})\right]$$

We first derive the result for the resident.

To satisfy incentive compatibility, we have

$$U_R^N(\theta) \geqslant U_R^N(\theta, \hat{\theta}), \ \forall\, \hat{\theta}, \theta$$

We also know that

$$U_R^N(\theta, \hat{\theta}) = U_R^N(\hat{\theta}) + \mathbb{E}_k \left[Q[t_A - t(\gamma(\hat{\theta}, \hat{k}))][m(\theta)\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta) - m(\hat{\theta})\bar{F}(\beta(\hat{\theta}, \hat{k}), \hat{\theta})] \right]$$

Then we have

$$U_R^N(\theta) - U_R^N(\hat{\theta}) \geqslant \mathbb{E}_k \left[Q[t_A - t(\gamma(\hat{\theta}, \hat{k}))][m(\theta)\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta) - m(\hat{\theta})\bar{F}(\beta(\hat{\theta}, \hat{k}), \hat{\theta})] \right] \quad (3.12)$$

Divided by $(\theta - \hat{\theta})$ at both side of inequality (3.12) and get the limit $\theta \to \hat{\theta}$, we get

$$\frac{\partial U_r^N(\theta)}{\partial \theta} = \mathbb{E}_k \left[Q[t_A - t(\gamma(\hat{\theta}, \hat{k}))] \frac{\partial \left[m(\hat{\theta})\bar{F}(\beta_0, \theta) \right]}{\partial \theta} \right] \quad (3.13)$$

Integrating (3.13) from $\underline{\theta}$ to θ will give us (3.10).

(3.11) can be proved with the same technique and hence omitted here. □

In mechanism design, constraints (3.10) and (3.11) are referred to as incentive compatibility constraints. The decision constrained by these equations will induce an outcome that both the residents group and contractor are truth-telling.

Then, government can determine the design rule of the newly built highway based on the following lemma.

Lemma 4. *The social optimal design* (β, γ) *when the central government has no information should satisfy*

$$(\beta^N, \gamma^N) \in \underset{\beta,\gamma}{\text{argmax}} \, (u_R(\theta) + u_c(k) - h_R(\theta) - h_c(k)) \tag{3.14}$$

where

$$h_R(\theta) = U_R^N(\bar{\theta}) - Q(t_A - t(\gamma)) \left[\frac{\partial \{\bar{F}(\beta, \tilde{\theta}) m(\tilde{\theta})\}}{\partial \theta} \frac{G_\theta(\theta)}{g_\theta(\theta)} + \bar{F}(\beta, \theta) m(\theta) \} \right]$$

and

$$h_c(k) = U_c^N(\bar{k}) - Q\bar{F}(\beta, \theta) \left[\frac{1}{\gamma} \left(\frac{G_k(k)}{g_k(k)} - k \right) + \beta(t_A - t(\gamma)) \right]$$

Proof. Based on (3.10) of Lemma 3, we have the following

$$\begin{aligned}
\mathbb{E}_\theta \left[U_R^N(\theta) \right] &= \mathbb{E}_\theta \left[U_R^N(\bar{\theta}) - \int_\theta^{\bar{\theta}} \mathbb{E}_k \left[Q[t_A - t(\gamma(\theta, k))] \frac{\partial \{\bar{F}(\beta, \tilde{\theta}) m(\tilde{\theta})\}}{\partial \theta} \right] d\tilde{\theta} \right] \\
&= U_R^N(\bar{\theta}) - \int_{\underline{\theta}}^{\bar{\theta}} \int_\theta^{\bar{\theta}} \mathbb{E}_k \left[Q[t_A - t(\gamma(\theta, k))] \frac{\partial \{\bar{F}(\beta, \tilde{\theta}) m(\tilde{\theta})\}}{\partial \theta} \right] d\tilde{\theta} dG_\theta(\theta) \\
&= U_R^N(\bar{\theta}) - \int_{\underline{\theta}}^{\bar{\theta}} G_\theta(\theta) \mathbb{E}_k \left[Q[t_A - t(\gamma(\theta, k))] \frac{\partial \{\bar{F}(\beta, \tilde{\theta}) m(\tilde{\theta})\}}{\partial \theta} \right] d\theta \\
&= U_R^N(\bar{\theta}) - \mathbb{E}_{\theta,k} \left[Q[t_A - t(\gamma(\theta, k))] \frac{\partial \{\bar{F}(\beta, \tilde{\theta}) m(\tilde{\theta})\}}{\partial \theta} \frac{G_\theta(\theta)}{g_\theta(\theta)} \right]
\end{aligned} \tag{3.15}$$

In (3.15), we get third line through integrate by part.

Similarly, we can prove that

$$\mathbb{E}_k \left[U_c^N(k) \right] = U_c^N(\bar{k}) - \mathbb{E}_{\theta,k} \left[Q\bar{F}(\beta(\theta, k), \theta) \frac{1}{\gamma(\theta, k)} \frac{G_k(k)}{g_k(k)} \right] \tag{3.16}$$

The expected monetary transfers between the central government and the residents group $X_R(\theta) = U_R(\theta) - u_R(\theta)$ and the one between central government and contractor is $X_c(k) = U_c(k) - u_c(k)$. Therefore, the expectation of $X_R(\theta)$ and $X_c(k)$ with respect to θ and k are

$$\begin{aligned}
\mathbb{E}_{\theta,k}[X_R(\theta)] &= \mathbb{E}_{\theta,k}\left[U_R^N(\bar{\theta}) - Q(t_A - t(\gamma))\left[\frac{\partial\{\bar{F}(\beta,\tilde{\theta})m(\tilde{\theta})\}}{\partial\theta}\frac{G_\theta(\theta)}{g_\theta(\theta)} + \bar{F}(\beta,\theta)m(\theta)\right]\right] \\
\mathbb{E}_{\theta,k}[X_c(k)] &= \mathbb{E}_{\theta,k}\left[U_c^N(\bar{k}) - Q\bar{F}(\beta,\theta)\left[\frac{1}{\gamma}\left(\frac{G_k(k)}{g_k(k)} - k\right) + \beta(t_A - t(\gamma))\right]\right]
\end{aligned}$$

Therefore, the solution given in (3.14) is locally incentive compatibility. We still need to prove that it is globally incentive compatibility. This is equivalent to prove that

$$U_R^N(\theta) \geqslant \mathbb{E}_k\left[X_R(\tilde{\theta}) + u_R(\theta,\tilde{\theta})\right] \text{ for all } \theta, \tilde{\theta} \tag{3.17}$$

and

$$U_c^N(k) \geqslant \mathbb{E}_\theta\left[X_c(\tilde{k}) + u_c(k,\tilde{k})\right] \tag{3.18}$$

(3.17) and (3.18) can be rewritten as

$$\mathbb{E}_k\left[\int_{\tilde{\theta}}^{\theta} Q[t_A - t(\gamma)]\frac{\partial\bar{F}(\beta,\tau)m(\tau)}{\partial\theta}d\tau\right] \geqslant \mathbb{E}_k\left[Q(t_A - t(\tilde{\gamma}))\left[\bar{F}(\tilde{\beta},\theta)m(\theta) - \bar{F}(\tilde{F},\tilde{\theta})m(\tilde{\theta})\right]\right] \tag{3.19}$$

$$\mathbb{E}_\theta\left[\int_k^{\tilde{k}} Q\bar{F}(\beta,\theta)\frac{1}{\gamma}dk\right] \geqslant \mathbb{E}_\theta\left[Q\bar{F}(\tilde{\beta},\theta)\frac{1}{\tilde{\gamma}}(\tilde{k} - k)\right] \tag{3.20}$$

(3.19) holds when β decreases in θ and $\bar{F}(\beta,\theta)$ decreases in β. (3.20) holds when $\dfrac{\bar{F}(\beta,\theta)}{\gamma}$ decreases in k. □

Proposition 5. *Under no information condition, the optimal design of the newly built highway, (β^N,γ^N), is determined by*

$$\begin{aligned} \tilde{\beta}^N &= \frac{\tilde{k}}{\gamma^N(t_A - t(\gamma^N))} \\ t'(\gamma^N) &= \frac{\tilde{k}}{(\gamma^N)^2\left(m(\theta)+\tilde{\beta}^N\right)} \end{aligned} \tag{3.21}$$

where $\tilde{\beta}^N = \beta^N + \dfrac{1}{2}\dfrac{G_\theta(\theta)}{g_\theta(\theta)}(1-m'(\theta))$ *and* $\tilde{k} = k + \dfrac{1}{2}\dfrac{G_k(k)}{g_k(k)}$

Proof. Based on Lemma 4, let $\bar{U}_g = (u_R(\theta)+u_c(k)-h_R(\theta)-h_c(k))$, then the first-order conditions gives that

$$\begin{aligned} \frac{\partial \bar{U}_g}{\partial \beta} &\Rightarrow (t_A - t(\gamma^N))\left(\beta^N + \frac{1}{2}\frac{G_\theta(\theta)}{g_\theta(\theta)}(1-m'(\theta))\right) = \frac{k+\frac{1}{2}\frac{G_k(k)}{g_k(k)}}{\gamma^N} \\ \frac{\partial \bar{U}_g}{\partial \gamma} &\Rightarrow t'(\gamma^N)\left(m(\theta)+\beta^N + \frac{1}{2}\frac{G_\theta(\theta)}{g_\theta(\theta)}(1-m'(\theta))\right) = \frac{k+\frac{1}{2}\frac{G_k(k)}{g_k(k)}}{(\gamma^N)^2} \end{aligned}$$

Let $\tilde{\beta}^N = \beta^N + \dfrac{1}{2}\dfrac{G_\theta(\theta)}{g_\theta(\theta)}(1-m'(\theta))$ and $\tilde{k} = k + \dfrac{1}{2}\dfrac{G_k(k)}{g_k(k)}$ and we get the (3.21).

□

From Proposition 5 we could observe that the optimal design of the infrastructure when there is no information only differs with the one under full information case in two terms: β and k. In mechanism design literature, the $\tilde{k}$ is the 'shadow cost' and here we also have the $\tilde{\beta}^N$ as 'shadow VOT threshold' which is related to the toll rate on the highway. Therefore, the optimal design for asymmetric information case is same as the symmetric one if we use the shadow cost and the shadow VOT threshold.

3.2.4 Timing of the model

In the PPP renegotiation game discussed in this chapter, the events happen as follows. The original design is determined to maximize expectation of social welfare in the pre-tender and tender phases. This original design is denoted as β_E and γ_E. After the PPP contract is awarded to the private contractor, σ, θ and k realize and are privately acquired by corresponding parties.

Then, the local official decide whether to kick off renegotiation process. If her decision is no, then the game ends and the original design will be carried out. The utility of the residents group and contractor, given the realization of θ and k and the optimal design (β_E, γ_E), will be

$$U_R^{NR}(\theta) = \mathbb{E}_k \left[Q\bar{F}(\beta_E, \theta) m(\theta)(t_A - t(\gamma_E)) \right] \tag{3.22}$$

and

$$U_c^{NR}(k) = \mathbb{E}_\theta \left[Q\bar{F}(\beta_E, \theta)\beta_E(t_A - t(\gamma_E)) - Q\bar{F}(\beta_E, \theta)\frac{k}{\gamma_E} \right] \tag{3.23}$$

respectively. If the official decides to renegotiate, she will offer a take-it-or-leave-it contract/agreement to the residents group and contractor.[4] Afterward,

[4]Here we use agreement and contract interchangeably because the interaction between official and residents group may not be in the form of a contract.

the other two parties can accept or reject the offer. If either of the parties disagree, there will be no renegotiation taking place and the original design will be implemented. If both parties accept the contract, all the parties will enter the renegotiation process.

In the renegotiation process, the local official will report her type to the central government to be either $\sigma = (\theta, k)$ or $\sigma = \emptyset$. If the report type is (θ, k), which implies that the central government possesses full information, the final design and the monetary transfer will be determined by (3.3). Otherwise, central government will let the residents group and contractor report their type and the design will be determined by (3.21) in Proposition 5.

Finally the design will be revised in compliance to the central/state government's standards or rules and the monetary transfer will be made. The timeline of the model is shown in Figure 3.1.

Notice that, as the outside option for the residents group and contractor (i.e. no renegotiation) is given in (3.22) and (3.23), the value of $\mathbb{E}_k\left[U_R^N(\bar{\theta}, k)\right]$ and $\mathbb{E}_\theta\left[U_c^N(\theta, \bar{k})\right]$ in (3.10) and (3.11) will be set as $\mathbb{E}_k\left[U_R^N(\bar{\theta}, k)\right] = U_R^{NR}(\bar{\theta})$ and $\mathbb{E}_\theta\left[U_c^N(\theta, \bar{k})\right] = U_c^{NR}(\bar{k})$ to minimize the total out-of-pocket expense of central government in asymmetric information case.

3.2.5 Delegation and collusion

In the real world, the management of PPP projects are usually delegated to local official rather than held by central or state government usually due to transaction cost.([48]) Therefore, the local official can coordinate with residents group

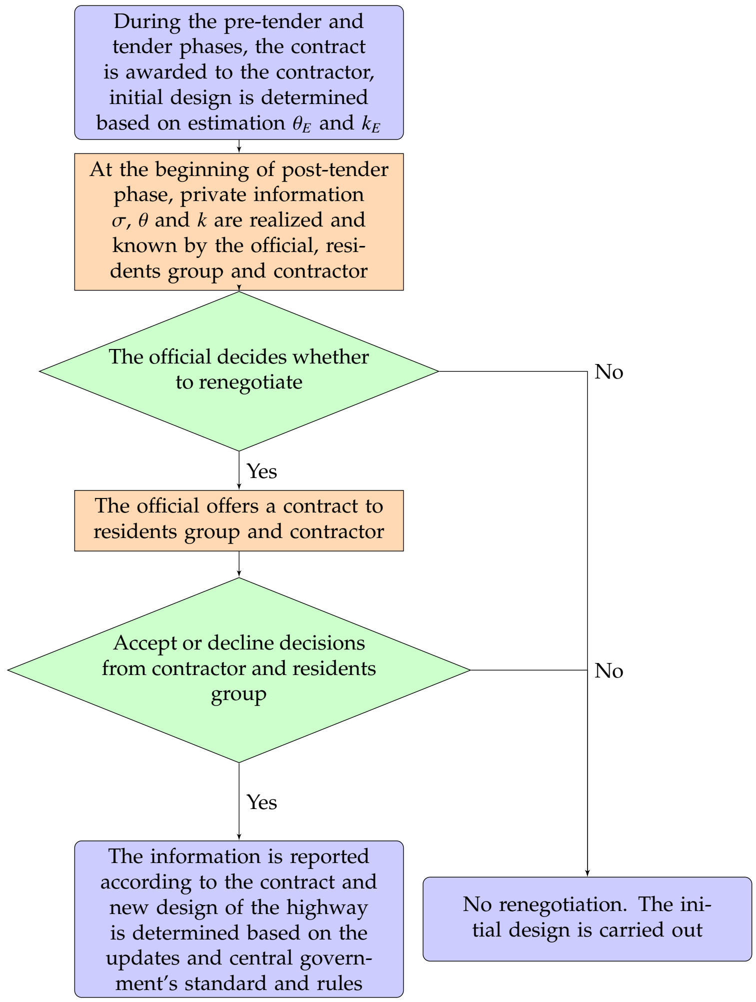

Figure 3.1: The flowchart of renegotiation process

and/or contractor to increase the benefit of their own and simultaneously harm the social welfare. For simplicity, we follow the settings of most mechanism design and collusion literature and assume that all the parties will commit to the contract they have agreed upon.[5] Further, assume that the contractor can not collude with the residents group.

Therefore, in the delegation settings, the monetary transfer from the government X_c and X_R will not be directly transferred to contractor and the residents

[5]For a review of literature in this field refer to Mookherjee (2006,9). Also, for literature with a more relax assumption, refer to [31].

group, respectively, but will be collected by official and redistributed to the two parites. Therefore, the local official has the opportunity to misappropriate the funding from central government. We assume that the monetary transfer between the local official and the residents group is $x_R(\hat{\theta})$ and between the local official and contractor $x_c(\hat{k})$. It is not necessary that $X_R = x_R$ or $X_c = x_c$.

In the following sections, we will first start with two benchmark cases where local official is benevolent (no collusion) and then discuss the distortion of the outcome in renegotiation process when collusion is possible.

3.3 Benchmarks

The problem stating in Figure 3.1 can be tackle by backward induction. Specifically, we can first consider the residents group and contractor's utility functions under different outcomes (renegotiation or no renegotiation) and then the choices of residents and contractor given a contract will be clear. Based on such information, the local official, whether benevolent or selfish, will design a renegotiation contract to maximize her expected utility. The official then can compare this maximal return from choosing renegotiation with the possible return from no renegotiation. She will then choose whichever maximizes her utility.

Let us formalize the aforementioned process as follows. As discussed above, the utility for the residents group and contractor under 'no renegotiation' (NR) is $U_R^{NR}(\theta)$ and $U_c^{NR}(k)$, respectively. On the contrary, if they both agree to renegotiate, they will act according to the contract because we assume that the contract is completely enforceable. Notice that the contract offered by local official consists of the monetary transfer given type report of both parties. $x_c(\hat{k})$ is the transfer from official to contractor and $x_R(\hat{\theta})$ the transfer from official to residents group. Therefore a contract/agreement between official, residents group and contractor is specified by $((\hat{\theta}, \hat{k}), x_R(\hat{\theta}), x_c(\hat{k}))$. Then if both parties accept the official's contract to renegotiate, their utility will become $U_c^R(\theta, \hat{\theta})$ and $U_R^R(k, \hat{k})$. As discussed above, the contractor will choose to renegotiate if $U_c^R(k, \hat{k}) > U_c^{NR}(k)$ and vice versa and similar for the residents group.

Expecting this results, the official will design a contract, $(x_R^*(\cdot), x_c^*(\cdot))$ to maximize her utility $U_o(\theta, k, \sigma)$:

$$(x_R^*(\cdot), x_c^*(\cdot)) = \underset{x_c, x_R}{\operatorname{argmax}}\, U_o(\theta, k, \sigma) \tag{3.24}$$

Let $U_o^R(\theta, k, \sigma)$ denote the expected utility when the official chooses to renegotiate and $U_o^{NR}(\theta, k, \sigma) = 0$ is the return if there is no renegotiate. Apparently, official chooses renegotiation when $U_o^R(\theta, k, \sigma) > U_o^{NR}(\theta, k, \sigma)$ and vice verse. In the following sections, we will discuss two benchmark cases where official is benevolent with or without full information following the above process.

3.3.1 Benevolent official with full information

First we consider the case when local official is benevolent, which means that she has same utility function as (3.2). In this case, the official will always let the central government being informed, that is $\sigma = (\theta, k)$. Therefore, the (β^F, γ^F) in (3.3) is implemented and transfers $X_c^R = X_R^R = 0$.

The solution (β^F, γ^F) maximizes the social welfare $U_g(\sigma = (\theta, k))$. The central government's costless implementation of social optimum solution thanks to the full information possessed by benevolent official.

The outcome of the whole renegotiation process is stated as follows.

Proposition 6. *When official is benevolent with full information, she will initiate renegotiation if and only if*

$$\begin{aligned} \theta < & \quad \theta_E \\ k < & \quad k_E \end{aligned} \tag{3.25}$$

where θ_E and k_E satisfy $\beta_E = \beta^F(\theta_E, k_E)$ and $\gamma_E = \gamma^F(\theta_E, k_E)$.

Proof. In the renegotiation game, if all the parties agree to renegotiate, the final design will be determined by (3.3). Therefore, the return for the contractor and the residents group are (BF,R denotes 'Benevolent officer with Full information, Renegotiation') $U_c^{BF,R}(k) = u_c(k)$ and $U_R^{BF,R}(\theta) = u_R(\theta)$, respectively. On the other hand, if design is not renegotiated, the return will be $U_c^{BF,NR}(k) = U_c^{NR}(k)$ and $U_R^{BF,NR}(\theta) = U_R^{NR}(\theta)$. Following the definition of θ_E, k_E that $\beta_E = \beta^F(\theta_E, k_E)$ and $\gamma_E = \gamma^F(\theta_E, k_E)$, we have $U_R^{NR}(\theta) = u_R(\theta, \theta_E)$ and $U_c^{NR}(k) = u_c(k, k_E)$.

Then we have the contractor and the residents group will accept to renegotiate if and only if

$$\begin{aligned} u_R(\theta) = u_R(\theta, \theta) & \quad > u_R(\theta, \theta_E) \\ u_c(k) = u_c(k, k) & \quad > u_c(k, k_E) \end{aligned} \tag{3.26}$$

As the functions $u_R(\theta, \hat{\theta})$ is decreasing in $\hat{\theta}$ and $u_c(k, \hat{k})$ is decreasing in $\hat{k}$,[6] we have the condition as shown in (3.25).

□

[6]Need formal proof.

Expecting this, it is obvious that the official will renegotiate the project as long as the original design meets the condition specified in (3.25). The renegotiation will not always happen even if it will increase the total social welfare. This is due to the fact that either contractor or the residents group will be worse off after renegotiation. If this happens, as the central government will not compensate the utility loss due to renegotiation, they will decline the offer from the official.

3.3.2 Benevolent official with no information

In this section, we will discuss another extreme case in the renegotiation game: a benevolent official has no information on (θ, k), that is $\sigma = \emptyset$. The outcome is given in the following proposition

Proposition 7. *If the official is benevolent with no information, she will initiate the renegotiation following an all-or-nothing manor: either she will always initiate the renegotiation or she will never initiate renegotiation. The renegotiation offer will be accepted or rejected by the residents group or contractor according to the realization of their types.*

Proof. If there is no renegotiation, the utility functions of the residents group and contractor are given in (3.22) and (3.23), respectively. However, as the official does not possess information on θ and k, she can only use the expectation to approximate the actual utilities of the two parties, ('N,NR' denotes 'No information, No Renegotiation')

$$
\begin{aligned}
U_R^{N,NR} &= \mathbb{E}_\theta\left[U_R^{NR}(\theta)\right] = \mathbb{E}_{k,\theta}\left[Q\bar{F}(\beta_E,\theta)m(\theta)(t_A - t(\gamma_E))\right] \\
U_c^{N,NR} &= \mathbb{E}_k\left[U_c^{NR}(k)\right] = \mathbb{E}_{k,\theta}\left[Q\bar{F}(\beta_E,\theta)\beta_E(t_A - t(\gamma_E)) - Q\bar{F}(\beta_E,\theta)\frac{k}{\gamma_E}\right]
\end{aligned}
\tag{3.27}
$$

If the renegotiation offer is accepted by all parties, a benevolent official with no information will report $\sigma = \emptyset$ and the social optimal design (β^N, γ^N) is implemented. Then the utility function of both parties are given in (3.15) and (3.16). As initiating renegotiation is costly for the official, she will initiate it if and only if

$$
\begin{aligned}
\mathbb{E}_\theta\left[U_R^N(\theta)\right] &> \mathbb{E}_\theta\left[U_R^{N,NR}(\theta)\right] \\
\mathbb{E}_k\left[U_c^N(k)\right] &> \mathbb{E}_k\left[U_c^{N,NR}(k)\right]
\end{aligned}
\tag{3.28}
$$

Notice that, the LHS and RHS in both inequalities in (3.28) are all numbers. Therefore, the official will follow a all-or-noting manor: either always initiating the renegotiation or never. This is because she does not know the exact realization of types of both parties.

On the other hand, as both parties know their own types, they will decide whether to accept or not the renegotiation offer by

$$
\begin{aligned}
U_R^N(\theta) &> U_R^{NR}(\theta) \\
U_c^N(k) &> U_c^{NR}(k)
\end{aligned}
\tag{3.29}
$$

This implies that the renegotiation offer will not always be accepted as the two parties may have actual renegotiation utility lower than the non-renegotiation one.

□

Proposition 7 indicates that although whether the residents group and contractor agree to renegotiate still depend on their private types, θ and k, the initiation of renegotiation by official does not depend on the realization. When the official has no information, a series of consistent decisions will be made (either renegotiation or not).

In reality, the official may neither possesses full information nor no information. Some literature discussed that the official can acquires indicating signals on the types of parties. Under this situation, it would be the combination of the cases we discuss above. The outcome of renegotiation result will neither be absolutely deterministic, nor be totally random to the official. Therefore, the initiation of renegotiation by the official will have some probability to be all-or-nothing (no information case) and some probability to be fully deterministic (full information case).

In this section, we discuss the renegotiation outcome when the local official is benevolent. In this following section, the assumption is the official is selfish and is able to collude with parties to maximize her own utility.

3.4 Collusion in renegotiation process

When local official is selfish, she will have incentive to collude with residents group and/or contractor if such behavior increases her utility. In this section, we will first discuss the result when local official collude with both parties, then analyze the situation when she coordinates with specific agent or part of the residents group.

The collusion game discuss here is initiated by official who will collude with all possible parties; that is, if she has the ability to collude with a certain party, she will always attempt to do so.[7] When the official contracts with different parties, she will specify the report sent to the central government, which will hence decide the design of the highway, and the monetary transfer between the official and the parties. In other word, the contract is specified by $(m(\theta, k, \sigma), x_r(\hat{\theta}), x_c(\hat{k}))$, where the message $m(\theta, k, \sigma) = (\hat{\theta}, \hat{k}, \hat{\sigma})$ and the monetary transfers from official to the residents group or contractor depend on the type reported.

In our model, there are two chances left for local official to benefit from collusion. From previous section, central government has to provide information rent to residents group and contractor when official has no information about their types. This lends opportunity to a selfish and fully informed official to reap these extra benefit as pointed out in [48]). This is because, when the official is informed, the information rent for the residents group and contractor is 0 if the official reports honestly. Therefore, an informed but selfish local official can collude with residents group and contractor to ask for bribes and report 'no information', $\sigma = \emptyset$, to central government. She then can leave the residents group and contractor with utility no worse than the situation when there is no renegotiation and take away all the information rent the central government leaves.[8] Therefore, when the local official possesses full information, from selfish motivation, given that there will be renegotiation, she will always report 'no information' and benefit from such misreport.

[7]As we show later, this is without loss of generality because collusion with more parties will always benefit the official.

[8]One more additional assumption needed here is that the official has full bargain power. As it is pointed out in other literature, for example [48], however, full bargain power is not a necessary condition. As long as the local official possesses at least some bargain power and is able to predict the result of the collusion, she can exert her ability to benefit from this.

Another opportunity the central government leaves for a selfish official to collude with contractor or the residents group is, the rigid rule of final design of the infrastructure blocked the possibility of renegotiation when the conditions (3.25) and (3.28) are not met under full information and no information cases, respectively. Through colluding with both parties, the local official is able to compensate the party with the utility loss. However, this would not be desirable because even the total utility becomes social optimal, part of it goes to official's private pocket.

Collusion and corruption between official (supervisor, monitor) and contractor (agent) are extensively discussed in the literature of collusion in mechanism design and corruption in PPP. However, few literature considers collusion with consumer and producer at the same time and the discussion about collusion with part of a heterogeneous group is absent.

In our model, we incorporate heterogeneous users and multiple agents to enable such analysis. Therefore, in this section, we will discuss the cases when official collude with both parties, the residents group only or part of the residents group.

3.4.1 Collusion with both parties

When the local official is selfish and can collude with both parties, mathematically it means that $X_c \neq x_c$ and $X_R \neq x_R$, that is, the official can compensate the utility loss or steal the utility gain of the two parties. We have the following proposition.

Proposition 8. *When local official colludes with both parties, we have the following* *results:*

- *If local official has no information, she will be indifferent in renegotiation;*
  - *Official will not gain utility from renegotiation;*
  - *The return of contractor and residents group will be same as the benevolent case;*
- *If local official has full information, she will be more likely to renegotiate than in benevolent case. The report is $\sigma = \emptyset$. Moreover,*
  - *Both parties' (contractor and residents group) ex post utilities are same as their 'no renegotiation' utility;*
  - *All the excessive utility will be taken away by official.*
  - *Both parties will always accept the renegotiation offer.*

Proof. We still follows the analysis process in Section 3.3 to study the result of the renegotiation game.

First assume that if both parties accept the offer from local official to renegotiate, then the local official will report $\sigma = \emptyset$ to the central government no matter what information she possesses. Then the new design will be (β^N, γ^N) in (3.21). The central government will transfer $X_c(k) + X_R(\theta)$ to the official who thereafter decides the redistribution of fund. If she has full information, the distribution of fund should satisfy the following constraints:

$$u_R(\theta) + u_c(k) + x_R(\theta) + x_c(k) \geqslant u_R(\theta, \theta_E) + u_c(k, k_E)$$

Otherwise, if she does not possess information, she has to provide the contractor and the residents group with the same incentive specified in (3.10) and (3.11) and thus she has to redistribute all the funds she received from the central government. Therefore, local official's return from the renegotiation game (let SCB denote Selfish official Colluding with Both parties)

$$U_o^{SCB}(\theta, k, \sigma) = \max\left[1_{\sigma\neq\emptyset}\left\{u_c(k) + X_c(k) + u_R(\theta) + X_R(\theta) - u_c(k, k_E) - u_R(\theta, \theta_E)\right\}, 0\right] \tag{3.30}$$

Where the function $1_{\sigma\neq\emptyset}$ is defined as

$$1_{\sigma\neq\emptyset} = \begin{cases} 1 & \text{if } \sigma \neq \emptyset; \\ 0 & \text{Otherwise.} \end{cases}$$

Given (3.30), the local official will be indifferent on renegotiation if she has no information. She will always attempt to renegotiate the design when (3.30) holds. Compared with the renegotiation condition in Section 3.3, (3.30) is less strict than (3.26) and same as (3.28). Therefore, renegotiation is more likely and design will be changed in full information case. However, the utilities of either contractor and the residents group will not change under full information condition.

Also, as the official has full information about the types of both residents group and contractor, she will initiate renegotiation offer if and only if she knows it will be accepted. Therefore, we will observe that the residents group and contractor will always accept the renegotiation.

□

From Proposition 8, collusion will have three takeaways on the PPP project. The first effect is that collusion increases the possibility of renegotiation when local official is fully informed. Informed official will attempt to capitalize the information advantage she has compared to the central government by colluding with different parties and hide the information. This indicates that, the observation in empirical study (such as [40]) that renegotiation in PPP usually happened in early stages after the contracts were awarded could also be a result of collusion.

The second effect of collusion is that, the total social welfare in the renegotiation of collusion is always less than or equal to the one if the official is benevolent. Attributed to the official always reporting no information, the final social welfare will always be $U_g^N(\theta, k)$ which is less than the first best social welfare. As a consequence, although the renegotiation seems to make the society better off, it is actually not. The central government does inflate its expense in the jurisdiction of the officer, however, all the extra benefit, which is the part in the curly bracket in (3.30), flows to the local official in the form of transfers we discussed above.

Thirdly, Proposition 8 also provides one important and effective way to detect collusion in renegotiation process. Although the informed official will hide her information and act as an uninformed one, the outcome of the renegotiation will be different. For an uninformed and benevolent official, if she attempt to renegotiate the design, the offer can be turned off by either the contractor or the residents group. However, for an informed but selfish official, every renegotiation offer from her will be accepted by the latter two parties because she will only initiate it whenever she know it will be accepted. Therefore, smooth renegotiation process can be a red flag for an official.

3.4.2 Collusion with one party only

Collusion with only one party is already extensively studied in literature. However, in the existing literature, collusion with one party with the presence of another non-colluding party is absent. In this section, the case that official colludes with only the residents group is presented.

If collusion is possible only between official and the residents group, but not between official and contractor, we have $X_c = x_c$ because the official can not side transfer money to or from the contractor. However, it is still possible that $X_R \neq x_R$. Similar as the section above, to be better off through collusion, the official will first attempt to increase the utility of the residents group and then take away a proper amount to ensure the group to be still willing to collude. The result of such collusion is given in the proposition below.

Proposition 9. *When local official colludes with only the residents group, we have the following results:*

- *If local official has no information, the result is unchanged from the benevolent official with no information ones;*
- *If local official has full information,*
  - *The renegotiation is more likely than benevolent case but less likely than the case that collude with both parties;*
  - *The residents group will always accept the offer to renegotiate.*

Proof. If the outcome is 'no renegotiation', the local official's utility is 0. Same as previous sections, the utility of the residents group in no renegotiation outcome is $u_R(\theta, \theta_E)$. Expecting this, the official has to provide the residents group with return at least equals to $u_R(\theta, \theta_E)$. On the other hand, as the official can not collude with the contractor, no side payment is possible.

If the officer has no information, $\sigma = \emptyset$, same as previous section, she will have to distribute all the utility to the residents group and the contractor to induce truth-telling. If she has full information but still reports no information, the central government will secure the contractor's utility as $\mathbb{E}_k\left[U_c^N(k)\right]$ and the residents group's utility as $\mathbb{E}_\theta\left[U_R^N(\theta)\right]$ by implementing the (β_N, γ_N). In turn, the official knows that the utility function of the residents group and the contractor are $U_R^N(\theta)$ and $U_c^N(k)$, respectively. Hence the condition that both parties will agree to renegotiate is

$$\begin{aligned} u_c^N(k) &> u_c(k, k_E) \\ u_R^N(\theta) &> u_R(\theta, \theta_E) \end{aligned} \tag{3.31}$$

It is obvious that the constraints when official is benevolent with full information is stricter because the utility transferred from central government to the residents group does not contain information rent. This implies that renegotiation happens more frequently then benevolent case even when only one party act along with the official. However, (3.31) is stricter than its counterparts when official colludes with both parities, (3.30). Therefore the renegotiation will be less likely in this case. Morever, similar to previous discussion, when the official possesses full information, the offer will always be accepted by the residents group and contractor.

□

In Proposition 9, compare (3.31) with (3.29), the renegotiation condition when official is benevolent with no information and selfish but informed look similar. In (3.31), the outside options on the RHS of two inequalities is the utilities if there is no renegotiation while in (3.29), it is the expectation of these utilities. Although the renegotiation decision made by the official under benevolent situation is all-or-nothing while under selfish situation it depends on the realization of type. They are equivalent ex ante, that is before the realization. Therefore, to prevent renegotiation ex ante, the central government would prefer this case than the case official colluding with both parties.

Another reason the central government should prefer this case is that from Proposition 9, with the presence of another non-colluding party, the condition for realizing corruption is stricter than when colluding with both parties is possible. This is because, if the official can collude with the contractor, when the utility the contractor get from renegotiation is less than no renegotiation, she can boost the utility by transfer more benefit she gets from the residents group. This whole process is impossible in the non-colluding contractor case.

This implies that, to prevent non-Pareto-improving renegotiation, even if eliminating all the possibilities is impossible, making collusion extreme hard with one party will effectively restrict the extent of corruption. In the real world Public-Private Partnership projects, as a legal identity, the contractors is usually much easier to be regulated compared with the residents group ([25]). The regulator should then focus on laws stipulating the behaviour of contractor and the interaction between it and local officials.

Although in this section, we only discuss the situation when local official colludes with the residents group, the outcome of the case when the local official colludes only with contractor can be derived similarly, which is left for interested readers.

3.4.3 Collusion with part of the residents

In this section we consider that, when local official colludes with part of the residents group. The local official may have own political preference and hence put more weight on the utility of part of the residents group, or, only some residents have the ability to directly interact with local official and influence her decision. Under both situations, the local official will ignore the rest of the residents group. There are two extreme cases, the colluding part of the residents is those with VOT larger than a given threshold, β_0, denoted as 'H' (high) and those with VOT less than another different threshold β_1, denoted as 'L' (low). For simplicity, we assume that the possible types θ and k will ensure group H always uses the newly built highway but group L always traveling on the existing roads. [9] Although the rest of the residents group can not influence the local official's infrastructure decision they will still be able to receive monetary transfer from central government (if any). However, the official cannot collude with them therefore can not change the amount of transfer accordingly.

Consider only residents group H with $VOT > \beta_0$ can influence the decision of local official. The population of group H is $Q\bar{F}(\beta_0, \theta)$. For simplicity, we assume that β_0 is large enough such that this group of residents will always choose the

[9]This is equivalent to assume that there exist a party that will always be influenced by both the infrastructure decision and the payment (H) and another group will only be influenced by the payment decision

newly built highway. Therefore, the travel time improvement group H enjoys from the newly built highway is $\mathbb{E}_k\left[Q\bar{F}(\beta_0,\theta)(m(\theta)+\beta_0)(t_A - t(\gamma))\right]$. The toll paid to the contractor will be $\mathbb{E}_k\left[\beta(t_A - t(\gamma))Q\bar{F}(\beta_0,\theta)\right]$. Then the utility function of this group of residents is

$$U_H(\theta,\hat{\theta}) = u_H(\theta,\hat{\theta}) + x_H(\hat{\theta}) \tag{3.32}$$

where $u_H(\theta,\hat{\theta}) = \mathbb{E}_k\left[Q\bar{F}(\beta_0,\theta)[(m(\beta_0)+\beta_0)[t_A - t(\hat{\gamma})]] - \hat{\beta}[t_A - t(\hat{\gamma})]Q\bar{F}(\beta_0,\theta)\right]$ is the utility directly get from the highway and $X_H(\hat{\theta})$ is the amount of monetary transfer from the central government. This amount should be a proportion of the monetary transfer from the central government to the residents group, that is $X_H(\hat{\theta}) = \bar{F}(\beta_0,\theta)X_R(\hat{\theta})$.

When the official has no information, to induce truth-telling from the residents group H, she has to guarantee a minimal utility level given in the following lemma.

Lemma 10. *When uninformed local official colludes with only residents group H, she has to provide the residents group with minimal utility*

$$\mathbb{E}_\theta\left[U_H(\theta)\right] = U_H(\bar{\theta}) - \mathbb{E}_{\theta,k}\left[Q(t_A - t(\gamma))\frac{\partial\bar{F}(\beta_0,\theta)(m(\theta)+\beta_0-\beta)}{\partial\theta}\frac{G_\theta(\theta)}{g_\theta(\theta)}\right] \tag{3.33}$$

Proof. This Lemma can be easily proved by similar process in previous sections. Therefore is omitted here. □

Then we have the following proposition.

Proposition 11. *When local official colludes only with residents group H:*

- *If the official has no information, she will be either strictly like, dislike or indifferent with the renegotiation;*
- *If the official has full information, renegotiation will be less likely than the case colluding with the whole residents group R.*

Proof. Although the monetary transfer from the central government to the residents group is as a whole, it could be divided into part that goes to residents group H and part does not. The monetary transfer goes to the residents group H when official has different reports are

$$X_H(\theta) = \begin{cases} \left[U_R^N - \mathbb{E}_\theta[u_R(\theta)]\right]\bar{F}(\beta_0, \theta) & \text{When official's report is } \sigma = \emptyset \\ 0 & \text{When official's report is } \sigma = (\theta, k) \end{cases} \tag{3.34}$$

Following the same process in the previous sections, if there is no renegotiation, for local official the return is 0, for residents group H it is $u_H(\theta, \theta_E)$ and for contractor it is $u_c(k, k_E)$. If all three parties agree to enter the renegotiation game (official, group H and contractor), the official will decide her report to choose the one with higher value in (3.34) .[10]

If the official does not have information, she will provide the residents group H with utility

$$U_H^N(\theta) = U_H(\bar{\theta}) - \int_\theta^{\bar{\theta}} \mathbb{E}_k \left[Q(t_A - t(\gamma)) \left[\frac{\partial \bar{F}(\beta_0, \omega)(m(\omega) + \beta_0 - \beta)}{\partial \omega} \right] \right] d\omega$$

to induce truth-telling.

[10]For now we assume that the higher one is no information. We need to revise this further.

Then the required monetary transfer to induce truthtelling given the report θ is (through integration by parts)

$$x_H(\theta) = U_H(\bar{\theta}) - u_H(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} \mathbb{E}_k \left[Q\bar{F}(\beta_0, \omega)(m(\omega) + \beta_0 - \beta) \frac{\partial t(\gamma)}{d\omega} \right] d\omega$$

Notice that when the official offer the contract to residents group H, she does not know the realization of θ, therefore, the expected monetary transfer is

$$\mathbb{E}_\theta \left[x_H(\theta) \right] = U_H(\bar{\theta}) - u_H(\bar{\theta}) + \mathbb{E}_{\theta,k} \left[Q\bar{F}(\beta_0, \theta)(m(\theta) + \beta_0 - \beta) \frac{\partial t(\gamma)}{\partial \theta} \frac{G_\theta(\theta)}{g_\theta(\theta)} \right] \tag{3.35}$$

While the expected transfer from the government to the residents group H

$$\mathbb{E}_\theta \left[X_H(\theta) \right] = (U_R(\bar{\theta}) - u_R(\bar{\theta}))\mathbb{E}_\theta \left[\bar{F}(\beta_0, \theta) \right] + \mathbb{E}_{\theta,k} \left[Q\bar{F}(\beta, \theta)\bar{F}(\beta_0, \theta) m(\theta) \frac{\partial t(\gamma)}{\partial \theta} \frac{G_\theta(\theta)}{g_\theta(\theta)} \right] \tag{3.36}$$

Therefore, the official will strictly prefer renegotiation if the expected transfer from the central government, (3.36) is larger than the required expected transfer from her to the residents group H, (3.35), which means that she can take away part of the benefit for herself. On the other hand, if (3.35) < (3.36), which means that the central government's fund is insufficient for the official to induce truthtelling from residents group H. It is also trivial that (3.35) = (3.36) indicates that the official is indifferent with the renegotiation.

If the official is fully informed, as we discussed in previous sections, she will leave exactly $u_H(\theta, \theta_E)$ for the residents group H and pass full amount of utility to contractor because he is non-colluding. Therefore the renegotiation condition is

$$\begin{aligned} u_c^N(k) &> u_c(k, k_E) \\ u_H(\theta) + X_H(\theta) &\geqslant u_H(\theta, \theta_E) \end{aligned} \tag{3.37}$$

Notice that (3.37) and (3.31) only differs in the second inequality. In (3.31), the second inequality can be rewritten as

$$U_R(\bar{\theta}) - u_R(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} Q\bar{F}(\beta, \omega)m(\omega)\frac{\partial t(\gamma)}{\partial \theta}d\omega \geqslant Q\bar{F}(\beta_E, \theta)m(\theta)(t_A - t(\gamma_E)) \tag{3.38}$$

$$U_R(\bar{\theta}) - u_R(\bar{\theta}) + \int_{\theta}^{\bar{\theta}} Q\bar{F}(\beta, \omega)m(\omega)\frac{\partial t(\gamma)}{\partial \theta}d\omega \geqslant Q(m(\theta) + \beta_0 - \beta_E)(t_A - t(\gamma_E)) \tag{3.39}$$

Because LHS of (3.38) and (3.39) are the same and on the RHS we have

$$\bar{F}(\beta_E, \theta)m(\theta) < m(\theta) < m(\theta) + \beta_0 - \beta_E$$

due to the assumption that $\beta_0 > \beta_E$, we have that the condition (3.38) is less strict than (3.39). Therefore, when the official colludes with the residents group H, she will be less likely to initiate a renegotiation.

It is still obvious that the local official is less likely to renegotiate than the case when she colludes with both parties. In consequence, the utility function of the official is (let SCH denote 'Selfish official Colluding with residents group H')

$$U_o^{SCH}(\theta, k, \sigma) = \max\left[1_{\sigma\neq\emptyset}\left\{u_H(\theta) + X_H(\theta) - u_H(\theta, k_E)\right\}, 0\right] \tag{3.40}$$

□

Proposition (11) provides further guidelines for regulating renegotiation game. When the official is informed, unlike the case official colluding with the entire residents group, the official colluding with an interest group will be less likely to initiate renegotiation in general. This is because, when there is renegotiation, part of monetary transfer will be taken by the residents she does not collude with ('free riders'). This makes renegotiation less attractive to her. Therefore restricting the collusion ability of official is beneficial.

However, when the official possesses no information, Proposition (11) and its proof indicates that the benefit of further restricting official's potential colluding party is not clear. She may strictly prefer renegotiation over no renegotiation. This will make the society worse off compared to when the official can collude with the whole party. Hence, whether constrain the collusion ability of the official depends on how difficult it is for the official to incentivize the residents group H.

3.5 Discussion

3.5.1 Official's preference on procurement cost

When colluding with residents group H, the official's utility function is given by (3.40) and based on the definition of u_H and X_H, we have when the official has full information and she reports no information $\sigma = \emptyset$ and her utility is

$$u_H(\theta) + X_H(\theta) - u_H(\theta, \theta_E)$$

$$= Q\left[\bar{F}(\beta_0,\theta) - \bar{F}(\beta_0,\theta)\right](m(\theta)+\beta_0-\beta_E)(t_A - t(\gamma_E))$$

$$- \int_{\theta}^{\bar{\theta}} Q\bar{F}(t_A - t(\gamma))d\left[\bar{F}(\beta_0,\theta)(m(\theta)+\beta_0)\right] \qquad (3.41)$$

As we discuss in previous sections, under no information condition, the design variable γ will increase in k. Therefore, it is easy to check that equation (3.41) will be increasing in k. This indicates that if the local official colludes with the residents group H, she will prefer higher unit cost of the road as this will increase the information rent central government transfer to her. With higher unit cost, the local official can help the residents group H has higher utility increase ex post. In PPP literature, private side innovation to decrease the procurement cost is one of the dominating advantage of PPP. However, here we illustrates that, with the threats of collusion, such an advantage may not be favored by local official.

Local official disliking the lower procurement cost has two effects. First, this preference will incentivize official to discourage contractor to make any attempt of innovation, especially considering that contractor could also be colluding with official. Second, such a preference can induce suboptimal choice in the tender phase of the infrastructure project. Expecting that renegotiation is inevitable and contractor's cost will influence her ex post return from renegotiation, the local official will select contractor with highest possible cost in the auction. Notice that 'highest possible cost' does not mean highest cost among all bidder. It could be the highest cost among bidders within a range. Such a behavior is hard to be detected because it could also be induced by the measure to avoid 'curse of the winner'.[11]

[11]Reference needed.

3.5.2 Multiple stakeholders in renegotiation game

Compared to other literature in renegotiation in public-private partnership, we consider a game where there are multiple stakeholders which include both consumers and producers in the renegotiation game. In this game, a selfish official would prefer renegotiation, which is in line with other literature. Moreover, we identify that, with the presence of a non-colluding party who can decline renegotiation offer, the non-social-optimal renegotiation will be less likely. The implication is two-fold: first, the central government should at least endorse some parties in PPP project with the ability to decline a government-led renegotiation process. Such an ability can greatly restrict the official's opportunity to kick off renegotiation process that benefit herself.

The second implication is that, central government should regulate and monitor the parties who has the ability to decline the renegotiation offers from the official. As Proposition 9 shows, when the official is only able to collude with one party with the presence of another party who can turn down the renegotiation contract, there is a large reduction in her willingness to start a renegotiation. Given that in PPP projects in real world, the number of parties who can influence the renegotiation is limited, such regulation is not difficult to be implemented.

3.5.3 Heterogeneity within stakeholders in PPP regulation

In this chapter, the residents party is heterogeneous which enables the official to collude with certain part of the group. In the discussion in Section 3.4.3, the official's colluding ability is restricted to only part 'H' and therefore the opportunity of renegotiation is reduced. Notice that group 'H' indicates those who directly benefit from the renegotiation. There is also part of the residents group, who has relatively low VOT, always uses the old highway, and does not benefit from the PPP project directly. We call this part of people as 'free rider' of renegotiation. In PPP renegotiation, part of a stakeholder group could be free rider, besides the users of old highway in this chapter, it could also be non-union workers, or part of the procuring consortium who will not be affected by renegotiation but receives information rent from the central government. If central government can prevent collusion between the official and the free riders, for example by auditing or increasing corruption cost, it will be more effective compared to regulation targeting on other parties.

3.5.4 Role of asymmetric information

In this chapter, unlike the renegotiation game in [43], we assume that the local official also possesses private information on whether she knows the private information of contractor and residents group. This consideration helps us understand how the official act with information advantage to central government and bargain power to the residents group and contractor. In this model, we observe that a selfish official with full information will be more interested in renegotiation than benevolent official who only initiate Pareto-improving renegotiation. This is due to that the selfish official will attempt to cash out the information rent she possesses. The informational asymmetry provides the official to pursue personal benefits from renegotiation. Such benefit may be in the form of money (such as bribe or political donation), political credit, or in other invisible forms such as underground agreement.([25])

We assume that the official can only manipulate her private information to the extent whether she knows or not the actual private information of contractor and the residents group. A more flexible setting will be the official can also misreport the real value of the private information of those two parties ([31]). However, only with this stricter assumption, the official already take a big advantage against central government's regulation. Even though central government sets hard, even rigid, rules on the optimality of the design of the highway, which seems prevents potential manipulation, in renegotiation game, it still leaves the local official room to exploit illicit benefits by choosing which project to renegotiate.

3.5.5 Incentive contract for official

If we take as given the fact that informational asymmetry cannot be easily altered, past literature suggests to offer a contractual agreement to official to make her truth-telling ([48]). The official will receive a larger reward for reporting informative type rather than $\sigma = \emptyset$. The amount is determined by the possible gain if a informed but selfish official report no information. By providing such incentive, the central government can restrain the possibility of collusion.

However, from the result in this chapter, the central government should be cautious in providing such incentive contract under multiple stakeholders assumption. Although such incentive contract can prevent non-benevolent renegotiation that would happen, it may facilitate other renegotiation that would not happen. For example, in colluding with only the residents group case, without incentive contract, the official will not initiate a renegotiation when both parties are better off from the renegotiation and she will take the gain from the residents group. However, with the incentive contract, although she will be honest in that case, she will prefer to initiate a renegotiation when only the contractor will be better off. This is because, without incentive contract, she cannot benefit from the utility gain from the contractor, while such gain will be provided by central government in the incentive contract.

Therefore, under multiple stakeholders settings, without the knowledge of colluding party, the central government can not effectively prevent corruption through providing incentive contract. This kind of contract can only partially prevent renegotiation and offer official with other opportunity to corrupt.

3.6 Policy implications and regulation guidelines

From the previous discussion, it is apparent that renegotiation as a result of collusion is not beneficial for the whole society and central government should eliminate opportunities for official to exploit personal benefit from it. In this section, as a summary, we provide policy implications and regulation guidelines for central government to prevent corruption and collusion in renegotiation of PPP. For convenience of the readers, every point is followed by the sections in which it is discussed.

- The result of renegotiation game is a good detection measure of collusion. If the renegotiation offers are always accepted by all parties and the official reports 'no information', it is a strong sign of corruption. (3.4.1, 3.4.2)
- Selection of higher procurement cost could be a sign of anticipating op-

portunities of collusion in post-tender phase. All the high cost selection should be justified. (3.5.1)

- Stakeholders other than government should be endorsed with power to decline renegotiation. (3.4.2, 3.5.2)
- Free riders (such as non-union workers, residents not influenced by PPP projects but will receive monetary transfers) and interest groups that can not decline renegotiation should be closely monitored and regulated. (3.5.2, 3.5.3, 3.5.4)
- Colluding only with non-free-rider group can help reduce the possibility of renegotiation that is not socially optimal. (3.4.2, 3.5.4)
- Incentive contract should not be implemented before the central government acquiring the information on who will collude with official. (3.5.5)

3.7 Main Findings

In this chapter we discover that, in line with [48], under asymmetric information the PPP projects are prone to collusion. The corrupted official has a tendency to renegotiation compared to benevolent official because of the information advantage she possesses. When the official possesses full information about the residents group and contractor, she realize personal benefit by lying to the central government and transferring utilities between the other two parties by side contracting. Therefore, in general, the possibility of government-led renegotiation increases as a result of collusion.

We also explore the situation where the official can only collude with only one party, assuming that due to perfect monitor or inability of collusion, the official can not collude with another one. Under this circumstance, the official is less likely to initiate the a non-social optimal renegotiation because it is difficult for her to transfer the utility between two parties by side contracting. This indicates that, even though eliminating collusion might be impossible, restraining the collusion ability of the official could also be beneficiary for the society.

Furthermore, we discuss the situation when the users are heterogeneous. We discover that, when the government official colludes with only part of the residents group, she will be either less likely to renegotiate contract unduly. This is because that the rest part of the residents could be free riders of the renegotiation and therefore renegotiate is less attractive to a selfish official, which indicates that corruption can further be alleviated by closely monitoring certain group of 'free rider' users, such as users not affected by the PPP projects, non-union workers, etc.

Lastly, we discuss the policy implication and regulation guildelines for central or state government in PPP projects. Here are some highlights of our results (A complete summary is in Section 3.6). We suggest that the central or state government should give rights to some of the stakeholders in PPP projects to decline renegotiation attempts. Also, these parties should be closely monitored because they are vulnarable to corruption. Heterogeneity will induce free rider inside a single stakeholder and such party should be closely monitored. The government can detect corruption ex post by monitoring the renegotiation outcome. If all the renegotiation offers from local official are constantly accepted by other parties and the local official always has uninformative types, it is a strong sign of corruption.

3.8 Contributions

Our contribution is three-fold:

Firstly, we extend the theory of mechanism design with a model of collusion between supervisor, producer and heterogeneous consumers. Previous research either only consider the supervisor colluding with only producer (e.g. [20], [56]) or only consumers ([15]), but not both. In this piece, by incorporating both consumers and producers, we show that collusion can be partially prevented if the supervisor's colluding ability is restricted to only one party.

Secondly, we bridge the gap between economic models and engineering models in PPP literature. Economic models, featured with simplicity and policy implications, and engineering models, with technical details and regulation guidelines, achieve big successes in PPP separately in the past. However, as PPP project is highly specialized, both economic and engineering should be put under the same umbrella to provide consistent policy implication and regulation guidelines. This requires a uniform model capable for both economic and engineering theories and models. However, to our best knowledge, such model is not available.

Lastly, as a result of building a uniform model compatible for both economic theories and engineering models, we provide several useful policy implication and operation guidelines. Some of them are already pointed out above.

CHAPTER 4

STAKEHOLDER MANAGEMENT, DECENTRALIZATION AND AGENCY PROBLEMS OF PRIVATE PARTICIPATION IN PUBLIC INFRASTRCUTURE MANAGEMENT

4.1 Introduction

Private participation in public procurement has already been recognized as an essential approach in providing public infrastructure and related services by both practitioner and researcher ([44]). Such form of procurement is usually referred to as Public-Private Partnership (PPP) which may include different variation, such as "Build-Operate-Transfer" (BOT) and "Build-Own-Operate" (BOO). In PPP, the private sector takes part of or whole ownership of the infrastructure and share revenue and risk with the government. Previous literature finds evidences supporting that by introducing private sector into traditional public infrastructure procurement, PPP improves the managerial, financial and technological efficiency of the process ([43]).

In this chapter, we build a framework studying corruption in PPP that is able to incorporate these various key factors, which, to our best knowledge, is not readily available yet. We build a hierarchical model with a central government, a local official, a contractor and a residents group to depict the decentralization in PPP. A benevolent central government delegates the decision to a local official through a governmental contract. Then the local official can individually interact with the contractor and the residents group. As stakeholders, both contractor and the residents group can influence the decison of the official through side transfer such as bribes. Moreover, the infrastructure project's design depends on some critical but uncertain factors. The realization of these factors, or types, is possessed privately by the residents group and contractor. The official may (resp. or may not) observe the real type of the other two parties, which is referred as possession 'full information' (resp. 'no information'). If she has 'no information'[1], she can only report so and the central government has to let both parties to report their own types. On the other hand, if she possesses 'full information', she can choose between reporting 'full information' or 'no information' (hiding her information from central government). If she reports 'no information', central government obtains nothing same as previous case. If she reports 'full information', the types of contractor and the residents group can be observed by central government without any distortion (hard information).

We apply this model to a post-tender phase renegotiation game to investigate how the corruption and collusion will influence the outcome and how the central government can prevent or take advantage of collusion. In our model, a highway project in the official's jurisdiction will be renegotiate due to the unexpected realization of uncertainty. The renegotiation game progresses as follows. In the pre-tender phase, the highway is designed based on the estimation of uncertainty and in the tender phase, the contract is signed. After the tender phase, the uncertainty realizes and both the official and the contractor may find renegotiation attractive and they both can propose a renegotiation offer. If neither party initiates renegotiation, the game ends and the initial design is carried out. Otherwise, one of the parties proposing renegotiation will lead it. If every party agrees on the proposal, the design is revised and the contract is resigned.

[1] In this chapter, we use 'her' for the local official, 'he' for the residents group and contractor, and 'it' for central or state government to avoid confusion.

4.2 The model

In this chapter we consider the renegotiation game in post-tender phase of a PPP project, specifically, a highway project between point A and B. There is an existing local road connecting these two points with constant travel time t_A. The design of new highway consists of two decision variables: the travel time and the toll rate. The travel time of the new highway is denoted as $t(\gamma)$ with γ denoting the V/C ratio on the highway. The local travellers are heterogeneous with regards to their value of time (VOT). Let β denote the smallest VOT of travellers. From user equilibrium, we know that this group of travellers is indifferent between using local road for free and new highway with toll rate p, which is

$$t_A = t(\gamma) + \frac{p}{\beta}$$

Therefore, the toll rate p can be indirectly express as $p = (t_A - t(\gamma))\beta$. Then we can use the pair (β, γ) to denote the decision variables of the new highway. Furthermore, assume that the cost of building the highway is kC, where C is the capacity of the highway and k is the cost of one unit of capacity.

The group of residents currently traveling between A and B is denoted as group r. we assume that the total demand between A and B does not change after the new highway being built. The residents have heterogeneous VOTs. The VOT follows Pareto distribution with cumulative density function (CDF):

$$F(\beta, \theta) = 1 - \left(\frac{\underline{\beta}}{\beta}\right)^{\theta}$$

where $\underline{\beta}$ is the lower bound of VOT value. Then given the toll rate set as β, the amount of users on the highway is

$$\bar{F}(\beta,\theta) = 1 - F(\beta,\theta) = \left(\frac{\underline{\beta}}{\beta}\right)^{\theta},$$

and hence the capacity C can be calculated as $C = \left(\frac{\underline{\beta}}{\beta}\right)^{\theta} \frac{1}{\gamma}$.

4.2.1 Stakeholders

In this chapter we consider four stakeholders in a decentralized PPP project: central government, local official, contractor and the residents group. When a project is procured through decentralization, the decision is most likely delegated to local officials from central government ([48]), where officials coordinate with selected contractors to determine the contract and design details of the newly built infrastructure. The travellers (residents) will either travel on existing local road or newly built highway. The highway user will be charged toll for the usage. The funding could come from either the user charge and also the central government fund.

In renegotiation in the post-tender phase, either the local official and the contractor can initiate a proposal. Such proposal should be approved by all three parties: government represented by the local official, the contractor and the residents group. Through out this chapter, we assume that the contractor, the residents group and the official are all self-interested. The contractor, acting as a private company, will attempt to maximize profit through renegotiation. The official is willing to take bribe from both contractor and the residents group, which may be in the form of personal benefit, political donation, or political capital such as the chances of being reelected. The local residents could also participate in the collusion to minimize their payment (toll and tax) and/or maximize the transportation benefit from the highway.

In the contrary, the central or state government in this chapter is regarded as benevolent and focuses on maximizing social welfare. However, central government does not possess the information needed to procure the infrastructure optimally and hence has to rely on the local official. In the following section, the information structure will be discussed.

4.2.2 Information structure

Our model entails adverse selection problem in economic literature. All three parties except central government possess private information. The contractor privately knows the unit procurement cost $k \in [\underline{k}, \bar{k}]$ and the residents group holds the parameter of VOT distribution, $\theta \in [\underline{\theta}, \bar{\theta}]$. Let $G_\theta(\cdot)$ and $G_k(\cdot)$ denote the cumulative distribution function of θ and k, respectively and $g_\theta(\cdot) = G'_\theta(\cdot)$, $g_k(\cdot) = G'_k(\cdot)$. The support and distributions of θ and k are public information. θ and k realize after the tender phase ends and are held by the residents group and the contractor respectively. The local official, on the other hand, has chance to learn the realization of θ and k. Let *sigma* denote the type of local official with $\sigma = (\theta, k)$ representing informed official and $\sigma = \emptyset$ uninformed official. During the renegotiation phase, all three parties need to report their type to central government, denoted as $(\hat{\theta}, \hat{k}, \hat{\sigma})$, which are not necessarily truthful. Although the reported types are subjected to manipulation, we follow the 'hard information' settings from [48], which means that if the local official possesses and reports 'full information', the central government can directly observe the real type of the residents group and contractor without possibility of manipulation.

4.2.3 Utility functions

The residents group r as a whole is maximizing the sum of the net benefit from the highway, $u_r(\cdot)$ and the subsidies from the government, $X_r(\cdot)$, with the expectation on contractor's type, k:

$$U_r(\theta, \hat{\theta}) = u_r(\theta, \hat{\theta}) + X_r(\hat{\theta}) \tag{4.1}$$

where $u_r(\theta, \hat{\theta}) = \mathbb{E}_k \left[Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta) m(\beta(\hat{\theta}, \hat{k}), \theta)(t_A - t(\gamma(\hat{\theta}, \hat{k}))) \right]$ denotes monetized value of travel time saving from the newly built highway minus the cost of toll.

The utility function of contractor is the profit from the newly built highway, $u_c(\cdot)$ plus the possible subsidies, $X_c(\cdot)$ given the expectation of the resident's group type θ:

$$U_c(k, \hat{k}) = u_c(k, \hat{k}) + X_c(\hat{k}) \tag{4.2}$$

where $u_c(k, \hat{k}) = \mathbb{E}_\theta \left[Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta)\beta(\hat{\theta}, \hat{k})(t_A - t(\gamma(\hat{\theta}, \hat{k}))) - Q\bar{F}(\beta(\hat{\theta}, \hat{k}), \theta)\frac{k}{\gamma(\hat{\theta}, \hat{k})} \right]$ is the toll revenue from the highway subtracted by the cost of building and operating the highway.

The central government is benevolent and maximizing the expected social welfare minus the out-of-pocket payment to both the residents group and the local contractor.

$$U_g(\theta, k, \hat{\theta}, \hat{k}) = \mathbb{E}_\theta \left[u_R(\theta, k, \hat{\theta}, \hat{k}) - X_r(\hat{\theta}, \hat{k}) \right] + \mathbb{E}_k \left[u_c(\theta, k, \hat{\theta}, \hat{k}) - X_c(\hat{\theta}, \hat{k}) \right]$$

If the central government possesses no information in the renegotiation, X_r and X_c will be determined according to mechanism design theory to ensure parties being truth-telling. If the central governmnet has full information, as it is possible that the renegotiation may make one party worse off while make the whole society better off, the government can compensate the utility loss of parties to enable the renegotiation.

Lastly, the official's utility function is denoted as $U_o(\theta, k)$. Her utility function depends on whether she is selfish or benevolent and what parties she can collude with. Therefore we will discuss in details in the following sections.

4.2.4 Timing of the model

In this chapter, we assume that both official led (O-led) and contractor led (C-led) renegotiations are possible. Based on this assumption, the renegotiation process works as follows.

Before the project starts, the central government will specify the optimal contract and design under different conditions and possible governmental contract with local official. The original design is determined before the post-tender phase of project and based on estimation of uncertain factors θ_E and k_E, that is, $\beta_E = \beta(\theta_E, k_E)$ and $\gamma_E = \gamma(\theta_E, k_E)$. After the implementation stage, θ, k and σ are realized and privately known by the residents group, contractor and local official, respectively.

Then the official and contractor simultaneously decide whether to initiate a renegotiation offer to other parties. If no party decides to initiate the renegotiation, the game ends immediately and the original design (β_E, γ_E) will be carried out and the utility of residents group and contractor given the realization (θ, k) will be

$$U_R^{NR}(\theta, k) = Q\bar{F}(\beta_E, \theta)m(\theta)(t_A - t(\gamma_E))$$

and

$$U_c^{NR}(\theta, k) = Q\bar{F}(\beta_E, \theta)\beta_E(t_A - t(\gamma_E)) - Q\bar{F}(\beta_E, \theta)\frac{k}{\gamma_E}$$

respectively. If only one party decides to initiate the renegotiation, other parties will decide whether to accept or decline the proposal. If both parties decide to initiate, the offer is randomly selected and other parties will decide whether to accept or decline the selected one. There is only one opportunity to propose renegotiation and therefore if the party decides not to initiate or its proposal is not selected, it will never be able to propose in the current renegotiation process.

If the renegotiation happens, the local official should first report her type $\tilde{\sigma} \in \{(\theta, k), \emptyset\}$ to central or state government. If she reports 'full information', $\sigma = (\theta, k)$, the central government is able to get the realization of (θ, k). Otherwise, in reporting 'no infromation' case, the central government let both the residents group and contractor to report their type $\tilde{\theta}$ and $\tilde{k}$ respectively.

In the renegotiation process, the local official will report her type to the central government to be either $\sigma = (\theta, k)$ or $\sigma = \emptyset$. If the report type is (θ, k), the central government is able to obtain full information. Otherwise, central government will let the residents group and contractor report their type. The revision of design will be determined by prespecified design based on the information central government obtains.

Finally the design is revised and possible the monetary transfer will be made. The timeline of the model is shown in Figure 4.1.

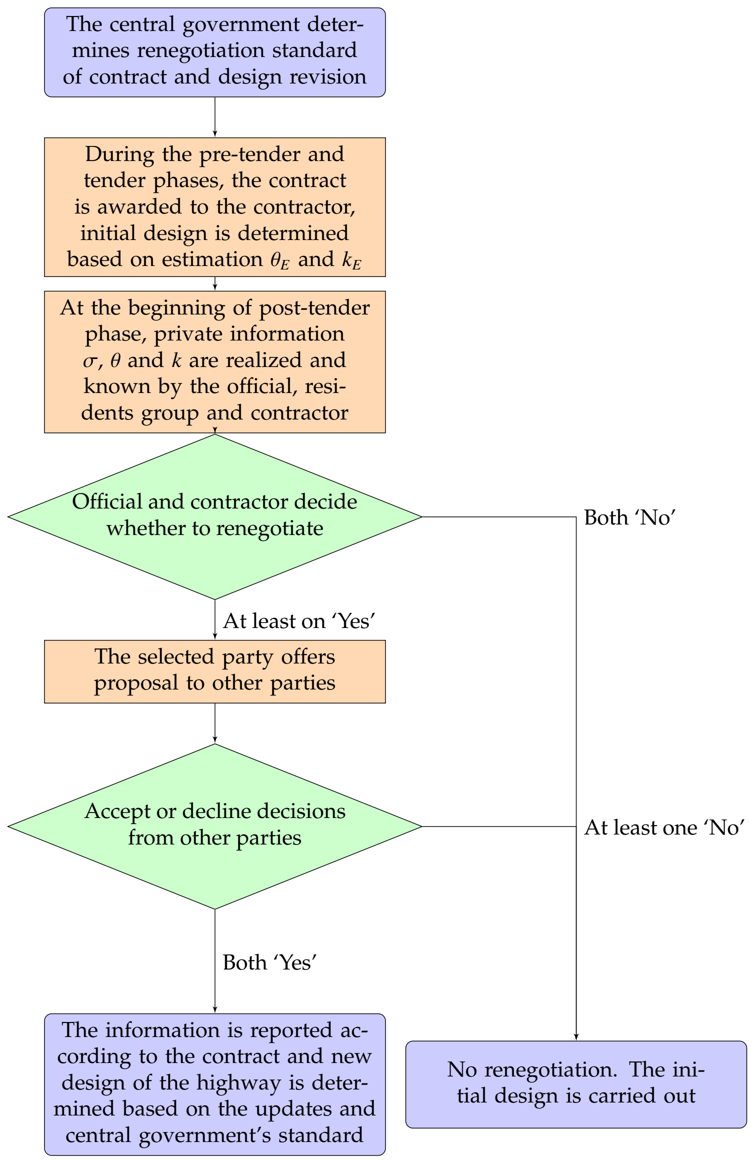

Figure 4.1: The flowchart of renegotiation process

4.2.5 Social optimal design

Without transfer, the social optimal design under full information can be determine by the following theorem.

Theorem 12. *The solution to the social optimal under full information is*

$$\begin{aligned}\beta &= \frac{k}{a}\frac{\theta}{1+\theta} \\ \gamma &= \frac{a}{\theta(t_A - t_0 - a)}\end{aligned} \tag{4.3}$$

Proof. This is a straightforward extension of [69] and [45]. For more detailed proof, interested readers can refer to their papers.

The social welfare without monetary transfer is

$$U_s(\theta, k) = Q\bar{F}(\beta, \theta)\left[(m(\beta, \theta) + \beta)(t_A - t(\gamma)) - \frac{k}{\gamma}\right] \tag{4.4}$$

The first order condition of (4.4) gives us (4.3).

□

Corollary 13. *Under full information condition, the followings hold:*

- *β is increasing in θ and increasing in k and γ is decreasing in θ and not influenced by the cost k;*
- *The contractor will always get 0 utility after renegotiation;*

- *The utility of residents group after renegotiation is*

$$u_r(\theta,k) = \underline{\beta}^{\theta+1}\left(\frac{a}{k}\right)^{\theta}\left(\frac{1+\theta}{\theta}\right)^{\theta+1}(t_A - t_0 - a)$$

- *The utility functions of residents group and contractor given the realization of (θ, k) and estimation (θ_E, k_E) are*

$$u_r(\theta,k,\theta_E,k_E) = \underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\right)^{\theta}\left(\frac{1+\theta_E}{\theta_E}\right)^{\theta+1}\frac{\theta_E}{\theta}(t_A - t_0 - a),$$

and

$$u_c(\theta,k,\theta_E,k_E) = \underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\frac{\theta_E+1}{\theta_E}\right)^{\theta+1}(t_A - t_0 - a)\frac{\theta_E}{a}(k_E - k)$$

Proof. Direct derivation from Theorem 12 □

From above corollary, we know that $\frac{\underline{\beta}a}{k}\frac{1+\theta}{\theta} < \frac{\underline{\beta}a}{k}2 < 1$, which means that $u_r(\theta,k)$ decreases in θ and k. Therefore the utility of the residents group will be decreasing with the inequality and the cost of procurement. The contractor will always get 0 utility from the renegotiation. Also, before renegotiation, both the residents group and the contractor's utility decrease in θ. The residents group's utility is not influenced by the realization of cost k, but the contractor is worse off for higher procurement cost.

The following theorem gives the optimal design under no information condition.

Theorem 14. *Under no information, the optimal design (β^N, γ^N) becomes*

$$\begin{aligned} \beta^N &\approx \frac{k + H_k(k)}{a}\frac{\theta}{1+\theta}\phi(\theta,k) \\ \gamma^N &\approx \frac{a}{\theta(t_A - t_0 - a)}\psi(\theta,k) \end{aligned} \tag{4.5}$$

where

$$\phi(\theta,k) \approx \frac{1}{1+\frac{\Lambda_1}{1+\theta}}$$
$$\psi(\theta,k) = \frac{1+\Lambda_1+\Lambda_2}{1-\frac{\Lambda_2}{\theta}}$$
$$\Lambda_1 = \frac{1}{2}\frac{k+H_k(k)}{a\underline{\beta}}\theta + \frac{H_\theta(\theta)}{\theta}\left(1-\frac{1}{2}\frac{a\underline{\beta}H_\theta(\theta)}{k+H_k(k)}\right)$$
$$\Lambda_2 = \frac{1}{\theta} + H_\theta(\theta)\log\frac{\theta(k+H_k(k))\phi(\theta,k)}{a\underline{\beta}(1+\theta)}$$

Proof. Based on Lemma 4 of [45], the optimal solution when central government does not have information is

$$(\beta^N,\gamma^N) \in \underset{\beta,\gamma}{\operatorname{argmax}}\Bigg[\left(\frac{\beta}{\theta}+\beta\right)\left((t_A-t_0-a)+\frac{a}{\gamma}\right)-\frac{k}{\gamma} - \left((t_A-t_0-a)+\frac{a}{\gamma}\right)\frac{\beta(-\theta\log\beta+\theta\log\underline{\beta}-1)}{\theta^2}H_\theta(\theta) - \frac{H_k(k)}{\gamma}\Bigg]$$

Then we can get

$$\beta^N = \begin{cases} \dfrac{k+H_k(k)}{a}\dfrac{\theta}{1+\theta}, & \text{when } \theta=\underline{\theta}, \\ exp\left(W\left(\dfrac{C}{B}e^{\frac{A}{B}}\right)-\dfrac{A}{B}\right), & \text{Otherwise.} \end{cases}$$

where, W is the Lambert W function defined as $ye^y = x \Rightarrow y = W(x)$ and

$$A = \frac{a}{\theta}(1 + \theta - H_\theta(\theta)(\log \underline{\beta} - \frac{1}{\theta}))$$
$$B = \frac{a}{\theta} H_\theta(\theta)$$
$$C = k + H_k(k)$$

Because $\frac{C}{B} e^{\frac{A}{B}} > e$, and from [14], $W(x) \approx \log \frac{x}{\log x}$ for $x > e$, then the β when $H_\theta(\theta) \neq 0$ becomes

$$\beta^N \approx \frac{k + H_k(k)}{a} \frac{\theta}{1+\theta} \phi(\theta, k)$$

where

$$\begin{aligned}
\phi(\theta, k) &= \frac{1}{1 + \frac{H_\theta(\theta)}{(1+\theta)} \left[\frac{1}{\theta} + \log \frac{\theta(k + H_k(k))}{a\underline{\beta} H_\theta(\theta)} \right]} \\
&\approx \frac{1}{1 + \frac{\Lambda_1}{1+\theta}}
\end{aligned}$$

Λ_1 can be calculated as

$$\begin{aligned}
\Lambda_1 &= H_\theta(\theta) \left[\frac{1}{\theta} + \log \frac{\theta(k + H_k(k))}{a\underline{\beta} H_\theta(\theta)} \right] \\
&\approx \frac{H_\theta(\theta)}{\theta} + \frac{1}{2} \left[\frac{\theta(k + H_k(k))}{a\underline{\beta}} - \frac{a\underline{\beta}(H_\theta(\theta))^2}{\theta(k + H_k(k))} \right] \\
&= \frac{1}{2} \frac{k + H_k(k)}{a\underline{\beta}} \theta + \frac{H_\theta(\theta)}{\theta} \left(1 - \frac{1}{2} \frac{a\underline{\beta} H_\theta(\theta)}{k + H_k(k)} \right)
\end{aligned}$$

Also we have

$$\gamma = \left[\frac{\frac{\theta}{\beta}(k + H_k(k))}{\frac{\theta^2 - 1}{\theta} - H_\theta(\theta) \log \frac{\beta}{\underline{\beta}}} - a \right] (t_A - t_0 - a)^{-1},$$

$$= \frac{a}{\theta(t_A - t_0 - a)} \psi(\theta, k)$$

where $\psi(\theta, k) = \dfrac{1 + \Lambda_1 + \Lambda_2}{1 - \dfrac{\Lambda_2}{\theta}}$ with $\Lambda_2 = \dfrac{1}{\theta} + H_\theta(\theta) \log \dfrac{\theta(k + H_k(k))\phi(\theta, k)}{a\underline{\beta}(1 + \theta)}$.

□

Immediately from Theorem 14, we have the following corollary:

Corollary 15. *Under no information case, to make both party truth-telling, the social optimal toll should smaller than the 'full information' case and the VC ratio should be larger than that.*

Proof. As $\phi(\theta, k) < 1$, $\beta^N < \beta$. As Λ_1 and Λ_2 are all larger than 1, $\psi(\theta, k) > 1$ and the $\gamma^N > \gamma$. □

Corollary 15 indicates that when the central government possesses no information, both the optimal toll and the VC ratio are distorted to induce truth-telling

Given the social optimal solution under different information situation, in the following sections, we will investigate the renegotiation outcomes when the official is benevolent or selfish.

4.3 Benevolent official

When the official is benevolent, she will implement the social optimal design in the renegotiation. The outcome under this condition serves as benchmark of the following sections. Also, the renegotiation conditions of the benevolent official are also constraints to the selfish official, that is, the selfish official has to mock the benevolent official in attempt to not being detected by the central government for misconduct. Therefore, even that selfish official finds it attractive to renegotiate but a benevolent official will not renegotiate, she cannot initiate the renegotiation.

4.3.1 Full information

When a benevolent official has full information, her utility function is same as the principal (central or state government), $U_o^{B,F}(\theta, k) = U_g^{B,F}(\theta, k) = u_r(\theta, k) + u_c(\theta, k) - X_r(\theta, k) - X_c(\theta, k)$ (As the government official possesses full information, she does not need to offer parties with information rent and hence the utility of contractor after renegotiation $u_c(\theta, k) = 0$). When the official has full information about the contractor and the residents group's types, she will initiate renegotiation process if and only if the new outcome will improve social welfare and also it will be accepted by the two parties. As initial renegotiation is always costly to the official and she possesses full information, such proposals will always be accepted by the two parties. Also, the contractor may also find it attractive to propose renegotiation when the real cost k is larger. The renegotiation game outcome is summarized as the following theorem.

Theorem 16. *When official is benevolent and informed, the renegotiation game out-*

come is:

- *Official will propose renegotiation when*

$$\left(1+\frac{1}{\theta}\right)^{1+\theta}-\left(1+\frac{1}{\theta_E}\right)^{1+\theta}\theta_E\left[\frac{1}{2}\frac{k_E-k}{k_E}\left(\frac{k}{k_E}\right)^{\theta}+\frac{1}{\theta}\right]>0$$

- *Contractor will propose renegotiation when*

$$k_E<k$$

Proof. A benevolent official will only renegotiate if and only if the outcome improves her utility function, which is equivalent to $u_r(\theta,k)-X_c(\theta,k)-X_r(\theta,k)>u_r(\theta,k,\theta_E,k_E)+u_c(\theta,k,\theta_E,k_E)$.

Under the bailout scenario, the residents group is compensated. Then the social welfare is

$$\begin{aligned}
&2u_r(\theta,k)-u_c(\theta,k,\theta_E,k_E)-2u_r(\theta,k,\theta_E,k_E)\\
=&2k^{-\theta}a^{\theta}\underline{\beta}^{\theta+1}\left(\frac{1+\theta}{\theta}\right)(t_A-t_0-a)\\
&\qquad-\underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\frac{\theta_E+1}{\theta_E}\right)^{\theta+1}(t_A-t_0-a)\frac{\theta_E}{a}(k_E-k)\\
&\qquad\qquad-2\underline{\beta}^{\theta+1}\left(\frac{a}{k}\right)^{\theta}\left(\frac{1+\theta_E}{\theta_E}\right)^{\theta+1}\frac{\theta_E}{\theta}(t_A-t_0-a)\\
=&\left(1+\frac{1}{\theta}\right)^{1+\theta}-\left(1+\frac{1}{\theta_E}\right)^{1+\theta}\theta_E\left[\frac{1}{2}\frac{k_E-k}{k_E}\left(\frac{k}{k_E}\right)^{\theta}+\frac{1}{\theta}\right]
\end{aligned}\tag{4.6}$$

The renegotiation condition is (4.6)> 0.

On the other hand, the contractor may also find the renegotiation attractive (intuitively, when cost shoots up). The condition of contractor to renegotiate is

$0 = \mathbb{E}_\theta[u_c(k)] > \mathbb{E}_\theta[u_c(k, k_E)]$. This indicates $k_E < k$. Under this condition, the contractor will only renegotiate when he needs bail-out. □

Theorem 16 tells us that the contractor will renegotiate when there is an unexpected shoot-up. However, the official is less likely to bail out the contractor as the renegotiation condition is (4.6)> 0 which is stricter than $k - k_E \geqslant 0$ because when $k \leqslant k_E$, (4.6) $< 0\ \forall\ \theta$.

4.3.2 No information

When the official has no information, her utility function becomes

$$U_o^{B,N}(\theta, k) = U_g^{B,N}(\theta, k) = \mathbb{E}_{\theta,k}\left[u_r(\theta, k) + u_c(\theta, k) - h_r(\theta) - h_c(k)\right],$$

which is different from its counter part when the official has full information due to the information asymmetry. We have the following theorem.

Theorem 17. *A benevolent official with no information will always renegotiate, but such proposal may be rejected by the residents group and the contractor. The contractor when the following inequalities are both satisfied:*

$$\mathbb{E}_\theta\left[2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}H_k(k)\right] > Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\underline{\theta}+1}\frac{\left(1-\left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E\log\frac{\beta_E}{\underline{\beta}}}(k_E - k)$$

$$\mathbb{E}_{\theta,k}\left[Q\underline{\beta}^{\bar{\theta}+1}\left(\frac{a}{k}\right)^{\bar{\theta}}\left(1+\frac{1}{\theta_E}\right)^{\bar{\theta}}\frac{1}{\bar{\bar{\theta}}}(1+\theta_E)(t_A - t_0 - a)\right.$$

$$-2Q\frac{H_\theta(\theta)}{\gamma^N\theta^2}\Big((t_A-t_0-a)\gamma^N+a\Big)\beta^N\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}(\theta\log\frac{\beta}{\underline{\beta}}-1)\Bigg]$$

$$> Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\underline{\theta}+1}\frac{k_E\left(1-\left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E\theta\log\frac{\beta_E}{\underline{\beta}}} \tag{4.7}$$

Proof. As the utility of no renegotiation is still $\mathbb{E}_{\theta,k}\left[u_r(\theta,k,\theta_E,k_E)+u_c(\theta,k,\theta_E,k_E)\right]$, she will only renegotiate when

$$\mathbb{E}_{\theta,k}\left[u_r(\theta,k)+u_c(\theta,k)-h_r(\theta)-h_c(k)\right] >$$
$$\mathbb{E}_{\theta,k}\left[u_r(\theta,k,\theta_E,k_E)+u_c(\theta,k,\theta_E,k_E)\right] \tag{4.8}$$

Also, such proposal is expected to be accepted by both parties when

$$\begin{aligned}\mathbb{E}_{\theta,k}[U_R^N(\theta,k)] &\geqslant \mathbb{E}_{\theta,k}[u_r(\theta,k,\theta_E,k_E)]\\ \mathbb{E}_{\theta,k}[U_c^N(\theta,k)] &\geqslant \mathbb{E}_{\theta,k}[u_c(\theta,k,\theta_E,k_E)]\end{aligned}$$

where,[2]

$$\mathbb{E}_{\theta,k}\left[u_r(\theta,k)+u_c(\theta,k)-h_r(\theta)-h_c(k)\right]$$

[2]Here as we consider a contractor bail-out situation, in the renegotiation problem we set the utility function of contractor and the residents group as $\mathbb{E}_\theta\left[U_c^N(\theta,k)\right]=0$ and $\mathbb{E}_k\left[U_r^N(\theta,k)\right]=\mathbb{E}_k[u_r(\theta,k,\theta_E,k_E)]$, respectively. This ensures the participation as well as consistency with the reality. Therefore, the utility of highest type (least utility from renegotiation can be calculated through $\mathbb{E}_k\left[U_r^N(\bar{\theta},k)\right]=\mathbb{E}_{\theta,k}[u_r(\theta,k,\theta_E,k_E)]+\mathbb{E}_{\theta,k}\left[Q(t_A-t(\gamma))\frac{\partial\bar{F}(\beta,\theta)m(\beta,\theta)}{\partial\theta}2H_\theta(\theta)\right]$ and $\mathbb{E}_\theta\left[U_c^N(\bar{\theta},k)\right]=\mathbb{E}_{\theta,k}[u_c(\theta,k,\theta_E,k_E)]+\mathbb{E}_{\theta,k}\left[Q\bar{F}(\beta,\theta)\frac{1}{\gamma}2H_k(k)\right]$

$$=\mathbb{E}_{\theta,k}\left[2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}(k+H_k(k))\left(\frac{1+2\theta-\frac{1}{\theta}-\frac{H_\theta(\theta)}{\theta}}{1-\frac{1}{\theta^2}-\frac{H_\theta(\theta)}{\theta}\log\frac{\beta^N}{\underline{\beta}}}-1-\theta\right)\right.$$

$$\left.-U_r^N(\bar{\theta},k)-U_c^N(\theta,\bar{k})\right]$$

$$\mathbb{E}_{\theta,k}\left[u_r(\theta,k,\theta_E,k_E)+u_c(\theta,k,\theta_E,k_E)\right]$$

$$=\mathbb{E}_{\theta,k}\left[Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\theta+1}\frac{1}{\gamma_E}\left(k_E\frac{1+\theta}{\theta}-k\right)\right]$$

$$=Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\underline{\theta}+1}\frac{k_E\left(1-\left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E\theta\log\frac{\beta_E}{\underline{\beta}}}$$

$$\mathbb{E}_{\theta,k}[U_c^N(\theta,k)]=\mathbb{E}_{\theta,k}\left[2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}H_k(k)\right]+\mathbb{E}_\theta[u_c(\theta,\bar{k},\theta_E,k_E)]$$

$$\mathbb{E}_{\theta,k}[U_r^N(\theta,k)]=\mathbb{E}_{\theta,k}\left[U_r^N(\bar{\theta},k)-Q(t_A-t(\gamma))\frac{\partial\{\bar{F}(\beta,\tilde{\theta})m(\tilde{\theta})\}}{\partial\theta}\frac{G_\theta(\theta)}{g_\theta(\theta)}\right]$$

$$=Q\underline{\beta}^{\bar{\theta}+1}\left(\frac{a}{k_E}\right)^{\bar{\theta}}\left(1+\frac{1}{\theta_E}\right)^{\bar{\theta}}\frac{1}{\bar{\theta}}(1+\theta_E)(t_A-t_0-a)$$

$$-\mathbb{E}_{\theta,k}\left[2Q\frac{H_\theta(\theta)}{\gamma^N\theta^2}\left((t_A-t_0-a)\gamma^N+a\right)\beta^N\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\left(\theta\log\frac{\beta}{\underline{\beta}}-1\right)\right]$$

$$=\mathbb{E}_\theta[u_r(\bar{\theta},k,\theta_E,k_E)]$$

$$+\mathbb{E}_{\theta,k}\left[u_r(\theta,k)\left(\frac{k}{(k+H_k(k))\phi(\theta,k)}\right)^{\theta}\left(1+\frac{\theta}{\psi(\theta,k)}\right)\left(1+\theta\log\frac{\beta^N}{\underline{\beta}}\right)H_\theta(\theta)\right]$$

$$\mathbb{E}_{\theta,k}[u_c(\theta,k,\theta_E,k_E)]=0$$

$$\mathbb{E}_{\theta,k}[u_r(\theta,k,\theta_E,k_E)]=Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\underline{\theta}+1}\frac{k_E\left(1-\left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E\theta\log\frac{\beta_E}{\underline{\beta}}}$$

$$u_r^N(\theta,k)=Q\underline{\beta}^{\theta+1}\frac{1}{\beta^\theta}\left(\phi(\theta,k)\right)^{-\theta}(t_A-t_0-a)\left(\frac{1}{\theta}+\frac{1}{\psi(\theta,k)}\right)$$

$$u_c^N(\theta, k) = Q\underline{\beta}^{\theta+1}\frac{1}{\beta^\theta}(t_A - t_0 - a)\left[1 + \frac{\theta}{\psi(\theta, k)} - \frac{1+\theta}{\phi(\theta, k)\psi(\theta, k)}\right]$$

which means that

$$\begin{aligned}
&\mathbb{E}_{\theta,k}\left[U_r^N(\theta, k)\right] = \mathbb{E}_{\theta,k}\left[2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}H_k(k)\right] > \mathbb{E}_{\theta,k}\left[u_r(\theta, k)\right] = 0 \\
&\mathbb{E}_{\theta,k}\left[Q\underline{\beta}^{\bar{\theta}+1}\left(\frac{a}{k}\right)^{\bar{\theta}}\left(1 + \frac{1}{\theta_E}\right)^{\bar{\theta}}\frac{1}{\bar{\bar{\theta}}}(1+\theta_E)(t_A - t_0 - a)\right. \\
&\qquad \left. -2Q\frac{H_\theta(\theta)}{\gamma^N\theta^2}\Big((t_A - t_0 - a)\gamma^N + a\Big)\beta^N\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\left(\theta\log\frac{\underline{\beta}}{\beta} - 1\right)\right] \\
&\qquad\qquad > Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\theta+1}\frac{k_E\left(1 - \left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E\theta\log\frac{\beta_E}{\underline{\beta}}}
\end{aligned} \tag{4.9}$$

Both constraints are always satisfied ex ante. However, contractor and the residents group may reject such proposal ex post. Therefore, an uninformed government officer attempts to renegotiate when (4.8) is satisfied.

Contractor will renegotiation when $\mathbb{E}_\theta\left[U_c^N(\theta, k)\right] \geqslant \mathbb{E}_\theta\left[u_c(\theta, k, \theta_E, k_E)\right]$ and also knowing that $\mathbb{E}_{\theta,k}\left[U_r^N(\theta, k)\right] > \mathbb{E}_{\theta,k}\left[u_r(\theta, k, \theta_E, k_E)\right]$, both of which always hold due to the design of the renegotiation proposal.

This translates to (4.7) □

Notice that (4.7) differs with (4.9) only in the first inequality. The first inequality in (4.7) does not rely on the expectation of random variable k which implies that under no information condition, the contractor will not always initiate renegotiation (but the official will). Therefore, in contrast to the full information condition, the contractor will renetiate less likely compared to the official.

Moreover, when the contractor initiate the renegotiation, the proposal will be easier to pass through due to the information advantage the contractor have compared to the uninformed government official.

4.4 Selfish official

When official is selfish, her utility function is the personal benefit she will obtain from the renegotiation. Therefore, the utility function can be written as

$$U_o^{S,F} = \mu \nu_c x_c(\theta, k) + \nu_r x_r(\theta, k)$$

where μ is the bargain power of the official, ν_c is the collusion return coefficient from contractor and ν_r is the collusion return from the residents group. $\mu = 0$ when the contractor possesses all the bargain power and the official can not solicit bribe from contractor through collusion. $\nu_c, \nu_r = 1$ when the collusion is 'frictionless', i.e. all the bribes going to the official will becomes her personal benefits while $\nu_c, \nu_r = 0$ when the collusion is so costly due to auditing or monitoring.

4.4.1 Full information

When official is selfish, her utility is the personal gain from the renegotiation which is in the form of bribe. The official can seek the opportunity of bribe in two ways: Reporting 'full information' and ask the party (or both party) who gain(s) from renegotiation for bribe (and other party will be compensated for loss by the central government), or reporting 'no information' and take the extra utility increase from both parties.

First consider when full information is reported. Under bail-out situation, the contractor gains utility if renegotiation happens. The utility gain of contractor from renegotiation is:

$$\Delta u_c^{S,F,RF} = u_c(\theta, k) - u_c(\theta, k, \theta_E, k_E) = \underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\frac{\theta_E+1}{\theta_E}\right)^{\theta+1}(t_A - t_0 - a)\frac{\theta_E}{a}(k - k_E)$$

The utility gain of residents group is

$$\begin{aligned}\Delta u_r^{S,F,RF} &= \max\{0,\ u_r(\theta, k) - u_r(\theta, k, \theta_E, k_E)\}\\ &= \max\left\{0, \underline{\beta}^{\theta+1} a^{\theta}(t_A - t_0 - a)\left[\left(\frac{1}{k}\right)^{\theta}\left(\frac{1+\theta}{\theta}\right)^{1+\theta} - \frac{\theta_E}{\theta}\left(\frac{1}{k_E}\right)^{\theta}\left(\frac{1+\theta_E}{\theta_E}\right)^{1+\theta}\right]\right\}\end{aligned}$$

Then the potential bribe towards the official will be

$$x_r = \Delta u_r^{S,F,RF} x_c = \Delta u_c^{S,F,RF}$$

The utility of official if she reports full information will be

$$\begin{aligned}U_o^{S,F,RF}(\theta, k) &= \mu\nu_c \Delta u_c^{S,F}(\theta, k) + \nu_r \Delta u_r(\theta, k)\\ &= \mu\nu_c\underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\frac{\theta_E+1}{\theta_E}\right)^{\theta+1}(t_A - t_0 - a)\frac{\theta_E}{a}(k - k_E)\\ &+ \nu_r \max\left\{0, \underline{\beta}^{\theta+1} a^{\theta}(t_A - t_0 - a)\left[\left(\frac{1}{k}\right)^{\theta}\left(\frac{1+\theta}{\theta}\right)^{1+\theta} - \frac{\theta_E}{\theta}\left(\frac{1}{k_E}\right)^{\theta}\left(\frac{1+\theta_E}{\theta_E}\right)^{1+\theta}\right]\right\}\end{aligned}$$

A sufficient condition is $k \geqslant k_E$. This is less strict than the renegotiation condition of benevolent official (4.6). Hence, by reporting 'full information', the official is constrained by the renegotiation condition of benevolent official.

On the contrary, the utility gain of contractor if official reports 'no information' is ('Selfish, Full information, Report No information')

$$
\begin{aligned}
&\Delta u_c^{S,F,RN}(\theta,k) = U_c^N(\theta,k) - u_c(\theta,k,\theta_E,k_E) \\
&= 2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}H_k(k) + u_c(\theta,\bar{k},\theta_E,k_E) - \underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\frac{\theta_E+1}{\theta_E}\right)^{\theta+1}(t_A - t_0 - a)\frac{\theta_E}{a}(k-k_E) \\
&= 2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}H_k(k) + \underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\frac{\theta_E+1}{\theta_E}\right)^{\theta+1}(t_A - t_0 - a)\frac{\theta_E}{a}(\bar{k}-k)
\end{aligned}
$$

Similarly the utility gain/loss of the residents group from the potential renegotiation is

$$
\begin{aligned}
&\Delta u_r^{S,F,RN}(\theta,k) = U_r^N(\theta,k) - u_r(\theta,k,\theta_E,k_E) \\
&= u_r(\bar{\theta},k,\theta_E,k_E) + u_r(\theta,k)\left(\frac{k}{(k+H_k(k))\phi(\theta,k)}\right)^{\theta}\left(1+\frac{\theta}{\psi(\theta,k)}\right)\left(1+\theta\log\frac{\beta^N}{\underline{\beta}}\right)H_\theta(\theta) \\
&\qquad - \underline{\beta}^{\theta+1}\left(\frac{a}{k_E}\right)^{\theta}\left(\frac{1+\theta_E}{\theta_E}\right)^{\theta+1}\frac{\theta_E}{\theta}(t_A - t_0 - a) \\
&= \underline{\beta}^{\theta+1}(t_A - t_0 - a)a^{\theta}\Bigg[\\
&\quad \left(\frac{1}{k}\right)^{\theta}\left(\frac{1+\theta}{\theta}\right)^{\theta+1}\left(\frac{k}{(k+H_k(k))\phi(\theta,k)}\right)^{\theta}\left(1+\frac{\theta}{\psi(\theta,k)}\right)\left(1+\theta\log\frac{\beta^N}{\underline{\beta}}\right)H_\theta(\theta) - \\
&\qquad \left(\frac{1}{k_E}\right)^{\theta}\left(\frac{1+\theta_E}{\theta_E}\right)^{\theta+1}\theta_E\left(\frac{1}{\theta}-\left(\frac{a}{k_E}\frac{1+\theta_E}{\theta_E}\right)^{\bar{\theta}-\theta}\frac{1}{\bar{\bar{\theta}}}\right)\Bigg]
\end{aligned}
$$

Therefore, the utility gain of the official is

$$U_o^N(\theta,k) = \mu\nu_c\Delta u_c^{S,F,RN}(\theta,k) + \nu_r\Delta u_r^{S,F,RN}(\theta,k)$$

Now, we can discuss under different scenarios (different combinations of μ, ν_r and ν_c, the outcome of the renegotiation game.

Official colluding with both parties with full bargain power ($\mu = 1$, $\nu_r = 1$ and $\nu_c = 1$)

We have the government official will renegotiate if and only if at least one of the two following conditions is satisfied:

$$4.6 > 0$$
$$U_o^N(\theta,k) > 0$$

The official can always report 'no information' because uninformed and benevolent official will always renegotiate. Also, the official will prefer to report 'no information' when

$$\begin{aligned} U_o^N(\theta,k) - (4.6) = {} & u_r(\theta,k) + u_c(\theta,k) - h_r(\theta) - h_c(k) \\ & - \left(\frac{\beta}{\beta_E}\right)^{\theta+1} \frac{1}{\gamma_E}\left(k_E - \left(1 - \frac{1}{\theta}\right)k\right) > 0 \end{aligned} \tag{4.10}$$

Compared to benevolent official, the selfish official will be more likely to renegotiate. Notice that the official may not be willing to report 'no information' even if she possesses full information. She will report 'full information' if (4.10) does not hold.

Official colluding with both parties with no bargain power ($\mu = 0$, $\nu_r = 1$ and $\nu_c = 1$)

Renegotiation opportunity will provide the contractor $\mathbb{E}_\theta \left[U_c^N(k) \right] = 0$ ex ante. Notice that the contractor can provide the official with bribe to induce her to report 'no information' in renegotiation, therefore we should check which will be preferred. If the official report full information, the contractor is expected to gain from the renegotiation by

$$
\begin{aligned}
&\mathbb{E}_\theta \left[u_c(\theta, k) \right] - \mathbb{E}_\theta \left[u_c(\theta, k, \theta_E, k_E) \right] \\
=&\underline{\beta}^{\theta+1} \left(\frac{a}{k_E} \frac{\theta_E + 1}{\theta_E} \right)^{\theta+1} (t_A - t_0 - a) \frac{\theta_E}{a} (k - k_E)
\end{aligned}
\tag{4.11}
$$

This is still dominated by the renegotiation condition when official reports full information, (4.6)> 0. Therefore, contractor can not always renegotiate when (4.11) > 0.

If the official reports 'no information', the utility gain will be[3]

$$
\mathbb{E}_\theta \left[U_c^N(\theta, k) - u_c(\theta, k, \theta_E, k_E) \right]
$$

[3]The contractor will claim all the extra utility and use part of them (larger than 0) as bribe. However as she don't have the exact information on the residents group's type, it is difficult. It should be, the contractor let the official take all the utility from the residents group, but will retain his own gain.

$$=\mathbb{E}_\theta\left[2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}H_k(k)\right]-Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\underline{\theta}+1}\frac{\left(1-\left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E\log\frac{\beta_E}{\underline{\beta}}}(k_E-k) \tag{4.12}$$

As the contract is designed in such a way that when official reports 'no information' the residents group will always accept the proposal ex ante, the contractor can always initiate the renegotiation when it increases his utility. Therefore, contractor-led renegotiation can be summarized as following

- (4.6) > 0 and (4.12) > 0 does not hold, no renegotiation led by contractor;
- Either (4.6) > 0 or (4.12) > 0 holds, but not both:
  - (4.6) > 0, contractor will renegotiate without colluding with official;
  - (4.12) > 0 holds, contractor will collude with official for reporting 'no information';
- Both condition holds:
  - (4.11) > (4.12), contractor leads the renegotiation without colluding with official;
  - (4.11) < (4.12), contractor leads the renegotiation and colludes with official for reporting 'no information'.

Above conditions indicate that a fully informed official will be more likely to lie in a O-led renegotiation than a C-led renegotiation. Also, in a renegotiation where official reporting 'no information', if $\mathbb{E}_\theta[U_c^N(\theta,k)] < 0$, no collusion exists. Although it is impossible for a government with information disadvantage to learn $\mathbb{E}_\theta[U_c^N(\theta,k)]$ because they don't know the realization k, this gives the supervising or auditing authority a guide to discover possible collusion. Moreover, larger θ induce more likely C-led renegotiation.

Official colluding with only contractor with full bargain power ($\mu = 1$, $\nu_r = 0$ and $\nu_c = 1$)

When the selfish official possesses full information, she can only benefit from the renegotiation with the contractor. Therefore, the renegotiation condition would be

- If official reports 'full information':

$$U_o^F(\theta,k) = -u_c(\theta,k,\theta_E,k_E) = Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\theta+1}\frac{k-k_E}{\gamma_E\theta} > 0$$

  Similarly, this is also constrained by the renegotiation condition when reporting 'full information', (4.6).

- If official reports 'no information':

$$2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}(k+H_k(k))\left(\frac{1}{1-\frac{1}{\theta^2}-\frac{H_\theta(\theta)}{\theta}\log\frac{\beta^N}{\underline{\beta}}}-1\right)$$
$$-Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\theta+1}\frac{k_E-k}{\gamma_E\theta} > 0$$
$$2Q\left(\frac{\underline{\beta}}{\beta^N}\right)^{\theta+1}\frac{1}{\gamma^N}(k+H_k(k))\left(\frac{\theta-\frac{H_\theta(\theta)}{\theta}+H_\theta(\theta)\log\frac{\beta^N}{\underline{\beta}}}{1-\frac{1}{\theta^2}-\frac{H_\theta(\theta)}{\theta}\log\frac{\beta^N}{\underline{\beta}}}\right)$$

$$- Q\left(\frac{\underline{\beta}}{\beta_E}\right)^{\underline{\theta}+1} \frac{k_E\left(1-\left(\frac{\underline{\beta}}{\beta_E}\right)^{\bar{\theta}-\underline{\theta}}\right)}{\gamma_E \theta \log \frac{\beta_E}{\underline{\beta}}} > 0$$

Incentive of reporting 'full information' deos not change in this scenario, but reporting 'no information' becomes less attractive due to the restriction of unable to collude with residents. Therefore the official will still be more likely to renegotiate the contract compared to benevolent official. However, she will be less incentivized compared to official colluding with both parties.

Official colluding with only contractor with no bargain power ($\mu = 0$, $\nu_r = 0$ and $\nu_c = 1$)

On the C-led renegotiation side, when official reports full information, the renegotiation condition is not changed. The gain of contractor from the renegotiation is still $-u_c(\theta, k, \theta_E, k_E)$ with the constraint (4.6) > 0. Because C-led renegotiation will not give a official reporting full information any extra benefit on the contractor side, not being able to collude with the residents group ensures that there will be no benefit for official through collusion.

However, when official reporting 'no information', contractor will still find it attractive to propose renegotiation. However, the renegotiation does happen less likely. This is due to the fact that the official can not compensate the residents group's possible utility loss using the utility gain from the contractor side and the renegotiation condition will be stricter. As reporting 'no information' always brings social welfare loss when official is fully informed, reduced opportunity of such renegotiation will benefit the society in general.

Official colluding with only residents group ($\mu = 1$ or 0, $\nu_r = 1$ and $\nu_c = 0$)

When the official can only collude with residents group, it is impossible for the contractor to influence the official's decision. Under contractor bail-out situation, reporting 'full information' is never attratice to a selfish official because she can not benefit from it any more. On the contrary, by reporting 'no information', a fully informed official can breach the information rent from central government to residents group. Therefore, a fully informed official will always prefer reporting 'no information'. A side effect of this behavior of official is that the contractor do not need to collude with official to induce higher benefit (if possible).

The renegotiation constraints are not changed under this scenario for both 'no information' and 'full information' cases.

4.4.2 No information

When the official has no information, she will not be willing to initiate the renegotiation because there will be no personal gain from it.

For the contractors, the renegotiation condition is (4.12) > 0, which is same as benevolent case.

4.5 Selfish official colluding with part of residents

As previous chapter states, the required monetary transfer from official to residents group H is

$$\begin{aligned}\mathbb{E}_\theta\left[x_h(\theta)\right] &= U_h(\bar{\theta}) - u_h(\bar{\theta}) + \mathbb{E}_{\theta,k}\left[Q\bar{F}(\beta_0,\theta)(m(\theta)+\beta_0-\beta)\frac{\partial t(\gamma)}{\partial\theta}\frac{G_\theta(\theta)}{g_\theta(\theta)}\right]\\ &= \mathbb{E}_k\left[Q\left(\frac{\beta}{\beta_0}\right)^{\bar{\theta}}\frac{\beta_0}{\bar{\theta}}a(\frac{1-\gamma(\theta_E,k_E)}{\gamma(\theta_E,k_E)}-\frac{1-\gamma^N(\bar{\theta},k)}{\gamma^N(\bar{\theta},k)})\right]\\ &\quad-\mathbb{E}_{\theta,k}\left[2Q\left(\frac{\beta}{\beta_0}\right)^{\theta}\left(\frac{\beta_0}{\theta}+\beta_0-\beta^N(\bar{\theta},k)\right)\frac{\frac{\partial\gamma^N(\theta,k)}{\partial\theta}}{(\gamma^N(\theta,k))^2}H_\theta(\theta)\right]\end{aligned}$$

On the other hand, the monetary transfer central government distributes to the residents group 'h' is

$$\begin{aligned}&\mathbb{E}_\theta\left[X_h(\theta)\right]\\ &= (U_R(\bar{\theta})-u_R(\bar{\theta}))\mathbb{E}_\theta\left[\bar{F}(\beta_0,\theta)\right]+\mathbb{E}_{\theta,k}\left[Q\bar{F}(\beta,\theta)\bar{F}(\beta_0,\theta)m(\theta)\frac{\partial t(\gamma)}{\partial\theta}\frac{G_\theta(\theta)}{g_\theta(\theta)}\right]\\ &= \mathbb{E}_k\left[Q\left(\frac{\beta}{\beta_0}\right)^{\bar{\theta}}\frac{\beta_0}{\bar{\theta}}a(\frac{1-\gamma(\theta_E,k_E)}{\gamma(\theta_E,k_E)}-\frac{1-\gamma^N(\bar{\theta},k)}{\gamma^N(\bar{\theta},k)})\right]\left(\frac{\beta}{\beta_0}\right)^{\theta}\frac{1}{\log\frac{\beta}{\beta_0}}\\ &\quad-\mathbb{E}_{\theta,k}\left[2Q\left(\frac{\beta}{\beta}\right)^{\theta}\left(\frac{\beta}{\beta_0}\right)^{\theta}\left(\frac{\beta_0}{\theta}+\beta_0-\beta^N(\bar{\theta},k)\right)\frac{\frac{\partial\gamma^N(\theta,k)}{\partial\theta}}{(\gamma^N(\theta,k))^2}H_\theta(\theta)\right]\end{aligned}$$

As we assumed that $\beta < \beta_0$, $\mathbb{E}_\theta[X_h(\theta,k)] < \mathbb{E}_\theta[x_h(\theta,k)]$. This indicates that the official can not directly use the central government's fund to induce truth telling within the residents group. This naturally can reduce the chance of collusion when official has no information.

On the other hand, if official colludes with only the residents group 'l' (low) with VOT less than β_1, she will not be interested in reporting full information because in that way she will not be benefit from it. On the other hand, she will always report 'no information' when it is possible (i.e. the condition of benevolent renegotiation is possible) because she can confiscate the monetary transfer from central government to residents group 'l'.

4.6 Anti-corruption program

In the previous sections, the outcomes of renegotiation games are derived. Given the bribe between official, contractor and the residents group, the central government can set up an anti-corruption program to incentivize the official to honestly report her type. As we state above, our focus is the scenario of contractor bailout under unexpected cost shoot-up or insufficient demand. In this section, we will derive such program given the results in previous sections. We will examine how would the central government setup the bailout program.

We consider two different approaches to fight against collusion. One is providing the official incentives for truth-telling, which let her voluntarily give up the opportunity to collude with contractor or the residents group. Such measure helps to obtain information from the official and hence brings benefit to the society. On the other hand, implementing this measure requires the central government to provide personal benefit (such as salary, promotion opportunity, etc.) to the official, which is costly. From literature of mechanism design, the cost of such incentive is distortion of the social optimal design. Denote the bonus of reporting 'full information' as $X_o(\theta, k)$. Such burden may annihilate welfare gain. The central government's utility, i.e. social welfare from the renegotiation, is the sum of utility of both parties extracted by bonus and compensation to the residents group, which is

$$U_g = u_r(\theta, k) + u_c(\theta, k) - X_o(\theta, k) - X_r(\theta, k) - X_c(\theta, k)$$

Another way is to restrict the collusion by regulation and supervision. As we discussed in previous sections, official may collude with different party or one part of a party (for example, potential users of new infrastructure or in other case, non-union worker). Therefore, the effectiveness of anti-corruption program is various under different collusion types and in the following section we also compare the benefit such regulation and supervision brings.

4.6.1 Official colluding with both parties

When the official colludes with both parties. In the O-led renegotiation, when the renegotiation condition is satisfied, the official's payoff is

$$\begin{aligned} S_o &= \max\{0, U_o^N(\theta, k) - u_c(\theta, k, \theta_E, k_E)\} \\ &= \max\{0, U_c^N(\theta, k) + U_r^N(\theta, k) - 2u_c(\theta, k, \theta_E, k_E) - u_r(\theta, k, \theta_E, k_E)\} \end{aligned}$$

Notice that the official will only initiate an O-led renegotiation whenever $S_o \geqslant 0$. Also, in the anti-corruption program, to ensure that the official is truth-telling the central government should provide her with transfer at least equal to S_o, which will be naturally binding.

$$X_o = S_o = U_c^N(\theta, k) + U_r^N(\theta, k) - 2u_c(\theta, k, \theta_E, k_E) - u_r(\theta, k, \theta_E, k_E) \tag{4.13}$$

Equation (4.13) indicates that the social welfare after implementing the anti-corruption program is $2u_r(\theta, k) - U_r^N(\theta, k) - U_c^N(\theta, k) + 2u_c(\theta, k, theta_E, k_E)$ which is larger than the social welfare if the official reports 'no information': $2u_r^N(\theta, k) - U_c^N(\theta, k) - U_r^N(\theta, k)$.

In a C-led renegotiation, if the official reports 'full information' there will be no corruption happening. However, when the official reports 'no information', corruption may exist when (4.11) < (4.12). Therefore, the central government should reward the official who report 'full information' by the possible utility gain for her, which is

$$\begin{aligned} S^c =& (4.12) - (4.11) + U_r^N(\theta, k) - u_r(\theta, k, \theta_E, k_E) \\ =& U_c^N(\theta, k) - u_c(\theta, k, \theta_E, k_E) \end{aligned}$$

It is obviously that $V^o > V^c$, which means that it is costlier to prevent O-led renegotiation than C-led one because the bonus paid to the official is higher.

The social welfare after implementing this (superscript 'B' denotes both party)

$$\begin{aligned} \Delta U^B =& u_r(\theta, k) - u_r(\theta, k, \theta_E, k_E) - u_c(\theta, k, \theta_E, k_E) \\ & - \max\left\{0, U_c^N(\theta, k) + U_r^N(\theta, k) - 2u_c(\theta, k, \theta_E, k_E) - u_r(\theta, k, \theta_E, k_E)\right\} \end{aligned}$$

$$- \max\{0, u_r(\theta, k, \theta_E, k_E) - u_r(\theta, k)\}$$

When the central government has to compensate the residents group for utility loss ($u_r(\theta, k) < u_r(\theta, k, \theta_E, k_E)$) and simultaneously award the government official for reporting 'full information', the change in utility becomes:

$$\begin{aligned}
\Delta U_a^B =& u_r(\theta, k) - u_r(\theta, k, \theta_E, k_E) - u_c(\theta, k, \theta_E, k_E) \\
&- U_c^N(\theta, k) + U_r^N(\theta, k) - 2u_c(\theta, k, \theta_E, k_E) - u_r(\theta, k, \theta_E, k_E) \\
&- u_r(\theta, k, \theta_E, k_E) - u_r(\theta, k) \\
=& 2u_r(\theta, k) - u_r(\theta, k, \theta_E, k_E) + u_c(\theta, k, \theta_E, k_E) - U_c^N(\theta, k) - U_r^N(\theta, k)
\end{aligned}$$

If no anti-corruption program is implemented, ΔU becomes

$$\begin{aligned}
\Delta U_c^B =& u_r^N + u_c^N - h_r - h_c \\
=& 2u_r^N + 2u_c^N - U_r^N - U_c^N
\end{aligned}$$

where

$$u_c^N(\theta, k) = Q \frac{\bar{F}(\beta^N, \theta)}{\gamma} \left[(k + H_k(k))\phi(\theta, k) \frac{\psi(\theta, k) + \theta}{1 + \theta} - k \right]$$

$$u_r^N(\theta, k) = Q \frac{\bar{F}(\beta^N, \theta)}{\gamma^N} (k + H_k(k))\phi(\theta, k) \frac{\frac{\psi(\theta, k)}{\theta} + 1}{1 + \theta}$$

It is possible that under this condition $\mathbb{E}_{\theta,k} \Delta U_a^B < \mathbb{E}_{\theta,k} \Delta U_c^B$. This will always be the case when

$$2\frac{Q\bar{F}(\beta^N,\theta)}{\gamma^N}\left[(k+H_k(k))\phi(\theta,k)\left(\frac{\psi(\theta,k)}{\theta}+1\right)-k\right]>$$
$$2\frac{Q\bar{F}(\beta,\theta)}{\gamma}\frac{1}{\theta}-\frac{Q\bar{F}(\beta_E,\theta)}{\gamma_E}\frac{k_E}{\theta}+Q\frac{\bar{F}(\beta,\theta)}{\gamma}(k_E-k)$$

which means that implementing anti-corruption program may induce higher social welfare loss, although it can deter the official from reporting no information.

4.6.2 Official colluding with only contractor

When the official only colludes with the contractor, the O-led renegotiation will give her $-u_c(\theta,k,\theta_E,k_E)$ by reporting full information and $U_c^N(\theta,k)-u_c(\theta,k,\theta_E,k_E)$ by reporting no information. Therefore to induce truth-telling, the central government should provide the official with $U_c^N(\theta,k)$.

On the other hand, in a C-led renegotiation, the official gets nothing from reporting full information but realizes personal gain of $U_c^N(\theta,k)-u_c(\theta,k)$ by reporting no information. Therefore, incentive given to the official is larger in O-led renegotiation. Compared with the official colluding with both parties, the official colluding with only contractor, lying in O-led renegotiation has higher incentive. Then the utility change of implementing anti-corruption program will be

$$\Delta U^C=u_r(\theta,k)+u_c(\theta,k)-U_c^N(\theta,k)-u_r(\theta,k,\theta_E,k_E)-u_c(\theta,k,\theta_E,k_E)$$

This indicates that the gain from regulating the interaction between the residents group and official is $\max\{U_r^N(\theta,k) - u_r(\theta,k,\theta_E,k_E), 0\}$. This value equals 0 when there is no renegotiation.

4.6.3 Official colluding with only the residents group

In O-led renegotiation, the official will gain $U_r^N(\theta,k) - u_r(\theta,k,\theta_E,k_E)$ from misreporting her type. Interestingly, the official will gain exactly the same value in C-led renegotiation. Then the utility change from implementation of the program will be

$$u_r(\theta,k) + u_c(\theta,k) - U_r^N(\theta,k) - u_c(\theta,k,\theta_E,k_E)$$

The improvement from regulating the contractor is $U_c^N(\theta,k)$. This indicates that the benefit from restricting contractor is higher than restricting the residents group. Therefore, regulating the private party should have higher priority than regulating the public.

4.7 Government policy insights and implications

From the discussion of previous sections, we have already investigated the outcome of renegotiation game and benefit and cost of anti-corruption program through providing official with incentives to be truth-telling or direct supervision on the interaction between official and other parties. In this section, we will discuss how these quantitative results would guide the design of government policy or governmental contracts.

Contractor should be endowed with sufficient bargain power in renegotiation

In section 4.4, when the contractor leads the renegotiation, although the official still has opportunity to achieve personal gain through collusion with the contractor, it is largely restricted compared to the O-led renegotiation case. This is due to the fact that, in C-led renegotiation, the contractor has full bargain power and hence seeking bribes is harder for the official in the renegotiation process. Equal or higher bargain power between government official and contractor has already been identified as a factor contributing to the success of a PPP project. Moreover, here we identify that it is also a factor to curb corruption in post-tender phase renegotiation.

Regulation and supervision of provider is more effective than user groups

It is obvious that the less opportunity the official can collude, the less likely the renegotiation will occur. For example, the renegotiation is less likely to happen when the official can only collude with only one party compared to the official can collude with both parties. This indicates that the central government should closely monitor all the stakeholders in a PPP project and prevent collusion to happen as much as possible. However, resources are limited and monitor may not be comprehensive and perfect. The government may be faced with tradeoff between monitor only some set of parties among all stakeholders of PPP project. Under this situation, this chapter suggests that regulation and supervision of different parties may have different yield for the central government.

As suggested in Section 4.6, regulation or supervision on contractor (collusion only exists between official and the residents group) will achieve higher social welfare compared to one on the residents group (official colludes only with contractor). This is understandable from previous point we made: restricting the possible collusion between official and contractor can prevent the government utilize its bargain power in O-led renegotiation and hence it is equivalent to awarding bargain power to contractor. This implies that, when the government has limited supervision ability, which is true in some developing countries, in PPP renegotiation the focus of regulation and supervision should be put on the providers, rather than the user groups.

Effectiveness of regulation based on users heterogeneity

This chapter also reveals the importance and effectiveness of taking user heterogeneity into consideration in post tender phase renegotiation. In Section 4.5, by restricting the collusion between official and residents group 'l', the official almost have no incentive to collude in renegotiation process. On the other hand, if the official is able to collude with only residents group 'l', the collusion and also the renegotiation will always happen. Therefore, we suggest that in regulating the corruption in renegotiation of PPP, the government should weight on the regulation of non-users of the new infrastructure. The central government in this chapter does not account for user heterogeneity and therefore leave opportunity to the official to obtain personal gain by colluding with residents group 'l'.

Limitation of anti-corruption program

In Section 4.6, we develop a anti-corruption program to fight against the collusion under the context of information asymmetry. Although such program can prevent the official to deliberately distort her report and hence prevent collusion between official and the residents group, it has two main limitations. The first limitation is that it sometimes can actually induce social welfare loss. In section 4.6.1, it is possible that implementing anti-corruption program through governmental contract will incur social welfare loss ex post compared to letting collusion happen without an anti-corruption program. This indicates that the central government actually take more risk in PPP project with the presence of collusion.

Another shortcoming of such anti-corruption program is that it can not fully exclude corruption between government official and the contractor. When the contractor is bailed out in a PPP renegotiation, even the anti-corruption program is in place, the contractor still has the incentive to bribe to the government official for possible financial rescue. Therefore, supervision and regulation is still always necessary and more effective than incentive programs in fighting against collusion because they not only can deal with the asymmetric information problem, but can also prevent the official to solicit bribe from a financial depressed contractor for bail-out.

Governmental contracts vs regulation

In Section 4.6, we discuss the social welfare change using different combination of governmental contracts and regulation. Notice that we make no assumption on the monitoring and supervision cost of colluding between official and the residents group and contractor. This is because such cost varies largely among differnet countries or even different subnational jurisdiction. However, we can still compare the social welfare change under different scenarios to contrast the effectiveness of these two measures. For example, by regulating the private party, the contractor, central government can guarantee a utility gain of $U_c^N(\theta, k)$ which implies that as long as the regulation cost is no higher than this amount, central government should prefer regulation than governmental contract.

4.8 Main Findings

One major finding is that in PPP, the private side should be endowed with more bargain power to reduce the degree of corruption. When the contractor possesses full bargain power, the official can not benefit from interacting with the contractor, which has two benefits: first, it directly reduces the return for the official because one of the major benefit of renegotiation is the bribe from the contractor; second, it reduces the monitoring cost on the interaction between the official and the contractor.

Also, we discover that, given the same regulation cost, in a bail-out event, it is most efficient to monitor the parties who are financially depressed. In this chapter, a contractor bail-out event is studied and it turns out that monitoring the interaction between the official and contractor is more effective than the one between official and residents. This is because in bail-out, the contractor is the stakeholder that benefit the most and hence has the largest incentive to bribe the official.

Moreover, we identify two limitation of anti-corruption program through governmental contract. The first limitation is that it may induce negative social welfare when the estimated cost is low and ex post utility to the contractor is high. Under this condition, the central government should monitor the contractor closely rather than attempt to use governmental contract to prevent corruption. Another limitation is that, anti-corruption program through governmental contract can not completely eliminate corruption. The contractor still has incentive to bribe the official when it is financially distressed.

Last but not least, by considering user heterogeneity, we discover that allowing the collusion only between official and the new infrastructure users can directly prevent collusion. This is because the cost of collusion is always higher than possible information rent the users can get from the central government.

4.9 Contributions

The contribution is three-fold:

Firstly, we build a framework taking into account all determining factors, including stakeholder interaction, asymmetric information, decentralized procurement, etc., of corruption problem in PPP. To our best knowledge, it is the first of its kind. Such a framework connects different existing literature covering corruption problem in infrastructure investment and management. Hence, it can draw us a comprehensive picture of how corruption happens in infrastructure project and how the central government can deal with it.

Secondly, our model specifies an indirect mechanism that can be implement in real world governmental contract. Previous studies usually emphasizes on the policy insights and hence focus on highly abstracted direct mechanism ([30]). Their conclusion is insightful but is not readily available for practitioners. On the other hand, our results, given by indirect mechanism, specifies how the central government can design contracts with its official, contractor or even residents group to prevent corruption in infrastructure projects.

Lastly, we contribute to the literature of post-tender phase corruption in PPP. As pointed out by [48] and [47], the study of corruption in post-tender phase corruption is scant [4]. This chapter provides detail guides for the government on how to prevent corruption in post-tender phase renegotiation.

[4] [48] and [45] are the only two exceptions.

CHAPTER 5

CONCLUSION

5.1 Final remarks

In infrastructure procurement, corruption is proven to be one of the most serious problems that not only harm the infrastructure level, but also impair the public trust. Stakeholder management, decentralization and accountability have been identified as three most important literature field and aspects of research in infrastructure procurement. In this dissertation, we build a conceptual framework incorporating these key factors to tackle the corruption problem in infrastructure management. This framework is applied to cost overrun problem and renegotiation in Public-Private Partnership. Although we have been building models under different context, we can get some general insights from these applications.

First and foremost, the results in above chapters illustrates the importance incorporating stakeholder management, decentralization and accountability in infrastructure procurement modeling. In Chapter 2, we mainly consider stakeholder management where the residents group has a huge impact on the official's decision. Therefore, infrastructure decision is distorted and sub-optimal cost overrun occurs. Further, in Chapter 3, we consider the impact of central government fund as well as the contractor. The situation becomes more complicated that the incentive contract may not be effective under some circumstances. In Chapter 4, we discuss that, when contractor may possess bargain power, it is socially beneficial to endow such power to restrict the possibility of collusion. Also, the use of central government fund in renegotiation, a feature of decentralized procurement, will further facilitate the corruption.

From the models, we find out that awareness raising is important to curb misconduct among officials. For example, in Chapter 2, raising the awareness of cost of infrastructure spending can reduce the degree of corruption. This is because, the local residents usually regard the spending on infrastructure as free because it is usually funded by central government. However, when local official use the local funding, it is actually a cost on the local residents group.

In this dissertation, we show that auditing or monitoring is an effective way to curb corruption. Although incentivizing the local official through governmental contract is regarded as a promising way in fighting against corruption, it has limitation compared to auditing or monitoring the official directly. This is because under decentralization environment, the central government fund is used to bail out the contractor. Therefore, the contractor has strong incentive to bribe the official in order to enable the renegotiation. Incentive governmental contract is unable to stop this sort of corruption. Therefore, auditing and monitoring should be relied on.

In the models, we consider user heterogeneity, which turns out to be vital in corruption context. We discover that, by restricting the possible collusion with free riders among users, central government stops collusion behavior of official without implementing any incentive contract. On the other hand, if the collusion is only possible with free riders, the degree of corruption will turn out to be more severe.

We also discover that corruption or misconduct is inevitable in infrastructure projects. This implies that the central government should not purely rely on ex post measures to fight against corruption because the measure itself is not perfect. Ex ante approaches, such us raising awareness of the public, improve ethical standard of officials and change the social culture that breeds corruption in the long term should be adopted.

Lastly, this dissertation provides a general way to model the infrastructure projects in other situations. Researcher and industrial practitioners can establish their own model and follow the work flow in this dissertation: benevolent case as a benchmark and consider selfish official case. After that, prevention measures can be discussed.

5.2 Cost overrun

In chapter 2, we build a 3-factor-2-stage model to reveal the difference between cost overrun induced by technical uncertainty and the one by political or economic drivers. We classify the cost overrun problem in infrastructure projects into two categories: ex-ante and ex-post cost overrun. Ex-ante cost overrun occurs at the decision stage (first stage) when the estimated cost is relatively smaller than the real cost. On the contrary, ex-post cost overrun occurs at the realization stage where the infrastructure is under-invested in decision stage and then expanded in realization stage which will incur extra cost.

Building, financing operating and maintaining the infrastructure will generate both positive utility and negative utility on different groups of stakeholders, especially residents and travelers. We discover that the presence of uncertainty and heterogeneity facilitates the government officer to build political credit by utilizing infrastructure project. Such motivation will cause under-estimated or under-designed decisions, which will induce cost overrun. The under-estimated decisions are usually made by the officers who try to disguise the social cost or exaggerate population benefiting from the newly built infrastructure ([33]). The officer will claim that the estimated cost is relatively low and propose a higher design plan. In the realization stage after the infrastructure being finished, the real cost will be higher than the estimated one and ex-ante cost overrun occurs.

Another form of cost overrun, ex-post cost overrun, is induced by under-designed decisions. Such decision comes from the jurisdiction where residents are fully aware of negative externality of the infrastructure although building the infrastructure is socially optimal. The government officer, trying to gain more supporters from the region affected by negative externality, scales down the design of infrastructure. This decision may lead to insufficient capacity, lack of security measures, etc. After the realization stage, when the extra demand is revealed by accidents or media coverage, contract is revised and extra work is done.

From our analysis, cost overrun is inevitable. Even the benevolent officer will make decisions inducing both ex-ante and ex-post cost overrun. However, such benevolent decision should be distinguished from the selfish decisions from two aspects: Firstly, the extent of cost overrun of benevolent decisions is less than the selfish ones, and secondly, the cost overrun from benevolent decisions has both ex-ante cost overrun and ex-post cost overrun, while the selfish ones may be strongly biased towards one category.

We also study the effectiveness of auditing in correcting the cost overrun problem. Although audit is widely regarded as a measure to prevent cost overrun, our result shows that if the central government could not make enough impact on the local residents, even the optimal audit mechanism could not prevent under-estimated or under-designed decision problems.

In chapter 2, we not only analyze the cost overrun problem in transportation infrastructure projects, but also build a modeling framework for study in cost overrun in generic infrastructure projects, mega projects, or even Olympic Games ([37]). We emphasize the importance of indirect indicator in the study of cost overruns.

5.3 Renegotiation in PPP

In Chapter 3, we discuss the collusion problem in a government-led renegotiation game in post-tender phase of a PPP project. The central government is unable to directly negotiate with the residents group or contractor of the project and therefore has to delegate them to a local official who is prone to corruption. In the game, we discover that a benevolent local official will be less likely to initiate a renegotiation compared to a selfish official because she does not have the ability to balance gain and loss between agents. To alleviate the negative effect of collusion, restricting the collusion ability of official will be helpful; that is, make the official only able to collude with one single party. This will reduce the renegotiation probability to the same level as benevolent and uninformed official. We also pointed out that, if we can further restrain the collusion to certain party within residents group, the unfavorable effect of collusion can be further confined because of the existence of free rider (i.e. other party within the residents group).

We report that the government official will prefer higher bidding cost in the tender phase if her collusion opportunity is confined to the residents group H. This indicates that she will not always choose the bidder with lowest bid ex ante, which can be proved through the observation that the bidder with the lowest bid will not always win the auction of concession contract.

We also suggest that the central government should evaluate the efficacy and cost of anti-corruption program using incentive contracts. Although incentive contract seems to be effective in reduce the chance of corruption, it requires the central government know exactly who the official can collude with. If incentive is provided mistakenly, such anti-corruption program will ironically encourage collusion when official can not beneift from collusion originally.

One effective (ex post) measure to detect collusion is monitoring the outcome of renegotiation games. If the government-led renegotiation is always successful and the official reports 'no information' constantly, it is a strong sign of possible corruption.

The corruption in post-tender phase of PPP is not well studied. That chapter extends existing theory in mechanism design, incorporating both and economic models and provides insightful policy implications and regulation guidelines.

5.4 Stakeholder management, decentralization and agency problem

As pointed out in Chapter 1, stakeholder management, decentralization and agency problems are three key factors in evaluating and tackling corruption problems in infrastructure projects. In chapter 4, we build a framework to study corruption in infrastructure procurement accounting for stakeholder interaction, decentralization and information asymmetry. The government, contractor and residents group considered in that chapter are regarded as the most important stakeholders in infrastructure projects. Further, the government is divided into central government and local government official. The contractor possesses potential bargain power in the negotiation with government official and the residents group can influence the decision of infrastructure projects through the official. Moreover, all parties except central government possesses private information.

We apply this model to study how corruption can influence the outcome of post-tender phase renegotiation and how central government can prevent this. Based on our results, central government should not rely on solving collusion problem through governmental contract. Monitoring and audit are necessary to eliminate collusion in renegotiation. We also discover that restrict the official's collusion ability to only infrastructure users can largely eliminate the corruption problem.

5.5 Future directions

5.5.1 Cost overrun

One future research direction is that applying the framework in chapter 2 into real cost overrun problem analysis. In that chapter, although we theoretically illustrates the ability of the model in cost overrun problem, the effectiveness is not verified in real world case. By doing so, we could also be able to identify the root cause of the cost overrun of that type of problem.

Another future direction is incorporating psychological consideration into the same framework. Although for simplicity, we do not consider the psychological issue in cost overrun problem, out framework is capable of psychological issue. By enriching the framework, there will be more interesting findings and more comprehensive results.

5.5.2 Renegotiation in PPP

Chapter 3 is a good starting point for research in corruption of PPP in post-tender phase and some interesting directions worth further exploration. The first direction is the interaction between the residents group and the contractor. In that chapter, we assume that two agents, the residents group and the contractor don't know each other's type. Furthermore, we assume that these two groups can not collude. These are assumptions that can be relaxed and we can explore how the official would react to the possible collusion in lower level and how the central government can possibly regulate this.

Another direction is generalize the current model to multiple agents case. In the real world PPP projects, the number of stakeholders is far larger than four, as we assumed in this chapter. To achieve full perspective of the real world PPP, incorporating more stakeholders, such as bank or financing source provider, workers union, etc, would be promising. Enriching the engineering details in our model can also be a fruitful directions.

5.5.3 Stakeholder management, decentralization and agency problems

There are several possible future directions: first, our framework is capable to problems in more complex environment. For example, stakeholder management of real world PPP projects usually also involves creditor, debt holder, other governmnet departments, etc. It is interesting and practical to build a model also incorporate these stakeholders to see how to quantitatively evaluate the impact of each stakeholder on the projects.

Another possible direction is, due to lack of real world data of incidence of corruption, it is promising to identify more flags or indications for discovering corruption in PPP projects and our framework could be a good starting point. As we identify in [45], corrupted official can be identified statistically through multiple projects. This will be another key step to bridge the theoretical and empirical studies of corruption.

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