INCOMPLETE CONTRACTS AND COST OVERRUNS

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1. Introduction

Instances of cost overruns in public procurement abound. This is especially true of procurement projects for the provisions of infrastructure facilities like, roads, railways, ports, airports, etc. The literature on the subject shows that the procurement based on cost-plus contracts is inherently vulnerable to cost overruns. On the other hand, the strategic considerations either on the part of the project sponsor or the bidder contractors are said to be the reason behind cost overruns exhibited by the fixed price contracts. The literature also shows that item-rate or unit-rate contracts based infrastructure projects are also highly susceptible to cost overruns.[1] Occasionally, even Public Private Partnership (PPP) projects have been reported to have experienced cost overruns. The literature argues that the contract renegotiations are a leading cause behind cost overrun in infrastructure projects. [2] As far as the relative frequency of cost overruns is concerned, several studies have argued that it is highest for the traditional procurement and is lowest for privatization contracts.[3] PPP contracts lie somewhere in the middle.[4] The more recent empirical literature on the subject has highlighted following additional interesting facts about cost overruns in public procurement projects. One, cost overruns tend to decline over time. Two, bigger projects experience much higher cost overruns compared to smaller ones; in absolute terms as well as a percentage cost overruns soar as with the project size. Three, compared to other sectors, projects from road, railways, urban-development, civil aviation sectors, as well as those from shipping and ports, and power sectors experience much longer delays and significantly higher cost overruns.[5]

However, there seems to be no theoretical work that explains why cost-plus, fixed-price, unit-rate and the PPP contracts exhibit differences with respect to cost overruns. Moreover, the existing literature does not explain why procurement projects exhibit the above cited

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[1]See Ganuza (1997,2007), Bajari and Tadelis (2001) and Arvan and Leite (1990), Bajari *et al* (2009), among others.

[2]Renegotiations of contracts for Boston harbor tunnel, a subway system in Athens, the Channel Tunnel between France and UK, and for many Airports in India, are only a few of the noted examples of cost overruns associated with contract renegotiations. In a study of 256 projects in Spain, Ganuza (1997) shows as much 62.7 percent instances of cost overrun are due to project renegotiations. In India, project renegotiation is a major cause of cost overruns (Anant and Singh, 2009), Singh (2010). For references to more case studies see Ganuza (2007) and Flyvbjerg *at el* (2002, 2003, 2004).

[3]See Grimsey and Lewis (2004; Ch 4), Bannett and Iossa (2006)

[4]See Mott MacDonald (2002), IPA (2007), and Yescombe (2008; Ch 2). A study by the House of Commons (2003) records that as much as 73 percent of projects under EPC contracts have experienced cost overrun. In contrast, the corresponding figure is only 22 percent of projects governed by PFI contracts. Also see Hanke (1987), Gilmore and Jensen (1998).

[5]See Odeck (2004), and Singh (2010).

differences in regarding cost overruns across sectors and within the given sector. This paper presents a first attempt on providing a theory that explains the above discussed feature of procurement projects.

The literature on delays and cost overruns is fairly large. In a series of interesting empirical studies covering twenty countries across the five continents, Flyvbjerg, Holm and Buhl (2002, 2003, and 2004) have shown that infrastructure projects often suffer from cost overruns. Merewitz (1973), Kain (1990), Pickrell (1990), Skamris and Flyvbjerg (1997), among others, have also come out with similar findings. In addition, there are numerous case studies depicting the extent and gravity of delays and cost overruns. However, these empirical works do not explain why delays and cost overruns occur. But, the theoretical literature on the subject offers several explanations. For example, Morris and Hough (1987), Arvan and Leite (1990), Gaspar and Leite (1989) and Ganuza (2007) attribute delays and cost overruns to imperfect information and technical constraints. According to these studies, due to imperfect estimation techniques and the lack of data, the estimated and the actual project costs turn out to be different. That is, delays and cost overruns are claimed to be a manifestation of 'honest' mistakes on the part of government officials. Another strand of the literature attributes cost escalations to political factors, i.e., to 'lying' by politicians. See, for example, Wachs, 1989; Kain 1990; Pickrell 1990; Morris 1990; and Flyvbjerg, Holm and Buhl 2002; Flyvbjerg, et al, 2004, among others. According to these works, politicians understate costs and exaggerate benefits in order to make projects saleable.

This literature offers several testable predictions. For instance, if time and cost overruns are only due to the imperfect estimation techniques, then one would expect the estimation errors to be 'small' compared to project cost, and unbiased with zero mean. Since, due to technological constraints, underestimation of cost should be as likely as overestimation. As a result, in each sector negative cost overruns should be as frequent as positive cost overruns. However, the emerging empirical literature shows that in most cases cost overruns are positive, and in many cases significantly higher than initially estimated costs.

At the same time the literature suffers from several limitations. For example, theoretical works by Ganuza (2007), Bajari and Tadelis (2001), and Gasper and Leite (1989), among others, do some explaining of why contracts are renegotiated. In these works, project renegotiations and cost overruns are attributed to the under investment in initial project design and to transaction costs. These work are important contributions. But, these works do not explains why different contracts lead to different outcomes with respect to renegotiations and cost overruns, etc.[6] Moreover, these works by and large are have studied the issue of cost overruns in a framework of 'complete' contracts. However, as a matter of reality the contracts for infrastructure projects are sufficiently 'incomplete'.

[6]Curiously, these works may lead to conclusions contrary to the observed outcomes. For instance, in Ganuza (2007), *ceteris paribus* a decrease in (competition) the number of bidders leads to an increase in the frequency of contract renegotiations. Presumably, in any sector due to financial constraints and risk aversion, the number of bidders will be lesser for PPP and privatization contracts than for traditional EPC contracts. Therefore, one would expect a lower frequency of contract renegotiation and cost overrun for EPC contracts, which just the contrary of the actually observed outcomes.

There is another set of studies that have analyzed the implications of the traditional procurement, PPP, and the Privatization contracts in the framework of incomplete contracts. Here, Hart, Shleifer and Vishny (1997), Hart (2003), Dewatripont and Legros (2005), and Benette and Iossa (2006), among others, are the notable contributions. In Hart (2003), traditional procurement is compared with PPPs. In HSV (1997) the focus is on in-house production and the privatization contracts. Benette and Iossa (2006) have compared all of the three forms of procurement, i.e., traditional, PPPs and Privatization contracts. However, In Hart (2003), in equilibrium, no contract gets renegotiated. In contrast, in HSV (1997), and Benette and Iossa (2006) depending on the ownership structure, either procurement contract always results in renegotiations or never. As a result, the observed differences among the EPC, PPP and privatization contracts with respect to contract renegotiations and cost overruns are not explained by any of these works. This is always or never is not the reality of real world contract. Moreover, these works do no focus on cost overruns.

In this paper, we explain the observed phenomena of the observed differences among the cost-plus, item-rate, fixed-price and PPP with respect to cost overruns. We show that the inherent nature of the cost-plus, item-rate, fixed-price and PPP contracts along with the contractual incompleteness holds the key to understanding why different contracts lead to different observed outcomes. It is pertinent to mention here that there may be other reasons for observed cost overruns in public projects.[7] However, our contention is that the incompleteness of contracts has lot of explaining to do.

Based on our model here we derive an empirical framework. We use the empirical framework to test the prediction made by our model using two large datasets on infrastructure projects in India.

In the following Section 2, we introduce the framework of analysis. We model provisioning of a public good or infrastructure service the government wants to provide to its citizens. The facility, e.g., road is built during the building phase and its services can be used during its operational/maintaince phase. In Section 3, we solve for the first best and some other optimization problems. In Section 4, we derive the equilibrium outcomes produced by different contracts. In Section 5 we compare costs under different types of contracts. In Sections 6 and 7 we test the prediction made by our model using a large dataset on infrastructure projects in India.

2. **Procurement Model**

The modeled developed here is equally applicable to both public as well as private procurement of non-standard goods. However, for the easy of exposition we consider a context in which a government wants to procure a public good or service; for example, surface transport or civil-aviation services, etc. We will model and analyze the alternative contractual arrangements for the procurement of a public goods or services.

[7]For example, some studies have argued that project promoters, especially politicians, routinely ignore, hide, or leave out important project costs so as to get as many projects started as possible. See Wachs, 1989, 1990; Flyvbjerg at el 2004. In a single case study of a rail transit project of Dallas in US, Kain 1990, argues that in run up to election politicians want to make a project look better by under reporting project costs.

Consider a context in which a government wants to procure a public good or service; for example, surface transport or civil-aviation services, etc. Such services generally require building and maintenance of physical assets or facilities such as roads, railways, airports, etc. Generally, the government employs contractor(s) to build these facilities. The contract between the government and the contractors can be only for the building or only for the maintenance of of a facility. In some cases, contract can require building as well as maintenance of a facility. We will use the terms 'facility' and 'good' interchangeably.

Procurement starts with the designing of the project for the good or the service to be procured. The project designing is characterized by the following three activities: One, the description of the scope of the project. *Scope of a project* is the description of 'output' features the project good or the facility must posses. It also specifies the list of work-items or the tasks that need to be performed to build the good. For example, for an expressway project the scope may specify the the length of the project highway, number of traffic lanes, number and locations of over-passes, under-passes, toll-plazas to be built-in, etc. Two, estimation of the number of the quantities of the work-items that need to be performed. Three, estimation of cost of project works, commonly known as the estimated project cost. It is standard to assume that it is the government (the buyer) who carries out all of these activities. For example, the government engineers determine the scope, list the work-items and estimate the cost of an infrastructure project.[8] On completion, details of project design are made available to the potential bidders. The winner gets the contract to build the good. For simplicity assume that the designing, bidding and signing of the contract all take place at time $t = 0$. Construction on the project site starts at date $t = 1$.[9]

Let us call the good initially designed good and described in the scope of the project to be the 'initial' good. Suppose, the number of possible work-items or the tasks that may need to be performed to build the initial good is $W \geq 1$. Let, q_i denote the quantity of the i^{th} work-item. Let c_i denote the *per-unit* cost of the i^{th} work-item. Suppose project designing takes place at time $t = 0$. Formally speaking, at $t = 0$, government agency responsible for execution of the project comes out with the estimates the vector of quantities of work-items, say $\mathbf{q}^e = (q_1^e, ..., q_W^e) \in \mathbb{R}_+^W$, and the vector of per-unit cost of work-items, say, $\mathbf{c}^e = (c_1^e, ..., c_W^e) \in \mathbb{R}_+^W$; where $q_i \geq 0$, $c_i \geq 0$ for all $i = 1, ..., W$.

So, the estimated project cost is $\mathbf{C}^e = \mathbf{q}^e.\mathbf{c}^e$. As is explained below, each of the designing activities is subject to error. For instance, the actual work quantities invariably turn out to be different from those provided in the initial design. As a result, the ex-post (actual) project costs are rarely equal to the estimated costs. But for now, suppose that the scope of a project, the list of work-items along with their quantities are all fixed. Specifically assume that the vector $\mathbf{q}^e$ has been determined to the last precision; therefore during construction phase no change in the quantities will be needed. Even then several factors can cause the vector of actual per-unit costs, say $\mathbf{c}^a = (c^a, ..., c_W^a)$, to differ from $\mathbf{c}^e = (c_1^e, ..., c_W^e)$. For instances,

[8]As a matter of fact, for infrastructure procurement, government engineers carry out all of the designing tasks. However, depending on the procurement contract to be used, the last two activities -finding out of the work-items and estimation of project cost- may be performed by the bidders, i.e., potential contractors. But, the scope of the project, i.e., the specifications of the good to be produced is always decided by the buyer/government.

[9]In reality, there is time gap between award of contract and the start of construction.

fluctuations in the price of inputs, *force majeure*, etc., can cause the actual costs be less or greater than the estimated one. The point is that even when there is no uncertainty regarding the work-items or their quantities, due to several uncontrollable input price-relevant contingencies that can arise during construction phase, the actual costs $C^a = \mathbf{q}^a.\mathbf{c}^a = \mathbf{q}^e.\mathbf{c}^a$, may turn out to be different from the estimated costs, $C^e = \mathbf{q}^e.\mathbf{c}^e$.

Let $\hat{C}_0$ denote the ex-post (actual) cost for the initial good. Let Ω be the set of the 'input-price-relevant' states of nature that can arise during construction. We will call the input-price-relevant contingencies as the cost-relevant contingencies. So, Ω is the set of the 'cost-relevant' states of nature that can arise during construction. In view of the above, for a given vector of quantities of work-items, $\hat{C}_0$ depends on the cost-relevant state of nature, say $\omega \in \Omega$, that arises during construction phase. I must hasten to emphasis that, regardless of ω, efforts put in by the contractor in managing and organizing project works are rather crucial for the magnitude of project costs.[10] Also, the quality of inputs used by contractor affects the costs. We will explicitly model these efforts. For the time being let us ignore these issues. So, $\hat{C}_0$ can be thought of as the construction costs for the initially designed good, when it meets the contractually agreed quality standards and the contractor puts in none of possible cost reducing efforts. In keeping with the standard practice assume that at the time of construction all the information about input prices is available. So, the construction costs can be determined precisely. However, at $t = 0$ there is uncertainty regarding input prices. Assume that for a given vector of quantities of work-items, at $t = 0$, $\hat{C}_0$ is a random draw on $[\underline{\hat{C}}, \overline{\hat{C}}]$, where $0 \leq \underline{\hat{C}} < \overline{\hat{C}} < \infty$. Let $\hat{F}(\hat{C}_0)$ and $\hat{f}(\hat{C}_0)$, respectively, be the distribution and the density functions for $\hat{C}_0$.

In real world, the designing of the good is any thing but perfect. So, there is uncertainty with respect to the quantities of works also, on top of the above discussed input-costs related uncertainty. As a matter of fact the actual quantities of work-items invariably turn out to be different from the estimated ones. The actual quantities can differ from the estimated ones simply on account of measurement errors; so for the project $\mathbf{q}^a \neq \mathbf{q}^e$ can hold simply because the initial estimates were made causally. Moreover, even if the initial estimates were arrived at carefully, the state of nature that arises during construction can necessitate some changes in the project design, in turn, making $\mathbf{q}^a$ different from $\mathbf{q}^e$. For example, the optimum mix of the concrete and bitumen, the type of foundations needed for flyovers, etc., also depend on the quality of soil at the project site. If the work conditions turn out to be different from those for which project was designed, there will be a change in the quantities of work-items. Sometimes, the condition (state of nature) at project-site may even necessitate what is known as a *change in scope* of the project; this means significant changes in the design and project works. For instance, a road project originally could be designed to simply resurface the existing stretch without any changes in the under-surface. However, the actual site conditions may necessitate strengthening of the under- surface and shoulders. This clearly would mean that the initial scope has be changed to accommodate new work-items and to revise the quantities of the existing work-items. Such changes, *per-se*, will make the actual project costs to differ from the estimated costs. On top of it, during construction phase the government may discover that some relevant works are missing from the original scope. For example,

[10]See Bajari and Tadelis (2001), Bajari *et al* (2009).

for a highway project government engineers may discover the need for more of flyovers or under-passes. Similarly, for a railways project the government may find that they have missed out on some safety measures in the initial design. Such realizations will also lead to renegotiations between the employer and the contractor to change the scope. At times, demand from local public can add to the list work-items, thereby necessitating a change in scope. An inevitable consequence of a change in the scope is that $\mathbf{q}^a$ becomes different from $\mathbf{q}^e$. Empirical studies suggest that a changes in scope, generally, leads to increases in the quantities of the existing work-items as well as bring in new tasks under the scope of the project.[11] Additional quantities and works, in turn, increase the project costs resulting in cost overruns.

Let us call the changes in the number of work-items or their magnitude as the 'output-relevant' changes. Since such changes require 'modification' in the internal or the external features of the initially designed good. As a result, the final output (good) that is built is different from the initially planned one. Different output-relevant states of nature may require different adaptations to or modifications in the initial good. Let Θ be the set of possible output-relevant states of nature that can arise during construction phase. Suppose the initial good has been designed assuming a particular output-relevant state of nature, say $\bar{\theta} \in \Theta$. During construction if the state of nature is actually $\bar{\theta}$, then no modification will be needed; however, if the realized state of nature is some $\theta' \in \Theta$ such that $\theta' \neq \bar{\theta}$, then the initial good will have to be modified. We will call the changed or modified good to be the 'modified' good.

In this background, whether the initial good needs be modified during construction phase or not depends on how exhaustive the initial design is. Here, there are several possibilities. Let us discuss some of them.

One, the initial design can be 'complete' in that it has contingent plan for all $\theta \in \Theta$, i.e., it specifies the work-items and their quantities for each and every $\theta \in \Theta$. In such a case, clearly no mid-way modifications in the initial good will be required. Since the initial design itself specifies the relevant internal and external features of the good, for each output-relevant state of nature that can possibly arise during construction.

Two, the initial design can be 'totally incomplete' in that it specifies only the essential works that need to be performed regardless of the output-relevant state of nature - the works that are common to all $\theta \in \Theta$. That is, the initially designed good is rather 'basic' in that it needs to be supplemented with additional works or features, to be of any use to the government. In theory, at least, the required additional works will differ across $\theta \in \Theta$.

Three, the initial design can be 'semi-incomplete'. It fully specify the $\theta-$contingent work-items and their quantities only for some of the possible output-relevant states of nature; for others it may specify just the essential works.

We will call a project design to be 'complete', if it has contingent plan for all $\theta \in \Theta$, i.e., if the initial design specifies the $\theta-$specific work-items and their quantities for all $\theta \in \Theta$; otherwise it will be incomplete. Let,

$$\bar{\Theta} = \{\theta |\ \theta\text{−contingent work-items and quantities have been specified in the initial design.}\}.$$

[11] See for example Bajari *et al* (2009).

Note that if the design is complete then $\bar{\Theta} = \Theta$. In case of the second design possibility described above, $\bar{\Theta} = \emptyset$. If the design belongs to the third category then $\emptyset \subset \bar{\Theta} \subset \Theta$. Suppose at $t = 1$, i.e., during the construction stage, the realized state of nature is θ. There are two possibilities; $\theta \in \bar{\Theta}$ or $\theta \in \Theta - \bar{\Theta}$. If $\theta \in \bar{\Theta}$, then no changes in the initial design are needed. On the other hand, when $\theta \in \Theta - \bar{\Theta}$, the $\theta-$specific modifications have to be designed and incorporated in the good. Let,

C_0 denote the (actual) cost of the modified good.

As in case of $\hat{C}_0$, C_0 is the cost of the modified good when no cost reducing efforts are put in by the contractor. The cost of the modified good, C_0, can be different from the estimated costs because the actual quantities turn out to be different from the estimated ones, i.e., $\mathbf{q}^a \neq \hat{\mathbf{q}}^e$ as well as because the actual per-unit costs of work-items turn out to be different from the estimated costs (due to future cost-relevant contingencies), i.e., $\mathbf{c}^a \neq \hat{\mathbf{c}}^e$. Note that $\mathbf{q}^a$ depends on the output-relevant states of nature $\theta \in \Theta$ that arises during the construction phase. Therefore, C_0 depends on θ as well as ω. Assume that all uncertainties get resolved at $t = 1$, when the cost-relevant and the output-relevant states of nature are observed. At $t = 1$ both parties observe ω, θ, $\hat{C}_0(\theta)$ and $C_0(\theta)$.

While at the time of construction, since all the relevant information is available, $C_0(\theta)$ can be determined precisely, at $t = 0$ there is uncertainty with respect C_0. We assume that at $t = 0$, $C_0(\theta)$ is a random draw on $[\underline{C}(\theta), \overline{C}(\theta)]$, where $0 \leq \underline{C}(\theta) < \overline{C}(\theta) < \infty$. Let, $F(C_0|\theta)$ and $f(C_0|\theta)$, respectively, be the distribution and the density functions for $C_0(\theta)$. We assume that $F(C_0|\theta)$ and $f(C_0|\theta)$ are part of common knowledge. Later on we will have more to say about C_0 and the relevant distributions.

Note that technically speaking for all $\theta \in \bar{\Theta}$ the initial good and the final good are the same. So, the following holds

$$(\forall \theta \in \bar{\Theta})[C_0(\theta) = \hat{C}_0(\theta)].$$

This means that for all $\theta \in \bar{\Theta}$, there is no uncertainty regarding the quantities of work-items. So, if the state of nature during construction phase θ is such that $\theta \in \bar{\Theta}$, then the actual cost can be different from the estimated cost only due to cost-relevant uncertainty.

As was discussed in the introduction mid-way changes in the project design, i.e., the number of project work-items and their quantities are a major source of cost overruns in infrastructure projects. Such cost overruns can be completed avoided if the initial design is complete, i.e., if $\bar{\Theta} = \Theta$. If designing were costless, governments will indeed make complete design to avoid cost overruns. Problem is that the contingent designing is a costly and painstaking task, i.e., at $t = 0$ planning and describing of state-contingent design requires costly efforts by the project government. Let,

$d =$ the effort put in designing at $t = 0$.

d and all other efforts in the paper are measured by their cost. By putting in higher effort in designing, government engineers can provide for a larger number of state-contingent designs at $t = 0$. This means that the 'size' of $\bar{\Theta}$ increases with d. In keeping with the literature on the subject we assume that the designing of the $\theta-$specific modifications/adaptations is costless at $t = 1$, i.e., when the state of nature θ has been revealed. Also, without any loss of generality assume that designing of the 'basic' good is costless. Let,

$$\pi = Prob\{\theta|\theta \in \bar{\Theta}\}; \text{ and } \ (1-\pi) = Prob\{\theta|\theta \in \Theta - \bar{\Theta}\}.$$

Obviously π increases with d. Later on we will all alow other factors to influence π. For simplicity, we assume that π is a continuous and differentiable function of d. Specifically,

$$\frac{\partial \pi(.)}{\partial d} > 0 \text{ and } \frac{\partial^2 \pi(.)}{\partial d^2} < 0, \lim \pi(.)_{d \to 0} = 0, \lim \pi(.)_{d \to \infty} = 1.$$

Let us now bring in the cost reducing efforts by the contractor. Assume that the contractor can put in costly but non-contractible effort to reduce construction costs at $t = 1$. Let,

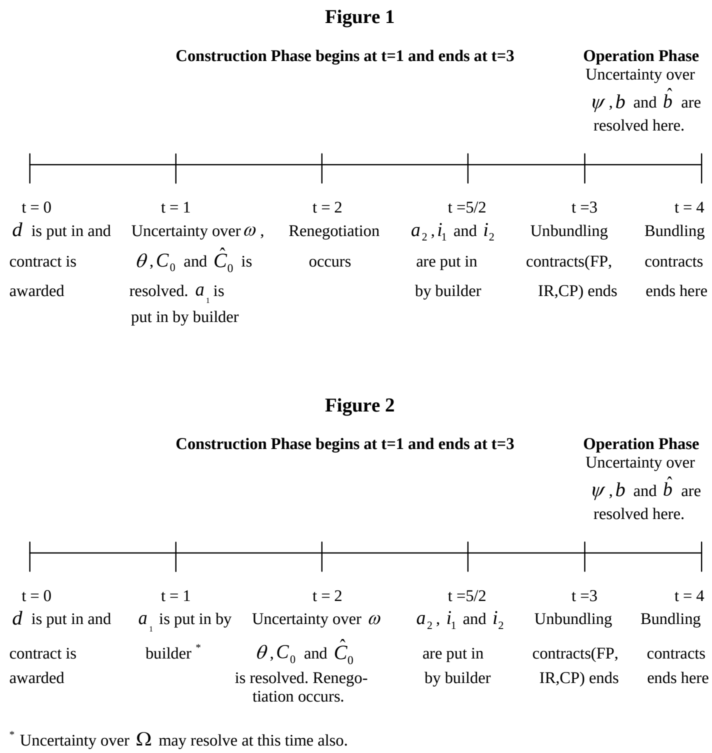
a_1 denote the construction costs reducing effort at $t = 1$.

One can think of a_1 as expenditure in search of alternative engineering designs, or efforts in searching and securing supply of imputes, etc. More specifically, if $\hat{C}_0$ is the realized construction cost of the initial good, then a_1 reduces the cost by $\hat{c}_1(a_1)$. Similarly, if C_0 is the realized cost of modified good, then a_1 reduces these cost by $c_1(a_1)$.

Since, the initial design provides for $\theta-$specific modifications only for $\theta \in \Theta$. Therefore, the initial contract signed at $t = 0$ can describe $\theta-$specific modifications only for $\theta \in \Theta$; it cannot do so for $\theta \in \Theta - \bar{\Theta}$. This means that if at $t = 1$ the state of nature $\theta \in \bar{\Theta}$, no output-relevant changes/adaptations are needed. As a result, the initial contract continues to govern the relationship between the parties. However, the initial contract cannot specify the output-relevant adaptations for the states of nature belonging to $\Theta - \bar{\Theta}$. So, if $\theta \in \Theta - \bar{\Theta}$, the parties will have to renegotiate the initial contract to incorporate the adaptations. The renegotiation takes places at $t = 2$. Note that contract renegotiation over output-relevant changes takes place during the construction period, especially after the effort a_1 has already been put in. Time line is provided in Figure 1.

Mid-way contract renegotiations are inevitable fall out on contractual incompleteness. Changes in the designs and scope of projects in the thick of construction activities is the reality of many (especially large) infrastructure projects. So, real world construction contracts are renegotiated in the middle of construction period, as is assumed here. Yet, one may be tempted to question the existence of time gap allowed here between when the parties realize the need for renegotiation (at $t = 1$) and when they actually undertake renegotiation (at $t = 2$). Here are some justifications. Real world contract renegotiations require the employer to come out with the details of the changes/adaptations needed. The contractor, on the other hand, has to submit the alternative ways/designs for incorporating the adaptations, along with their costs. These activities and negotiations over the details and terms of changes required are time consuming, resulting in the time gap. It seems realistic to assume that $\hat{c}_1(a_1)$ and $c_1(a_1)$ are observed at $t = 2$; that is, though $\hat{C}_0$ and C_0 are observed at $t = 1$ but the costs $\hat{C}_0 - \hat{c}_1(a_1)$ and $C_0 - c_1(a_1)$ are observed at $t = 2$, after the cost reducing effort, if any, has been put in by the contractor. Moreover, this time line allows us to keep the analysis simple and yet enables a stark demonstrates the incentive effects of contractual

Figure 1.



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incompleteness. However, in the interest of completeness we, extend our framework to a setting wherein the state of nature θ (and may be ω also) is revealed at $t = 2$ and renegotiations are undertaken at $t = 2$. Everything else remains the same. That is, we consider the time line as in Figure 2 as well. However, for now let us move along the time line as in Figure 1.

As we will show our results hold for both the time lines. Only assumption that is crucial for our results is that contract renegotiation takes place after the effort a_1 has already been put in.

Next, we allow the possibility of more non-contractible efforts by the builder contractor. It is here that our model goes beyond the existing models on cost overruns. Assume that during the construction, the builder can undertake innovations that affect the construction and maintenance costs of the good. Let,

a_2 denote the construction costs reducing effort put in during construction.

One can think of a_2 as effort put in to reduces construction costs for project works but at the expense of quality/standards of project works. For example, by a_2 can be effort in search of inferior quality inputs and designs, etc. The scope for effort a_2 depends on whether deviations from the contractually-specified work standards are easily detectable or not. Several factors like non-verifiability of output standards, corruption, etc., can increase the scope for a_2.[12] In contrast, as discussed earlier a_1 can be thought of as innovative effort put in by the contractor to reduce construction costs for project works without diluting the quality or standards of the output.

It is natural to think that the contractor can put in quality shading effort all along the construction phase. However, for concreteness assume that a_2 is put in after renegotiations, say at $t = \frac{5}{2}$. Let a_2 reduce construction costs of the initial good by $\hat{c}_2(a_2)$ and those of the modified good by $c_2(a_2)$. Apart from affecting the construction costs, the cost saving efforts a_1 and a_2 may have consequences for the operation and maintenance ($O\&M$) costs of the good. The $O\&M$ costs are incurred during period $t = 3$ and $t = 4$. Before proceeding further let us model these costs. Let,

$\hat{\psi}$ be the $O\&M$ cost of the initial good.
ψ be the $O\&M$ cost of the modified good.

Ideally, the $O\&M$ costs will also depend on the nature of specific features, which depend on the output-relevant state of nature. Assume that $\hat{\psi}(\theta)$ is a random draw from $[\underline{\hat{\psi}(\theta)}, \overline{\hat{\psi}(\theta)}]$, where $0 \leq \underline{\hat{\psi}(\theta)} < \overline{\hat{\psi}(\theta)} < \infty$. Similarly, $\psi(\theta)$ is a random draw from $[\underline{\psi(\theta)}, \overline{\psi(\theta)}]$, where $0 \leq \underline{\psi(\theta)} < \overline{\psi(\theta)} < \infty$. Let,

$\hat{G}(\hat{\psi}(\theta))$ and $\hat{g}(\hat{\psi}(\theta))$, respectively, be the distribution and the density function for $\hat{\psi}(\theta)$.
$G(\psi(\theta))$ and $g(\psi(\theta))$, respectively, be the distribution and the density function for $\psi(\theta)$.

For the time being, we can afford to ignore the dependence of these functions on θ. We consider the following two interesting possibilities regarding the effects of a_1 and a_2 on the $O\&M$ costs.

$$(\forall \psi \in (\underline{\psi}, \overline{\psi}))[\frac{\partial G(\psi|.)}{\partial a_1} = 0] \ \& \ (\forall \psi \in (\underline{\hat{\psi}}, \overline{\hat{\psi}}))[\frac{\partial \hat{G}(\hat{\psi}|.)}{\partial a_1} = 0] \tag{2.1}$$

$$(\forall \psi \in (\underline{\psi}, \overline{\psi}))[\frac{\partial G(\psi|.)}{\partial a_2} < 0 \ \& \frac{\partial^2 G(\psi|.)}{\partial a_2^2} < 0]. \tag{2.2}$$

[12]The nature of contract can also affect the scope of a_2. For instance, a design-and-build contract can give the contractor opportunity to use cheaper (may be unsafe) design. On the other hand, if the design if fixed by the sponsor, then the contractor does not have this opportunity.

and

$$(2.3) \qquad (\forall\psi \in (\underline{\hat{\psi}}, \overline{\hat{\psi}}))[\frac{\partial \hat{G}(\hat{\psi}|.)}{\partial a_2} < 0 \ \& \frac{\partial^2 \hat{G}(\hat{\psi}|.)}{\partial a_2^2} < 0].$$

That is, a_1 reduces construction costs without increasing the $O\&M$ costs. However, innovation a_2 is quality shading in nature. It reduces construction costs but at the same time leads to an increase in the $O\&M$ costs.

Further assume that during the construction, at $t = \frac{5}{2}$, the contractor can put in two more innovative efforts; i_1 and i_2. Alternatively, i_1 and i_2 can be thought of as non-contractible investments. These innovations/investments reduce the $O\&M$ costs by improving the quality of project works. If implemented, i_1 and i_2 affect the $O\&M$ costs as follows:

$$(2.4) \qquad (\forall a_1, a_2, i_2)(\forall\psi \in (\underline{\psi}, \overline{\psi}))[\frac{\partial G(\psi|a_2, i_1, i_2)}{\partial i_1} > 0 \ \& \frac{\partial^2 G(\psi|a_2, i_1, i_2)}{\partial i_1^2} < 0]$$

and

$$(2.5) \qquad (\forall a_1, a_2, i_1)(\forall\psi \in (\underline{\psi}, \overline{\psi}))[\frac{\partial G(\psi|a_2, i_1, i_2)}{\partial i_2} > 0 \ \& \ \frac{\partial^2 G(\psi|a_2, i_1, i_2)}{\partial i_2^2} < 0].$$

Apart from affecting the $O\&M$ costs, i_1 and i_2 affect the benefits from the usage of the good. Investment i_1 is desirable. In contrast, investment in innovation i_2 is socially unproductive in that it reduces the benefits as modeled below in detail. Let,

$\hat{b}$ be the benefits from the initial good.
b be the benefits from the modified good.

That is, b denotes benefits if the state-specific adaptations are incorporated in the good. Benefits are enjoyed by the project sponsor during the $O\&M$ phase between $t = 3$ and $t = 4$. If project is for the provision of public good or service, b and $\hat{b}$ can be taken as the social benefits from the project. Generally, there is uncertainty regarding the benefits, especially from infrastructure projects. We model it as follows: $\hat{b}$ is a random draw from $[\underline{\hat{b}}, \overline{\hat{b}}]$, where $0 \leq \underline{\hat{b}} < \overline{\hat{b}} < \infty$. Similarly, b is a random draw from $[\underline{b}, \overline{b}]$, where $0 \leq \underline{b} < \overline{b} < \infty$.[13] Let,

$\hat{H}(\hat{b})$ and $\hat{h}(\hat{b})$, respectively, be the distribution and the density functions for $\hat{b}$.
$H(b)$ and $h(b)$, respectively, be the distribution and the density function for b.

We assume that expected benefits from the good are greater than the expected total construction costs, and it is efficient to incorporate the $\theta-$specific features.

As we will see, efficient ex-post negotiations means that $\theta-$specific features are always implemented even if the initial design does not provide them. As a result, the relevant $O\&M$ costs will be ψ and the benefits will be b, with their respective distributions.

As was mentioned earlier, investment i_1 is socially desirable. Not only does it reduce the $O\&M$ costs but also increases the benefits from the good. In contrast, investment in

[13] Without any loss we can assume that these functions are identical across all $\theta \in \Theta$

innovation i_2 is socially unproductive in that it reduces benefits. If implemented, i_1 and i_2 affect the benefits as follows:

$$(\forall i_2)(\forall b \in (\underline{b}, \overline{b}))[\frac{\partial H(b|i_1, i_2)}{\partial i_1} < 0 \; \& \frac{\partial^2 H(b|, i_1, i_2)}{\partial i_1^2} > 0]; \; \& \tag{2.6}$$

$$(\forall i_1)(\forall b \in (\underline{b}, \overline{b}))[\frac{\partial H(b|i_1, i_2)}{\partial i_2} > 0 \; \& \; \frac{\partial^2 H(b|i_1, i_2)}{\partial i_2^2} < 0]. \tag{2.7}$$

The effects of i_1 and i_2 on distribution $\hat{H}$ are similar their effect on distribution $H(b)$.

Remark 1. It is worth emphasizing that innovations a_1, a_2, i_1 and i_2 are not mutually exclusive. However, depending on the context there may or may not be scope for a particular innovation. Note that a_2, i_1 and i_2 are put in during the during construction phase, after the renegotiations over additional features. Also, a_1 and a_2 should be considered as innovative efforts that can be implemented without any additional costs, apart from the cost of efforts themselves. In contrast, i_1 and i_2 can be considered either as innovative efforts that can be implemented without any additional costs, or as innovations whose implementation leads to an increase in the construction costs. Therefore, while efforts a_1 and a_2 always reduce the total construction costs, investments i_1 and i_2, in contrast, add to the total construction costs.

Formally, assume that implementation of innovation i_1 increases the construction costs of the initial good by $\hat{c}_3(i_1)$ and those of the modified good by $c_3(i_1)$, where $\hat{c}_3(i_1) \geq 0$ and $c_3(i_1) \geq 0$. Similarly, implementation of innovation i_2 increases the construction costs of the initial good by $\hat{c}_4(i_2)$ and those of the modified good by $c_4(i_2)$, where $\hat{c}_4(i_2) \geq 0$ and $c_4(i_2) \geq 0$. Clearly, $\hat{c}_3(i_1) = 0$ and $c_3(i_1) = 0$ mean that i_1 can be implemented without any increase in the construction costs. Similarly for i_2.

Remark 2. To repeat, the builder contractor can implement efforts a_1, a_2, i_1 and i_2 without violating the contract. So, in order to undertake and implement these efforts, the builder firm need not renegotiate the original contract.[14] However, we have taken functions $\hat{c}_1(.)$ $\hat{c}_2(.)$, $c_1(.)$, $c_2(.)$, etc., to be deterministic only to simplify the presentation. The inefficiency is easily ensured by assuming that these are stochastic functions of a_1 and a_2, etc.

Plausibly the scope and efficacy of various innovations discussed above will depend on the internal and external features of the good produced, which in turn depend on the states of nature. Therefore, we allow the scope of innovative efforts to depend on the states of nature. We do so by allowing their effect on construction costs to depend on the observed costs $\hat{C}_0$ and C_0, which differ across the states of nature. As a result, $\hat{c}_1(.)$ is a function of a_1 as well as of $\hat{C}_0$, and $c_1(.)$ is a function of a_1 as well as of C_0. Similarly for $\hat{c}_2(.)$ and $c_2(.)$, etc. For every possible $\hat{C}_0$ and C_0, we assume $\frac{\partial \hat{c}_j(a_j,\hat{C}_0)}{\partial a_j} > 0$, $\frac{\partial^2 \hat{c}_j(a_j,\hat{C}_0)}{\partial a_j^2} < 0$, $\frac{\partial c_j(a_j,C_0)}{\partial a_j} > 0$, $\frac{\partial^2 c_j(a_j,C_0)}{\partial a_j^2} < 0$, $\frac{\partial \hat{c}_j(0,\hat{C}_0)}{\partial a_j} > 1$, $\frac{\partial c_j(0,C_0)}{\partial a_j} > 1$, for all $j = 1, 2$. Moreover, $\frac{\partial \hat{c}_3(i_1,\hat{C}_0)}{\partial i_1} > 0$, $\frac{\partial^2 \hat{c}_3(i_1,\hat{C}_0)}{\partial i_1^2} \geq 0$, $\frac{\partial c_4(i_2,,C_0)}{\partial i_2} > 0$, $\frac{\partial^2 c_4(i_2,C_0)}{\partial i_2^2} \geq 0$. For simplicity, assume $\frac{\partial^2 \hat{c}_j(.)}{\partial x \partial y} = 0$ and $\frac{\partial^2 c_j(.)}{\partial x \partial y} = 0$ for all $j = 1, 2$, $x, y = a_1, a_2, i_1, i_2$.

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[14]This means that a, e and i are non-contractible *ex-ante* as well as *ex-post*. For more on the ex-post non-contractibility of efforts/innovations see Hart (1995, 2003), Hart and Moore (2007).

Now, consider any realization of θ, $\hat{C}$ and C_0. If a_1, a_2, i_1 and i_2 are implemented, then the total construction of the initial good are

$$\begin{aligned} & \hat{C}_0 - \hat{c}_1(a_1, \hat{C}_0) - \hat{c}_2(a_2, \hat{C}_0) + \hat{c}_3(i_1, \hat{C}_0) + \hat{c}_4(i_2, \hat{C}_0) + a_1 + a_2 + i_1 + i_2 \\ = \; & \hat{C}(a_1, a_2, i_1, i_2, \hat{C}_0) + a_1 + a_2 + i_1 + i_2. \end{aligned}$$

The total construction of the initial good are

$$\begin{aligned} & C_0 - c_1(a_1, C_0) - c_2(a_2, C_0) + c_3(i_1, C_0) + c_4(i_2, C_0) + a_1 + a_2 + i_1 + i_2 \\ = \; & C(a_1, a_2, i_1, i_2, C_0) + a_1 + a_2 + i_1 + i_2. \end{aligned}$$

In view of the above assumptions, we have $\frac{\partial \hat{C}_0(.)}{\partial a_j} < 0$; $\frac{\partial^2 \hat{C}_0(.)}{\partial a_j^2} > 0$; $\frac{\partial C(.)}{\partial a_j} < 0$; $\frac{\partial^2 C(.)}{\partial a_j^2} > 0$; where $j = 1, 2$. Similarly, $\frac{\partial \hat{C}_0(.)}{\partial i_1} \geq 0$; $\frac{\partial^2 \hat{C}_0(.)}{\partial i_1^2} \geq 0$; *i.e.*, $\frac{\partial C(.)}{\partial i_1} \geq 0$; $\frac{\partial^2 C(.)}{\partial i_1^2} \geq 0$; $\frac{\partial C(.)}{\partial i_2} \geq 0$; $\frac{\partial^2 C(.)}{\partial i_2^2} \geq 0$.

3. Optimization Problems and the First-Best

To start with, let us formulate the optimization problems assuming time line as in Figure 1. Recall, when investment decisions regarding a_1, a_2, i_1, and i_2 are made still there is uncertainty about benefits as well as $O\&M$ costs of the good. But, it is always efficient to incorporate output-relevant modifications in the good. In this case, for any given realization of θ, C_0 and $\hat{C}$, the first-best optimization problem can simply be written as:

$$\begin{aligned} \max_{a_1, a_2, i_1, i_2} \{Z \; \equiv \; & \int_{\underline{b}}^{\overline{b}} b h(b|i_1, i_2) db - C(a_1, a_2, i_1, i_2, C_0) - \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2, i_1, i_2) d\psi \\ - \; & a_1 - a_2 - i_1 - i_2\}. \end{aligned}$$

Alternatively and equivalently, when there is no discounting, we can solve for first best w.r.t. a_1 at $t = 1$, and w.r.t. a_2, i_1, and i_2 $t = \frac{5}{2}$. Let $(a_1^*, a_2^*, i_1^*, i_2^*)$ be solution to the above optimization problem, which clearly depends on C_0. Therefore, for any arbitrary realization of C_0, the first best efforts $a_1^*(C_0)$, $a_2^*(C_0)$, $i_1^*(C_0)$ and $i_2^*(C_0)$ solve the following necessary and sufficient first order conditions, respectively and simultaneously:[15]

$$-\frac{C(a_1, a_2, i_1, i_2, C_0)}{\partial a_1} \leq 1, \tag{3.1}$$

$$-\frac{C(a_1, a_2, i_1, i_2, C_0)}{\partial a_2} - \int_{\underline{\psi}}^{\overline{\psi}} \psi \frac{\partial g(\psi|a_2, i_1, i_2)}{\partial a_2} d\psi \leq 1, \tag{3.2}$$

$$-\frac{C(a_1, a_2, i_1, i_2, C_0)}{\partial i_1} + \int_{\underline{b}}^{\overline{b}} b \frac{\partial h(b|i_1, i_2)}{\partial i_1} db - \int_{\underline{\psi}}^{\overline{\psi}} \psi \frac{\partial g(\psi|a_2, i_1, i_2)}{\partial i_1} d\psi \leq 1, \tag{3.3}$$

$$-\frac{C(a_1, a_2, i_1, i_2, C_0)}{\partial i_2} - \int_{\underline{b}}^{\overline{b}} b \frac{\partial h(b|i_1, i_2)}{\partial i_2} db - \int_{\underline{\psi}}^{\overline{\psi}} \psi \frac{\partial g(\psi|a_2, i_1, i_2)}{\partial i_2} d\psi \leq 1; \tag{3.4}$$

where (3.1) holds with equality. (3.2), (3.3) and (3.4) will hold with equality iff $a_2^*(C_0) > 0$, $i_1^*(C_0) > 0$ and $i_2^*(C_0) > 0$, respectively. We assume that for all C_0, $a_2^*(C_0) = 0$ but $i_1^*(C_0) > 0$ and $i_2^*(C_0) > 0$.

[15] Note that in (3.2), (3.3) and (3.4) the last term on the LHS differs across $\theta \in \Theta$. But for simplicity of notations we have suppressed θ. We will continue to do so in the following as well.

On the other hand, a total cost (construction plus $O\&M$ cost) minimization problem will solve

$$\min_{a_1,a_2,i_1,i_2}\{C(a_1,a_2,i_1,i_2,C_0)+\int_{\underline{\psi}}^{\overline{\psi}}\psi g(\psi|a_2,i_1,i_2)d\psi+a_1+a_2+i_1+i_2\}.$$

Let $(a_1^{**},a_2^{**},i_1^{**},i_2^{**})$ be solution to the above optimization problem. For any arbitrary realization of $\hat{C}$ and C_0, the total cost minimizing efforts $a_1^{**}(C_0)$, $a_2^{**}(C_0)$, $i_1^{**}(C_0)$ and $i_2^{**}(C_0)$ will simultaneously solve the necessary and sufficient first order conditions given by (3.1), (3.5), (3.6) and (3.7), respectively.

$$-\frac{\partial C(a_1,a_2,i_1,i_2,C_0)}{\partial a_2}-\int_{\underline{\psi}}^{\overline{\psi}}\psi\frac{\partial g(\psi|a_2,i_1,i_2)}{\partial a_2}d\psi \leq 1, \tag{3.5}$$

$$-\frac{\partial C(a_1,a_2,i_1,i_2,C_0)}{\partial i_1}-\int_{\underline{\psi}}^{\overline{\psi}}\psi\frac{\partial g(\psi|a_2,i_1,i_2)}{\partial i_1}d\psi \leq 1, \tag{3.6}$$

$$-\frac{\partial C(a_1,a_2,i_1,i_2,C_0)}{\partial i_2}-\int_{\underline{\psi}}^{\overline{\psi}}\psi\frac{\partial g(\psi|a_2,i_1,i_2)}{\partial i_2}d\psi \leq 1. \tag{3.7}$$

In view of the above, (3.5) and (3.7) hold with equality. Assume (3.6) also holds with equality.

However, the construction cost minimization problem is simply

$$\min_{a_1,a_2,i_1,i_2}\{C(a_1,a_2,i_1,i_2,C_0)+a_1+a_2+i_1+i_2\}.$$

Let $(a_1^{***},a_2^{***},i_1^{***},i_2^{***})$ be solution to the above optimization problem. For any arbitrary realization of $\hat{C}_0$ and C_0,

$$i_1^{***}(C_0)=i_2^{***}(C_0)=0, \tag{3.8}$$

and $a_1^{***}(C_0)$ and $a_2^{***}(C_0)$ will solve (3.1) and (3.9), respectively.

$$-\frac{\partial C(a_1,a_2,i_1,i_2,C_0)}{\partial a_2}=1. \tag{3.9}$$

A comparison of the above first order conditions offers us the following relations among the various effort levels:

$$\begin{cases} 0<a_1^{*}=a_1^{**}=a_1^{***} & ; \\ 0=a_2^{*}=a_2^{**}<a_2^{***} & ; \\ 0=i_1^{***}<i_1^{**}<i_1^{*} & ; \\ 0=i_2^{***}<i_2^{*}<i_2^{**} & . \end{cases} \tag{3.10}$$

4. **Contracts and Equilibria**

If innovative efforts a_1, a_2, i_1 and i_2 were all contractible, then regardless of the degree of incompleteness in the initial design, the Coase theorem implies that the parties will always settle for the first-best level of these efforts. But, the efforts are assumed to be non-contractible. In contrast, total construction cost $C(a_1,a_2,i_1,i_2)$, net of cost of efforts, is assumed to be verifiable and contractible. Therefore, the cost-plus contracts are feasible. Later on we will discuss the issue of contractibility of $C(a_1,a_2,i_1,i_2)$ in detail. In addition to the Cost-Plus contracts, we will study the Fixed-Price contracts, the Item/Unit-Price contracts and what we term as 'Bundling with Fixed Price' contracts. These contracts together along with their variants account for most of the procurement contracts (See Bajari and Tadelis; 2001.) The parties opt for one of these contracts at $t = 0$.

As the name indicates, a cost-plus contract reimburses the contractor for construction costs and gives him an additional payment. Fixed-price contract, on the other hand, promises a fixed payment for the works specified in the initial contract. Item-rate contracts are a variant of fixed-price contracts and are explained in the following. Under cost-plus, fixed-price and unit-price contracts, the contractor is responsible only for construction works. Maintenance of the good is not his responsibility. Therefore, the contractual relation between the parties end at $t = 3$. However, there is one important difference among these three contract types. Under cost-plus contracts the project sponsor bears all of the construction costs related risks. In contrast, under a fixed-price contract the contractor bears most of the construction costs related risks. The unit-price contracts fall in between these extremes.

The Bundling with Fixed Price (BP) contracts belong to a different class altogether. Under a BP contract, the contractor is required not only to construct the facility possessing contractually agreed features but also to maintain it during the $O\&M$ phase. In lieu, he is offered a fixed price. The contractor bears most of the construction costs related risks and all of maintenance cost related risks. Such contracts are also called the Public Private Partnership (PPP) contracts. Under these contracts, the contractual relation between the parties lasts till $t = 4$.

As was discussed earlier, if at $t = 1$ the state of nature $\theta \in \Theta - \bar{\Theta}$, the initial contract needs to be renegotiated to incorporate the $\theta-$specific modifications.

We will assume that $\mathbf{q}^a$, i.e., actual quantities of work-item are verifiable. Before proceeding further we need to discuss the verifiability of the cost of modifications. Let,

$\hat{\hat{C}}_2(a_1, a_2, i_1, i_2)$ denote the cost of modifications in the initially good.

Clearly, $\hat{\hat{C}}_2(a_1, a_2, i_1, i_2) = C(a_1, a_2, i_1, i_2) - \hat{C}(a_1, a_2, i_1, i_2)$. The important question is whether $\hat{C}(a_1, a_2, i_1, i_2)$ and $\hat{\hat{C}}_2(a_1, a_2, i_1, i_2)$ are individually verifiable. Note that the initial and the modified features are intertwined parts of the same good and are constructed simultaneously. Therefore, while a good has been constructed it may not be possible to verifiably separate the costs of the initial feature from that of the modifications. This means that $\hat{C}(a_1, a_2, i_1, i_2)$ and $\hat{\hat{C}}_2(a_1, a_2, i_1, i_2)$ may not be verifiable. We will consider alternate assumptions about the verifiability of these costs. As we will see in the following, if $\hat{C}(a_1, a_2, i_1, i_2)$ and $\hat{\hat{C}}_2(a_1, a_2, i_1, i_2)$ are individually verifiable, then during renegotiations a change in contract type itself becomes a theoretical possibility, say from FP contract $t = 0$ to CP contract at $t = 2$. However, to start with we will assume that while renegotiating the initial contract the parties with stay put with the same contract type (may be because $\hat{C}(a_1, a_2, i_1, i_2)$ and $\hat{\hat{C}}_2(a_1, a_2, i_1, i_2)$ are not individually verifiable). That is, if the initial contract is FP contract, the renegotiated contract will also be a FP contract; i.e., only the terms of the initial contract get renegotiated.

4.1. **Cost-Plus Contracts.** Under a Cost-Plus (CP) contract the contractor is paid the verifiable cost of construction along with an additional (constant) sum. That is, a CP contract is a linear contract such that the contract price

$$P^{CP} = P^{CP}(C(a_1, a_2, i_1, i_2)) = \sigma_0 + \sigma C(a_1, a_2, i_1, i_2),$$

where $\sigma_1 = 1$ and $\sigma_0 \in \mathcal{R}$. Now, consider realization of any arbitrary θ, $\hat{C}_0$ and C_0 at $t = 1$. If it turns out that $\theta \in \bar{\Theta}$ then no changes are required and the design provided in the initial contract is implemented. So, the builder contractor will solve

$$\max_{a_1,a_2,i_1,i_2} \{P^{CP} - C(a_1, a_2, i_1, i_2, C_0) - a_1 - a_2 - i_1 - i_2\}, i.e.,$$

$$\max_{a_1,a_2,i_1,i_2} \{\sigma_0 - a_1 - a_2 - i_1 - i_2\}.$$

However, if $\theta \in \Theta - \bar{\Theta}$ then the additional features need to be specified. During the renegotiation the project sponsor provides the details of additional features. We assume that the initial contract empowers the project sponsor to asks for modifications on the basis of a CP contract. This is indeed true of cost plus contracts.[16] In such a scenario, when $\theta \in \Theta - \bar{\Theta}$, the renegotiated contract price is

$$P^{CP_R} = \sigma_0^R + \sigma_1 C(a_1, a_2, i_1, i_2, , C_0) = \sigma_0^R + C(a_1, a_2, i_1, i_2, C_0),$$

where $\sigma_0^R \in \mathcal{R}$. So, the builder contractor will solve

$$\max_{a_1,a_2,i_1,i_2} \{\sigma_0^R - a_1 - a_2 - i_1 - i_2\}.$$

Denote the solution to the builder contractor's optimization problem by $(a_1^{CP}, a_2^{CP}, i_1^{CP}, i_2^{CP})$. Now, it is straightforward to see that

$$(\forall \theta \in \Theta)(\forall \hat{C}_0)(\forall C_0) \begin{cases} 0 = a_1^{CP}(C_0) < a_1^*(C_0) & ; \\ 0 = a_2^{CP}(C_0) = a_2^*(C_0) & ; \\ 0 = i_1^{CP}(C_0) < i_1^*(C_0) & ; \\ 0 = i_2^{CP}(C_0) < i_2^*(C_0) & . \end{cases} \tag{4.1}$$

4.2. **Fixed-Price Contracts.** As discussed earlier, under a FP contract the contractor of paid a fixed price, say P^{FP}, for the works specified in the initial contract. Generally these are Design-and-Build contracts. That is, the builder is given option to come out with innovative designs. Recall, the initial contract specifies the works for the standard good and works required by specific adaptations for the states of nature $\theta \in \bar{\Theta}$. Consider any arbitrary realization of θ, $\hat{C}_0$ and C_0 at $t = 1$. If $\theta \in \bar{\Theta}$, the builder contractor will solve:

$$\max_{a_1,a_2,i_1,i_2} \{P^{FP} - C(a_1, a_2, i_1, i_2, C_0) - a_1 - a_2 - i_1 - i_2\}. \tag{4.2}$$

Denote the solution to the contractor's optimization problem by $(a_1^{FP}, a_2^{FP}, i_1^{FP}, i_2^{FP})$. It is easily verified that for any given C_0 and $\hat{C}_0$, we have $i_1^{FP}(C_0) = i_2^{FP}(C_0) = 0$. But, $a_1^{FP}(C_0)$ and $a_2^{FP}(C_0)$ will solve (3.1) and (3.9), respectively. Therefore, we get

$$(\forall \theta \in \bar{\Theta})(\forall \hat{C}_0)(\forall C_0) \begin{cases} i_1^{FP}(C_0) = i_1^{***}(C_0) = 0 & ; \\ i_2^{FP}(C_0) = i_2^{***}(C_0) = 0 & ; \\ a_1^{FP}(C_0) = a_1^{***}(C_0) = a_1^*(C_0) = a_1^{**}(C_0) > 0 & ; \\ a_2^{FP}(C_0) = a_2^{***}(C_0) > a_2^*(C_0) = a_2^{**}(C_0) = 0 & . \end{cases} \tag{4.3}$$

When $\theta \in \Theta - \bar{\Theta}$, there will be renegotiation over the provisions of modified good. For such instances, we will solve for equilibrium outcome using backward induction. First we will determine the equilibrium levels of a_2, i_1 and i_2 than find out a_1. So, take any given

[16] See Bajari and Tadelis (2001).

level of a_1. First of all note that in the absence of renegotiation only the initial good will be constructed. That is, at $t = \frac{5}{2}$ the contractor will choose a_2, i_1, i_2 to solve

$$\min_{a_2,i_1,i_2} \{\hat{C}(a_1, a_2, i_1, i_2, \hat{C}_0) + a_2 + i_1 + i_2\}.$$

Denote the solution by $(a_2^{FP_{NR}}, i_1^{FP_{NR}}, i_2^{FP_{NR}})$, subscript NR for no-renegotiation. Clearly, for any given $\hat{C}_0$ and C_0, $i_1^{FP_{NR}}(\hat{C}_0) = i_2^{FP_{NR}}(\hat{C}_0) = 0$. But, $a_2^{FP_{NR}}(\hat{C}_0)$ will solve

$$-\frac{\partial \hat{C}(a_1, a_2, 0, 0)}{\partial a_2} = 1. \tag{4.4}$$

Also, for any given a_1, in the absence of renegotiations the contract's ex-post payoff is

$$P^{FP} - \hat{C}(a_1, a_2^{FP_{NR}}, 0, 0, \hat{C}_0) - a_2^{FP_{NR}}, \tag{4.5}$$

where $a_2^{FP_{NR}}$ solves (4.4) above. Moreover, the total ex-post social surplus is

$$\int_{\underline{\hat{b}}}^{\overline{\hat{b}}} \hat{b}\hat{h}(\hat{b}|0,0))d\hat{b} - \int_{\underline{\psi}}^{\overline{\psi}} \hat{\psi}\hat{g}(\hat{\psi}|a_2^{FP_{NR}}, 0, 0)d\hat{\psi} - \hat{C}(a_1, a_2^{FP_{NR}}, 0, 0) - a_2^{FP_{NR}}. \tag{4.6}$$

However, there will be renegotiation and the contractor will be receive additional fixed payments determined by Nash bargaining. Let P^{FP_R} be the renegotiation surplus appropriated by the contactor. Therefore, for any given level of a_1, after the renegotiation, i.e., at $t = 2$ the builder contractor will choose a_2, i_1, i_2 to solve

$$\max_{a_2,i_1,i_2} \{P^{FP} + P^{FP_R} - C(a_1, a_2, i_1, i_2, C_0) - a_2 - i_1 - i_2\}.$$

Recall all efforts are non-contractible. Therefore, for any given fixed values of P^{FP} and P^{FP_R} and any given level of a_1, at $t = 2$ the builder contractor's optimization problem is akin to the following:

$$\min_{a_2,i_1,i_2} \{C(a_1, a_2, i_1, i_2, C_0) + a_2 + i_1 + i_2\}.$$

As before, we get $i_1^{FP_R}(C_0) = i_2^{FP_R}(C_0) = 0$, and $a_2^{FP_R}(C_0)$ will solve (3.9), i.e., $a_2^{FP_R}(C_0) = a_2^{***}(C_0)$.

Since a_1 is chosen before renegotiation, to find out its equilibrium level we need to derive P^{FP_R} and the renegotiation payoff for the contractor. P^{FP_R} is determined by Nash-bargaining, i.e., is a fraction of the increase in social surplus due to renegotiation. So, for given a_1,

$$\begin{aligned}
P^{FP_R} &= \alpha[\int_{\underline{b}}^{\overline{b}} bh(b|i_1^{FP_R}, i_2^{FP_R})db - \int_{\underline{\hat{b}}}^{\overline{\hat{b}}} \hat{b}\hat{h}(\hat{b}|i_1^{FP_{NR}}, i_2^{FP_{NR}}))d\hat{b} \\
&- (\int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{FP_R}, i_1^{FP_R}, i_2^{FP_R})d\psi - \int_{\underline{\psi}}^{\overline{\psi}} \hat{\psi}\hat{g}(\hat{\psi}|a_2^{FP_{NR}}, i_1^{FP_{NR}}, i_2^{FP_{NR}})d\hat{\psi}) \\
&- (C(a_1, a_2^{FP_R}, i_1^{FP_R}, i_2^{FP_R}, C_0) - \hat{C}(a_1, a_2^{FP_{NR}}, i_1^{FP_{NR}}, i_2^{FP_{NR}}, \hat{C}_0)) \\
&- (a_2^{FP_R}(C_0) - a_2^{FP_{NR}}(\hat{C}_0))],
\end{aligned}$$

where $\alpha \in (0,1)$. In view of perfect foresight, $P^{FP_R}(a_1)$ is determined by

$$\begin{aligned} P^{FP_R} &= \alpha[\int_{\underline{b}}^{\bar{b}} bh(b|0,0)db - \int_{\underline{\hat{b}}}^{\bar{\hat{b}}} \hat{b}\hat{h}(\hat{b}|0,0))d\hat{b} \\ &- (\int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{FP_R},0,0)d\psi - \int_{\underline{\psi}}^{\overline{\psi}} \hat{\psi}\hat{g}(\hat{\psi}|a_2^{FP_{NR}},0,0)d\hat{\psi}) \\ &- C(a_1,a_2^{FP_R},0,0,C_0) + \hat{C}(a_1,a_2^{FP_{NR}},0,0,\hat{C}_0)) \\ &- a_2^{FP_R}(C_0) + a_2^{FP_{NR}}(\hat{C}_0)] \end{aligned} \tag{4.7}$$

where $a_2^{FP_R}(C_0) = a_2^{***}(C_0) > a_2^{FP_{NR}}(\hat{C}_0)$, and $a_2^{FP_{NR}}(\hat{C}_0)$ solves (4.4).

At $t = \frac{3}{2}$, anticipating efficient renegotiation, the contractor will choose a_1 to maximize his renegotiation payoff; that is, sum of disagreement payoff given by (4.5), and his share in renegotiation surplus given by (4.7). Simplifying, the contractor's problem can be written as

$$\min_{a_1}\{(1-\alpha)\hat{C}(a_1,a_2^{FP_{NR}},0,0,\hat{C}_0) + \alpha C(a_1,a_2^{FP_R},0,0,C_0) + a_1\}, i.e.,$$

$a_1^{FP_R}(C_0)$ will solve

$$-(1-\alpha)\frac{\partial\hat{C}(a_1,a_2^{FP_{NR}},0,0,\hat{C}_0)}{\partial a_1} - \alpha\frac{\partial C(a_1,a_2^{FP_R},0,0,C_0)}{\partial a_1} = 1. \tag{4.8}$$

That is, $0 < a_1^{FP_R}(C_0) < a_1^{***}(C_0)$. Hence, we get the following:

$$(\forall\theta \in \Theta - \bar{\Theta})(\forall\hat{C}_0)(\forall C_0)(\forall\alpha) \begin{cases} i_1^{FP}(C_0) = i_1^{***}(C_0) = 0 & ; \\ i_2^{FP}(C_0) = i_2^{***}(C_0) = 0 & ; \\ 0 \leq a_1^{FP_R}(C_0,\alpha) < a_1^{***}(C_0) & ; \\ 0 < a_2^{FP_R}(C_0,\alpha) = a_2^{***}(C_0) & . \end{cases} \tag{4.9}$$

4.3. **Item-Rate Contracts.** Under these contracts, the builder contractors is paid for the actual quantities of work items, according to a pre-agreed rate. Under these contracts, the design is provided by the sponsor. The initial contract provides for the work items as well as compensation rates for all $\theta \in \bar{\Theta}$, i.e., $\mathbf{q}(\theta) \in \mathbb{R}_+^W$ and $\mathbf{p}^{IR}(\theta) \in \mathbb{R}_+^W$ have been fixed for all $\theta \in \bar{\Theta}$.

Let $C(a_1,a_2,i_1,i_2,\theta) = \mathbf{c}(a_1,a_2,i_1,i_2,\theta).\mathbf{q}(\theta)$ denote the cost of construction of $\mathbf{q}(\theta)$ works. Now consider realization of any arbitrary $\theta \in \Theta$. If $\theta \in \bar{\Theta}$, the builder contractor will solve:

$$\max_{a_1,a_2,i_1,i_2}\{\mathbf{p}^{IR}(\theta).\mathbf{q}(\theta) - C(a_1,a_2,i_1,i_2,\theta) - a_1 - a_2 - i_1 - i_2\}.$$

Let $P^{IR}(\theta) = \mathbf{p}^{IR}(\theta).\mathbf{q}(\theta)$. Therefore, the contractor's optimization problem can be written as:

$$\max_{a_1,a_2,i_1,i_2}\{P^{IR} - C(a_1,a_2,i_1,i_2,,C_0) - a_1 - a_2 - i_1 - i_2\}.$$

Denote the solution to the contractor's optimization problem by $(a_1^{IR},a_2^{IR},i_1^{IR},i_2^{IR})$. Note that for any given $\theta \in \bar{\Theta}$, $P^{IR}(\theta)$ is a fixed number. This means that for all $\theta \in \bar{\Theta}$, contractor's optimization problem is similar to (4.2). In fact, it is easily verified that for any given C_0

and $\hat{C}_0$, we have $i_1^{IR}(C_0) = i_2^{IR}(C_0) = 0$. But, $a_1^{IR}(C_0)$ and $a_2^{IR}(C_0)$ will solve (3.1) and (3.9), respectively. Therefore, we get

$$(4.10) \qquad (\forall\theta \in \bar{\Theta})(\forall\hat{C}_0)(\forall C_0) \begin{cases} i_1^{IR}(C_0) = i_1^{***}(C_0) = 0 & ; \\ i_2^{IR}(C_0) = i_2^{***}(C_0) = 0 & ; \\ a_1^{IR}(C_0) = a_1^{***}(C_0) = a_1^{*}(C_0) = a_1^{**}(C_0) > 0 & ; \\ a_2^{IR}(C_0) = a_2^{***}(C_0) > a_2^{*}(C_0) = a_2^{**}(C_0) = 0 & . \end{cases}$$

When $\theta \in \Theta - \bar{\Theta}$, there will be renegotiation over the provisions of modified good. As a result, $\mathbf{q}(\theta) \in \mathbb{R}_+^W$ and $\mathbf{p}^{IR}(\theta) \in \mathbb{R}_+^W$ will be renegotiated. However, the problem remains essentially as under the FP contracts. Arguments similar to the previous subsection can show that $a_1^{IR_R}(C_0)$ will solve

$$(4.11) \qquad -(1-\alpha)\frac{\partial\hat{C}(a_1, a_2^{IR_{NR}}, 0, 0, \hat{C}_0)}{\partial a_1} - \alpha\frac{\partial C(a_1, a_2^{IR_R}, 0, 0, C_0)}{\partial a_1} = 1.$$

Assuming $\frac{\partial\hat{c}_1(.)}{\partial a_1} < \frac{\partial c_1(.)}{\partial a_1}$, we get $0 < a_1^{FP_R}(C_0) < a_1^{***}(C_0)$. Hence, we get the following:

$$(4.12) \qquad (\forall\theta \in \Theta - \bar{\Theta})(\forall\hat{C}_0)(\forall C_0)(\forall\alpha) \begin{cases} i_1^{IR}(C_0) = i_1^{***}(C_0) = 0 & ; \\ i_2^{IR}(C_0) = i_2^{***}(C_0) = 0 & ; \\ 0 \le a_1^{IR_R}(C_0, \alpha) < a_1^{***}(C_0) & ; \\ 0 < a_2^{IR_R}(C_0, \alpha) = a_2^{***}(C_0) & . \end{cases}$$

4.4. **Bundling or PPP Contracts.** PPP contracts are popularly know as Design-Build-Finance-Operate and Maintain contracts. Several types of bundling or PPP contracts are used for public procurement of goods and services by the governments world over. However, these contracts have two essential and common features: one, the tasks of construction of project good and its maintenance are performed by the same contractor (or the same consortium of contractors); two, all of the maintenance risks most of construction related risks are borne by the contractor. The bundling or the PPP contracts differ largely in terms of the degrees to which the usage or the commercial are borne by the contractor. Here we consider what we call 'Bundling with Fixed Price' or simply 'Bundling with Price' (BP) contracts. Under a BP contract the sponsor signs a contract with a contractor (or a consortium of contractors) to contract pre-assigned works and maintain the project good for a pre-agree period of time. In terms of our terminology, the contractor is paid a fixed price and is responsible for construction of good with output features specified in the initial contract as well as for its maintenance during $t = 3$ and $t = 4$. The contractor is paid fixed price, say P^{BP}, mutually agreed at $t = 0$. However, P^{BP} can also be interpreted as the expected value of future revenue stream in case the usage or the commercial risk is borne or shared by the contractor.

Recall, the initial contract fully describes the initial features and specific feature for only for the states of nature $\theta \in \bar{\Theta}$. If $\theta \in \Theta - \bar{\Theta}$, the sponsor will have to pay extra price for the specific features.

Now, consider any realization of any arbitrary θ, $\hat{C}_0$ and C_0 at $t = 1$. If $\theta \in \bar{\Theta}$, no renegotiation is required and the contractor has to construct fully equipped good. So, the contractor will solve:

$$\max_{a_1,a_2,i_1,i_2} \{P^{BP} - C(a_1, a_2, i_1, i_2) - \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2, i_1, i_2)d\psi - a_1 - a_2 - i_1 - i_2\}.$$

Denote the solution by $(a_1^{BP}, a_2^{BP}, i_1^{BP}, i_2^{BP})$. Clearly, the contractor's optimization problem is identical to the total cost minimization problem. So, $a_1^{BP}(C_0), a_2^{BP}(C_0), i_1^{BP}(C_0)$ and $i_2^{BP}(C_0)$ will solve (3.1), (3.5), (3.6) and (3.7), respectively. Indeed, the following claim holds.

$$(\forall\theta \in \bar{\Theta})(\forall\hat{C}_0)(\forall C_0)\begin{cases} i_1^{BP}(C_0) = i_1^{**}(C_0) > 0 & ; \\ i_2^{BP}(C_0) = i_2^{**}(C_0) > 0 & ; \\ a_1^{BP}(C_0) = a_1^{**}(C_0) = a_1^{*}(C_0) = a_1^{***}(C_0) & ; \\ a_2^{BP}(C_0) = a_2^{**}(C_0) = a_2^{*}(C_0) = 0 & . \end{cases} \tag{4.13}$$

Next consider the case $\theta \in \Theta - \bar{\Theta}$. In this case, in the absence of renegotiation, the contractor will produce and maintain the initial good. So, for given level of a_1, the contractor will solve

$$\min_{a_2,i_1,i_2}\{P^{BP} - [\hat{C}(a_1,a_2,i_1,i_2) + \int_{\underline{\hat{\psi}}}^{\overline{\hat{\psi}}} \hat{\psi}\hat{g}(\hat{\psi}|a_2,i_1,i_2)d\hat{\psi} + a_2 + i_1 + i_2]\}.$$

Denote the solution by $(a_2^{BP_{NR}}, i_1^{BP_{NR}}, i_2^{BP_{NR}})$, subscript NR for no-renegotiation.

However, there will be renegotiation and the contractor will receive additional fixed payments determined by Nash bargaining. Let P^{BP_R} be the renegotiation surplus appropriated by the contactor. In view of the non-contractibility of efforts, for any given fixed values of P^{BP} and P^{BP_R} and any given level of a_1, at $t = 2$ the contractor's problem can be written as:

$$\min_{a_2,i_1,i_2}\{C(a_1,a_2,i_1,i_2,C_0) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2,i_1,i_2)d\psi + a_2 + i_1 + i_2\}.$$

That is, $a_2^{BP_R}(C_0)$ $i_1^{BP_R}(C_0)$ and $i_2^{BP_R}(C_0)$ will still solve (3.5), (3.6) and (3.7), respectively. Also, for given a_1,

$$\begin{aligned} P^{BP_R} &= \alpha[\int_{\underline{b}}^{\overline{b}} bh(b|i_1^{BP_R}, i_2^{BP_R})db - \int_{\underline{\hat{b}}}^{\overline{\hat{b}}} \hat{b}\hat{h}(\hat{b}|i_1^{BP_{NR}}, i_2^{BP_{NR}}))d\hat{b} \\ &- (\int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{BP_R}, i_1^{BP_R}, i_2^{BP_R})d\psi - \int_{\underline{\psi}}^{\overline{\psi}} \hat{\psi}\hat{g}(\hat{\psi}|a_2^{BP_{NR}}, i_1^{BP_{NR}}, i_2^{BP_{NR}})d\hat{\psi}) \\ &- C(a_1, a_2^{BP_R}, i_1^{BP_R}, i_2^{BP_R}) + \hat{C}(a_1, a_2^{BP_{NR}}, i_1^{BP_{NR}}, i_2^{BP_{NR}}) \\ &- C_A(a_1, C_0, \hat{C}_0) - a_2^{BP_R}(C_0) + a_2^{BP_{NR}}(\hat{C}_0) \\ &- i_1^{BP_R}(C_0) + i_1^{BP_{NR}}(\hat{C}_0) - i_2^{BP_R}(C_0) + i_2^{BP_{NR}}(\hat{C}_0)], \end{aligned} \tag{4.14}$$

where $\alpha \in (0, 1)$ and $a_2^{BP_R}(C_0) = 0$.

At $t = \frac{3}{2}$, anticipating efficient renegotiation, the contractor will choose a_1 to maximize his renegotiation payoff; that is, sum of disagreement payoff and his share in renegotiation surplus given by (4.14). Simplifying, the contractor's problem can be written as

$$\min_{a_1}\{(1-\alpha)\hat{C}(a_1, a_2^{BP_{NR}}, 0, 0, \hat{C}_0) + \alpha C(a_1, a_2^{BP_R}, 0, 0, C_0) + a_1\}, i.e.,$$

$a_1^{BP_R}(C_0)$ will solve

$$-(1-\alpha)\frac{\partial\hat{C}(a_1, a_2^{BP_{NR}}, 0, 0, \hat{C}_0)}{\partial a_1} - \alpha\frac{\partial C(a_1, a_2^{BP_R}, 0, 0, C_0)}{\partial a_1} = 1. \tag{4.15}$$

Therefore, we get $a_1^{FP}(\alpha) < a_1^*$. Therefore, the following holds:

$$(\forall\theta \in \Theta - \bar{\Theta})(\forall\hat{C}_0)(\forall C_0)(\forall\alpha)\begin{cases} i_1^{BP_R}(C_0) = i_1^{**}(C_0) > 0 & ; \\ i_2^{BP_R}(C_0) = i_2^{**}(C_0) > 0 & ; \\ 0 < a_1^{BP_R}(C_0,\alpha) = a_1^{FP_R}(C_0,\alpha) < a_1^{***}(C_0) & ; \\ a_2^{BP_R}(C_0) = a_2^{*}(C_0) = a_2^{**}(C_0) = 0 & . \end{cases} \tag{4.16}$$

Remark 3. Since the contractor is delegated the right/option to improve the design of the project under FP and BP projects, the scope of innovative innovation a_1 is larger under these contracts. Expected the following should hold $a_1^{IR}(\alpha) < a_1^{FP}(\alpha)$ and $a_1^{IR}(\alpha) < a_1^{BP}(\alpha)$. We take that $a_1^{IR}(\alpha) = a_1^{BP}(\alpha)$. We will have more to say on this issue.

5. **Cost Comparisons**

In the following subsection, we will compare the construction and construction plus maintenance costs under the above discussed contracts. Let us begin by deriving the expected costs under various contracts considered above.

Consider realization of any arbitrary of the state of nature θ, and construction costs $\hat{C}_0$ and C_0. Under a CP contract, regardless of whether $\theta \in \bar{\Theta}$ or not, for all $\hat{C}_0$ and C_0, $a_1^{CP} = 0$, $a_2^{CP} = 0$, $i_1^{CP} = 0$, $i_2^{CP} = 0$. Hence, the construction costs will be equal to

$$C(0,0,0,0) = C_0.$$

On the other hand, under a FP contract, construction costs will be equal to

$$\begin{cases} C(a_1^{***}, a_2^{***}, 0, 0) + a_1^{***}(C_0) + a_2^{***}(C_0) & \text{if } \theta \in \bar{\Theta}, \\ C(a_1^{FP_R}, a_2^{***}, 0, 0) + a_1^{FP_R}(C_0) + a_2^{***}(C_0) & \text{if } \theta \in \Theta - \bar{\Theta}, \end{cases} \tag{5.1}$$

where $0 < a_1^{FP_R}(C_0) < a_1^{***}(C_0)$ and solves (**??**).

Similarly, under a IR contract, construction costs will be equal to

$$\begin{cases} C(a_1^{***}, a_2^{***}, 0, 0) + a_1^{***}(C_0) + a_2^{***}(C_0) & \text{if } \theta \in \bar{\Theta}, \\ C(a_1^{IR_R}, a_2^{***}, 0, 0) + a_1^{IR_R}(C_0) + a_2^{***}(C_0) & \text{if } \theta \in \Theta - \bar{\Theta}, \end{cases} \tag{5.2}$$

where $0 < a_1^{FP_R}(C_0) < a_1^{***}(C_0)$ and solves (**??**).

However, under a BP contract, construction costs will be

$$\begin{cases} C(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) + a_1^{**}(C_0) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0) & \text{if } \theta \in \bar{\Theta}; \text{ and} \\ C(a_1^{FP_R}, a_2^{**}, i_1^{**}, i_2^{**}) + a_1^{BP_R}(C_0) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0) & \text{if } \theta \in \Theta - \bar{\Theta}, \end{cases} \tag{5.3}$$

where $0 < a_1^{BP_R}(C_0) < a_1^{**}(C_0)$ and solves (4.15).

As far as total (construction plus maintenance) costs are concerned, under a CP contract, total costs are

$$C(0,0,0,0) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|0,0,0)d\psi. \tag{5.4}$$

Under FP contract, total costs are

$$(5.5)\quad \begin{cases} C(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{***}, i_1^{***}, i_2^{***})d\psi + a_1^{***}(C_0) & \\ +a_2^{***}(C_0) + i_1^{***}(C_0) + i_2^{***}(C_0) & \text{if } \theta \in \bar{\Theta}\text{; and} \\ C(a_1^{FP_R}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{***}, i_1^{***}, i_2^{***})d\psi & \\ +a_1^{FP_R}(C_0) + a_2^{***}(C_0) + i_1^{***}(C_0) + i_2^{***}(C_0) & \text{if } \theta \in \Theta - \bar{\Theta}. \end{cases}$$

Similarly, under IR contract, total costs are

$$(5.6)\quad \begin{cases} C(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{***}, i_1^{***}, i_2^{***})d\psi + a_1^{***}(C_0) & \\ +a_2^{***}(C_0) + i_1^{***}(C_0) + i_2^{***}(C_0) & \text{if } \theta \in \bar{\Theta}\text{; and} \\ C(a_1^{IR_R}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{***}, i_1^{***}, i_2^{***})d\psi & \\ +a_1^{IR_R}(C_0) + a_2^{***}(C_0) + i_1^{***}(C_0) + i_2^{***}(C_0) & \text{if } \theta \in \Theta - \bar{\Theta}. \end{cases}$$

In contrast, under BP contract, total costs are

$$(5.7)\quad \begin{cases} C(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{**}, i_1^{**}, i_2^{**})d\psi + a_1^{**}(C_0) & \\ +a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0) & \text{if } \theta \in \bar{\Theta}\text{; and} \\ C(a_1^{BP_R}, a_2^{**}, i_1^{**}, i_2^{**}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{**}, i_1^{**}, i_2^{**})d\psi & \\ +a_1^{BP_R}(C_0) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0) & \text{if } \theta \in \Theta - \bar{\Theta}. \end{cases}$$

Let EC^{CP}, EC^{FP} and EC^{BP} be the expected (ex-post) construction costs under a CP, FP and BP contract, respectively.[17]

Let ETC^{CP}, ETC^{FP} and ETC^{BP} be the expected construction costs under a CP, FP and BP contract, respectively.

Proposition 1.
$(\forall\alpha \in (0,1))(\forall\pi(d) \in [0,1])[ETC^{BP} < ETC^{FP},\ ETC^{BP} < ETC^{IR}\ \&\ ETC^{BP} < ETC^{CP}]$.

Proof. By the definitions of $(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**})$ and $(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***})$ and the fact that $(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) \neq (a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***})$ the following holds: $(\forall\hat{C}_0)(\forall C_0)$,

$$([C(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{**}, i_1^{**}, i_2^{**})d\psi + a_1^{**}(C_0) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0)]$$
$$< [C(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{***}, i_1^{***}, i_2^{***})d\psi + a_1^{***}(C_0) + a_2^{***}(C_0)]),$$

since $i_1^{***}(C_0) = i_2^{***}(C_0) = 0$. Therefore, $(\forall\theta \in \bar{\Theta})(\forall\hat{C}_0)(\forall C_0)$

$$\begin{aligned} &[C(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{**}, i_1^{**}, i_2^{**})d\psi + a_1^{**}(C_0) + a_2^{**}(C_0) \\ &+i_1^{**}(C_0) + i_2^{**}(C_0)] \\ &< C(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi|a_2^{***}, i_1^{***}, i_2^{***})d\psi \\ &+ a_1^{***}(C_0) + a_2^{***}(C_0)]. \end{aligned} \tag{5.8}$$

[17]The expected (ex-post) construction cost should not be confused with initially estimated project costs, which are discussed later.

Moreover, from (**??**) and (**??**), we have

$$(\forall\theta \in \Theta - \bar{\Theta})(\forall C_0)(\forall \hat{C})(\forall\alpha) \begin{cases} i_1^{BP_R} = i_1^{**} > i_1^{***} = i_1^{FP_R} = 0 & ; \\ i_2^{BP_R} = i_2^{**} > i_2^{***} = i_2^{FP_R} = 0 & ; \\ 0 < a_1^{BP_R}(C_0, \hat{C}_0, \alpha) = a_1^{FP_R}(C_0, \hat{C}_0, \alpha) \leq a_1^{**}(C_0) & ; \\ a_2^{BP_R}(C_0, \hat{C}_0) = a_2^{**}(C_0) = 0 < a_2^{***}(C_0) = a_2^{FP_R}(C_0) & . \end{cases} \tag{5.9}$$

That is, when $\theta \in \Theta - \bar{\Theta}$, under a BP contract the levels of a_2, i_1 and i_2 are as required by the objective of the total cost minimization. Whereas under a FP contract corresponding levels of a_2, i_1 and i_2 are inefficient from the perspective of total cost minimization; there is under-investment in i_1 and i_2 and there is excessive investment in undesirable effort a_2. Besides, the level of a_1 is the same under both types of contracts. Since, given our assumptions, the total construction cost minimization problem is convex, therefore, $(\forall\theta \in \Theta - \bar{\Theta})(\forall C_0)(\forall \hat{C})(\forall\alpha)$

$$\begin{aligned} &+[C(a_1^{BP_R}, a_2^{**}, i_1^{**}, i_2^{**}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi | a_2^{**}, i_1^{**}, i_2^{**}) d\psi + a_1^{BP_R}(C_0, \hat{C}_0, \alpha) + a_2^{**}(C_0) \\ &+ i_1^{**}(C_0) + i_2^{**}(C_0)] \\ &< [C(a_1^{FP_R}, a_2^{***}, i_1^{***}, i_2^{***}) + \int_{\underline{\psi}}^{\overline{\psi}} \psi g(\psi | a_2^{***}, i_1^{***}, i_2^{***}) d\psi \\ &+ a_1^{FP_R}(C_0, \hat{C}_0, \alpha) + a_2^{***}(C_0)]. \end{aligned} \tag{5.10}$$

(**??**) and (**??**) imply that regardless of whether $\theta \in \bar{\Theta}$ or $\theta \in \Theta - \bar{\Theta}$, total cost are strictly less under a BP contract than under a FP contract. That is, $ETC^{BP} < ETC^{FP}$. Similarly, it can be proved that $ETC^{BP} < ETC^{IR}$ and $ETC^{BP} < ETC^{CP}$. □

Proposition 2. $(\forall\alpha \in (0,1))(\forall\pi(d) \in [0,1])[EC^{FP} < EC^{BP},\ EC^{FP} \leq EC^{IR}, \& EC^{FP} < EC^{CP}]$.

Proof. By the definitions of $(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**})$ and $(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***})$ and the fact that $(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) \neq (a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***})$ the following holds: $(\forall \hat{C}_0)(\forall C_0)$,

$$\begin{aligned} &([C(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) + a_1^{**}(C_0) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0)] \\ &> [C(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***}) + a_1^{***}(C_0) + a_2^{***}(C_0)]), \end{aligned}$$

since $i_1^{***}(C_0) = i_2^{***}(C_0) = 0$. Therefore, $(\forall\theta \in \bar{\Theta})(\forall \hat{C}_0)(\forall C_0)$,

$$\begin{aligned} &[C(a_1^{**}, a_2^{**}, i_1^{**}, i_2^{**}) + a_1^{**}(C_0) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0) \\ &> C(a_1^{***}, a_2^{***}, i_1^{***}, i_2^{***}) + \quad a_1^{***}(C_0) + a_2^{***}(C_0)]. \end{aligned} \tag{5.11}$$

Moreover, from (**??**) and (**??**), we have

$$(\forall\theta \in \Theta - \bar{\Theta})(\forall C_0)(\forall \hat{C})(\forall\alpha) \begin{cases} i_1^{BP_R} = i_1^{**} > i_1^{***} = i_1^{FP_R} = 0 & ; \\ i_2^{BP_R} = i_2^{**} > i_2^{***} = i_2^{FP_R} = 0 & ; \\ 0 < a_1^{BP_R}(C_0, \hat{C}_0, \alpha) = a_1^{FP_R}(C_0, \hat{C}_0, \alpha) \leq a_1^{**}(C_0) & ; \\ a_2^{BP_R}(C_0) = a_2^{**}(C_0) = 0 < a_2^{***}(C_0) = a_2^{FP_R}(C_0) & . \end{cases} \tag{5.12}$$

That is, when $\theta \in \Theta - \bar{\Theta}$, under a FP contract the levels of a_2, i_1 and i_2 are as required by the objective of the total cost construction minimization. Whereas under a BP contract corresponding levels of a_2, i_1 and i_2 are inefficient from that perspective; there is excessive investment in i_1 and i_2 and there is under-investment in effort a_2. Besides, the level of a_1 is the same under both types of contracts. Since, given our assumptions, the total construction cost minimization problem is convex, therefore, $(\forall\theta \in \Theta - \bar{\Theta})(\forall C_0)(\forall\hat{C})(\forall\alpha)$

$$+[C(a_1^{BP_R}, a_2^{**}, i_1^{**}, i_2^{**}) + \ a_1^{BP_R}(C_0, \hat{C}_0, \alpha) + a_2^{**}(C_0) + i_1^{**}(C_0) + i_2^{**}(C_0)]$$
$$> [C(a_1^{FP_R}, a_2^{***}, i_1^{***}, i_2^{***}) + a_1^{FP_R}(C_0, \hat{C}_0, \alpha) + a_2^{***}(C_0)].$$

Now, (**??**) and (**??**) imply that regardless of whether $\theta \in \bar{\Theta}$ or $\theta \in \Theta - \bar{\Theta}$, construction cost are strictly less under a FP contract than under a BP contract, i.e., $EC^{BP} > EC^{FP}$. Similarly, it can be proved that $EC^{CP} > EC^{FP}$, etc. □

In view of the above, compared to IR under BP contract the level of construction cost reducing effort a_1 is higher. This, ceteris paribus, means lower construction costs under BP. But, under BP the levels of construction cost increasing investments i_1 and i_2 are also strictly higher. So, we make the following empirically testable conjecture:

Hypothesis 1. Ceteris paribus, $(\forall\alpha \in (0,1))(\forall\pi(d) \in [0,1])[EC^{IR} < EC^{BP}]$.

This, ceteris paribus, compared to an IR contract, construction costs higher under a BP contract. As we will show this indeed is the case.

Now it is easy to conjecture on how the incompleteness of initial design will affect the expected (ex-post) construction costs. For a given project with Θ as the set of possible outcome-relevant states of nature, consider two possible levels of completeness say $\bar{\Theta}_1$ and $\bar{\Theta}_2$ such that $\bar{\Theta}_1 \subset\subset \bar{\Theta}_2$. Let, $\pi_1 = Prob\{\theta \mid \theta \in \Theta_1\}$ and $\pi_2 = Prob\{\theta \mid \theta \in \Theta_2\}$. Clearly, $\pi_1 < \pi_2$. Let us call the design with $\bar{\Theta}_1$ as design One and with $\bar{\Theta}_2$ as design Two. Now consider realization of any arbitrary θ, $\hat{C}_0$ and C_0 at $t = 1$. If $\theta \in \bar{\Theta}_1$ or if $\theta \in \Theta - \bar{\Theta}_2$, regardless of the contract used, the final construction costs will be the same under both the designs. However, the above analysis implies that if $\theta \in \bar{\Theta}_2 - \bar{\Theta}_1$, then the final construction cost will be lower under design Two compared to design One. Therefore, it follows that the expected construction costs decrease as design of a project becomes more and more complete; specifically as $\bar{\Theta}$ becomes larger. Since π increases as $\bar{\Theta}$ becomes larger. Therefore, the expected construction costs decrease with π.

Formally, in view of equations (**??**)-(**??**), we get the following result.[18]

Proposition 3.

(i) $(\forall\alpha \in (0,1))(\forall\pi(d) \in [0,1))[\dfrac{\partial EC^{CP}}{\partial\pi} = 0, \ \dfrac{\partial EC^{FP}}{\partial\pi} < 0, \ \dfrac{\partial EC^{IR}}{\partial\pi} < 0, \ \& \ \dfrac{\partial EC^{BP}}{\partial\pi} < 0]$.

(ii) $(\forall\alpha \in (0,1))(\forall\pi(d) \in [0,1))[\frac{\partial ETC^{CP}}{\partial\pi} = 0, \ \frac{\partial ETC^{FP}}{\partial\pi} < 0, \ \frac{\partial ETC^{IR}}{\partial\pi} < 0, \ \& \ \frac{\partial ETC^{BP}}{\partial\pi} < 0]$.

5.1. **Cost Overruns.** The positive [negative] cost overruns are said to have occurred if the final construction costs are greater [less] than the initially estimated construction costs. In our model, the ex-post construction costs is well defined random variable that can take any value within the specified limits. But, so far we have not defined the (initially) estimated construction costs. Even in theory the estimated project costs can be defined in several ways; for example depending on whether only the cost estimates take into account of all $\theta \in \Theta$ or only of $\theta \in \bar{\Theta}$ or just consider cost of the basic good. Therefore, the magnitude as well as probability of cost overrun can vary significantly depending on how the initial cost estimates are arrived at.

[18] In this and the following claims changes in π are assumed to be as explained here.

However, our model is capable of making some predictions for any given definition of the expected project cost. For instance, take any project with any initial design specification set $\bar{\Theta}$. For the later reference, let us call the initially estimated estimated project cost as INITIALCOST and denote it by k. Regardless of how the value k is arrived at, as long as it is well within the limits of the possible values of the ex-post construction costs, we can make comparison across procurement contracts.

5.1.1. **Comparison Across Contracts.** We know that for every possible of state of nature during the construction phase, the construction costs are higher if the project is implemented with a PP contract, compared to FP and IR contracts. This means that the probability of actual construction costs exceeding number k is higher for a PP contract. Therefore, we can make the following claim.

Proposition 4. *Take any project with any given degree of design incompleteness, the probability and magnitude of cost overruns is higher for a PP contract than for FP and IR contracts.*

Moreover, for the purpose of empirical analysis of cost overruns, it is crucial to keep in mind the actual methodology used by government engineers for the estimation of the expected costs.

5.1.2. **Comparisons Across Projects.** So far we have assumed π to be a function of d only and explained how π varies d, i.e., the effort put in designing of a given project. In real world π depend on not only the effort but also on the 'complexity' of the project at hand as well as on the prior experience of the designer with project planning.

An illustration may be helpful here. Consider two classes of projects, say A and B. Suppose both contain road projects only, or railways projects only. Let Θ_A [Θ_B] be the set of possible output-relevant states of nature for A [B]; such that $\Theta_B \subset \Theta_A$ holds, perhaps because class A has relatively big projects. Take any given finite level of d, the effort in project designing. Given our assumption and as is true of real world, with finite d, $\theta-$specific plans can be described only for a subset of Θ_B and therefore of Θ_A; say $\bar{\Theta}_A = \bar{\Theta}_B = \bar{\Theta}$. Since $\Theta_B - \bar{\Theta}_B \subset \Theta_A - \bar{\Theta}_A$, it is easy to see that probability of contract renegotiation for class A is higher than for class B, i.e., $(1 - \pi_A) > (1 - \pi_B)$, i.e., $\pi_A < \pi_B$. In other words, for given level of designing effort, initial design and therefore initial contracts will be more incomplete for class A, than for class B.

Alternatively, suppose $\Theta_B = \Theta_A$ but the states of nature in set Θ_A are more difficult to design, specify and negotiate over than in the set Θ_B - may be due to difficult terrain. This would mean that for given d, $\bar{\Theta}_A \subset \bar{\Theta}_B$. Again, we get $\Theta_B - \bar{\Theta}_B \subset \Theta_A - \bar{\Theta}_A$, i.e., $\pi_A < \pi_B$. In either case, it is meaningful to call class project A is more complex than class B.
Let,

s denote the complexity of the project; and

t denote the level of prior experience of the project sponsor.

Formally, we say that a project [or class of projects] A is more complex than project [or class of projects] B, if

$$(\forall d)(\forall t)(\forall \pi \in (0,1))[\pi(d, s_A, t) < \pi(d, s_B, t)]. \tag{5.13}$$

Intuitively, (5.13) can hold either because the set of states on nature for project A, say Θ_A, is 'larger' than for project B, say Θ_B, or because the states of nature in set Θ_A are more difficult to specify than in the set Θ_B or both.

From (5.13) it follows that the probability of project redesigning, i.e., of the contract renegotiation is higher for class A. But, what does our model predicts about the relative frequency and magnitude of cost overruns for the above classes of projects, A and B? More generally, what are the implications of project complexity for the probability and magnitude of cost overruns across projects? To be able to answer these questions, we need to make some behavioural assumption about the project cost estimation techniques. Since we want to test our predictions using the available datasets, it is all the more important that we be mindful of the project cost estimation techniques actually used by project planners.

Discussions with several engineers involved in project designing for road and railways sectors suggest that estimates of construction costs at the project planning stage are arrived at in the following manner: First, the cost estimates of the essential work-items are made; Second, additional allowance is made for the changes in the project works due to 'commonly experienced' contingencies.[19] In terms of our terminology, the estimated construction costs are arrived at by adding the estimated cost of the basic good with the expected costs of modifications required by the states of nature in the set $\bar{\Theta}$.

Let us assume that the effort d put in by the project planner is fixed regardless of the size and complexity of the project at hand; in particular, it does not increase in proportion the complexity of the project - the above described methodology actually used confirms this scenario. In such a situation, $\pi_A < \pi_B$ will hold. This means, compared to those in class B, class A projects will need midway renegotiation/ redesigning at $t = 2$ more frequently. We have already seen that the possibility of redesigning/renegotiations stunts the cost reducing effort by the contractor, resulting in higher construction costs. Also, since the initial design provides essentially for only the basic works, redesigning would generally (though not always) bring in $\theta-$specific additional works. Additional works inevitably increase the project costs. Therefore, our model predicts that more complex projects will exhibit a higher frequency as well as magnitude of cost overruns. For instance, construction projects are inherently more complex than those involving simple purchase of machinery. So, the construction projects are expected to show relatively high cost overruns. With the class of construction projects, the cost overruns are expected to increase with the complexity.

The implications of prior experience with project implementation for the incompleteness of initial design seem to be obvious. Project designing naturally improves as officials become more and more experienced with project implementation. After all, with experience project designers will become better educated about the possible states of nature and their requirements. As a result, they will be able to include increasing number of the states of nature in the initial design itself, reducing the incompleteness of the initial design as well as of the contract. That is, the other things, including the level of d, held constant π will increase with the experience, i.e., we would expect the following:

$$(\forall d)(\forall s)(\forall \pi \in (0,1))[t_A > t_B \Rightarrow \pi(d, s, t_A) > \pi(d, s, t_B)]. \tag{5.14}$$

In view of the above discussion, (5.13) and (5.14) offer the following:

[19]The contingency allowance is about 10-20 percent of the cost of the basic good.

Proposition 5. *Ceteris paribus, the following holds:*
(*i*) $(\forall \alpha \in (0,1))(\forall s)(\forall t)[\frac{\partial EC^{CP}}{\partial s} = 0, \quad \frac{\partial EC^{FP}}{\partial s} > 0, \ \& \ \frac{\partial EC^{BP}}{\partial s} > 0]$.
(*ii*) $(\forall \alpha \in (0,1))(\forall s)(\forall t)[\frac{\partial ETC^{CP}}{\partial s} = 0, \quad \frac{\partial ETC^{FP}}{\partial s} > 0, \ \& \ \frac{\partial ETC^{BP}}{\partial s} > 0]$.
(*iii*) $(\forall \alpha \in (0,1))(\forall s)(\forall t)[\frac{\partial EC^{CP}}{\partial t} = 0, \quad \frac{\partial EC^{FP}}{\partial t} < 0, \ \& \ \frac{\partial EC^{BP}}{\partial t} < 0]$.
(*iv*) $(\forall \alpha \in (0,1))(\forall s)(\forall t)[\frac{\partial ETC^{CP}}{\partial t} = 0, \quad \frac{\partial ETC^{FP}}{\partial t} < 0, \ \& \ \frac{\partial ETC^{BP}}{\partial t} < 0]$.

6. Data

The above derived results provide several testable predictions. Though while providing the arguments we have been referring to similar of same sector projects, the results derived above are likely to hold generally. We test the empirical validity of these claims for a infrastructure sectors in general. However, we will focus on the road and railways sectors in particular. Since most projects in these sectors are construction projects and therefore provide a more suitable real world context for our model. This section provides the data description and present an overview of the delays and cost overruns in infrastructure projects in India. In the subsequent section, I will derive the empirical framework offered by our theory model and its results.

6.1. **Data Description.** We have two datasets of infrastructure projects. The first dataset includes 928 projects implemented during April 1992-June 2009. All of these projects have been funded and executed by relevant department of Government of India. Each project in the set is worth Rs 200 million or more. This dataset has been compiled from quarterly reports of the programme implementation division of the Ministry of Statistics and Programme Implementation (MOSPI).[20] Projects in this set are quite diverse in terms of the nature of procurement activities covered by the projects. Given that projects are from seventeen different sectors, ranging from Atomic Energy and Finance to Urban-development, the heterogeneity across projects is not surprising. In fact, projects within a sector are also quite diverse; for example some of the power sector projects are construction project while others have involved simple purchase of machines such as turbine. Yet, road, railways and urban-development sectors make for a somewhat homogeneous group; most projects in these sectors are construction projects. Similarly, many of civil aviation, ports and power sector projects are predominantly construction based projects. In contrast, in sectors like telecom and atomic energy, a large number of projects are for purchase and/or installation of equipments.

The second dataset has 195 road projects on national highways (NH) in India. These projects have been financed and sponsored by the National Highways Authority of India (NHAI). Source for this dataset is the NHAI. This set includes most of the 169 road projects contained in the first dataset.[21] However, this is a larger set. Moreover, for highways projects the NHAI dataset is richer in terms of project characteristics. For instance, for each project in this set we know whether it is a public funded or a privately funded project. That is, whether

[20] According to MOSPI reports, during April 1992-June 2009, a total of 1069 projects have been completed. But, unfortunately, the required information for only 928 projects; for the remaining projects, information on one or the other aspect was missing. These missing projects were started in seventies and early eighties.

[21] However, there are some road projects in the first dataset which are absent from the NHAI dataset, and *vice-versa.*The difference arises because MOSPI gives information only on projects worth more than 200 million rupees and irrespective of their implementing agency but NHAI dataset includes all projects executed by NHAI. Some reporting errors are also there.

a project is a PPP or not. We also have information regarding date of award of contract. The MOSPI does not provide information on date of award of contract. So, this dataset enables us to explore the issues of delays and cost overruns during the project implementation phase, by excluding the delays between date of approval and date of award of contract. For every project in either dataset, we have compiled information on the aspects mentioned in Table 1.

6.2. **Definitions:** Every infrastructure project has to undergo several stages: from planning of the project, to its approval, to awarding of contract(s), to actual construction/procurement, and so on. Broadly put, a project's lifecycle has three phases; development, construction, and operation-and-maintenance phase. In the beginning of the development phase, the project sponsoring department prepares estimates of time and cost (funds) needed to complete the project. An expected date of completion is also announced. The actual date of completion is invariably different from the expected date. We define 'time overrun' as the time difference between the actual and the initially planned (i.e, expected) dates of completion. We measure the time difference in months. A related term used in the paper is the 'implementation phase'. It is defined as the duration in which a project is planned to be completed. For NHAI dataset 'implementation phase' is calculated as the time duration from the date of award of procurement contract to the expected date of completion/execution of the project as per the contract. For MOSPI does not provide the date of contract award. So for this dataset, implementation phase is calculated as the duration between the date of approval of the project and its expected date of completion at the time of approval. For each project we can define percentage time overrun as the ratio of the time overrun and the implementation phase for the project(multiplied by hundred). Clearly, the time overrun and therefore the percentage time overrun can be positive, zero or even negative. Similarly, we define 'cost overrun' as the difference between the actual cost and the initially projected (i.e., expected) cost of the projects. The initially expected cost is called the initial project cost. These are cost estimates for project works and generally are arrived at using current input prices. The actual costs become known only at the time of completion at the end of phase two. The projected costs are the estimated costs when a project is planned. Percentage cost overrun for a project is defined as the ratio of the cost overrun and the initially anticipated cost of the project(multiplied by hundred). Again, percentage cost overrun can be positive, zero or negative.

6.3. **Summary Statistics.** Table 2 provides summary statistics for the larger dataset. As is evident from the statistics, there are wide-ranging variations across sectors in terms of the number of projects, average percentage delays, and cost overruns, and their standard deviations. For analytical convenience, we have divided the MOSPI dataset into several sectoral and regional categories. The sectoral categories are: One, road, railways and urban-development; Second, civil aviation, shipping and ports and power projects; Third, telecom and atomic energy; Fourth, all other projects. The regional categories are: One, states of Punjab, Haryana, Delhi, Gujarat, and Maharashtra; Two, states of A.P, Tamil Nadu, Karnataka and Kerala; Three, states of North-East and Jammu and Kashmir; Fourth, the rest of the Indian states. Table 3 provides the number of projects belonging to each category. Later on we will explain the rationale behind these groupings in detail.

As mentioned earlier, we will have closer look at the data on Road and Railways projects. Tables 5-7 provide summary statistics for the Road and Railways projects. As far as road projects are concerned, while the implementation phase and cost overruns have increased in recent years, there has been decline in the percentage time overruns. As far as railways projects are concerned, initial years witnessed a decline in delays and cost overruns along with the implementation phase. However, in recent years cost overruns have gone up along with the implementation phase.

I must point out that while analyzing the Road sector individually we will use NHAI dataset, given its richer informativeness. For the study of Railways projects we are restricted to use MOSPI dataset, since this is the only source of information for these projects. Moreover, when we compare the two sectors simultaneously, in the interest of coherence and consistency we will be working with the MOSPI dataset for both the sectors.

7. The Empirical Framework and Results

7.1. **Regression Models.** The sections 4 and 5, offers several testable predictions. However, to test them we need measures of project complexity as well as experience. Is there a general measure of complexity available? The project size seems to be a reasonable measure of complexity. Presumably the complexity increases with project size. Since, compared to smaller ones, bigger projects involve more works. The designing and coordination problems naturally increase with the number and magnitude of works, in turn, increasing the complexity. If so, our question boils down to determining the measures of project size. The data provides two measures of project size. The first is the initially estimated project cost. It seems to be a good measure of project size, its complexity, and hence of the contractual incompleteness. Following the terminology in Singh (2010), we will call the estimated project cost to be simply the INITIALCOST.[22] The second measure is the implementation phase; the duration in which a project is initially planned to be completed. We will term this measure as the IMPLEMENTATIONPHASE, or the IMPLPHASE for short. Plausibly, *ceteris paribus*, projects involving larger number of works are more complex than those requiring a smaller number. Similarly, projects with more new and complicated works are more complex than those for standard works. Obviously, as the number of works and intricacy increase, it will take longer to complete the project. Presumably, the project planners will increase the implementation phase in proportion to its complexity. In other words, the IMPLPHASE is proportional to the complexity of the project.

As far as experience with project designing is concerned, we measure it in term of number of months that have elapsed since the start of the first project in the sector or dataset under consideration. We call the duration as TIMELAPSE. We will denote its square by TIMELAPSESQ or TIMELAPSE^2. *Ceteris paribus*, the contractual incompleteness is expected to decrease with TIMELAPSE. As a result, the cost overruns are also expected to come down. To sum up, our model offers the following testable hypotheses:

Hypothesis 2. Ceteris paribus, the cost overruns and their probability will

(1) be higher for PPP projects;
(2) be higher for CIVIL-CONSTRUCTION projects;
(3) increase with INITIALCOST;
(4) increase with IMPLPHASE;

[22] The initially expected project cost, rather than the actual cost, is a better indicator of the size and incompleteness of the contract. Due to cost overrun, the final cost can be large even for small projects. The same argument applies to the implementation phase.

(5) decrease with TIMELAPSE.

Apart from project complexity and experience, there are other factors too that have implications for cost overruns. Delay or time or overrun in project implementation is one such factor. Arguably, any delay in implementation will cause cost overrun for the project. This can happen simply on account of inflation itself. If there are delays, inputs will become more expensive and, in turn, will cause an increase in the project cost. Moreover, certain overhead costs have to be met as long as the project remains incomplete. Delays should increase these costs also. Also, a long delay may cause depreciation of project assets, necessitating expenses on repairs or replacements. At the same time, it is pertinent to keep in mind that contract renegotiation is a time consuming and generally contested process. This means it is expected to cause not only cost overruns but also delay. If so, project complexity and experience affect the time overruns too. This suggests a simultaneity between cost and time overruns. However, as is shown in Singh (2010), while there is simultaneity between the two, the causation runs from delays to cost overruns and not the other way around.

The model and the above discussion suggests the following regression model:

$$\begin{aligned} PCTO &= \alpha_0 + \alpha_1 TIMELAPSE_t + \alpha_2 TIMELAPSE_t^2 + \alpha_3 INITIALCOST_t \\ &+ \alpha_4 IMPLPHASE_t + \alpha_5 DRRU_t + \alpha_6 DCSPP_t + \alpha_7 DTA_t \\ &+ \alpha_8 DSTATES_t + \alpha_9 DMRICH_t + \alpha_{10} DRICH_t + \alpha_{11} DNE_t + \epsilon_{1t} \end{aligned} \tag{7.1}$$

$$\begin{aligned} PCCO &= \alpha_0 + \alpha_1 TIMELAPSE_t + \alpha_2 TIMELAPSE_t^2 + \alpha_3 INITIALCOST_t \\ &+ \alpha_4 IMPLPHASE_t + \alpha_5 DRRU_t + \alpha_6 DCSPP_t + \alpha_7 DTA_t \\ &+ \alpha_8 DSTATES_t + \alpha_9 DMRICH_t + \alpha_{10} DRICH_t + \alpha_{11} DNE_t \\ &+ \alpha_{12} PCTO + \epsilon_{2t} \end{aligned} \tag{7.2}$$

We have used dummies DRRU, DCSPP, DTA to test the last conjecture in Proposition 4. DRRU is dummy for road, railways and urban-development projects, and DCSPP for projects in civil aviation, shipping and ports, and power sectors. As was discussed in Section 2, most projects in Road, Railways and Urban-development sectors are construction projects. Majority of projects in Civil Aviation, Shipping and Ports, and Power sectors too involve construction and are complex even otherwise. Construction projects are typically more complex and therefore more difficult to plan and execute than is the case with non-construction projects. The degree of incompleteness of the initial contract is higher for construction projects. So, compared to other sectors, projects in road, railways, urban-development, civil aviation, shipping and ports, and power sectors should exhibit higher cost overruns. We have used separate dummies for two reasons: One, projects in the latter category are generally unique in terms of its requirements. So, learning from across projects is limited; Two, projects in road, railways and urban-development sectors are more homogeneous, in that most project involve construction. Dummy DTA is for telecom and atomic energy sectors. Most projects in these sectors are for procurement of equipments and machinery. Designing of such projects is expected to be fairly complete and therefore not vulnerable to cost overruns.

Apart from sectoral dummies, we have included regional dummies as well. Here idea is to capture the effects of infrastructure and governance on delays and cost overruns. If a state/region has better transport, power and telecommunication infrastructure in place, it will be easier to execute projects in that state. Generally, richer states are said to be in possession of superior infrastructure. In contrast, due to law and order as well as difficult terrain, project implementation is likely to be difficult in the North-Eastern states and Jammu and Kashmir. To check statistical validity of these conjectures, states have been clubbed in four categories. Five richest states, in terms of per-capita income, are grouped together. These are Haryana, Punjab, Delhi, Gujarat and Maharashtra. We have used dummy DMRICH for these states. In the next category, we have four southern states: Andhra Pradesh, Karnataka, Kerala and Tamil Nadu. These states have well above average per-capita GSDP and are considered to be better governed. For these the dummy used is DRICH. In the third category we have the North-Eastern states and Jammu and Kashmir with dummy DNE. Dummy dummy DSTATE has been used for inter-state projects.

We estimated several close versions of the above model. The estimation has been undertaken for all of the seventeen sectors; for road and railways sectors combined; and for road and railways sectors individually.

In order to check our claim regarding relative cost overruns for PPP project versus others, we have used the logit probability function

$$p = P(Z) = \frac{e^Z}{1 + e^Z},$$

where for the base model we have

$$\begin{aligned} Z &= \sigma_0 + \sigma_1 PCTIMEOVERRUN + \sigma_2 TIMELAPSE_t + \sigma_3 INITIALCOST_t \\ &+ \sigma_4 IMPLPHASE_t + \sigma_5 DPPP_t + \sigma_6 DMRICH_t + \sigma_7 DRICH_t \end{aligned}$$

7.2. **Results.** For each variant of our base model, we treated the relevant dataset for outliers and influential observations. For each version and every application of the model the two error terms are uncorrelated with each other. However, a significant number of observations get dropped as outliers. For instance, for all the sectors together we have 928 observations, out of which 131 have turned to be outliers.[23]

7.2.1. ***All Sectors.*** The regression results for all of the seventeen sector projects are presented in Table 8. Model 1 is the same as our base model and is estimated using OLS technique. For this model, most of our hypotheses have turned out to be correct. For both cost as well as time overrun equations, TIMELAPSE has negative coefficient and is extremely significant at 1 percent for time as well as cost overrun equation. Besides, in both the equations, the coefficient of TIMELAPSESQ is positive and significant at 1 percent. That is, the downward trend for percentage cost and time overruns is statistically significant. However, the effect is is U-shape, which is not surprising. After all, as project planners move up the learning curve, additional learning is expected to come down. The coefficient of INTIALCOST in equation (2) is positive and extremely significant at 1 percent. However, the coefficient of IMPLPHASE in equation (2) is not significant! However, at a close look this

[23]A close look at the dropped outliers shows that for many projects in the dataset the time and the cost overruns figures appear to be rather incredible. Several projects have experienced very long positive time overruns and simultaneously huge but negative cost overrun. There are many projects with time overrun of 20 percent or more and negative cost overruns of at least 70 percent! Most probably these are instances of reporting errors. For more on this issue see Singh (2010).

outcome should not be entirely surprising, since both INTIALCOST and IMPLPHASE are picking up the same effect; namely the implication of the project size. Result of Model 2 confirm this conclusion. If we drop INTIALCOST, variable IMPLPHASE becomes significant. Time overrun is one of the most important factors behind cost overruns. The coefficient of PCTGTIMEOVERRUN is positive and extremely significant at 1 percent. Indeed, regardless of the underlying cause, delays in implementation are a major factor behind cost overruns. As predicted, variables DRRU and DCSPP have turned out to be positive and extremely significant for delays as well as cost overruns. That is, the other factors held constant, compared to the other sectors, the road, railways, urban-development projects have experienced higher delays and cost overruns. The same is the case with civil aviation, shipping and ports, and power sector projects. However, dummies DTA and DSTATE have not shown any consistency.

A robustness check has been done by estimating the model using Quantile regression on the entire dataset of 928 projects(Table 9). In view of a large number of outliers this check is helpful; Compared to OLS, the Quantile regression is less vulnerable to the effects of outliers. Results are very similar to those reported in Table 8.

7.2.2. ***Railways and Roads:*** If we estimate the base regression model for roads and railways, results corroborate the predictions of theoretical model. The results are presented in Table 10. As far as variables TIMELAPSE, and TIMELAPSESQ are concerned, the results are similar to those for all the sectors combined. In particular, TIMELAPSE has negative coefficient and is extremely significant at 1 percent for time as well as cost overrun equation. With positive and somewhat significant coefficient TIMELAPSESQ continues to exert U-shape effect on cost overruns. However, the coefficient of TIMELAPSESQ is less significant in time overrun equation.

However, results are somewhat different regarding variables INTIALCOST and IMPLPHASE. The coefficient of IMPLPHASE in equation (2) is positive and extremely significant at 1 percent. However, the coefficient of INTIALCOST in equation (2) is negative though not highly significant. That is, when effect of other factors is held fixed, cost overruns swell as IMPLPHASE increases. The result is as expected. On the other hand, *ceteris paribus*, increase in INTIALCOST has dampening impact on percentage cost overruns! In equation (1) IMPLPHASE has negative and extremely significant (at 1 percent) effect; INTIALCOST has no significant effect on time overruns. That is, *ceteris paribus*, percentage time overrun decreases with implementation phase. However, in view of the arguments presented above, the results are not entirely surprising.

Result of the logit regression are also along the expected lines. As Table 11 shows, probability of cost overrun has declined overtime. *Ceteris paribus* complex projects have higher probability of cost overruns, etc.

7.2.3. ***Roads:*** In this subsection, let us take a close look at the performance of national highways projects in terms of delays and cost overruns. Tables 12 presents the relevant results. The Model M1 is essentially the base model, except the addition of PCTIMEOVERRUN-square and PPP dummy among explanatory variables - of course the sectoral dummies are not relevant here. The first set of results (under M1) are based on OLS regressions. First important observation relates to the effect of time overrun on cost overrun. Here effect is quadratic in nature. Informally and somewhat loosely speaking, this implies that short delays in implementation do not matter much for cost overruns. However, longer delays do increase cost overruns.[24] As far as variables TIMELAPSE, and TIMELAPSESQ are concerned, both are highly significant and the results are similar to those for all the sectors combined. That is, other things held fixed, the effect of TIMELAPSE is quadratic in nature for both delays as well as cost overruns, as before. However, results are different regarding variables INTIALCOST and IMPLPHASE. In contrast, now the variable IMPLPHASE in equation (2) is positive and extremely significant at 1 percent. That is, when effect of other factors is held fixed, cost overruns swell as IMPLPHASE increases. The result is as expected. However, the coefficient of INTIALCOST in equation (2) is negative though not very significant.

In equation (1), the coefficient of INTIALCOST is positive and significant implying that delays increase with the project size. On the other hand, IMPLPHASE has negative and extremely significant (at 1 percent) effect. That is, *ceteris paribus*, time overrun decreases with implementation phase! However, on a closer look, the result make sense. For illustration, consider two same-sector and same-works and therefore same-cost projects. Between these projects, the one with the longer IMPLPHASE should show shorter percentage time overrun; since it has already got more time to complete the same number of works. While it seems plausible to expect the absolute time overrun to increase with project size/IMPLPHASE, but, ceteris paribus, there is no reason to expect delays to increase in percentage terms with the IMPLPHASE.

What is the combined effect of the above variables? It seems the implementation phase is driving the results. Since the implementation phase has gone up in recent years, as a consequence while there has been decline in the percentage time overruns, but cost overruns have increased. Graphs 1-4 shows these trends clearly.

As far as PPP projects are concerned, the result are very striking but are very much as predicted by our theoretical model. The other factors held fixed, compared to non-PPP projects, PPP projects have exhibited significantly higher cost overruns. The coefficient of PPP dummy is positive and extremely significant at 1 percent, regardless of the dataset and regression technique used. Moreover, these projects have also shown shorter time overrun. Therefore, factors other than delays are largely responsible for cost overruns experienced by the PPP projects. This further strengthen the validity of the theory model used in the paper.

The number of outliers identified by the STATA continues to be significant; it dropped 57 observations as outliers.[25] Therefore, to confirm veracity of the results, we have run Qunatile regressions. Moreover, instead of using STATA to identify outliers, we have manually inspected outlier observations and dropped them; this exercise resulting in dropping of only 11 observations.[26] OLS results from remaining 184 observations are presented under M2. As is clear from the results, the above discussed variables continue to have same signs and levels of significance. However, the rich states do not show significantly and consistently superior

[24] If we estimate the base model, i.e., Model M1 without PCTIMEOVERRUN square, the PCTIMEOVERRUN does not come out to be very significant. Value of R-square also suggest that M1 is a better model for road sector.

[25] This disquieting feature is common to all of OLS regressions, regardless of the model used and sector studied.

[26] Under graphical method, we used partial regression plots of each independent variable for identifying the outliers. Partial regression plot of a variable say, X_1, will plot the residuals obtained by regressing dependent variable on all independent variables on $y-$axis and residuals, obtained by regressing X_1 on all other independent variables on $x-$axis. By, Frisch-Waugh Theorem, the slope of the line thus, obtained is the coefficient of X_1. The observations lying far off are considered as the potential candidates for dropping as outliers. Observations which after being dropped from the model change the slope of the line are considered as the influential observations.

performance.

Again, result of the logit regression are also along the expected lines: Probability of cost overrun has declined overtime. *Ceteris paribus* complex projects have higher probability of cost overruns, etc. Most notably as is predicted by our model, PPP projects have significantly higher probability of cost overruns.

7.2.4. ***Railways:*** The regression model used for railways projects is the same as our base model, except for the addition of DCIVILWORKS as an explanatory variable. As was explained in Section 2, we have divided railways projects in two categories; namely, civil construction projects and others. Civil construction projects by definition are the projects involving (civil engineering) construction works. DCIVILWORKS is dummy for these projects; other projects are largely for procurement and installation of equipments, etc. Of course the sectoral dummies are not relevant here. Tables 13 shows the regression results for railways projects. As far as variables TIMELAPSE, and TIMELAPSESQ are concerned, the results are similar to those for all the sectors combined and for the national highways projects. That is, the U-shape effect continues for delays as well as cost overruns.

The coefficient of IMPLPHASE in equation (2) is positive and extremely significant at 1 percent. Moreover, the coefficient of INTIALCOST in equation (2) is also positive and significant. That is, when effect of other factors is held fixed, percentage cost overruns increase with IMPLPHASE as well as with INTIALCOST. As was the case with road projects, in equation (1) IMPLPHASE has negative and extremely significant at 1 percent effect; INTIALCOST has no significant effect on time overruns; perhaps due to the same reason. As before, project implementation is not significantly better in rich states.

What is the combined effect of the above variables for railways projects? Again, the implementation phase seems to be driving the results. Initially, there was decline in delays and cost overruns due to declining implementation phase. In recent years cost overruns have gone up along with the implementation phase. Graphs 5-8 show these trends clearly.

However, one result related to railways projects is of especial interest. Note that in equation (2), dummy DCIVILWORKS has positive and extremely significant coefficient. This means that, compared to non-construction projects, construction projects have experienced significantly higher cost overruns; clearly an outcome predicted by our theoretical model. So, this result is yet another confirmation of validity of our theoretical model.

Figure 2. OLS Table 1
1.pdf

TABLE 1:

S. No.	ASPECT/VARIABLE	DESCRIPTION	DATA SOURCE
1	DATE OF PROJECT START	It is the start date of the project	MOSPI reports
2	INITIAL DATE OF COMMISSIONING	It is the initially planned (i.e, expected) date of completion of the project	MOSPI reports
3	ACTUAL DATE OF COMMISSIONING	It is the actual date of completion of the project	MOSPI reports
4	TIMEOVERRUN	The time difference (in months) between the actual and the initially planned date of completion	OUR CALCULATIONS based on the data collected from MOSPI reports. .
5	IMPLEMENTATION PHASE	The duration in which a project is planned to be completed, i.e., the duration between the date of approval of the project and its *expected* date of completion.	OUR CALCULATIONS based on the data collected from MOSPI reports.
6	PCTIMEOVERRUN	The ratio of the time overrun and the implementation phase for the project (multiplied by one hundred).	OUR CALCULATIONS based on the data collected from MOSPI reports.
7	INITIAL PROJECT COST	The initially projected (i.e., expected) cost of the project.	MOSPI reports
8	ACTUAL PROJECT COST	The actual cost at the time of completion of the project.	MOSPI reports
9	COST OVERRUN	The difference between the actual cost and the initially projected (i.e., expected) cost of the project.	OUR CALCULATIONS based on the data collected from MOSPI reports.
10	PCCOSTOVERRUN	The ratio of the cost overrun and the initially anticipated cost of the project (multiplied by one hundred).	OUR CALCULATIONS based on the data collected from MOSPI reports.
11	TIMELAPSE	It is the time (in months) that has lapsed since May 1974 to the date of approval of the project. The *first* project in our dataset on all sectors was approved in May 1974.	OUR CALCULATIONS based on the data collected from MOSPI reports.
12	SECTOR	The infrastructure sector to which the project belongs.	MOSPI reports
13	STATE	The state in which the project is located.	MOSPI reports and publications of the Ministry relevant for the Sector

Figure 3. Table 2
2.pdf

Table 2: Summary Statistics: All Sectors

		% Cost Overrun				% Time Overrun			
Sector	Number Of Projects	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Atomic Energy	12	15.05	113.12	-84.89	265.12	301.02	570.48	-3.13	2033.33
Civil Aviation	51	-2.07	38.97	-80.32	109.18	67.20	56.01	-12.20	289.29
Coal	102	-11.42	91.72	-99.73	466.23	30.42	69.70	-93.33	359.57
Fertilizers	16	-12.57	28.92	-67.75	50.13	26.53	41.80	-18.18	109.30
Finance	1	132.91	.	132.91	132.91	302.78	.	302.78	302.78
Health and family Welfare	2	302.30	92.96	236.56	368.03	268.04	208.63	120.51	415.56
I & B	7	14.00	62.97	-34.60	134.64	206.98	140.57	101.67	491.43
Mines	5	-33.16	20.65	-62.78	-9.88	42.44	36.23	-2.78	98.11
Petrochemicals	3	-12.22	25.92	-28.40	17.68	74.43	3.05	70.91	76.19
Petroleum	125	-15.82	29.12	-80.87	106.77	38.52	50.31	-41.67	242.86
Power	108	51.09	271.36	-61.83	2603.96	33.55	54.89	-50.00	202.08
Railways	123	94.06	178.33	-65.49	1287.98	118.05	141.13	-2.17	1100.00
Road Transport and Highways	169	14.50	61.09	-93.86	416.72	46.48	54.66	-28.26	317.39
Shipping and Ports	61	-1.35	84.35	-90.37	574.38	118.64	276.79	-7.14	2150.00
Steel	44	-15.41	47.32	-91.85	235.88	50.49	60.08	-25.00	305.56
Telecommunication	74	-33.82	56.22	-98.40	279.46	248.82	253.98	-18.18	1200.00
Urban Development	24	12.31	50.27	-48.81	144.00	66.44	44.58	3.60	166.67
Total	928	15.06	131.26	-99.73	2603.96	79.46	152.98	-93.33	2150.00

Table 3: Category-wise distribution of projects (all sectors)

Sectors/States	**Number of projects**
Road, Railways, and Urban-development	316
Civil Aviation, Shipping and Ports and Power	221
Inter-state; Spanning across multiple states	91
Punjab, Haryana, Delhi, Gujarat, Maharashtra,	252
A.P, Tamil Nadu, Karnataka, Kerala	222
North-East and J&K	64

Table 4: Summary Statistics: Aspects Covered (all sectors)

Variables	Mean	Std. Dev.
PCGECOSTOVRRN	15.06	131.26
PCGETIMEOVRRN	79.50	152.98
TIMELAPSE	290.03	63.59
$TIMELAPSE^2$	88153.83	34162.54
INITIAL COST	291.46	619.20
IMPLPHASE	45.39	48.08

Figure 4. Table 5
5.pdf

Table 5: Summary Statistics: Delays and Cost overruns (Road and Railways)

Sector	Road (NHAI data)			Railways (MOSPI data)		
	PPPs	Non-PPPs	ALL Projects	PPPs	Non-PPPs	ALL Projects
Number of Projects	50	145	195	0	123	123
%age of projects with positive Time Overrun	74	78.62	77.44	NA	98.37	98.37
Mean %Time Overrun	17.49	49.30	41.1438 4	NA	118.05	118.045
%age of projects with positive Cost Overruns	74	55.172	60	NA	82.11	82.11
Mean % Cost Overruns	21.39	5.98	9.93	NA	94.06	94.06

Table 6: Summary Statistics: Road Projects (NHAI data)

Variable	Mean	Std. Dev.	Min	Max
TIME LAPSE (MONTHS)	53.18974	26.17467	0	108
TIME LAPSE Sq (MONTHS Sq)	3510.749	3113.801	0	11664
INITIAL COST	226.9915	164.0463	12.15	710
IMPLEMENTATION PHASE	31.69231	8.373848	14	82
COST OVERRUN(%age)	9.92837	31.18886	-83.014	159.097
TIME OVERRUN (%age)	41.68907	46.64695	-31.579	274.0741
TIME OVERRUN Sq	3902.758	7654.422	0	75116.59

Table 7: Summary Statistics: Railways Projects (MOSPI data)

Variable	Mean	Std. Dev.	Min	Max
TIME LAPSE (MONTHS)	233.7642	61.07575	0	374
TIME LAPSE Sq (MONTHS Sq)	58345.63	26145.37	0	139876
INITIAL COST	93.63854	130.8549	6.74	968
IMPLEMENTATION PHASE	65.78862	38.10065	11	239
COST OVERRUN(%age)	94.06268	178.3289	-65.49	1287.98
TIME OVERRUN (%age)	118.0493	141.1263	-2.17	1100
TIME OVERRUN Sq	33690.33	121846.7	0	1210000

Figure 5. Table 8
8.pdf

TABLE 8: ALL SECTORS

Variables	Model 1 PCGETIMEOVRRN (% Time Overrun)	Model 1 PCGECOSTOVRRN (% Cost Overrun)	Model 2 PCGETIMEOVRRN (% Time Overrun)	Model 2 PCGECOSTOVRRN (% Cost Overrun)
PCGETIMEOVRRN		0.0854 [0.0224] (0.000)		0.0949 [0.0220] (0.000)
TIMELAPSE	-2.8993 [0.3714] (0.000)	-2.7328 [0.3662] (0.000)	-2.2846 [0.3037] (0.000)	-2.3500 [0.3782] (0.000)
TIMELAPSE Sq	0.0039 [0.0006] (0.000)	0.0043 [0.0006] (0.000)	0.0029 [0.0005] (0.000)	0.0037 [0.0006] (0.000)
INITIAL COST	-0.0016 [0.0053] (0.758)	0.0144 [0.0033] (0.000)		
IMPLPHASE	-1.8848 [0.1565] (0.000)	0.1430 [0.1117] (0.201)	-1.7513 [0.1449] (0.000)	0.2170 [0.1058] (0.041)
DRRU	52.4719 [5.3119] (0.000)	40.0284 [3.4134] (0.000)	51.1584 [5.1512] (0.000)	37.4532 [3.3739] (0.000)
DCSPP	23.1145 [4.7073] (0.000)	20.1239 [3.3279] (0.000)	21.7332 [4.6854] (0.000)	17.5595 [3.3167] (0.000)
DTA	155.6228 [17.3884] (0.000)	-29.5410 [6.9564] (0.000)	159.2271 [17.5965] (0.000)	-33.5075 [6.6734] (0.000)
DSTATES	-9.5303 [6.1470] (0.121)	3.9355 [4.9466] (0.427)	-12.2252 [5.6048] (0.029)	4.7312 [4.6512] (0.309)
DMRICH	-2.6099 [5.5619] (0.639)	-0.4604 [3.2476] (0.887)	-2.9584 [5.2901] (0.576)	1.6575 [3.2676] (0.612)
DRICH	-4.8560 [5.0631] (0.338)	-4.7192 [3.0916] (0.127)	-6.2061 [4.9688] (0.212)	-4.2426 [3.0811] (0.169)
DNE	-2.8802 [7.4362] (0.699)	14.1414 [6.3857] (0.027)	3.1680 [11.1237] (0.776)	15.5355 [7.9015] (0.050)
CONSTANT	615.0301 [56.1885] (0.000)	383.9315 [55.8855] (0.000)	514.6568 [45.2008] (0.000)	324.6392 [58.0830] (0.000)
Observations	797	797	793	793
R-squared	0.4856	0.4521	0.4698	0.4059

* White's heteroscedastic consistent estimates. Robust standard error in square parentheses. P-value in round parentheses.

Figure 6. Table 9
9.pdf

TABLE 9: ALL SECTORS Quantile Regression

Variables	Model 1 PCGETIMEOVRRN (% Time Overrun)	Model 1 PCGECOSTOVRRN (% Cost Overrun)	Model 2 PCGETIMEOVRRN (% Time Overrun)	Model 2 PCGECOSTOVRRN (% Cost Overrun)
PCGETIMEOVRRN		0.0238 [0.0135] (0.078)		0.0210 [0.0108] (0.051)
TIMELAPSE	-1.6575 [0.1667] (0.000)	-3.3612 [0.1750] (0.000)	-1.6125 [0.1631] (0.000)	-3.3535 [0.1395] (0.000)
TIMELAPSE2	0.0019 [0.0003] (0.000)	0.0053 [0.0003] (0.000)	0.0018 [0.0003] (0.000)	0.0053 [0.0003] (0.000)
INITIAL COST	0.0003 [0.0027] (0.923)	0.0048 [0.0030] (0.112)		
IMPLPHASE	-1.3812 [0.0389] (0.000)	0.0511 [0.0418] (0.221)	-1.3557 [0.0381] (0.000)	0.0482 [0.0333] (0.149)
DRRU	42.0435 [4.3663] (0.000)	38.8320 [4.6669] (0.000)	41.5236 [4.2510] (0.000)	37.9306 [3.6947] (0.000)
DCSPP	21.3950 [4.8514] (0.000)	12.6426 [5.1749] (0.015)	21.2230 [4.7542] (0.000)	13.3243 [4.1366] (0.001)
DTA	126.6826 [6.6537] (0.000)	-20.3786 [7.6012] (0.007)	127.7805 [6.5350] (0.000)	-21.3393 [6.0619] (0.000)
DSTATES	-6.7338 [5.9723] (0.260)	9.6266 [6.3671] (0.131)	-7.0454 [5.8716] (0.230)	11.3310 [5.0564] (0.025)
DMRICH	-3.5019 [4.3897] (0.425)	1.7691 [4.6549] (0.704)	-4.4538 [4.3183] (0.303)	1.6225 [3.7226] (0.663)
DRICH	-7.1624 [4.5287] (0.114)	-1.3236 [4.7965] (0.783)	-7.1073 [4.4368] (0.110)	-0.8019 [3.8363] (0.834)
DNE	2.1731 [7.2072] (0.763)	14.7062 [7.6990] (0.056)	2.3591 [7.0501] (0.738)	16.0438 [6.1209] (0.009)
CONSTANT	404.0795 [22.5214] (0.000)	490.4227 [23.8009] (0.000)	396.2734 [22.1004] (0.000)	490.8609 [19.0289] (0.000)
Observations	928	928	928	928
Pseudo R2	0.1851	0.2143	0.1851	0.2128

* Robust standard error in square parentheses. P-value in round parentheses.

Figure 7. Table 10
10.pdf

TABLE 3 – ROADS AND RAILWAYS

Variables	Ordinary Least Square		Quantile Regression	
	PCGETIMEOVRRN (% Time Overrun)	PCGECOSTOVRRN (% Cost Overrun)	PCGETIMEOVRRN (% Time Overrun)	PCGECOSTOVRRN (% Cost Overrun)
PCGETIMEOVRRN		0.1274 [0.0648] (0.051)		0.0745 [0.0370] (0.045)
TIMELAPSE	-1.1443 [0.3883] (0.004)	-3.3797 [0.5844] (0.000)	-1.2023 [0.2232] (0.000)	-4.3269 [0.3129] (0.000)
TIMELAPSE2	0.0005 [0.0007] (0.502)	0.0056 [0.0010] (0.000)	0.0009 [0.0004] (0.046)	0.0070 [0.0006] (0.000)
INITIAL COST	0.0051 [0.0274] (0.852)	-0.0347 [0.0208] (0.096)	0.0112 [0.0200] (0.577)	-0.0112 [0.0244] (0.648)
IMPLPHASE	-1.9426 [0.2736] (0.000)	0.7148 [0.1870] (0.000)	-1.5738 [0.1282] (0.000)	0.5481 [0.1872] (0.004)
DSTATES	-12.9842 [10.8660] (0.233)	1.4669 [13.4085] (0.913)	0.9132 [8.2953] (0.912)	7.5682 [10.7704] (0.483)
DMRICH	-15.1608 [8.6738] (0.082)	-2.6082 [7.3012] (0.721)	-10.3133 [7.0070] (0.142)	1.0570 [8.6700] (0.903)
DRICH	-11.5019 [6.8865] (0.096)	1.1477 [5.4644] (0.834)	-9.3751 [6.3429] (0.141)	2.3770 [7.9098] (0.764)
DNE	Dropped	Dropped	1.9158 [15.9629] (0.905)	19.6844 [19.6709] (0.318)
CONSTANT	457.4337 [65.1024] (0.000)	480.3877 [85.9529] (0.000)	414.4814 [34.8002] (0.000)	637.0103 [51.4321] (0.000)
Observations	230	230	292	292
R-squared/ Pseudo R2	0.5125	0.4819	0.2572	0.2371

* Robust standard error in square parentheses. P-value in round parentheses.

Figure 8. Table 11
11.pdf

TABLE 11
Logit Regressions: Dependent variable Pr(COST OVERRUN)

	Roads		Roads+Railways
TIME OVERRUN(%age)	-0.0153 [0.0095] (0.1074)	-0.0186 [0.0099] (0.0612)	0.0059 [0.0025] (0.018)
TIME OVERRUN Sq(%age)	0.0001 [0.0001] (0.0907)	0.0002 [0.0001] (0.0299)	
INITIALCOST (Rs Cr.)	-0.0021 [0.0011] (0.0666)	-0.0008 [0.0013] (0.5052)	0.0002 [0.0010] (0.8563)
IMPLEMENTATION PHASE	0.0135 [0.0204] (0.5079)	0.0161 [0.0209] (0.4428)	0.0172 [0.0086] (0.0456)
PPP	**1.5387** **[0.5179]** **(0.0030)**	**1.8253** **[0.5220]** **(0.0005)**	
DMRICH	-0.8982 [0.4592] (0.0505)	-1.2153 [0.4764] (0.0107)	0.2136 [0.3818] (0.5758)
DRICH	-0.3808 [0.3694] (0.3026)	-0.6337 [0.4038] (0.1166)	0.0605 [0.3039] (0.8423)
TIME LAPSE (MONTHS)		-0.1084 [0.0374] (0.0038)	-0.0098 [0.0038] (0.0093)
TIME LAPSE Sq (MONTHS)		0.0008 [0.0003] (0.0088)	
CONSTANT	0.6978 [0.7457] (0.3494)	3.4494 [1.1701] (0.0032)	2.0586 [1.4188] (0.1468)
Observations	192	192	292
LR Chi Sq	20.84	32.99	38.99
Prob>Chi Sq	0.004	0.0001	0.0002
Pseudo R2	0.0811	0.1294	
LogLikelihood Ratio	-118.03	-111.01	

Robust p values in parentheses; Robust standard errors in brackets

Figure 9. Table 12
12.pdf

Table 11: Roads:

VARIABLES	Ordinary Least Squares: COST OVERRUN (%age)	Ordinary Least Squares: TIME OVERRUN (%age)	Ordinary Least Squares (outliers dropped by inspection): COST OVERRUN (%age)	Ordinary Least Squares (outliers dropped by inspection): TIME OVERRUN (%age)	Quantile regression: COST OVERRUN (%age)	Quantile regression: TIME OVERRUN (%age)
TIME OVERRUN (%age)	-0.1776 [0.0903] (0.0508)		-0.1744 [0.1173] (0.1395)		-0.1215 [0.1245] (0.3303)	
TIME OVERRUN Sq	0.0015 [0.0007] (0.0260)		0.002 [0.0012] (0.0866)		0.001 [0.0007] (0.1604)	
TIME LAPSE (MONTHS)	-1.1612 [0.4230] (0.0067)	1.9594 [0.5520] (0.0005)	-2.1936 [0.4325] 0.0000	0.9171 [0.6971] (0.1906)	-1.5213 [0.4991] (0.0026)	1.2425 [0.4690] (0.0088)
TIME LAPSE Sq (MONTHS Sq)	0.0082 [0.0034] (0.0163)	-0.0173 [0.0045] (0.0002)	0.0166 [0.0035] 0.0000	-0.0095 [0.0056] (0.0920)	0.0116 [0.0042] (0.0057)	-0.0108 [0.0039] (0.0065)
INITIALCOST (Rs. Cr)	-0.0258 [0.0144] (0.0752)	0.0332 [0.0237] (0.1636)	-0.0214 [0.0189] (0.2580)	0.064 [0.0268] (0.0183)	-0.036 [0.0214] (0.0947)	0.0287 [0.0202] (0.1580)
IMPLEMENTATION PHASE	0.9865 [0.3373] (0.0039)	-0.7062 [0.5486] (0.1997)	1.2234 [0.3130] (0.0001)	-1.4963 [0.6335] (0.0197)	0.7759 [0.3457] (0.0260)	-0.8759 [0.2977] (0.0037)
PPP	22.3232 [6.1658] (0.0004)	-28.4085 [6.2554] 0.0000	24.4391 [4.5762] 0.0000	-17.5805 [7.5527] (0.0215)	24.2055 [7.2033] (0.0009)	-24.9968 [6.6570] (0.0002)
DMRich	-3.1642 [5.0102] (0.5285)	-13.6599 [8.5320] (0.1112)	-5.9812 [4.1281] (0.1498)	-35.0389 [8.1718] 0.0000	-5.8278 [7.1019] (0.4129)	-14.9314 [7.0723] (0.0361)
DRich	-5.0952 [4.2294] (0.2299)	-0.6757 [6.9418] (0.9226)	-3.1267 [3.8764] (0.4214)	-9.3567 [7.1885] (0.1954)	-3.284 [5.9907] (0.5842)	-0.177 [5.8975] (0.9761)
Constant	16.2952 [14.1429] (0.2508)	21.708 [21.2865] (0.3092)	31.4254 [15.2501] (0.0414)	68.8723 [25.7870] (0.0085)	30.4993 [16.5192] (0.0664)	39.2564 [15.9488] (0.0147)
Observations	185	185	137	137	195	195
R-squared	0.2312	0.1957	0.4108	0.2694	0.1152	0.1503

Robust p values in round parentheses; Robust standard errors in square brackets.

Figure 10. Table 13
13.pdf

Table 12: Railways Projects:

Dependent Variable: PCRTIMEOVERRUN
Method: Least Squares
Included observations: 123

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	544.7779	116.0922	4.692631	0.0000
INITIALCOST	0.042906	0.081913	0.523802	0.6014
IMPPHASE	-2.575687	0.362348	-7.108319	0.0000
PCGSDP	0.000184	0.000968	0.190480	0.8492
TIMELAPSE	-1.587628	0.815480	-1.946862	0.0538
TIMELAPSE^2	0.001241	0.001762	0.704306	0.4826
DCIVILWORKS	40.52796	22.15674	1.829149	0.0698

R-squared	0.344330	Mean dependent var	116.2405
Adjusted R-squared	0.312346	S.D. dependent var	138.6047
S.E. of regression	114.9378	Akaike info criterion	12.37900
Sum squared resid	1624915.	Schwarz criterion	12.53341
Log likelihood	-797.6351	F-statistic	10.76574
Durbin-Watson stat	1.732902	Prob(F-statistic)	0.000000

Dependent Variable: PCRCOSTOVERRUN
Method: Least Squares
Sample: 1 123
Included observations: 123
Newey-West HAC Standard Errors & Covariance (lag truncation=4)

Variable	Coefficient	Std. Error	t-Statistic	Prob.
C	606.9070	189.8339	3.197043	0.0018
INITIALCOST	0.054242	0.048457	1.119395	0.2652
IMPPHASE	1.502780	0.381751	3.936545	0.0001
PCGSDP	-5.20E-05	0.000759	-0.068568	0.9454
TIMELAPSE	-5.423991	1.312248	-4.133358	0.0001
TIMELAPSE^2	0.009919	0.002536	3.911202	0.0002
DCIVILWORKS	90.32347	22.03809	4.098517	0.0001
PCRTIMEOVERRUN	0.114300	0.032237	3.545603	0.0006

R-squared	0.710361	Mean dependent var	90.19885
Adjusted R-squared	0.693742	S.D. dependent var	173.0885
S.E. of regression	95.78816	Akaike info criterion	12.02172
Sum squared resid	1119395.	Schwarz criterion	12.19818
Log likelihood	-773.4117	F-statistic	42.74482
Durbin-Watson stat	1.977357	Prob(F-statistic)	0.000000

Note: PCGSDP is the per-capita SGDP product of the state in which project is located. Results a similar if we replace this variable with regional dummies.