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Title (TBC) – Procurement Choices and Infrastructure Costs

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1 Introduction

For many countries around the world building new infrastructure or repairing the existing one stands near the top of the political agenda. On one hand they face the political challenge of securing more funding. On the other, potentially large efficiency gains could be achieved spending the funds that are available. One such area is procurement design.

In the past decades contract theory yielded several Nobel laureates (e.g. Oliver Williamson, Oliver Hart). Their insights led to significant advances in various aspects of how we contract. In the case of infrastructure delivery however, our understanding of the outcomes of different contractual models is very limited despite decades of their use. There is a general lack of empirical data to test whether our theoretical comprehension is complete.

Available evidence from testing contract and auction theory propositions allows us to explain the performance of the most common and simplest procurement formats (a Design-Bid-Build contract with a cost-plus payment mechanism, procured in an auction) relatively well.

This is not the case for other procurement formats or larger projects. For example, it is still not fully clear whether contracts that bundle the Design&Build phase outperform the traditional Design-Bid-Build contract, where the two phases are procured separately. Similarly, the implications of using high-powered incentives that lead to greater time and cost certainty in major projects are unclear. Any judgment on other dimensions is even more challenging. In the absence of evidence industry perceptions need not match reality.

Furthermore, the fact that data on some dimensions of project performance are available and publicly observable can create a bias in procurement and contracting choices against those that are not. For example, cost overruns bear serious reputational concerns and are relatively easy to measure. It is far more difficult to determine whether a project was relatively “expensive”.

By implication, public clients today procure billions of USD of transport and other infrastructure around the world without a full view of the trade-offs between different project performance objectives.

¹ The analysis and the findings of this paper do not necessarily reflect the views of the International Transport Forum at the OECD or the QUT.

Using available evidence on road infrastructure from advanced economies this paper will focus on one trade-off – the pursuit of cost certainty v total cost. We will show:

A) High-powered contracts (such as fixed-price/fixed date construction contracts used in PPPs) are disproportionately more costly than less powerful traditional procurement contracts, a phenomenon which contract theory to date does not explain well.

B) That point A) is a symptom of a larger issue – empirically we know relatively little about how procurement choices affect contract outcomes in (infrastructure) procurement. To make progress on this front we need to introduce systematic infrastructure cost and performance benchmarking, which will also include procurement choices as an explanatory variable. This point however is not yet recognized by policy makers.

We build our case on existing evidence. Despite the seemingly narrow focus (high v low powered contracts) contract outcomes interact with other procurement choices as well (procured through negotiations or auction; bundled design and construction or not). In consequence our paper requires a relatively complete overview of procurement choices, related theory and empirical evidence relevant for infrastructure procurement.

The 2nd section of this paper provides a brief historical overview of the main procurement choices.

The 3rd section surmises the general characteristics of procurement choices today.

The 4th section captures what contract and auction theory predict with regard to high and low powered contracts. In the same section we also highlight the relevance of key performance dimensions of projects (cost/time variability, cost relative to the physical output, quality).

The 5th section provides an overview of empirical data available to assess to what extent evidence matches theoretical predictions. It juxtaposes low powered procurement options against high-powered ones. In terms of infrastructure most available evidence comes from transport infrastructure or road projects.

The 6th section presents a case study how procurement choices are informed in today's practice.

The 7th section presents a recent new approach to procurement of major infrastructure

The 8th section concludes with a discussion. It highlights where the theoretical predictions and empirical evidence do not meet. It also highlights a need for international infrastructure benchmarking to advance the theory and practice of contract design.

We note that in its evidence review this paper specifically focuses on the most advanced economies with competent public clients and institutions. Two reasons merit this choice. The first is that the availability of evidence for advanced economies is much greater. The second is that we can more easily focus on the interaction between procurement practices and project outcomes, without serious white

noise from the issues of systematic corruption and underdeveloped institutions, i.e. these will have a far lesser significance than in the developing world.

2 History and procurement choices

The challenges that we face in infrastructure procurement today were always present. Our methods may have improved over time but so has the complexity of what we're building. Heated discussions about whether and when cost-plus or lump-sum contracts are better were documented already in the 19th century England. Against a much more varied procurement context the same issues are still of interest today.

The history of public works contracting is ancient. In the Roman Empire for example, the first roads were designed and built by the army with the aid of civilian labour. Over time in the Roman Empire these activities were contracted out to contractors - master builders (Adkins and Adkins 2014). The works were given away through a tender and it is assumed that the lowest price was the winning criteria (Du Plessis 2004).

The master builder was an all-in-one profile, responsible for the design and delivery of the project. It wasn't until the Middle Ages, when increasing complexity of projects and the broader availability of paper (used to make pre-construction plans) led to the establishment of a specialised profession, responsible for the design of the project (i.e. the "designer" or Architect), separating it from the function of the builder (Kostof 2000). By implication, the builder now got involved later in the project development process, when the design was (or should have been) already worked out in detail. This was also the birth of the oldest and to date dominant delivery model (also for infrastructure), called Design-Bid-Build (DBB).

Aside from the delivery model, there are other contract dimensions that define performance incentives for the contractor. The earliest documented considerations of risk allocation and incentives in contracts go to Roman Empire times. In his 10 books on Roman construction practices Caesar Julius' chief engineer Vitruvius acknowledged the importance of construction risk allocation. In terms of incentives to the builders for example he proposed to Caesar Augustus the reintroduction of a practice from ancient Greece (Morgan 1960)²:

"When a [master builder] accepts the charge of a public work, he has to promise what the cost of it will be. His estimate is handed to the magistrate, and his property is pledged as security until the work is done. When it is finished, if the outlay agrees with his statement, he is complimented by decrees and marks of honour. If no more than a fourth has been added to his estimate, it is furnished by the treasury, and no penalty is inflicted. But when more than one-fourth has been spent in addition on the work, the money required to furnish it is taken from his property."

² The oldest construction codes go back to Hamurabi 1754 BC (Prince 1904), where the principle of an eye for an eye was observed. For example, for a collapsed building which killed its owner, the builder was to be put to death as well.

The above is an example of an early payment mechanism to incentivise performance that has some similarities with today's pain/gain sharing in contracts. The basic payment mechanisms widely used today were also documented around medieval times. Construction contracts from the Spanish city of Girona in the 14th century were observed to be applying three different formats, including unit price and lump-sum (Chamorro et al. 2018). Unit price (also known as admeasurement or bill of quantities) contracts define rates per unit of work. Estimates of quantities are provided at the beginning and a correction applied at the end given the actually executed quantities. A lump-sum (or fixed price) contract on the other hand would determine the cost of the contract in advance without a detailed cost breakdown.

Expert discussions on the performance of the two payment mechanisms were documented already between 1800 – 1830 when the UK, exhausted by the war with the French wanted to be more careful about spending public money. The proponents of the lump-sum contract argued that this is the only way of keeping within ones cost estimates (Port, 1967, 97):

“an architect before he can make a [lump-sum] contract must make a specification, in which he must set down everything that can possibly occur... Before a [lump-sum] estimate can be made he must digest his plan, and every part of it must be made out, and he must put down on paper every detail that will possibly happen; and therefore you are sure that the architect must do his duty in the first instance...”.

As we shall see in the review of theoretical and empirical work, many of the old dilemmas remain unresolved.

Today most if not all public infrastructure managers in advanced economies contract parts or all of design, construction, and maintenance activities to the market. Exceptions in advanced economies however existed until recently³.

Based on the evidence from the 20th century the projects became more complex, more expensive (Brooks and Liscow 2019) and in terms of size larger (Flyvbjerg 2014).

The next section broadly explains what are the general characteristics of the main procurement options that exist today and sets the scene for the review of theory and empirical evidence.

3 Broad characteristics of (infrastructure) procurement choices

The brief historical introduction above highlighted three key dimensions of procurement choices: how do we select the contractor, what is the scope of work he's hired for, and on what basis will he be remunerated. Building on Kennedy et al. (2018) we define these as follows:

- *How do we select the contractor*

The bidder selection process between the moment a call for proposals is published to the moment the contract is signed with the preferred contractor. Multiple options exist in-between

³ Prior to reforms that ended in 2003 the Norwegian Public Roads Administration planned and built 60% of the main roads itself (40% was subject to competitive tendering) (Odeck 2014).

a lowest price auction and a negotiation with a single bidder. Negotiations facilitate the exchange of pre-contract information that reduces uncertainty at the expense of competition. They also imply greater discretion in bidder selection.

- *The scope of work the contractor is hired for*
The delivery model defines the stage of the project development (design maturity) at which a contractor is engaged, and for what scope of works/services (e.g. build-only, design and build, related risk allocation etc.).
- *On what basis will the contractor be remunerated*
Contract power relates to the effectiveness of risk transfer and how strong the rewards or penalties are to manage performance metrics such as cost/time. The payment method is a key element of contract power. Two polar opposites in this regard are cost-plus a fee or the lump-sum approaches.

In practice the combinations between the options in the three dimensions are not random⁴.

The available literature shows that the workhorse of transport infrastructure procurement remains the Design-Bid-Build model, procured through a low bid auction and a cost-plus⁵ (bill of quantities) payment mechanism (e.g. Minchin et al. 2013; FHWA 2016). This is true regardless of the project size. This procurement format is considered to be low-powered. Risk transfer to the contractor is minimal. A lump-sum contract would be considered a high-powered contract.

For major projects, ranging from several USD million to hundreds of millions other alternative contracting approaches have started slowly increasing in use since the 1990 in some advanced economies like the US, UK, Australia, Sweden, Netherlands. (e.g. FHWA 2016 for US, ...). In this paper our scope does not extend beyond Design-Build and its close relative the Engineering-Procurement-Construction contract (EPC), which is the default option for Public-Private Partnerships (PPPs).

Both alternatives can be procured through auctions or negotiated procedures, though the latter should be preferred. They typically rely on the lump-sum payment mechanism.

A key distinction among the three delivery models above is at what time in the project development is the contractor (=winning bidder) expected to price the project. A Design-Bid-Build contractor would bid at a stage when the design is fully developed. In Design-Build only an outline design will be available, where the engineering is well below 50% complete. For an Engineering-Procurement-Construction bidder there will be no outline design. He starts with an output specification, describing what functions

⁴ More detail about the broad options possible under all three dimensions is available in Annexes 1-3.

⁵ The economics literature distinguishes between cost-plus and fixed price contracts, whereas in construction contract law several formats could qualify. The “cost-plus” captures both the re-measurement and “cost-plus fee” payment mechanisms, while the fixed price contracts refer to lump-sum payment mechanism.

the asset should perform. The Design-Build and Engineering-Procurement-Construction bidder are expected to develop and price their solutions during the bidding process⁶.

Because the two alternatives also transfer design risk and ask for a high cost certainty through the lump-sum payment mechanism and additional incentive mechanisms (e.g. liquidated damages for delays), they are considered to be an even higher-powered procurement formats, with very high-risk transfer.

Against this introduction we next look at why the economic theory predicts that the high-powered formats should perform better than the low powered ones. Contract and auction theory deal with our subject.

4 Contract theory applications to infrastructure/construction procurement

In terms of how much risk one should transfer in a contract, the principal-agent theory defined the problem as a trade-off between incentives and insurance. Incentives are provided through transferring risk or making the agent's payoff dependent on his effort. The agent's risk aversion implies there is a cost to risk transfer. Hence, lower agent's risk aversion allows the principal to provide more incentives by making his payment dependant on his effort, while higher risk aversion increases the gains from insuring the agent and reduces the pay-for-performance sensitivity (Holmstrom and Milgrom 1987). In short, risk transfer should be executed at a level, where the risk premium does not offset the gains from increased effort.

On top of this basic relation, contract theory predicts the effect of contract power made for two settings – for complete and incomplete contracts.

In complete contracts there are no ex-post renegotiations. The bidder's price fully reveals his revenue expectations ex-ante. This could be the case for smaller and simpler contracts in infrastructure delivery.

In incomplete contracts the bidder's price no longer reveals his revenue expectations. Renegotiations during contract execution are expected by the bidders. Contracts are incomplete because writing comprehensive contracts is costly (Coase 1937, Williamson 1975, 1985, and Klein et al 1978), the project is too complex or the mere uncertainty of the future makes a complete contract impossible. Cost overruns in projects for example are a manifestation of this principle.

4.1 Contract power and complete contracts

The narrative of complete contracts is followed by the principal-agent theory. Its core focus is the information asymmetry between the principal and the agent, which leads to adverse selection issues ex-ante and moral hazard ex-post contract signature (Laffont & Tirole, 1993).

⁶ In practice these default options represent what is common, but they may not be always observed. E.g. the level of outline design that the procuring entity makes available could vary.

Adverse selection in the bidder selection process is a problem, where the principal does not know the true efficiency of the agent. This makes it difficult for the principal to determine, who will invest the most effort at a given incentive. The theoretical solution to the adverse selection problem has been to offer the (potential) agents a menu of contracts, which allow them to be interested in the trade and reveal their true type (Hart and Holmstrom 1987). Because in the complete contract setting the initial bid fully reveals the contractor's revenue expectations up front and there can be no ex-post renegotiation, the lump-sum (high-powered) contract will ensure the best contractor is chosen in the competition (Bajari and Tadelis 2001).

The moral hazard post contract signature manifests as quality shading. If the quality of the output is difficult to monitor, the contractor will reduce the quality to cut cost and increase profit margins. In this case high power incentives will exacerbate quality shading (Holmstrom and Milgrom, 1991). If the quality is observable (at least after the job is finished), we can hold the agent financially accountable for his actions (Laffont & Martimort, 2001), e.g. through performance guarantees.

The theoretical prediction of this part of contract theory is that in complete contracts we should rely on high-powered schemes.

4.2 Contract power and incomplete contracts

Contractual incompleteness creates incentives for ex-post bargaining and good and bad-faith renegotiation (Williamson, 1979; Grossman & Hart, 1986; Hart & Moore, 1990; Hart, 1995). The first is necessary due to unforeseen events and the second is the result of strategic behaviour to extract additional rents. The need to absorb changes leads to adaptation cost.

The early proposition was that low powered contracts should be preferred for dealing with contractual incompleteness (Williamson 1985; Bajari & Tadelis 2001). Low powered incentives have adaptability advantages. In construction for example, this would be because cost-plus contracts help solve the additional payments if the actual quantities differ from the estimated ones, i.e. unit prices in the bill of quantities offer a starting price list to evaluate variation claims⁷. The lump-sum contract on the other hand only involves a general cost breakdown and it is not usual for it to contain a price/quantity breakdown as in the cost-plus (bill of quantity) contracts. Hence the lump-sum contract is more rigid and involves greater transaction cost to renegotiate.

Later, the property rights theory (PRT) (Hart, 1995; 2003; Iossa & Martimort, 2015) proposed that it is possible to solve the incomplete contract problem and use high powered incentives at the same time.

In property rights theory the appropriate assignment of ownership or residual control rights gives the owner of the asset bargaining power in situations beyond those defined in the contract. The logic of this approach was manifest in the Design & Build contract where any issues with incomplete design are internalized within a single contract. Going one step further, in a Public-Private Partnerships (PPP) the residual control rights are transferred to a private party.

⁷ The contractor will still try to renegotiate the unit prices for the added work, however the initial unit-prices in the bill of quantities offer a reference point. This "anchor" is not available in the lump-sum arrangement.

In a stereotypical PPP, a dedicated project company (a Special Purpose Vehicle) enters the contractual relationship with the public sector. The agreement between them defines an output specification, i.e. what the project is meant to achieve, as opposed to what the project is (the input). The PPP is the bundling of project phases, from design to operations, in one long-term contract (e.g. design-build-finance-operate-maintain, or DBFOM⁸, contract). The project company finances the project and recovers its investment either through a service level agreement with the public client or by being granted the right to charge the users of the infrastructure (Engel, Fischer, and Galetovic 2014). The project company does not itself execute the project but organizes the execution through a network of contracts, passing the technical risks onto its suppliers (e.g. construction risk to the construction contractor).

In such an arrangement the issues of incomplete contracts are internalized through two key incentives:

- the output specification approach implies that the private sector partner obtains the residual control (ownership) rights to the infrastructure asset, i.e. chooses the solutions to meet the predefined service standards. This approach is supposed to reduce contractual incompleteness issues, compared to the traditional approach, where the input is defined by the public client⁹. The output specification also implies a full transfer of design, construction, and operations risk – a lump-sum/fixed date contract.
- The bundling of asset construction and operation/maintenance into one single contract also incentivises the private partner to invest into quality at the construction phase if such investments lower the project's lifecycle operating/maintenance cost.

Iossa & Martimort (2015)¹⁰ formalized these propositions and found that the Design-Build-Operate-Maintain bundle provision beats traditional procurement if benefits from bundling are significant¹¹. A key proposition that defines their results is the assumption that the life-cycle cost optimisation savings offset the (additional) risk premia of a high-powered (PPP) contract, where the private party bears the operations risk, hence they suggested bundling and high-powered contracts go hand in hand¹².

⁸ While this is a common term to describe the broad contract arrangement in a PPP, the phase of design and build is contracted as the Engineering-Procurement-Construction contract. As laid out in section three this format also bundles the design and build phases, but is generally tendered against an output specification. No outline design is made available.

⁹ The transfer of control rights also incentivizes investment into relation-specific assets (sunk with no or limited alternative use), i.e. infrastructure, despite the presence of an incomplete contract. In theory it would also incentivize innovation.

¹⁰ In an earlier paper (Iossa and Martimort 2012) they included uncertainty in user demand as a factor in the risk premium and noted that the PPP only makes sense if the private party can assess the risk well. Hence bundled contracts would make sense for less complex contracts. This point was not transferred to the more recent paper or applied in the context of construction risk.

¹¹ An analogue approach could be applied to a Design-Build contract only, arguing that contract incompleteness due to design issues would be internalized in this contract format.

¹² They also acknowledge that the long-term nature of this contractual arrangement brings with it additional uncertainty (due to exogenous shocks), which may lead to renegotiation of the PPP contract itself (i.e. despite the PRT approach contractual incompleteness remains an issue).

An implicit assumption to the conclusion above is also that competition would not be affected by the process of bidder selection, bundling, and the high power of the contract.

Hence, the theoretical prediction in this section is that we should use high-powered incentives also in bundled contracts (i.e. where residual control is transferred).

The main body of contract theory is focused on issues arising from opportunistic behaviour and incomplete contracts with the onus on how to deal with post contract uncertainty. The trade-off between providing incentives for efficiency and reducing ex-post transaction cost due to renegotiations is at its centre. What has received less attention in this shift from principal-agent to property-rights theory is how the delivery model and contract power solutions interact with the bidder selection process. The amount of information the bidders have pre-contract to price the project is taken as a given.

4.3 Auction theory and contract power

Auction theory too considers the procurement in the complete and incomplete contract setting. Conversely to contract theory, it focusses on the bidder selection process and considers the project delivery model and contract power as a given. It does not consider delivery models or contract power. It does however yield insights for their application.

The traditional auction theory view has been that the benefits of competition always outweigh any other auction mechanism that involves fewer bidders (Bulow and Klemperer 1996). A key assumption behind this finding is (as initially in contract theory) that of complete contracts, i.e. that the object of the auction can be well defined, which means the (lowest) price becomes the key determinant of the optimal result.

As we noted above, in infrastructure procurement the more complex the object of procurement, the less complete the contract. With competition the solution of contract theory was to reduce the power of the contract or to bundle project phases. Auction theory proposed a third solution.

Goldberg (1977) suggested that competition for the contract stifles communication between the principal and the agent, which may lead to a suboptimal specification of the project. He argued that the bidders might have important information about construction practices, prices or other aspects that might allow the client to prepare a better informed tender, reducing ex-post adaptation cost. So far theoretical work tried to formalize the trade-off between ex-ante information exchange (in negotiations) and ex-post renegotiation in auctions (Herweg & Schmidt, 2017).

In cases, when the public clients repeatedly contract with a pool of the same firms the issue of incomplete contracts could also be managed by long-term relations - relational contracting, i.e. through the use of reputational mechanisms (Spagnolo 2012).

Reliance on mechanisms other than competition at the same time implies greater discretion in bidder selection on the side of the procuring entity. As a result, there is greater scope for corruption, favouritism or other practices that do not necessarily lead to best procurement results.

Both adjustments to the traditional view, which prefers auctions, focus on contractibility and by implication uncertainty as a source of adaptation cost. This has also been the main focus how uncertainty is considered in contract theory.

In a limited stream of auction theory literature (Milgrom & Weber 1982, Goeree and Offerman 2003), uncertainty affects the bidders' ability to price the subject of the tender (or risk) efficiently. Specifically, bidders can lack information about the true cost of the object that is being tendered¹³. When this is so, they will also not be able to accurately assess potential ex-post changes, and in consequence additional ex-post revenue opportunities. If bidders are risk averse, the perceived risk variance and the resulting risk premiums at a given level of competition will be higher.

Goeree and Offerman (2003) identify two effects of more information/lower uncertainty. First, if more information is made publicly available to the bidders, risk premia will get lower, and bidding will get more aggressive.¹⁴ Second, more public information may reduce the entry barriers for less experienced firms, increasing the number of competitors, which has a knock-on effect on the aggressiveness of the bidding again.

What the above implies is that contracts could be complete, a good level of competition could be present, the most efficient bidder could win, but the procurement of a project would still be inefficiently expensive if the bidders did not have sufficient information about the true cost of the object procured.

The theoretical prediction in this case does not explicitly extend to the question of when can we use high-powered contracts. Implicitly though it can be deduced that especially in the case of the latter the exchange of pre-contract information will be a key requirement.

¹³ As Goeree and Offerman (2003) explain, in private value auctions, bidders know their own value for the commodity but are unsure about others' valuations. In contrast, common value auctions pertain to situations in which the object for sale is worth the same to everyone, but bidders have different private information about its true value. The standard textbook example for a private value auction is the sale of a painting. A well-known example for a common value auction is the sale of oil drilling rights, which, to a first approximation, are worth the same to all competitors. In the real world most auctions a mix of both. If for example the competitors for the oil drilling rights used different technologies (=their cost structures would be different), their private valuations of the rights would be different. Hence, if the common value of the object is uncertain a bidder with a moderate private value and an overly optimistic estimate of the common value may outbid a rival with a superior private value but more realistic conjectures about the common value. If the common value were less uncertain, then bidders with superior private values (=the most efficient bidders) would consistently prevail, leading potentially to an even higher auction result. Goeree and Offerman's (2003) proposition is similar but distinct from the Principal Agent Theory problem of adverse selection driven by information asymmetry between principal and agent and cannot be solved by a menu of contracts.

¹⁴ The same result in conventional financial economics would be attributed to improved risk pricing efficiency (Makovšek and Moszoro 2018). It implies that risk premia do not only arise due to reduced risk diversification possibilities. They are also a result of the inability to accurately assess risk. As investors are risk averse disproportionate mark-ups are added to accommodate the lack of information about risk.

4.4 What theory does not yet address?

The contract and auction theories together consider the aspect of uncertainty in four dimensions:

- a) As a source of information asymmetry between the principal and the agent that interferes with the identification and selection of the most efficient bidder pre-contract
- b) As a source of information asymmetry between the principal and the agent, which ensures stronger incentives actually lead to higher effort post-contract
- c) As a source of renegotiations and adaptation cost post-contract
- d) As a source of more aggressive bidding pre-contract.

There is no economic theory that would unify the views of both theories in a single model. A point that has received insufficient attention is that the risk variance during the contract execution is not just a question of choice who will bear it, but that it can be reduced or increased. A further unaddressed key question is, whether it is more sensible to create the information to reduce the risk variance sooner in the project development cycle or later and who should do it.

Goldberg (1977) illustrated that if the bidders bore the cost of risk identification, it would be absorbed as overhead and included in future bids. Conversely, if the client fully compensated bidding cost that would equal a cost-plus contract negotiated with a single bidder. In the pre-contract phase, it would be inefficiently costly, but these costs could well be offset by greater efficiency in the contract execution phase (more aggressive bidding and better contract specification or engineering solutions).

If bidders are to bear the cost of risk identification, is it efficient all bidders (including the losers) produce the same information (all detect the same risks separately)? Against the prospect that they might lose, do bidders invest sufficiently in information production? These are major issues for the procurement of complex projects that remain unaddressed in theory.

The next section looks at empirical evidence to assess, whether the prediction of theory when high-powered contracts are to be preferred, are confirmed.

5 Empirical evidence on how procurement choices matter for project outcomes in infrastructure

The theoretical review predicts that high-powered contracts will be the best option in relatively small and simple projects, where the issues of incomplete contracts are expected to be limited. It also suggests that high-powered contracts can be used in more complex projects if the delivery model bundles the project development phases (transfers residual control).

The auction theory proposes that increased pre-contract information exchange is beneficial, reducing issues from incomplete contracts. This aspect will be especially relevant in contracts where more risk is transferred, i.e. high-powered contracts.

The evidence review is structured in the following steps.

First, we review evidence investigating the relevance of pre-contract exchange of information.

Second, we review work that tested contract theory propositions – the adaptation cost, profit margins, and relative cost of low and high-powered Design-Bid-Build contracts. These studies pursue small projects.

Third, as there are no studies that would assess the same categories with precision in large projects, evidence is compiled that allows a view on whether adaptation cost in larger projects increase and whether raising contract power in delivery models that bundle project phases disproportionately increases the cost.

Our focus on project size in the narrative reflects the absence of a broadly accepted system for classifying infrastructure projects by complexity. Hence, we assume, that as size grows by orders of magnitude, so does project complexity.

In terms of how the procurement choices above affect project outcomes, the minimum configuration to control for the trade-offs would include cost certainty (i.e. cost overruns), overall cost per physical unit of infrastructure, and quality.

We found that that the quality of infrastructure is not explicitly controlled in any of the studies. Implicit control follows from the fact that the studies we review predominantly focus on road infrastructure contracts in advanced economies. Road design standards are well established with a long tradition and quality supervision by the procuring entities is considered to be effective, i.e. quality shading is not considered to be a pervasive issue (as reported e.g. in Bajari, Houghton, and Tadelis (2014) or Bolotnyy and Vasserman (2019)).

5.1 Bidder selection and the relevance of pre-contract information exchange

Negotiations allow for more space to exchange pre-contract information than auctions. By definition, a negotiated process also reduces the power of competition, since a single bidder is normally pre-selected, with which the negotiation takes place. A competitive dialogue represents a compromise¹⁵, where in parallel negotiations take place with a few bidders. Negotiation bears increased transaction cost for both parties to the contract and also requires strong in-house competence on the side of the public client. There are no empirical studies that would investigate these relationships in terms of project outcomes^{16 17}.

¹⁵ See Appendix 1 for more detail.

¹⁶ A related set of studies investigates whether increased discretion in bidder selection leads to better outcomes or more corruption and opportunistic behaviour. Since greater discretion can be achieved regardless of whether one is using auctions or negotiations or a combination (through bidder selection criteria, restricted access...), this issue does not help investigate our points in the introduction of this paper (does higher contract power lead to disproportionately more costly contracts).

¹⁷ Lessons from the private sector (Bajari, McMillan, and Tadelis 2009) showed that in residential construction industry (private – private transactions) negotiated projects are generally awarded to more efficient or more

Increased pre-contract information exchange, however, is also possible in auctions. Procurement authorities have the possibility to share risk related information on the object of procurement, regardless of the bidder selection approach. The theoretical prediction was (Goeree and Offerman 2003) that making more information available during the tendering phase (i.e. reducing uncertainty) can lead to more aggressive bidding and also affect market entry.

Kosmopoulou and Zhou (2014) show how removing an exogenous risk factor for the contractors reduces the price of the winning bids in road construction. Considerable time may pass between the actual bid submission and contract completion. If input prices are volatile (e.g. oil), contractors need to be mindful of potential future price variations that affect the cost of their products (e.g. asphalt). As they cannot do much to control these costs, they are a source of exogenous uncertainty. In the US, multiple institutions applied pass-through formulas for inputs affected by considerable price variability. The Oklahoma Department of Transport (ODOT) applied such a formula for asphalt mixtures (i.e. an oil related input). If the initial oil price grew by more than 3%, an automatic additional payment would be disbursed to the contractor. Between August 2006 and June 2009, ODOT granted a net additional payment to firms equal to 5.05% of the value of eligible contracted items, in return achieving an 11.7% reduction (on average) in the price of winning bids for the eligible items. The study relied on several empirical methods to confirm its findings, including difference-in-difference and discontinuity regression design.

In the case of De Silva et al. (2008) the procurement authority made additional information available, which led to reduction in bid prices. The Oklahoma Department of Transport (ODOT) in the past published the bill of quantities without detailed internal estimates of unit prices. It then changed its policy and started revealing its estimate for each component of the project¹⁸. The study compared the winning bids for asphalt pavements and bridge work. Asphalt paving projects are relatively straightforward as the job descriptions typically specify an area of roadwork to be surfaced, the depth of surfacing required, and the material to be used. In bridge work, there is more uncertainty. Soil conditions at a site may not be fully known until excavation work begins and repairs may not be fully understood until some demolition work is undertaken. The analysis included the State of Oklahoma, where the procurement protocol changed, and the State of Texas, where it remained the same (i.e. a difference-in-difference approach was used). In total over 13 000 submitted bids by construction firms were analysed over the period 1998–2003. No change was recorded for asphalt projects, while the average bid for the bridge projects was reduced by 9.6%, with average winning bid reduced by 9%.

experienced contractors. Caution is however necessary when trying to draw lessons from private-private contract relationships and transpose them to public-private relationships. Spiller (2009) proposed that third-party and governmental opportunism increase the incentives of public managers and private investors to raise contractual rigidity. In consequence public contracts are born with less flexibility than purely private contracts. Recent evidence confirms this is indeed the case (Beuve, Moszoro, and Saussier 2019). Do they need to be more rigid in the case of major infrastructure or does that lead to more harm than good even in the most advanced economies remains to be determined.

¹⁸ ODOT [released] “a set of individual cost estimates for each quantity of material used and each important task involved. As a result, this policy change provides detailed information that can reduce substantially the uncertainty related to common components of the cost. For example, in one case, the state can reveal the cost of excavation which depends on soil conditions, and in another, the cost of a specific bridge repair which depends on the extent of the damage” (De Silva, Kosmopoulou, and Lamarche 2009).

Using the same data as above De Silva, Kosmopoulou, and Lamarche (2009) investigated bidder entry and survival. Entrants are typically less informed as opposed to the incumbents hence there is also a difference in efficiency. If an entrant wants to penetrate the market, he must take greater chances in bidding. If he does not become experienced (informed) within a reasonable period, the losses will force him to exit. In this particular sample there was 322 incumbent firms and 109 entrants participating on over 2000 auctions. Using panel data regression, it was found that the information release reduced the bidding differential between entrants and incumbents attributed to information asymmetries. Secondly, the median length of entrant presence in the Oklahoma procurement auctions increased by 68%.

The available empirical literature above refers to auctions in cost-plus contracts using the Design-Bid-Build delivery model¹⁹, i.e. a detailed design is already available at the bidding stage. The evidence concerns small and by implication simpler projects²⁰. Yet even at this level significant and disproportionate (e.g. absorbing a 5% input price uncertainty, led to 11% reduction in winning bid price) impacts of uncertainty have been measured. In relation to the theoretical predictions, this section confirmed that reducing uncertainty for the bidders ex-ante positively affects the winning bid price and competition. No empirical work investigates larger, more complex projects, and the impact of negotiations.

5.2 Small projects and the relevance of contract power

Theory considers that the cost-plus (i.e. bill of quantities) payment mechanism is more suitable for dealing with renegotiations than a lump-sum arrangement (Bajari and Tadelis 2001). Hence, in the absence of transferring property rights (i.e. in vertically unbundled contracts) the lump-sum arrangement should be applied on smaller, more complete contracts. Cost-plus arrangements should be applied on larger, more complex and therefore more incomplete contracts. But what is “small” and how much more complete are smaller contracts?

The empirical work testing contract theory focuses on contracts, with an average size below USD 5 million.

The evidence concerns the Design-Bid-Build delivery model, procured through a lowest price auction, implying very limited pre-contract information exchange, however the design documentation is expected to be fully developed.

¹⁹ The delivery model or contract power are not mentioned explicitly. The mentioning of auctions and the use of the bill of quantities imply however that these were cost-plus Design-Bid-Build contracts.

²⁰ Absolute bid size in USD is not mentioned. An approximate contract size can be inferred from Kosmopoulou and Zhou (2014). They reported that eliminating oil price fluctuation, generated savings of 5% amounting to USD 23 million on over 600 auctions. They further report that these savings concern eligible (i.e. oil price related) items that represent about 40% of the project value. These numbers together lead to an average project size of about USD 1.5 million.

5.2.1 Contract power and performance in small contracts

Bajari, Houghton, & Tadelis (2014) focused on adaptation cost in highway construction. The mean contract size is USD 2 million and the contracts are cost-plus, i.e. low powered. As noted earlier, quality was controlled for implicitly (i.e. supervision road delivery is commonly acknowledged as effective).

The authors first develop a theoretical bidder behaviour model where contractors form rational expectations about the ways in which actual quantities will differ from estimated ones and whether changes in scope will be required. The model is then applied on panel data to estimate the mark-up for adaptation cost in the bids. A separate model is then used to assess the relevance of adaptation cost versus other sources of mark-ups, such as private information rents.

A key takeaway from this paper was the finding that competition worked and that adaptation cost were a much bigger issue than private information rents. The adaptation cost represented 7-14% of the winning bid and ranged between 55 cents to 2 dollars for every dollar of change. The average bidder could expect a profit margin of 3.5%.

The paper also showed what was the extent of uncertainty bidders faced. The bidders foresaw where the ex-post adaptation would happen in the contract. They strategically priced items in the bill of quantities²¹ and included in the initial bid a “discount” based on expected renegotiations during the execution of the contract.

In an extension of the Bajari, Houghton, & Tadelis (2014) approach Bolotnyy and Vasserman (2019) measured how risk averse bidders are in Design-Bid-Build contracts. They simulated what would occur to project cost if the contract power were to be increased. Their data builds Massachusetts Department of Transport 440 bridge maintenance projects executed between 1998 and 2015 with an average contract value of USD 2.7 million.

When bidders reduce their ex-ante bid in the expectation of ex-post adjustments, their main uncertainty is that they miss-estimate the adjustments. In Bolotnyy and Vasserman (2019) a substantial accuracy in the strategic behaviour of the bidders has been demonstrated. The bidders can accurately foresee in the bill of quantities which items quantities will be underestimated. On average for each 1% of quantity underestimation in an item, its unit price is increased by 0.085%²².

The same study also assessed what would happen with the price of the average winning bid, had the procuring authority switched from a cost-plus to a lump-sum contract under which there would be no ex-post adaptation. This implies that bidders would need to not only estimate well in which items there will be changes but also, what the changes in quantities will be. In this case the bidders would have to

²¹ In cost-plus DBB contracts bids are typically submitted through a bill of quantities, which lists expected quantities for the key items and unit prices next to them. Bidders adapt their unit prices for individual items by increasing the prices for the items, where they suspect quantities have been underestimated.

²² Bidders cannot push the unit prices of underestimated items and discounts for the items where they suspect the quantities are estimated accurately into extreme. When the procuring authority can detect a bid is materially imbalanced a bidder could be disqualified. The advantage on the side of the bidders in practice is that it is difficult to determine what “materially imbalanced” means with precision.

express their full revenue expectations in the winning bid. Based on estimating the bidders' risk aversion the study showed that the switch would make an average winning bid in the sample a 133% more expensive.

The counterfactual above implies a lump-sum result without ex-post adaptation due to errors and omissions in the design documentation. Effectively then, what the simulation shows is not the result of a Design-Bid-Build lump-sum arrangement. It is the result of a Design-Build lump-sum contract, where in the bidder selection phase, the bidders would have developed and completed the design documentation to the extent, implied in the initial sample of the study (and there were no further scope changes from the client).

Reconciling the above results with theoretical predictions, and in the absence of more precise complexity measures, projects as large as a few million already seem to be too complex and in consequence too incomplete to use a lump-sum contract. There is no empirical evidence to test how small and simple the infrastructure projects would need to be to yield reasonably complete contracts.

On the other hand, the result of Bolotnyy and Vasserman (2019) suggest, bundled delivery models carry a significant cost premium even when assumed the contractors during the bidding process would develop the same detailed design as is normally available in Design-Bid-Build contracts. The objective of contract completeness could be met, but at significant additional cost. This result does not align well with the predictions of contract theory, which sees adaptation cost as the main challenge to contract power selection. [DM1]

This section observed small projects with an average size well below USD 5 million. How does the level of adaptation cost for projects in the range of several USD10 or USD100 million develop? What would happen if we applied bundled delivery models and lump-sum requirement on much larger projects?

5.3 Large(r) projects and the relevance of contract power

Papers that tested contract theory propositions offer a precision view how well bidders foresee ex-post contract changes in the project, what part is the added cost of adaptations, and what part are the profit margins.

Similar studies as above do not exist for larger, more complex projects. In the next sections we therefore draw additional insights from the following sources:

- A body of contract and project management literature on cost overruns can reveal, how adaptation cost is developing with project size in Design-Bid-Build cost-plus contracts.

This will tell us what is the scope of ex-post changes contractors can expect in larger projects, compared to the two studies reviewed above. More change implies a higher premium if a switch to lump-sum were made.

- The same literature can also show, whether bundled (i.e. Design-Build and Engineering-Procurement-Construction lump-sum) contracts lead to greater contract completeness and therefore cost certainty.

This will tell us, to what extent bidders in bundled contracts need to fully express their revenue expectations ex-ante.

- A single study on motorway construction in the EU compares the cost per physical unit for high-powered (lump-sum Engineering-Procurement-Construction) and low-powered (cost-plus Design-Bid-Build) contracts for large projects.

This will tell us, what is the cost premium for cost certainty in large projects.

5.3.1 Cost overruns, adaptation cost and contract size

Papers that investigated cost overruns offer a rougher measure, without the detailed insight into adaptation cost or profit margins²³.

Cost overruns are not the same concept as adaptation cost. If cost overruns are high, however, adaptation cost will be high as well. Cost overruns represent the total value of changes to the initial contract. As explained in Bajari, Houghton, and Tadelis (2014) a part of cost overruns comes directly from the additional work that was not anticipated (by the client). Adaptation cost come in addition as the result of disruption to the normal work flow and the resulting haggling, disputes and opportunistic behaviour during renegotiations²⁴. Put simply, it is the difference between the unit price for an item in the initial contract and the elevated unit price for the extra piece of work after renegotiation.

The no. 1 direct reason²⁵ for cost overruns that consistently appears in the construction management literature on transport infrastructure is scope creep, followed by errors and omissions in the design of the project (Makovšek 2013).

Cost overruns are typically calculated as the difference between the total ex-post cost of a contract and its initial reference value. In this section and the table below we're looking at the literature that measured cost overruns v. the award price. Typically, the studies capture entire populations of projects over a select time period.

²³ In this case the notion of "contract" and "project" is considered identical.

²⁴ As seen from their paper and Bolotnyy and Vasserman (2019) contractors can predict changes in simple contracts. These are included in their bids together with the expected earnings, which are then competed away (in their case) and represent a small part of the actual cost overrun. This is also why the cost overrun reported by Bajari, Houghton, and Tadelis (2014) is substantially lower (5.7%) than the adaptation cost.

²⁵ What the root cause of direct reasons is a different question. For example is the dominant explanation optimism bias or deliberate misrepresentation by the project's promoters or is it more mundane reasons such as inadequate risk management, ex-post stakeholder pressure that could not be foreseen and managed ex-ante...).

Table 1. Cost overruns in Design-bid-Build projects measured against contract value (at award) as the reference estimate

Source	Project type	Time period*	N	Project size (mean in million)	Average Cost overrun (%)	SD (in %)	Geography
(Ellis et al., 2007)	Roads & bridges	1998–2006	1908	USD 2.8	9.36	N/A	USA, Florida
(Bordat et al. 2004)*	Roads	1996-2001	599	Not directly reported (small)	5.6	N/A	USA, Indiana
(Bordat et al. 2004)*	Bridge	1996-2001	621	Not directly reported (small)	8.1	N/A	USA, Indiana
(Bhargava et al., 2010)	Roads	1995-2001	1862	USD 0.9	6.1	24.4	USA, Indiana
(Hintze and Selestead 1991)*	Roads	1985–1989	110	Not directly reported (small)	9.2	1.22	USA, Washington
Bajari,** Houghton, and Tadelis (2014)	Roads	1999-2005	819	USD 2.7	5.7	11.8	US (California)
(Love et al. 2019) ²⁶	Roads	1999-2017	18	USD197	5.7	12	Hong Kong
(ITF 2018a)***	Roads and bridges	2008-2017	28	EUR 75	9.3	8.1	Slovakia
(FHWA 2016)	Roads	2004-2015	134	USD 21.6	4.1	9.1	US

Note: (*) 89% of projects was below USD 2.5 million. (**) The authors don't report on cost overruns v the winning bid but versus in-house pre-bid estimate. Since the mean winning bid is 5.4% lower than the mean pre-bid estimate, the actual cost overruns measured against the winning bid in their sample would be marginally higher (***) The entire motorway programme in the stated period.

The table above does not show a stark difference between projects below USD 5 million and projects reaching sizes of several ten million. Overall, the systematic cost overruns reach at most 9%.

Research on smaller project sizes showed that cost overruns increase do with project size²⁷. Gkritza & Labi (2008) on a sample with an average project size of USD 1 million show a 1.55% growth in cost

²⁶ Shared by authors based on original data.

²⁷ The same has been determined for Navy construction projects (Jahren and Ashe 1990).

overrun for each 1% growth in contract award value. They acknowledge however that the relationship is non-linear. This rate of growth does not extend onto larger projects, as already at several USD 10 million the systematic cost overruns would quickly exceed 50% or more. Very large projects of several USD 100 million would have systematic cost overruns of several 100%. This is not confirmed in the table above or by FHWA (2016)²⁸ who found no relation between project size and cost overrun for larger projects in the size range up to USD 357 million. This is not to say however that for very large, mega projects, cost overruns will not be substantially larger on average.

Based on the evidence above, we therefore cannot conclude that with the Design-Bid-Build model larger contracts are more incomplete than smaller ones in ranges up to a few hundred million.

Further evidence on cost overruns in large projects

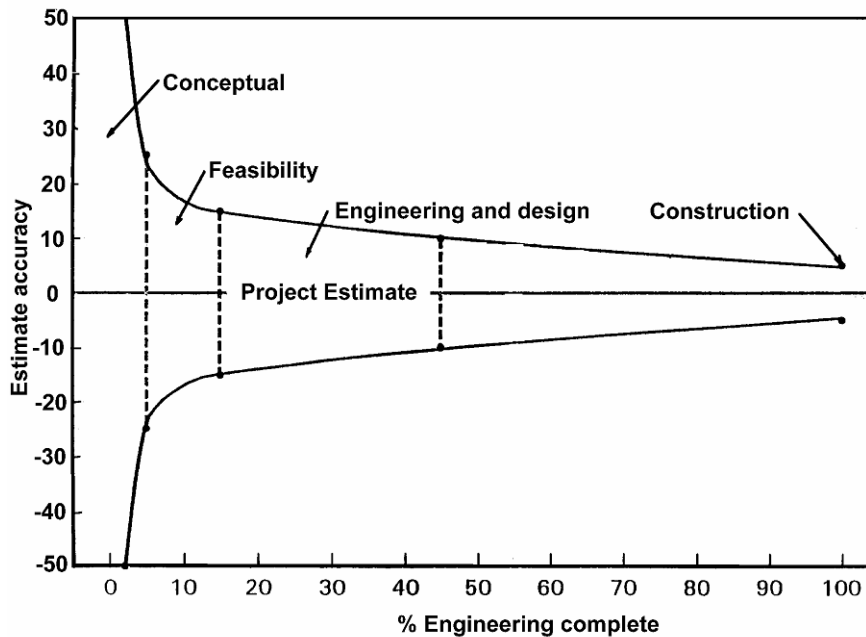
In addition to the studies in Table 1 a body of evidence exists which measured cost overruns against the formal decision to build²⁹. It further corroborates the point that cost overruns (and by implication adaptation cost in contracts) in large projects are not disproportionately larger as in smaller ones.

As the formal decision to build occurs earlier in the project development, the estimates are less accurate since the design documentation is not yet fully developed. The textbook example below illustrates this point.

²⁸ This analysis was not included in the original report and was confirmed by subsequent analysis of the data by the authors (personal communication with authors/Keith Molenaar).

²⁹ This body of evidence is concerned with the presence of systematic errors in the cost (or benefit) estimates at the time, when a decision is formally made to proceed with the project development. If costs are systematically underestimated (or benefits systematically overestimated) then project appraisal may be affected. The formal decision to build is normally taken long before the project is mature enough to reach tendering. The studies do not observe contracts specifically and a project may consist of many different contracts. They also do not report on any procurement dimension used in the contracts. Further review of available work in this domain is available in ITF (2018) or Cantarelli et al. (2012).

Figure 1. Cost estimation accuracy over the life of the project



Source: Schexnayder, Weber, and Fiori (2003).

The evidence for road projects does not fully correspond to the textbook exposition. A consistent systematic cost overrun of around 20% ranging from several USD 10 to several hundred million has been shown. This is the case for advanced economies of the world (e.g. Flyvbjerg, Holm, & Buhl (2003) for Western Europe; Cantarelli, Van Wee, Molin, & Flyvbjerg, (2012) for Netherlands; Makovšek, Tominc, & Logožar (2012) for Slovenia)³⁰.

Hence, the early estimates are not only less accurate in terms of their dispersion around the mean. The less developed the project design, the more costs are systematically underestimated. As the level of engineering becomes more complete, cost underestimation will decrease. The formal decision to build in the studies above is typically made at an outline design stage (much less than 50% of engineering complete).

³⁰ What is the root cause of cost overruns measured against the decision to build (or the award price) is subject to on-going work. The explanations range from optimism bias or deliberate misrepresentation by the project's promoters (Flyvbjerg, Holm, and Buhl 2002) to technical explanations (Eliasson and Fosgerau 2013; Börjesson, Eliasson, and Lundberg 2014; Makovšek 2014) where the methods used to create inputs for project selection were imperfect, while the users had no ex-post information to correct for errors. What is clear, is that when projects get very large, the key determinant of cost overruns becomes the length of the project gestation period – the amount of time spent on project development before it reaches the tendering phase (Cantarelli et al., 2012; Flyvbjerg, Holm, and Buhl 2003). Hence if a project requires a large number of years or decades to reach a decision to build, it is more likely to experience higher cost overruns. A case in point are very large projects.

For a Design-Bid-Build (or any) contract to achieve a 20% cost growth against the award price, the winning bid on average would have to be made at a cost level, that corresponds to a project's estimate very early in its development and then the contract would need to consistently lead to a 20% cost overrun. This though is not what the evidence for larger project sizes in Table 1 suggests.

In summary, the evidence above further corroborates that Design-Bid-Build road projects, ranging from USD 10 million to several hundred million experience average cost overruns well below 20%.

An important stylized feature of cost overrun distributions measured against the contract award price or the decision-to-build estimate throughout almost all studies is a distribution asymmetric to the left with a tail to the right.

5.3.2 Do bundled lump-sum contracts lead to greater cost certainty?

More complete contracts imply greater pressure on the bidders to express their revenue expectations ex-ante and stresses the importance of pre-contract information exchange. In transport infrastructure bundled contracts are commonly applied in large projects.

Design-Build contracts

The Design-Build model bundles design and construction phase in a single contract. Bidders in this case are commonly selected based on best value³¹, following a negotiation with the winner, i.e. a negotiated procedure. The level of design provided to the bidders can range from 0-50% (K. R. Molenaar, Songer, and Barash 1999) of engineering, but is commonly concentrated on the low end of the range. The dominant payment mechanism applied is lump-sum (Chen et al., 2016; FHWA, 2016).

A rare example of a study which tried to control for complexity³², bidder selection process, delivery model and payment mechanism (but not cost per physical unit) was that of FHWA (2016). Data for 291 projects was collected with a large share of bigger projects (mean USD 27 million, SD=41 million), however the results were statistically insignificant³³. That said though, the difference in cost overruns measured for Design-Bid-Build and Design-Build projects was also very small³⁴.

One of the key challenges for researchers of this topic was that the introduction of Design-Build delivery model is relatively recent event, starting in the 1990-ies. As a result most other studies faced the issues of small, unrepresentative samples, statistical significance issues, difference in project size magnitudes

³¹ In this case the price is one of the criteria for bidder selection and bidders are not (primarily) or a non-price competition takes place.

³² One of the most cited studies on private sector vertical construction (residential or commercial/industrial buildings) contract performance (Konchar and Sanvido 1998, 102) also controlled for project complexity. The sample included 155 Design-Build projects and 116 Design-Bid-Build projects. Facilities built were divided in six types. However, in multivariate linear regression nor the cost overrun differences nor cost per physical unit (USD/sqm²) for the two delivery models were statistically significantly different.

³³ This is also a rare example of a study that included data on payment mechanism and procurement process.

³⁴ DBB (bidder selection by lowest bid criterion) = 4.1%; DB (bidder selection by lowest bid criterion) = 2.8%; DB (bidder selection by best value criterion) = 4.0%. A similar result was for 117 civil infrastructure DB projects (which included road projects) by Chen et al. (2016), where a systematic cost overrun of 5.8% was measured.

and therefore complexity etc (Warne 2005; FHWA 2006; Shrestha et al. 2007; Shrestha et al. 2007; Shrestha, O'Connor, & Gibson, 2012; Minchin et al. 2013; Park and Kwak 2017).

In summary, the evidence does not show that the Design-Build delivery model, where the negotiated procedure is more commonly used, lead to greater contract completeness than Design-Bid-Build.

The nature how renegotiations can occur though is different than in the Design-Bid-Build. In the latter case a detailed design is made available to the contractor. This leaves the responsibility for design errors and omissions with the public client but at the same time also gives him control with regard to what exactly the engineering solution is. In the Design-Build contract an outline design is made available during bidding. In consequence most of the responsibility for design errors and omissions need to be internalized by the contractor leaving a much smaller scope for him to claim design error or omission. The public client no longer defines a detailed solution but provides a functional (output) specification, to which the asset needs to perform.

A logical conclusion would be that because the cost overruns in Design-Build contracts are not smaller, this must be because the public client wasn't able to fully define ex-ante what functions it wants for the asset to perform. In consequence changes are required during construction, which lead to further adaptation cost³⁵. This point finds support in a study of 45 major Design-Build road projects in the Netherlands³⁶ (Verweij, van Meerkerk, and Korthagen 2015)³⁷. There is a strong presence of mega projects in the sample with the mean project value of EUR190 million. The authors found that on average 50% of the cost growth could be attributed to scope changes³⁸.

Engineering-Procurement-Construction contracts

In the Design-Build contract commonly an outline design is made available during the bidding. This is not common in the Engineering-Procurement-Construction contract. The public client has even less control over what exactly the solution will be and defines his expectations exclusively through an output specification. The lump-sum payment mechanism is the default option for this delivery model.

In transport infrastructure such contracts are primarily used due to the application of Public-Private Partnerships (PPPs or P3 in the US)³⁹. A PPP is a project finance arrangement where private debt and equity are used to finance the project and are paid back from the cash flow generated by the project. As lenders have no other recourse, they try to insure against risk that they can't manage well or is not their core business. Construction risk is transferred to the construction contractor through an Engineering-

³⁵ As noted in the theory review the adaptations will also cost more than they would in a Design-Bid-Build procurement, through a bill of quantities tender.

³⁶ 38 of these were road projects.

³⁷ The study did not report the cost overrun against the contract award value. In addition, some projects were still in execution.

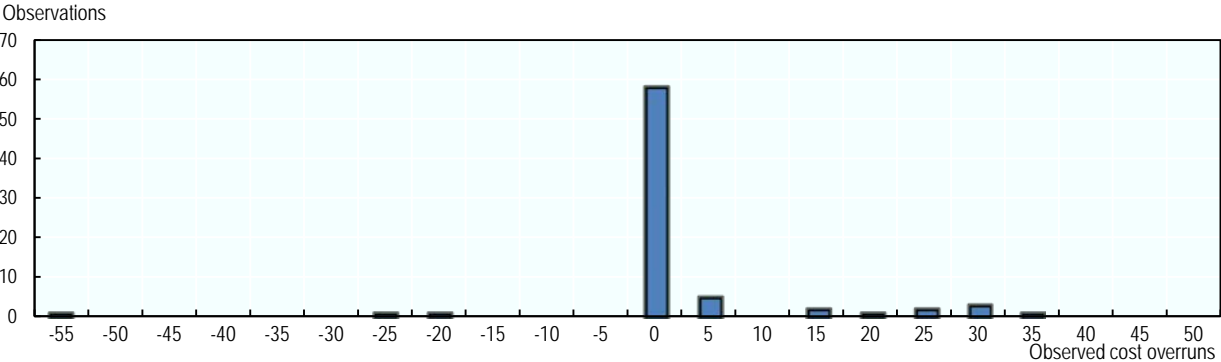
³⁸ Of the rest, 12% could be directly attributed to incomplete contracts (incomplete, incorrect, conflicting contract terms), 35% of changes was due to technical necessities (e.g. ground conditions turned out different than expected), and changes in laws and regulations (3%).

³⁹ PPPs are also referred to through one of their many variants, most commonly as Design-Build-Finance-Maintain-Operate (DBFMO) contracts.

Procurement-Construction contract alongside a range of incentives against non-performance⁴⁰. The bidders are normally selected through the negotiated process.

Blanc-Brude & Makovšek (2013) analysed a database of 75 project finance schemes, ranging from USD 24 million to USD 13 billion. The sample is a mix of private-private transactions as well as PPPs⁴¹. The projects come from five continents and different sectors, including transport (14 roads and 12 other types). This dataset is unique in the sense that it represents the performance of the contractor as reported to the lenders. Effectively cost overruns in this case represent the construction risk exposure of the lenders and owners in the project company. The mean cost overrun of the sample is 2.6% (SD=11.4). With the median cost overrun at 0% the risk is diversifiable, hence project finance completely insulates the investors from it. However, unlike the rich distribution of cost over- and under runs around the mean in other (publicly financed) procurement options in this particular case 18 projects were delivered with cost overruns, three with cost under runs⁴², 54 projects were delivered exactly on cost (Figure 5).

Figure 2. Cost overruns in project finance (NATIXIS dataset, n=75, 1993-2010)



Source: Blanc-Brude & Makovsek (2013).

Raisbeck, Duffield, & Xu (2010) collect data on 21 PPPs and 33 traditionally procured projects (the procurement dimensions are not reported) from different sectors in Australia. They confirm that PPPs suffer almost no delays, compared to traditional procurement. They cannot confirm with statistical significance though that cost overruns measured v the contract award stage are smaller (2.4% for PPPs v 13.8% for publicly financed projects). They include a review of literature commonly used in policy discussions, which are mainly industry studies suffering from a variety of sampling or representativity issues.

⁴⁰ The Natixis sample of major project finance projects (Blanc-Brude and Makovsek 2013) includes for example liquidated damages in case of delay (per day or per week), performance guarantees, full completion guaranties (a third party guarantee that the project will be completed even if the main contractor defaults).

⁴¹ The data does not allow explicit identification. Nevertheless, the sector implies, whether the project were PPPs or private-private transactions. In total 43 projects were marked as to transport, social accommodation, and “environmental”. In all these sectors, project finance arrangements would have to be PPPs (e.g. roads, social housing projects, landfills). The average cost overrun of these projects was 1%.

⁴² This does not imply that the contractor saved money and gave it back (it is a lump-sum contract), but that the project was cancelled or the project scope was reduced. Conversely, cost overruns can be a result of scope increases introduced by (and paid for) by the client.

In this particular case the evidence does suggest that Engineering-Procurement-Construction contracts are more complete and cost overruns are much lower than in other procurement alternatives investigated so far⁴³.

5.3.3 Are high-powered bundled contracts more expensive

In our evidence review for large projects no empirical work existed that would also compare cost per physical unit.

A single study to date investigated the relative performance of construction cost per physical unit for “traditional procurement” (Design-Bid-Build contracts)⁴⁴ and PPPs (Engineering-Procurement-Construction contracts) (Blanc-Brude, Goldsmith, and Vällilä 2009). The sample is based on road contracts, tendered between 1990 – 2005 in the European Union. The study stands out from the others in that it targets large contracts, ranging from EUR 20 – 300 million, consisting of 56 PPPs and 101 traditionally procured projects. Controlling for road type, terrain, economies of scale, portions of bridge and tunnel work⁴⁵, size, and country (=institutional environment), the study found that the ex-ante (award) PPPs cost 24% more per lane kilometre.

An important characteristic of the Blanc-Brude, Goldsmith, and Vällilä (2009) sample is also that the projects in questions were European Investment Bank supported projects. This implies that the preparation and the execution of the bidder selection process benefited from the advice, due diligence and potential technical assistance from the bank. Thus, as far as quality of preparation or the execution of the bidder selection process is concerned the performance of the sample is expected to be above average. There are no other indications in this study that the results (the difference between the PPPs and traditionally procured projects) could be affected by potential selection bias⁴⁶.

As the study above captured contract cost at or close to award⁴⁷ and not ex-post cost further elaboration is necessary and we cannot yet conclude that Engineering-Procurement-Construction contracts carry a substantial cost premium to low powered alternatives. As laid out in Makovšek & Moszoro (2018), two issues need to be acknowledged.

First, given all we know about cost overruns the 24% cost premium for PPPs seems to be much higher than the average cost overrun observed in Design-Bid-Build contracts. In addition, PPPs too exhibit cost overruns albeit small. In Table 1 cost overruns in Design-Bid-Build projects reach at most 9%. In the

⁴³ This result also implies that there are fewer changes to projects while they are being executed. It is not immediately clear why this format would perform better than Design-Build contracts, which are also procured through negotiated procedure. One explanation though is, that the complicated financial and legal structure of PPPs makes changes prohibitively expensive for the public authorities.

⁴⁴ According to the study the majority of the “traditional procurement” sample are Design-Bid-Build cost-plus contracts with a small presence of Design-Build lump-sum contracts.

⁴⁵ Large bridges were separate projects and were excluded from the sample.

⁴⁶ As noted in the beginning of the section the study did control for numerous dimensions that would affect complexity and performed several robustness checks across several alternative subsample specifications.

⁴⁷ Its interpretation of ex-ante cost estimate data was also addressed in greater detail in Makovšek (2013).

previous section Engineering-Procurement-Construction projects have been recorded to reach cost overruns of 2%. Hence, there is indication that even if Blanc-Brude et al. (2009) had ex-post data on final contract cost a significant premium would persist.

Second, a major argument why infrastructure would be more expensive in PPPs as opposed to traditional procurement is life-cycle cost optimisation. Arguably the long-term involvement in the project incentivises the private owners to build a higher quality infrastructure to save on maintenance cost later. While this may indeed be the case, there is no empirical evidence to show the observance of this principle is systematically worse in publicly financed infrastructure. Moreover, despite declarative embrace there were practical obstacles to the introduction of these principles Meng & Harshaw (2009). The UK National Audit Office (NAO 2007) found that traditionally procured hospitals were not built to a higher standard of quality. For roads specifically the German Court of Audit (Bundesrechnungshof 2014) investigating German motorway PPPs came to the same conclusion⁴⁸.

In summary, high-powered (i.e. lump-sum Engineering-Procurement-Construction) contracts procured through negotiation can lead to more complete contracts (greater cost certainty) but are substantially more costly than low powered alternatives. In road infrastructure, limited available evidence suggests this premium is not a result of building to a higher standard.

Against our review of how economic theory informs procurement choices and the evidence on procurement outcomes, the next section looks at how governments procure in practice.

6 How are procurement choices informed today?

The government guidance on procurement or procurement law predominantly focuses on the bidder selection (e.g. the EU directives on procurement).

The choice of the delivery model and contract power is commonly informed through operational level guidance, specifically, the multi-attribute utility approach - MAUA (Chang and Ive 2002). Derivatives of this approach have been developed since the 1970-ies. Today, MAUA is enshrined in numerous government procurement practice guidelines (e.g. Molenaar, Harper, and Yugar-Arias 2014 for highway infrastructure in the US).

MAUA begins with subjective weightings applied to a range of attributes of desired project outcomes that the client considers important (e.g. speed of delivery, cost certainty...). These weightings are then multiplied by a utility factor representing the extent to which a procurement option satisfies each attribute. The most desirable procurement is the option with the highest score.

This approach is subject to multiple challenges. The first issue is the available evidence on procurement choices and project outcomes:

⁴⁸ Two potential explanations were put forward. First, building to a different standard is inhibited by strict technical rules and regulations. Second, risk averse lenders may prefer tried and tested methods rather than experimentation.

- Most available evidence is predominantly associated with cost overruns, delays, and construction speed (in this paper we focused on the first). Hence, clients are incentivised to focus on those attributes, which are observable. Empirically, as shown in this paper so far, the trade-offs are not well understood.
- Beyond the evidence on immediate construction outcomes, there is a dearth of knowledge of the effect procurement choices have on operations and maintenance outcomes. The utility of procurement choices along these two long-term dimensions cannot be objectively established.

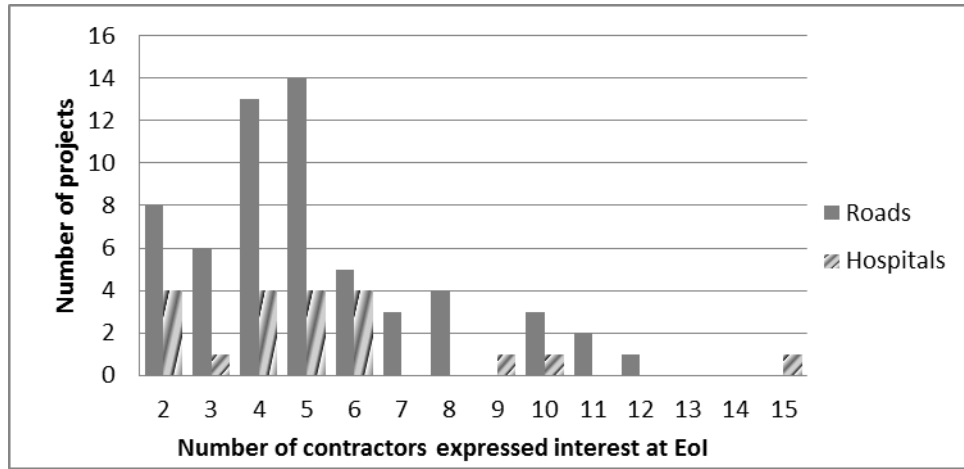
The second issue is methodological. MAUA defines the cause i.e. procurement mode utility (e.g. EPC contracts have better on-budget delivery) in the same terms as the effect (e.g. on-budget delivery for this project will be important). With the lack of comprehensive evidence how different procurement choices affect outcomes, MAUA becomes dominated by a few short-term objectives. It becomes a tautology. A non-tautological and scientific approach to procurement choices would see the effect of procurement defined and measured in different terms than the procurement mode.

Furthermore, MAUA is not built to inform the impact of contract size or procurement choices on the market response – for example the number of bidders and their behaviour.

This state of practice has tangible consequences. For example, in Teo (2014) and Bridge and Bianchi (2014) a survey of 87 major road and health projects, worth AUD32 billion in Australia was performed. It determined that Australian road and health agencies used a procurement approach that closely resembles MAUA. Among the main findings were:

- A low number of higher value projects account for an appreciably higher proportion of the overall value;
- The majority of road and health projects are delivered as single contracts;
- Larger value projects (over AUD100 million) were dominated by Design and Construct, Alliancing, Early Contractor Involvement, and Managing Contractor approaches, which exclude operations and/or maintenance as part of the contract;
- The budget was established in collaboration with the contractor (including a pain share/gain share regime) in the majority of health projects; and
- Figure 1 shows the Expressions of Interest (EOI) for this sample - almost 50 % of projects achieved between two and four EOI; competition was strongly adversely affected.

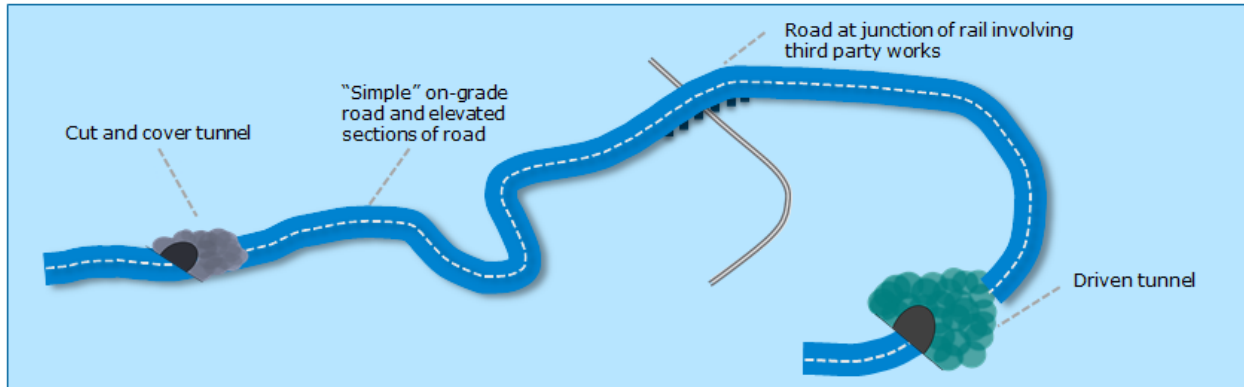
Figure 3. Expressions of Interest in Australian major roads and health projects



Source: Based on Teo (2014) and Bridge and Bianchi (2014).

To illustrate some of the likely market failure associated with the distribution in Figure 1, one of the road projects that generated only two EOIs is depicted below in Figure 2. This project was considered by the project team to be complex. The road needed to cross an existing rail line and there was a lack of geotechnical information in the driven tunnel. Changes to both aspects (where exactly the road will cross and where exactly the tunnel will go) implied potential changes to third party permits and approvals. As such the project team included adaptive capacity as one of the key client attributes and this was also weighted highly in the selection of the procurement mode for this road. Accordingly, an alliance mode of procurement was used that corresponded strongly with the heavily weighted adaptive capacity attribute.

Figure 4. An Australian major road project with two Expressions of Interest



Source: Based on Teo (2014) and Bridge and Bianchi (2014).

However, around 50 % of this road comprises relatively straightforward on-grade road and elevated structures. The scale of this more straightforward work (without any permits and approval risk) would have suited local smaller civil engineering construction firms very well. And since there were many more of these smaller contractors than Tier 1 contractors, there would have likely been much more competition and a much greater downward pressure on a significant proportion of the price of the project.

More recent guidance on procurement in the best of cases moves in the direction of asking the decision makers how their procurement choices, including contract scoping, will shape the response of the market, but does not yet offer an evidence-based process that would lead to an answer (e.g. HM Treasury 2014). An example of a recent advance in that domain is presented in the next section.

7 Procurement reform: A case study

We cannot say that infrastructure managers do not consider questions on what activities should be organized in-house and what should be procured on the market. Or that they ignore the questions of project size or whether and in how many contracts it should be broken down.

Common sense may dictate that if for example, among many activities to deliver a project only two or three firms produce a required activity on the market, procuring the entire project as a single contract reduces competition. The bidders will organize around the two firms and form two market consortia, reducing the effect of competition for all other project activities as well.

Likewise, when considering bundling project stages in a PPP (Design-Build-Finance-Maintain-Operate) contract all activities do not interact in terms of life-cycle cost optimisation. Moving the earth or third-party infrastructure has no relevance for the life-cycle maintenance cost of a road or a bridge. If

included in the PPP though that capital expenditure will carry the added private financing cost⁴⁹ and the premium for using a high-powered long-term contract with the contractors.

These examples though are a small part of the implications of procurement choices. What is needed is a model to guide procurement in a non-tautological, evidence-based and holistic manner.

A recent advance in this area is an approach developed and trialled in an Australian Research Council grant that that deploys a combination of New Institutional Economics and the capabilities perspective to develop a procurement strategy (Bridge and Bianchi 2014; Teo 2014). This approach is cited by Australia's Productivity Commission (Productivity Commission 2014) and is currently undergoing further trials in a major road project and a major health project in Australia, with results to be published by the end of 2020.

The orthodox position in the construction management literature on procurement holds that clients face a trade-off in the utility they derive from different procurement options, such as speed, cost or certainty (Ive and Chang 2007). The same trade-offs also inform the MAUA approach, the challenges of which have been laid out in the section above.

The new procurement decision model pursues a fundamentally different path. It first breaks down a project into separate activities and then analyses these to inform the make-or-buy decision, contract scoping decision (including the bundling of project phases), and lastly whether the contractual relationship should be more collaborative or adversarial. The objective of the analysis of activities is to avoid *ex ante* market failure (arising from the market's power to set prices associated with thin competition) and *ex post* market failure (arising from renegotiations, associated negative opportunist behaviour by the contractor, or hold-up). This activity assessment informs the contract scoping decision that proceeds to exclude those project activities that would have likely led to market failure.

We now present a brief summary of the key steps in the model including illustrations from the case study mentioned in the previous section (see Figure 4).

7.1 A model for Procurement Design Assessment

The first step in the model is to identify the activities in the project. The key challenge here was to avoid a level of detail, which would make further analysis of activities impractical. A guiding principle for the identification is the highest level of firm specialisation on the market. Furthermore, activities should be technically bounded (distinct knowledge and/or skill set) and non-trivial (relative to the size of project) project design, construction, operation and maintenance activities. In the case study the road project was broken down into 61 activities as shown in Figure 5.

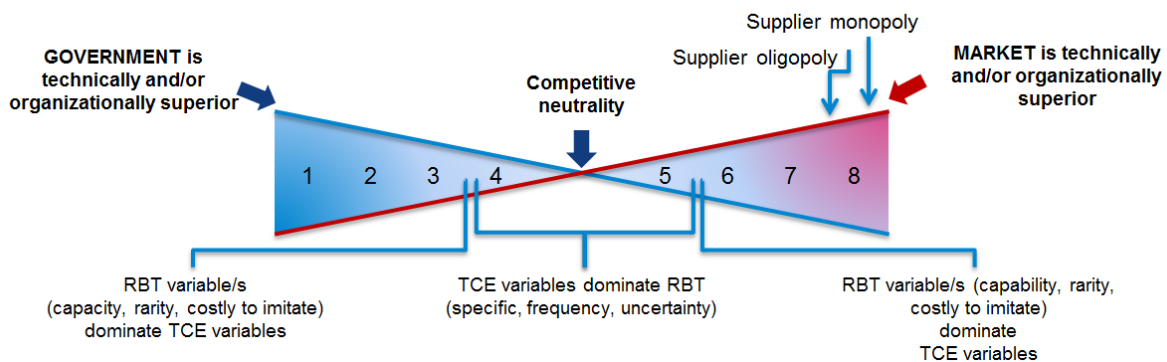
⁴⁹ Makovšek and Moszoro (2018) lay out the reasons and literature, why the true cost of private financing would be higher even after accommodating the fact that risk is expressed differently in the public (ex-post) and the private sectors (ex-ante).

Figure 5. Step 1: Activity Analysis

Design	Construction	Operations & Maintenance
<i>Design of construction</i> 1. Civil and structural engineering design 2. Civil and structural engineering design to the driven tunnel 3. Traffic engineering design 4. Mechanical and electrical engineering design including: air quality and ventilation 5. Fire safety design for tunnels 6. Landscaping and urban finishes design <i>Design of performance specification of maintenance</i> 7. Plan for routine maintenance, programmed maintenance and rehabilitation of road pavement, road furniture, drainage maintenance & ITS 8. Plan for reactive and programmed maintenance to specialist linings, mechanical and electrical and fire elements in driven tunnel	<i>Cut and cover tunnels</i> 9. Relocation of existing public utility plant, 10. Removal works, 11. Traffic management, 12. Bored piles, 13. Excavate and shotcrete, 14. Earthworks, 15. Structural, 16. Precast concrete, 17. Waterproofing, 18. Drainage, 19. Pavement, 20. Modifications to existing bridge and footpath, 21. Demolition, 22. Realignment of rail track <i>Driven tunnel</i> 23. Excavation in tunnel and shotcrete, 24. Waterproofing, 25. Structural, 26. Precast concrete – barriers, kerbs and wall, 27. Drainage, 28. Trimming and backfill of main tunnel, 29. Pavement, 30. Ventilation fan <i>Road at grade</i> 31. Bulk excavation, 32. Subgrade preparation, 33. Drainage, 34. Concrete pavement, 35. Precast concrete: barriers, kerbs, 36. Retaining walls, 37. Asphalt pavement, 38. Re-alignment of existing busway, 39. Traffic management <i>Bridge, ramps, median, walkway and bikeway structures</i> 40. Traffic management, 41. Earthworks, 42. Pile foundation, 43. Structural works, 44. Precast concrete: barriers, kerbs <i>Bus stations</i> 45. Water and stormwater, 46. Electrical and communication, 47. Pile foundations, 48. Cast <i>insitu</i> concrete (lift well, platforms, and bus bays), 49. Structural steelwork, 50. Roofing and drainage, 51. Cladding and louvres, 52. Glazing, 53. Mechanical services, 54. Lift installation in bus stations <i>Remaining construction activities in multiple parts of the project</i>	59. Intelligent Transport Systems and traffic operations 60. Inspections & data collection, including implementation of reactive routine and programmed maintenance to all parts in project (including driven tunnel) - roads/pavement and furniture 61. Inspections & data collection, including implementation of reactive (emergency) maintenance

In Step 2, the model assesses each of the project-specific activities in terms of their Transaction Cost Economics (TCE) attributes (i.e. frequency, asset specificity, uncertainty) and Resource-Based Theory attributes (i.e. rarity, costly to imitate) as proposed in Bridge and Tisdell (2004). This framework is depicted in Figure 6.

Figure 6. Step 2: Make-or-Buy Analysis



Following a structured questionnaire each activity is scored⁵⁰ on TCE and RBT variables. The role of each variable in determining the structure of a firm has been empirically verified for both respective theories. Based on these Bridge and Tisdell (2004) designed 8 competitive theoretical states - patterns that correspond to particular variable characteristics. For example, at level 8 the characteristics of variables

⁵⁰ At present there is no broadly accepted nomenclature to classify construction activities objectively or through an automated process. But it is feasible that in the future such classifications could be developed and data systematically collected from the market participants.

are such that a firm (the supplier) could maintain a sustainable competitive advantage in the market. This would be because the activity is of large scale or size, and/or requires a rare technology. This limits the number of market firms that are capable of carrying out the activity, resulting in limited competition (Teo 2014).

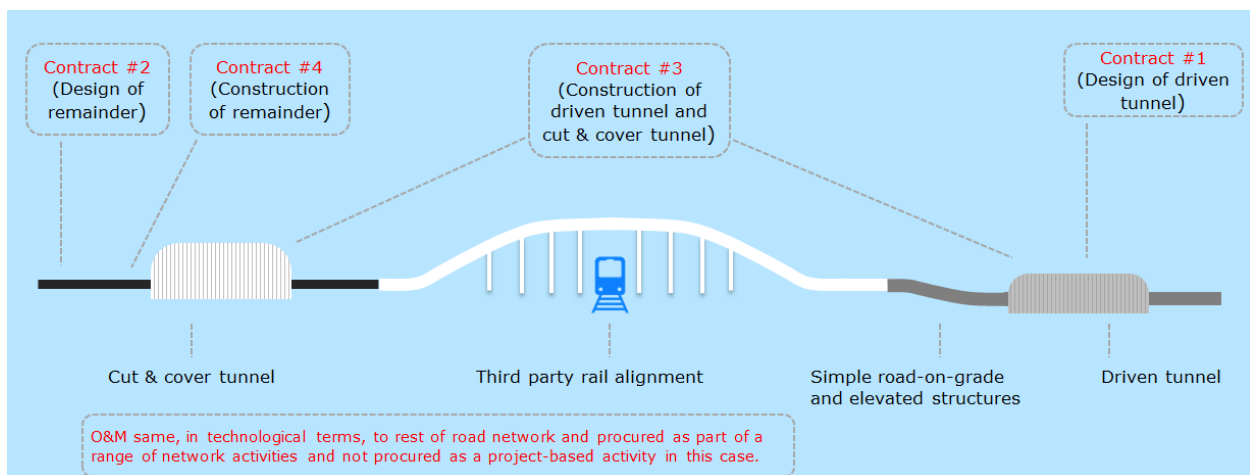
Based on the score assigned, each activity falls in a theoretical pattern 1 through 8. Those activities that are assigned a pattern 1 through 4 are considered most efficiently insourced and so the remaining steps in the model focus only on the procurement of those activities assigned a pattern 5 through 8.

In Step 3, the model guides the user to explore bundling of activities – defining the contract scope.

For our case study, the design of all works (except to the driven tunnel); the construction of all works (except the driven tunnel and cut and cover tunnel); and the installation of all mechanical and electrical works were all assessed as pattern 6 and 7 activities. However, the bundling of these activities would have created a pattern 8 bundle and so the model recommended bundling only the construction activities. Meanwhile, the design of driven tunnel was assessed as pattern 8 activity and the construction of the driven tunnel and cut and cover tunnel were assessed as a pattern 5 activity. Hence, the analysis in this step led to 4 contract bundles as shown in Figure 7.

It's worth noting that there may be cases in which a pattern 8 activity cannot be partitioned as a separate contract because of physical proximity of the activity and other activities. For example, there could be highly specialist and proprietary activities in a building management system (BMS) in large facilities like hospitals. Here, it makes sense, from the viewpoint of the management function, to bundle all these activities in a Mechanical and Electrical (M&E) contract because they are physically compact within the BMS. In this situation, a nominated supplier approach for those pattern 8 activities in the M&E contract would be efficient. That is, this approach would maintain the likelihood of otherwise good competition from more general M&E contractors.

Figure 7. Step 3: Bundling Analysis



Finally, in Step 4 the model guides the user to re-assess the TCE and RBT variables, but this time at the level of each of the 4 contract bundles. The objective of the exercise is to determine the best

relationship for each contract. The relationship spectrum ranges from collaborative (relational exchange) at one extreme to adversarial on the other (discrete exchange). The model remains abstract and does not inform a detailed solution⁵¹.

For example, the model assessed the TCE and RBT in contracts #2 and #4 as lacking potential for pre-contact or post market failure. Hence, a discrete exchange (price competition) including a high-powered payment mechanism was deemed efficient.

At time of the case study above, the model could not yet acknowledge an important issue this paper seeks to address – the role of uncertainty as a source of ex-ante risk pricing failures. Hence, its recommendations at the very least with regard to contract power would have to be amended.

That said, contract #4 represents around 50% of this road and comprise relatively straightforward on-grade road and elevated structures. The scale of this more straightforward work in Contract #4 would have suited local Tier 2 or Tier 3 civil engineering construction firms well. And since there were many more of these smaller contractors than Tier 1 contractors (including the Tier 1 contractor that led the alliance in this case study), there would have likely been much strong competition and significant downward pressure on a significant proportion of the price of the project. Hence, the procurement strategy recommended by the model would have likely been appreciably more efficient than the single contract alliance contract that was the actual approach selected.

In summary, the existing considerations of procurement in economic theory and construction management literature take the contract scope as a given and provide advice from that point on. Important decisions that will strongly affect procurement outcomes will have already been made by that point.

As projects grow, they become complex organizations. In that sense the considerations in the theory of the firm and how firms attain competitive advantages become relevant for the procuring entity and the project. This is what the model presented above attempts to achieve. Given the current procurement practice the structured approach of informing the make-or-buy and contract scoping decisions by taking an activity level perspective represents a step forward in itself. An empirical ex-post analysis of the full predictive power of the model, however, will only be possible once a sufficient number of applications has been executed to allow meaningful quantitative analysis.

8 Discussion – the opposing forces in contracts

The objective of this paper was to show that in infrastructure procurement, high powered contracts lead to disproportionately higher cost, when compared to lower powered contracts all else being equal.

⁵¹ In essence relational exchange implies procurement methods based on negotiation and delivery models with greater embedded collaboration (such as the Early Contractor Involvement) and more risk sharing in the payment mechanisms (e.g. target pricing - pain/gain sharing). The discrete exchange on the other hand leads to delivery models procured through low price auctions and higher contract power.

To build our case we focussed on the evidence from advanced economies to minimize the issue of stable institutional environments and the rule of law. We picked road infrastructure because of the relatively homogenous nature of this infrastructure type, long established design standards, and no broad reported issues with quality shading in contract execution.

In our discussion we first turn back to our initial question, are high-powered contracts disproportionately more costly and why.

Second, we stress that the same information that could help reduce uncertainty contractors face in bidding for infrastructure contracts would also help us better understand the performance of different procurement choices.

Lastly, we argue that the modern approach to procurement should be fundamentally revisited to optimally balance, what the government is procuring from the market, in what contract sizes and boundaries between them. These choices precede much of the discussion in this paper, but will fundamentally co-determine procurement outcomes.

8.1 The performance of high-powered v low-powered contracts

Contract theory predicts low-powered contracts are a better solution for dealing with adaptation cost and suggests high-powered incentives should be applied, when contracts are sufficiently complete. This could be the case when a project is sufficiently simple or when the delivery model makes the contract “complete” by transferring property rights. Contract theory does not deal with the relevance of pre-contract exchange of information or when in the development cycle of the project its price must be established.

The evidence capturing projects with average sizes of USD 1 -200 million shows that all projects in cost-plus Design-Bid-Build contracts will experience systematic cost overruns in a single digit percentage and therefore adaptation cost.

For small projects low profit margins and effective competition were demonstrated and contractors had a reasonably precise grasp of the risks they are taking. When bidding, they could predict in the bill of quantities, which items have been underestimated.

Yet, even in such simple settings a risk premium of 133% was estimated (in Bolotnyy and Vasserman 2019) if the same projects were procured through a complete contract – a high-powered, bundled format, i.e. lump-sum Design-Build. The premium is disproportionate to the potential cost overrun of a few percentage points it has to absorb. Similarly, other cited examples too point to disproportionate responses to reducing uncertainty pre-contract (e.g. Kosmopoulou and Zhou 2014).

In the bundled contract formats the bidders must themselves develop a design during bidding. Construction risk is also comprehensively transferred and implies uncertainties much larger than guessing, which items in the bill of quantities have been underestimated.

Moreover, contractors cannot assess risk in the same way as investors do⁵². Whereas investors could hope to rely on large time series of performance data, this is not the case for contractors. The pricing of design and construction risks relies heavily on expert risk workshops; whereby experienced practitioners make informed guesses about the corresponding probabilities and impacts (Makovšek & Moszoro 2018). A further unhelpful factor is that governments have not fully exploited the possibilities of ex-post analysis and performance benchmarking (OECD 2017).

In this context it is surprising that the actual premium for achieving cost certainty, such as in Engineering-Procurement-Construction contracts in PPPs, is not much higher than the 24%, as measured in Blanc-Brude et al. (2009)⁵³! Although in the particular case there is only limited evidence to argue that the 24% premium is not the result of building to a higher standard, other evidence (as above) corroborates that building on-time and on-budget alone will yield a disproportionate premium.

The order of magnitude difference with the 133% estimated in Bolotnyy and Vasserman (2019) can though at least in part come from their approach, i.e. the assumption of Constant Absolute Risk Aversion, which is an exponential function. It may not reflect real life. On the other hand, Nobel prize winners Kahneman and Tversky (1979) suggest that individuals tend to underweight larger probabilities, but overweight those that approach zero. Hence the presence of low probability, high impact events could substantially affect the contractors' risk perceptions and in consequence risk pricing. This is exactly what cost overrun distributions asymmetric to the left with a tail to the right imply. Indeed, in larger, more complex projects, the consequences of low probability, high impact events could be detrimental not just to the project but also the contractor⁵⁴. Hence, a small transfer of risk or uncertainty is still expected to yield a disproportionate premium.

Against these points, pre-contract information exchange will play a decisive role, but only limited empirical research on its impact was so far pursued. Evidence on procurement of rail and road

⁵² A more recent version of the approach also considers project specific v network specific activities in cases where the design and construction pertain to the delivery of network infrastructure. In this case maintenance and operations can be performed network wide and hence economies of scale need to be considered as well.

⁵² Until recently, investors in infrastructure assets could not price risk efficiently because the adequate indices on the risk/return profiles of homogenous groups of infrastructure assets did not exist even after several decades of increased private investment into infrastructure. Recently progress was made towards establishing infrastructure as an asset class with a precise definition and benchmarks (<https://edhec.infrastructure.institute/>). Another G20 initiative is underway.

⁵³ It is not straightforward to conclude that these premia transform into abnormal profits for major contractors for a variety of reasons. For example, construction firms generally pursue multiple business lines so the profitability of major projects would be drowned in the noise of other projects. Construction firms can be organized in several complementary profit centres. In the case of PPPs for example it is not uncommon to see an equity investor and a contractor being part of the same holding structure. The owners can choose when the profits will be expressed through the equity investment and when through the contractor. There is noise due to market cycles. Lastly, construction firms can dump risk too down the supply chain, which would imply, they aren't necessarily the ones making money, but their insurers and subcontractors.

⁵⁴ In 1991 the undersea tunnel bore for the Stoerebelt connection in Denmark water broke in through the face of the bore. Against the rules a worker forgot to close a bulkhead door, which flooded the tunnel and the Tunnel Boring Machine (TBM), resulting in massive delays and damage (Vincentzen and Smedegaard Andersen 2018).

infrastructure in projects above EUR 50 million in the EU suggests that less than a quarter relied on negotiated procedures and fraction of that competitive dialogue (Rouboutsos 2019).

Following our review of the relevance of procurement choices, the theory and evidence, we have to acknowledge that these lead to a nexus of opposing forces. Strengthening pre-contract information exchange through negotiation reduces uncertainty for the contractor at the expense of competition. Bundling design and build may reduce adaptation cost during project execution, but implies greater uncertainty in risk pricing at the bidding stage. Lastly, these choices interact with contract power, i.e. how much cost certainty do we want up front. Contract and auction theory have not yet reconciled these dimensions in a unified approach.

In summary at present the public policy makers (or the industry) have no complete view of the consequences of their procurement preferences. Owners report simple reasons on why one procurement approach was preferred over another. For example the primary reason for choosing Design-Build delivery model is faster delivery (Songer and Molenaar 1996). Data on cost overruns is becoming more commonly available and being on budget and on time has reputational concerns. Comparative information on cost is however unavailable. The same is true for “value” or quality. These gaps in evidence could lead to suboptimal decision-making or worse, create perverse incentives.

In the EU, a 10-year analysis (2006-2016) of road and rail works procurement showed a two-tiered market for traditionally procured projects or PPPs. While the competition was strong for small projects, for contracts above EUR 10 million the top 4 contractors won 30% of the total awarded contract value (Rouboutsos 2019). Given the theory and evidence treated in this paper so far procurement choices do have a strong impact on the competitive response. This market situation isn’t a fully exogenous circumstance for the governments. It is co-created by the governments with the procurement approaches they use.

We turn to the issue of data availability, the role of governments, and what our review suggests for the future of procurement in the last subsection.

8.2 Reducing uncertainty through public information

Our exposition so far stressed the role of information on risk and procurement outcomes. Recently the International Transport Forum at the OECD (ITF) (Kennedy et al. 2018) mapped some of the best practices that are applied in reducing bidder uncertainty in major projects.

As noted above however one of the major challenges especially in public infrastructure is the absence of comprehensive and systematic benchmarking in terms of project outcomes. This has been a major inhibition also to this paper which has focused mainly on cost. Extending on categories of time and quality or adding maintenance on top would reveal an even more scarce volume of evidence.

To this date for example it is not possible to compare infrastructure cost per physical unit in a robust (normalized) fashion. We’re unable to say whether a kilometre of a 2x2 motorway built to a similar

standard in say UK is more or less expensive than in Germany and if it is, why⁵⁵. The same is true for railways and many other types of infrastructure. No international database that would with any confidence compare infrastructure project outcomes exists.

More recently however limited progress has been made. The UK committed in its Transport Infrastructure Efficiency Strategy (DfT 2017) to pursue infrastructure benchmarking and issued the first benchmarking principles in 2019⁵⁶. Australia has been pursuing infrastructure benchmarking for several years.⁵⁷ A comprehensive road asset management standard is also developed in multiple countries, though it does not yet extend to procurement choices and outcomes⁵⁸. As project sizes increase however, fewer potential observations become available. This makes it less likely that individual countries (unless they are among the largest economies) could successfully pursue a quantitative analysis.

The ITF recently proposed an international transport infrastructure benchmarking initiative that would give a quantitative analysis the best possible chance, but countries have been slow to step forward (ITF 2018b). The benchmarking would begin with road infrastructure delivered in the recent past with the database updated on a periodic bases as the partnering organisations, i.e. the data owners would deliver new projects. The data owners, the ITF and potential research partners (e.g. universities) would have to agree on the data points per project collected and benchmarking objectives. Over time, the database could grow to include data preceding procurement (i.e. planning/quality of project selection), and data on operations and maintenance (service levels/quality).

In conclusion, we do not argue that the lowest cost (at a given quality) is the only noble goal in infrastructure procurement. Others will matter as well, depending on the context. We do argue, however that we do not have a sufficient empirical understanding of the trade-offs of procurement choices. While the majority of transport infrastructure budgets are spent on smaller and simple contracts, which are relatively well understood, potential suboptimal procurement choices on fewer but larger projects will have greater impact. Benchmarking initiatives, such as those above could be an important step towards informing major procurement improvements. More fundamentally though, the issues of bidder selection process, delivery model, and payment mechanism as defined in this paper are at the tail of what should be a comprehensive approach to procurement. This has to begin with the make-or-buy and contract scoping questions.

⁵⁵ The UK tried to benchmark with the Netherlands several years ago with very limited success (IUK 2010)

⁵⁶ <https://www.gov.uk/government/publications/best-practice-in-benchmarking>

⁵⁷ https://www.bitre.gov.au/data_dissemination/priority_projects/cost_benchmarking_infrastructure_investments.aspx

⁵⁸ The Australian example is available here: <https://austroads.com.au/publications/asset-management/ap-t334-18>

Appendix 1. Procurement options

The procurement procedures are described below as defined in the EU directives (2014/24/EU; 2014/25/EU). They will have analogue counterparts in the US and other advanced economies that will serve the same purpose. These procedures are described briefly on the European Commission site https://europa.eu/youreurope/business/public-tenders/rules-procedures/index_en.htm.

Table 2. Procurement procedures in the EU

Procedure	Description
Open procedure (Article 45)	In an open procedure any business may submit a tender. The minimum time limit for submission of tenders is 35 days from the publication date of the contract notice. If a prior information notice was published, this time limit can be reduced to 15 days.
Restricted Procedure (Article 46)	Any business may ask to participate in a restricted procedure, but only those who are pre-selected will be invited to submit a tender. The time limit to request participation is 37 days from the publication of the contract notice. The public authority then selects at least 5 candidates with the required capabilities, who then have 40 days to submit a tender from the date when the invitation was sent. This time limit can be reduced to 36 days, if a prior information notice has been published
Negotiated procedure with prior call for competition (Article 47)	In a negotiated procedure the public authority invites at least 3 businesses with whom it will negotiate the terms of the contract. Most contracting authorities can use this procedure only in a limited number of cases, for example for supplies intended exclusively for research or testing purposes. The contracting authorities in sectors such as water, energy, transport or postal services may use it as a standard procedure. The time limit to receive requests to participate is 37 days from the publication of the contract notice. This can be reduced to 15 days in extremely urgent cases, or 10 days if the notice is sent electronically.
Competitive dialogue (Article 48)	This procedure is often used for complex contracts such as large infrastructure projects where the public authority cannot define the technical specifications at the start. After the publication of the contract notice, interested businesses have 37 days to request participation. The public authority must invite at

Procedure	Description
	least 3 candidates to a dialogue in which the final technical, legal and economic aspects are defined. After this dialogue candidates submit their final tenders.

Source: EU directives (2014/24/EU; 2014/25/EU).

Further to the bidder selection process, the selection criteria can also influence whether the client has more or less discretion in the choice of the bidders. The table below illustrates the criteria commonly present in the US highway procurement.

Table 3. Basic bidder selection options

Criteria	Description
Low bid (lowest price)	Lowest price wins.
Economically most advantageous offer (=Best value)	Best score based on multiple weighted criteria wins. These could include qualifications, cost, time or other measures.
Qualifications-based (=non-price competition)	The criteria are defined based on measures of the bidders past performance or references. Qualifications could also be part of a two-stage process with pre-selection or included as one of the factors in the Economically most advantageous offer

Table 4. Frequency of basic bidder selection options in road infrastructure procurement

Procurement Procedure	DBB (n = 134)	CM/GC (n = 34)	DB/LB (n = 39)	DB/BV (n = 77)
Low bid	80%	0%	100%	0%
A+B (cost + time)	13%	0%	0%	18%
Best value	1%	47%	0%	61%
Qualifications-based	1%	41%	0%	0%
Other or not classified	5%	12%	0%	21%

Source: FHWA (2016).

Appendix 2. Delivery models

Table 5. Commonly-used delivery models

Delivery model type	Broad structure
DBB (Design-Bid-Build (“Traditional delivery”))	Design and construction separately and sequentially tendered to the private sector. Design either undertaken in-house, or outsourced (for larger projects). Contractors engaged on basis of complete design (input-specified), with clients providing a design warranty. Contracts predominantly fixed price, but cost-plus (unit price) or hybrid forms (e.g. surety bonds in the US) are also used if conditions are uncertain.
DB (Design&Build) (K. R. Molenaar, Songer, and Barash 1999)	Design and construction are procured together from the private sector. At the time a request for proposal is issued, the design developed up to an outline design level and the results are defined through an output specification (defines performance/end result) or a prescriptive specification (defines method and material). Contracts are predominantly fixed price/lump-sum.
EPC (Engineering-Procurement-Construction or DBFMO as commonly-used in PPPs)	This option is similar to the DB variant with the two distinctions. Generally there is no outline design available, only a specification of the functions the asset needs to perform. The contractual penalties for non-performance (e.g. delay) can also be more severe than in a DB contracts. In PPPs, the project company (the SPV) contracts the design and construction through an EPC contract (and an operations and maintenance contract)
ECI (Early Contractor Involvement)	Typically involves a two-stage process, with clients engaging a limited pool of contractors to work alongside designers, followed by a competed DB stage (with designers integrated into the contractor). Mostly used where conditions are highly uncertain, or when considerable innovation is required.
Construction manager/general contractor (CM/GC)	The agency procures professional services on a qualifications or best-value basis from a construction manager during the design phase to offer suggestions on innovations, cost and schedule savings, and constructability issues. Upon completion of the design or individual design packages, the contractor and agency negotiate a price for the construction contract, and then the construction manager acts as a general contractor to complete construction. The contract can employ a guaranteed maximum price administered on a cost-reimbursable basis, unit price, or lump-sum contract (FHWA 2016). This approach is relatively popular in the US and is similar to ECI.
Alliancing	Clients and selected contractors jointly prepare project scope and target cost; and agree a shared risk/reward mechanism (cost incentive). Parties are bound by open-book accounting, no blame/no dispute policy and unanimous decision-making. Project functions – transcending planning, design and construction – are integrated through a joint project management board. Mostly used where conditions are highly uncertain and/or complex.

Source: Kennedy et al. (2018), adapted by the author.

Appendix 3. Payment mechanisms

Table 6. Commonly-used payment mechanisms

Payment mechanism	Broad structure
Re-measurement (also known as bill of quantities; unit price)	Using the re-measurement method (the measured or unit price contract), the works actually done are measured based on the individual rates and prices offered by the contractor in their bid in the bill of quantities (prepared by the employer). The bill of quantities contains particular items and gives a description of the work and quantity. Every individual item and the respective rate or price must be properly contemplated and its content clearly understood to avoid disputes. The contractor will evaluate the rates and prices in the bill of quantities while keeping in mind prices for the materials, products, labour, equipment, plants, and so on (e.g., per cubic meter cost of the pit to be excavated). This process is called estimating and affords a means for the employer of comparing tenders received once they have been priced.
Cost-plus a fee (also known as cost reimbursable)	Under the cost-plus method, the contractor receives from the employer not only the payment for reasonable and properly incurred cost, but also a fee for overhead and profit. This method is more appropriate for high-risk projects where a lump-sum price (which takes all contingencies into account) would be too high. To encourage the contractor to perform the works for the lowest possible price, some additional mechanisms can be used, for example, the maximum guaranteed price or target price, described below. Under this arrangement, contractors are usually obliged to maintain comprehensive and contemporary cost records and the employer usually reserves the right to audit the claimed cost to ensure they have been reasonably and properly incurred. The profit and overhead surcharge will be subject to competition in the tender period.
Lump-sum (fixed-price)	Under the lump-sum method, a pre-agreed sum (regardless of actual cost incurred) is paid by the employer and the works actually done are not measured but paid against the schedule of payments, mostly once the predetermined sections (or milestones) are finished or when the project is fully completed. The lump-sum price is also influenced by claims, variations, and adjustments based on the particular contractual risk allocation, claims options and variation (and adjustments) procedure.
Guaranteed maximum price	Employers sometimes want to cap the total contract price using the guaranteed maximum price to allocate all risks of potential price increases to the contractor. This approach is used and accepted for example in the United States using the construction management at risk delivery method. The main drawback of such a system is that it must be perfectly thought out in respect of risk allocation, insurance, securities, and financial reserves (or risk surcharges). Such a setup is not appropriate for projects where numerous hazards with major risks are pending and it is not possible to price such risks transparently.
Target price contract	Under this regime during the works two things happen in parallel. The contractor is generally paid their actual costs plus a fee on a regular basis. The initial target price is adjusted during the works in accordance with claims and variations (compensation events) and their estimated cost. On completion, these two elements are compared. If there is a saving or a cost increase as against the target, then the parties share such savings or cost increases in the agreed proportions set out when the contract was agreed.

Source: Klee (2018).

The frequency of different payment methods in the US highway procurement is illustrated in the table below.

Table 7. Use of payment mechanisms in the US highway procurement

Payment Method	DBB (n = 134)	CM/GC (n = 34)	DB (low bid) (n = 39)	DB (best value) (n = 77)
Lump-sum	2%	3%	85%	91%
Cost-plus fee*	2%	0%	0%	0%
Re-measurement*	93%	38%	5%	0%
Guaranteed maximum price	0%	56%	0%	4%
Other or not classified	3%	3%	10%	5%

Note: Contract value ranged from USD 69 thousand to USD 358 million with a mean of USD 27 million.
 (*) Description adjusted, Cost-plus fee was orig. "cost reimbursable" and Re-measurement was orig. "unit price".

Source: FHWA (2016).

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