Procurement Choices and Infrastructure Costs

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Contents

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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 how we choose to procure projects - the procurement strategy.

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 instance, in dimensions other than speed of delivery, 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.

To inform the process of procurement, contract and auction theory to date arrived to broad predictions with regard to three key procurement choices:

a) Bidder selection
    - In complex projects increased exchange of pre-contract information should lead to more aggressive bidding and reduce the end cost of the project.
    - Because the increased pre-contract information exchange can also help reduce the need for costly renegotiations during contract execution, in complex projects negotiations should be preferred to auctions.
b) Delivery model
    - Contracts that bundle project phases (e.g. Design and Build) should help reduce the incidence of renegotiations.

c) Incentive power.
   - Fixed-price or lump-sum contracts are to be preferred in contracts, where there is little to no renegotiations, i.e. contracts are complete. In all other cases cost-plus contracts should be used.

Combined, these predictions suggest that for example a lump-sum contract that combines the phases of design and construction (or also operations and maintenance) procured through a negotiated process should outperform a cost-plus contract, where the design and construction were procured separately, and the winning bidder was selected through an auction.

In this paper we find that the available evidence does not match the predictions well, especially when it comes to larger, more complex projects. Negotiation and bundling do not clearly lead to less renegotiation per se. An important cause for this is the inability of the public clients to specify their full needs in advance. An investigation into the root causes behind this result is beyond the scope of this paper.

We also show that high-powered incentives, requiring high certainty of on-budget and on-time delivery carry a disproportionate cost premium even in the absence of renegotiations, i.e. complete contracts. We argue that this mismatch between predictions and evidence is best explained by the underappreciated role of uncertainty. Currently uncertainty in contract theory is mainly recognized as a driver of post-contract renegotiations. It has, however, an equally important role as a driver of risk contingencies, when bidders need to price the contract in the bidder selection phase.

As a result efficiency gains in high-powered contracts may be more than offset by contingencies in the private supply chain, driven by uncertainties implicit to complex major infrastructure and the long-term nature of the contracts. The same consideration would apply to high-powered and long-term contracts such as road PPPs[2].

The research and decision-making challenges above are 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. A consequence of this state of affairs is that the current approaches governments use to inform procurement strategies of projects leave a wide margin for further improvement.

Looking towards to future, we conclude the paper by acknowledging that resolving the issues of bidder selection, project phase bundling, and incentive power still does not represent a comprehensive procurement strategy. This is because two essential choices precede these decisions. Firstly, the make or buy question - which capabilities should a procurement entity procure from the market and which

[2] In road PPPs for example, both the construction and the maintenance part have very strict on-budget requirements, i.e. have to be almost fully priced ex-ante. There are no ex-post corrections due to competitive pressure or incentive regulation. In the case of sea port PPPs for example, competition could be present for the same catchment area, providing persistent incentives for efficiency and eroding abnormal rents.

should it build in-house. Secondly, aside from the question of bundling project phases, there is a question whether a project be procured through one or several parallel contracts and where should the boundaries between them lie. Both choices will importantly pre determine the competitive response, well before we start planning the bidder selection process. Both choices also require stepping outside of the purview of auction and contract theory, taking lessons from other new institutional economics theories and beyond.

We note that in its review of evidence 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. A great majority of the available evidence concerns road infrastructure.

1.1 The road map to this paper

In what follows the 2nd section of the paper begins with a brief historical overview of procurement and contracting, from Roman times until today. This overview serves to introduce basic infrastructure procurement or contracting concepts and reveals that many fundamental procurement problems remain relevant to this day.

The 3rd section takes the basic concepts introduced in the historical overview and explains in greater detail the main infrastructure procurement choices – bidder selection, delivery model, and incentive power. As most of the available evidence on our topics concerns road infrastructure we outline the dominant options used in that market.

The 4th section captures what parts of economic theory relate to infrastructure procurement. The auction theory focuses on the bidder selection process and considers the choice of the delivery model or incentive power as a given. Contract theory takes the reverse view and considers the bidder selection choice as a given. Key predictions of auction and contract theory with regard to the main infrastructure procurement choices are distilled.

The 5th section provides an overview of empirical data available to assess to what extent evidence matches theoretical predictions. In terms of infrastructure most available evidence comes from transport infrastructure or road projects. To the extent possible, large sample quantitative research is captured.

In the 6th section we outline how advanced economies approach the procurement of major transport infrastructure. The most developed aspect here is the process of bidder selection, where the rules are enshrined in legislation. Choices with regard to the delivery model and incentive power are left to operational guidance. Recent developments in the UK and Australia are also presented.

A discussion concludes the paper in the 7th section. It highlights where the theoretical predictions and empirical evidence do not meet and stresses the importance for international infrastructure benchmarking to advance the theory and practice of procurement. Recent advances also suggest an expanded concept of what a procurement strategy should entail is needed.

2 History and procurement choices

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 recently[3]. The beginnings of public works contracting though are ancient. In terms of the make or buy question in the Roman Empire for example, the first roads were designed and built by the army with the aid of civilian or slave 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, 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)[4]:

"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."

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

[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).

[4] 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.

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[5]) 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...”.

Against a much more varied procurement context the same issues as highlighted above are still of interest today. Our methods may have improved over time but so has the complexity of what we’re building. As we shall see in the review of theoretical and empirical work, many of the old dilemmas remain unresolved.

The procurement history was dominated by the idea that competitive bidding yields the best results, inhibiting alternatives. Negotiations were only allowed, when competition was not possible. In the US for example the construction of the federal interstate system began with the 1956 act. Until the 1990-ies this programme was almost exclusively procured through competitive bidding based on the lowest price, using a Design-Bid-Build delivery model. Still dominant today (FHWA 2016), the primary payment mechanism was the bill of quantities approach. The domination of competitive bidding was enshrined through a legislation, which favored competitive bidding (23 U.S. Code § 112. Pub. L. 85–767). Other methods were allowed only on a declarative level, i.e. they could only be considered provided they “are effective in securing competition”. Effectively methods based on negotiation were not desirable.

In the 20th century the projects became more complex, more expensive (Brooks and Liscow 2019) and in terms of size larger (Flyvbjerg 2014). In the recent decades, particularly for larger projects, a greater penetration of procurement models where negotiations need to play a stronger role is taking place.

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.

[5] Another term used for this payment mechanism in economics are scaling auctions.

3 Broad characteristics of (infrastructure) procurement choices

After a public client made a make-or-buy decision, i.e. decided to procure from the market, 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 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*[6]
  Incentive (or 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 incentive 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 random[7].

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-plus[8] (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.

For major projects, ranging from several USD million to hundreds of millions other alternative contracting approaches have slowly started increasing in use since the 1990 in some advanced economies like the US, UK, Australia, Sweden, Netherlands (e.g. FHWA 2016 for US).

The US slowly followed and in the US road infrastructure procurement the introduction of alternative contracting approaches began more systematically with the initiation of FHWA's Special Experimental

[6] All three choices contribute together to the amount of risk the contractor is bearing.
[7] More detail about the broad options possible under all three dimensions is available in Annexes 1-3.
[8] 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. We note that cost-plus fee contracts are almost never used in infrastructure procurement and are prohibited in some jurisdictions (e.g. US; FTA 2016).

Project No. 14 (SEP-14) in 1990. Once cleared by the FHWA the new approaches are no longer considered experimental, hence the state road agencies can use them on Federal-aid projects without FHWA's approval. In 2004, the FHWA initiated SEP-15, which allowed contracting agencies to explore innovative approaches that address all phases of project development, such as PPP's.

In this paper our scope does not extend beyond Design-Build (DB) and its close relative the Engineering-Procurement-Construction contract (EPC), which is the default option for Public-Private Partnerships (PPPs).

Both alternatives are typically procured through negotiated procedures and rely on the lump-sum payment mechanism[9].

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 typically between 10-20% complete. An output specification will be available though, describing what functions the asset should perform. For an Engineering-Procurement-Construction contract bidder there will be no outline design and only the output specification will be available. The Design-Build and Engineering-Procurement-Construction bidders are expected to develop and price their solutions during the bidding process[10].

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 high-powered procurement formats, with very high-risk transfer.

In the next section we look at the key predictions economic theory has made with regard to the three procurement choices above. We do not deal with the make or buy question as that would deserve a full separate paper and instead focus on the three procurement choices outlined above.

4 Economic theory applications to infrastructure/construction procurement

There are two streams of economic theory that deal with the basic procurement choices outlined earlier, auction theory and contract theory.

Auction and contract theory have a different focus. Auction theory focusses on the bidder selection process and considers the project delivery model and incentive power as a given. It does not consider

[9] In the US competitive bidding is used to secure a low bid or a best value proposal (FHWA 2016). That said the Code of Federal Regulations CFR, 23 CFR § 636 allows significant two-way information exchange activities between the proposal submition and bidder selection to reduce uncertainties or errors in the proposals. Recent research confirms this to be the case (Calahorra, Torres-Machi, and Molenaar 2019). For this reason in economics this approach to bidder selection would qualify as "negotiations".
The US variant of competitive dialogue – competitive negotiations is applied in PPP procurement.
[10] 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.

delivery models or incentive power. It does however yield insights or consequences for their application. Conversely, the main focus of contract theory has been the delivery model selection and incentive power. The results of the bidder selection process are in this case a consequence of incentive power choices.

In both theories there is also a basic distinction between two types of contracts – complete and incomplete contracts.

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

In an incomplete contract the bids no longer fully reveal the bidders' revenue expectations. 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. The 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 and what is more easily observable, cost overruns[11].

4.1 Bidder selection and auction theory propositions

The traditional auction theory view has been that the benefits of competition always outweigh any other auction mechanism that involves fewer bidders (Bullow and Klemperer 1996). A key assumption behind this finding is 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.

The more complex the object of procurement however, the less complete the contract, hence auction theory adopted two main alternatives to auctions – negotiations and relational contracting. Both imply a trade-off with reduced completive pressure.

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).

[11] These two terms are not equivalent and the distinction is explained later in the paper.

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 renegotiations and adaptation cost.

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 rather than enable renegotiations. Specifically, bidders can lack information about the true cost of the object that is being tendered[12]. 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.[13] 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 bundled or high-powered contracts. Implicitly though it can be deduced that especially in these cases the exchange of pre-contract information will be a key requirement.

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[12] 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.

[13] The same result in conventional financial economics would be attributed to improved risk pricing efficiency (Makovšek and Moszoro 2018) through a mechanism more straightforward than that of Goeree and Offerman (2003). 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.

4.2 The choice of the delivery model and contract theory propositions

Contract theory consists of two streams, the principal-agent theory and the property rights theory. It is the latter that proposes it is possible to solve the incomplete contract problem by bundling the contract phases (Hart, 1995; 2003; Iossa & Martimort, 2015).

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.

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 DBFOM[14], 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 client[15]. 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.

[14] 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.

[15] 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.

Iossa & Martimort (2015)[16] formalized these propositions and found that the Design-Build-Operate-Maintain bundle provision beats traditional procurement if benefits from bundling are significant[17]. 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 hand[18]. An implicit assumption to the conclusion above is also that the bidder selection stage would not be affected by bundling and the high power of the contract.

Hence, the theoretical prediction is that through bundling project phases (i.e. the transfer of residual control), we can eliminate or reduce contract incompleteness.

4.3 The choice of incentive power and contract theory propositions

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 ensuring 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, the principal-agent theory in a complete contract setting applies the issues of the opportunistic behaviour of agents due to the information asymmetry between the agent and the principal. Two problems emerge - the adverse selection ex-ante and moral hazard ex-post contract signature (Laffont & Tirole, 1993).

Adverse selection in the bidder selection process can occur because the principal does not know the true efficiency of the agents (i.e. the bidders). This makes it difficult for the principal to determine, who will exert the most effort at a given incentive. If contracts are complete however, the initial bid fully reveals the contractor's revenue expectations up front and there can be no ex-post renegotiation. This means that when renegotiations are unlikely, a high-powered incentive, i.e. a lump-sum (high-powered) contract will ensure the best contractor is chosen in the competition (Bajary and Tadelis 2001).

When contracts are incomplete the initial bid will not fully reveal the contractor's revenue expectations and renegotiations will occur. Three theoretical solutions were put forward.

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[16] 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.

[17] 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.

[18] 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).

Hart and Holmstrom (1987) sought to address the adverse selection problem in the context of incomplete contracts by offer the (potential) agents a menu of contracts, which allow them to be interested in the trade and reveal their true type.

McAfee and McMillan (1986) combined a bidding model with adverse selection and moral hazard challenges. They suggested that neither cost plus nor fixed price contracts are desirable in an incomplete contract setting. The proposed solution is an incentive contract which makes the payment depend both on the bid and on realized costs: if realized costs exceed the firm's bid, the firm is responsible for some fraction of the cost overrun; if the firm succeeds in holding its costs below its bid, it is rewarded by being allowed to keep part of the cost underrun. A caveat to this result is that in their model cost plus contracts give the contractor no incentive to bid aggressively, hence these contracts are never optimal.

A third option recommends low powered incentives (Williamson 1985; Bajari & Tadelis 2001). Low powered incentives have adaptability advantages. In construction for example, this would be because cost-plus contracts involve a bill of quantities to which the bidders need to assign unit prices. If the actual quantities differ from the estimated ones, i.e. unit prices in the bill of quantities offer a reference price list to evaluate variation claims[19]. 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. A key driver behind this thinking is the assumption that the information asymmetry ex ante, i.e. that the private party knows more than the public one, hence the adverse selection, isn’t the main issue. Both parties equally face future uncertainties.

Lastly, 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, assuming ex-post quality can be monitored. Thus, if bundling leads to greater contract completeness, bundling and high-powered incentives should go hand in hand.

If contracts are incomplete, several options are put forward. The obvious choice is to prefer low-powered incentives. More sophisticated propositions suggested the use a menu of contracts to ensure effective self-selection of the most efficient bidder. Lastly, a target price contract was proposed by McAfee and McMillan (1986). In it the public and the private party agree on a target in the competition phase and then share the savings or the losses at the end of the project (see Appendix 3).

[19] 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.

4.4 What theory does not yet address?

There is no economic theory that would reconcile the perspectives of the auction and contract theory in a single model. One aspect that stands out in particular is the underappreciated role of uncertainty in contract theory, where it presently plays three roles:

a) 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

Uncertainty in contract theory however, is not yet acknowledged as a source of less aggressive bidding or excessive contingencies ex-ante. In short, it matters how well the bidders know the risks they are taking at the moment they need to price the contract.

A direct extension of the point above 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 sections look at whether the empirical evidence matches theoretical predictions in the procurement of infrastructure.

5 Testing theoretical predictions and available evidence

Our review of auction and contract theory revealed a range of applications to infrastructure (or construction) procurement. The available empirical evidence allows us to further assess the following predictions, arranged below according to three basic procurement choices:

a) Bidder selection
    - In complex projects increased exchange of pre-contract information should lead to more aggressive bidding and reduce the end cost of the project.

- Negotiations should be preferred to auctions, because they allow an increased pre-contract information exchange and thus help reduce the need for costly renegotiations during contract execution.

b) Delivery model

- Contracts that bundle project phases (e.g. Design and Build) should also help reduce the incidence of renegotiations.

c) Incentive power

- Fixed-price or lump-sum contracts are to be preferred in contracts, where there is little to no renegotiations, i.e. contracts are complete. In all other cases cost-plus contracts should be used.

Other alternative propositions on how to inform incentive power in incomplete contracts in infrastructure procurement cannot be assed due to lack of use in practice (the case for menus of contracts) or lack of evidence about the performance of the solution (the case for the target price contract)[20].

With regard to the predictions that we can assess, ideally the evidence would allow us to secure a view of comparative statics, i.e. how a change in a single procurement choice, keeping all else equal, affects the project outcomes. The outcomes would in their minimum configuration control for the trade-offs between cost certainty (i.e. cost overruns), overall cost per physical unit of infrastructure, and quality. Since no piece of evidence meets this ideal and since project outcomes can depend also on factors other than procurement choices, several explanations with regard to the interpretation of the evidence in this paper are required.

Geographically, in its review of evidence 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 the quality of governance. Poor execution of procurement processes or contract management can be a substantial factor affecting project outcomes. For the same reason we do not pursue evidence that concerns regional or local authorities[21].

We found that that the quality of infrastructure is not explicitly controlled in any of the studies. Fortunately, in general most of the available evidence concerns road infrastructure in advanced

[20] In practice this option is used in collaborative type projects, where the public and private party jointly manage the execution. A high level of professional competence on the public side is required. Furthermore, the effectiveness of the method lies on the assumption that the public side can monitor the required cost of the contractor effectively. If that were not the case, the contractor would be incentivized to bid with a high target and build on cost, maximizing private rents, essentially transforming this approach to a lump-sum contract.

[21] Evidence on the impact of increased discretion in bidder selection and rare attempts to compare the outcomes of negotiations v auctions almost in the entirety come from this strata (e.g. Coviello, Guglielmo, and Spagnolo (2018), Palguta and Pertold (2017), Chabrost (2018), Baltrunaite et al. (2018)), mainly showing a negative impact of increased discretion. A single study of larger projects for road authorities in the US also exhibits a negative impact Park and Kwak (2017)

economies. Road design standards in this case 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 an issue. There is no evidence available that would suggest otherwise. The same assumption is adopted in several large sample studies (e.g. in Bajari, Houghton, and Tadelis (2014) or Bolotnyy and Vasserman (2019)).

6 Does increased pre-contract information exchange increase bidding aggressiveness

Negotiations allow for more space to exchange pre-contract information than auctions. By definition, a negotiated process reduces the power of competitive pressure, since the number of bidders with which one can simultaneously negotiate and mutual transaction cost will imply participation restrictions. As a consequence, a negotiated process implies a trade-off between reduced competitive pressure and increased ex-ante information exchange.

That said, increased ex-ante exchange of information or the reduction of the uncertainties faced by the bidder can also be achieved 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 project[22]. The study compared the

[22] 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

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%. There is no information available unfortunately, whether contract renegotiations were affected as well.

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 model[23], i.e. a detailed design is already available at the bidding stage. The evidence concerns small and by implication simpler projects[24]. Yet even at this level significant and disproportionate impacts of uncertainty have been measured (e.g. absorbing a 5% input price uncertainty, led to 11% reduction in winning bid price). 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.

7 Do negotiations and bundling lead to less renegotiation

Following the exposition of economic theory less renegotiation reduces adaptation cost. Bajari, Houghton, & Tadelis (2014) analysing auction procured Design-Bid-Build cost-plus road projects in the US with a mean size of USD 2 million showed that these can be significant on a sample of 3,661 bids. Several models were used to break down the outcomes into separate effects. The adaptation cost represented 7-14% of the winning bid and ranged between 55 cents to 2 dollars for every dollar of

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).

[23] The delivery model or incentive 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.

[24] 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.

change. The bidders could foresee, where adaptation will be necessary and the private rents are competed away (the average bidder could expect a profit margin of 3.5%). This though is the case for small projects, where uncertainty the bidders face is limited.

The theoretical prediction is that negotiations might facilitate increased pre-contract exchange of information and reduce the need for renegotiations. The more complex the project the stronger the case.

Lessons from the private sector (Bajari, McMillan, and Tadelis 2009) show that in residential construction industry (private – private transactions) negotiated projects prevail and are generally awarded to more efficient or more experienced contractors. There is no analysis however that would test the impact on procurement outcomes. Caution is also 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). By implication, public managers in a negotiated process may be less flexible than private ones.

For infrastructure procurement[25], however, there is no evidence that would test the impact of the introduction of negotiations, keeping all else equal, for example in Design-Bid-Build projects. The use of negotiations in Design-Bid-Build contracts has a limited function, since the solution to the engineering challenge is already defined (through a detailed design). What is left to be negotiated in public sector procurements is the interpretation of the specifications and the price. This means negotiations or competitive dialogue would have the greatest value in delivery models, where the bidders can also inform the solution – specifically in our case Design-Build and Engineering-Procurement-Construction contracts. Evidence is available, that allows us to assess, whether renegotiations in these cases are less significant than in auction procured Design-Bid-Build projects. To do so, we look at cost overruns on road projects.

Cost overrun evidence is spread over small and large projects, which may exhibit different levels of complexity and ultimately interfere with out interpretation of the evidence. Hence our first task is to get a view how cost overruns develop with project size.

7.1 Cost overruns in the Design-Bid-Build delivery model and project size

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) the first part of cost overruns comes directly from the additional work that was not anticipated (by the client). Adaptation cost (the second part) come in addition as the result of disruption to the normal work flow and the resulting haggling,

[25] A few studies exist that try to capture negotiation effects, but do not do so in terms of procurement outcomes and/or refer to lower levels of the government (e.g. Baltrunaite et al. (2018), Chever and Moore (2017)).

disputes and opportunistic behaviour during renegotiations[26]. 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 reason[27] 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. Most studies capture entire populations of projects over a select time period.

[26] 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.

[27] 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)[28]	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 do increase with project size[29]. Gkritza & Labi (2008) on a sample with an average project size of USD 1 million show a 1.55% growth in cost

[28] Shared by authors based on original data.
[29] 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)[30] 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 above this range, 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.

7.1.1 Further evidence on cost overruns in large projects

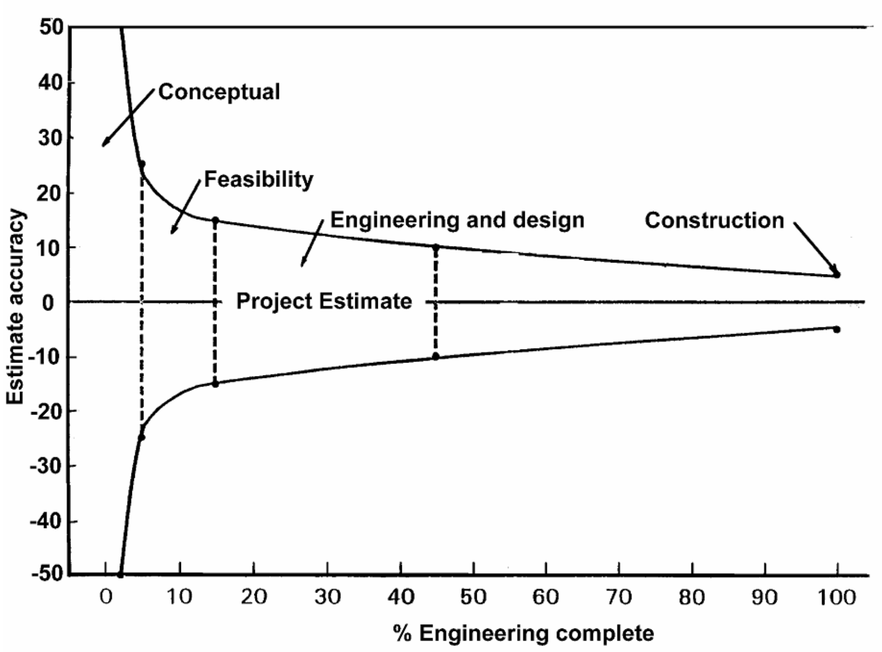
In addition to the studies in Table 1 a body of evidence exists which measured cost overruns against the formal decision to build[31]. It further corroborates the point that cost overruns (and by implication adaptation cost in contracts) in large projects are not disproportionately larger as in smaller 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.

[30] 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).

[31] 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)[32].

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 (between 10-20% of engineering complete).

[32] What is the root cause of cost overruns measured against the decision to build (or the award price) is subject to on-going work and is likely not the same for mega projects, which capture substantial political attention and the rest. 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.

7.2 Do bundled delivery models lead to less renegotiation

More complete contracts imply greater pressure on the bidders to express their revenue expectations ex-ante and stress the importance of pre-contract information exchange. In transport infrastructure bundled delivery models are commonly applied in large projects and in conjunction with high-powered incentives, i.e. lump-sum payment mechanism.

7.2.1 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 value[33] through a negotiated procedure. The level of design provided to the bidders can range from 0-50% (Molenaar, Songer, and Barash 1999) of engineering, but is commonly concentrated on the low end of the range. The payment mechanism applied is lump-sum (Chen et al., 2016; FHWA, 2016).

A rare example of a study which tried to control for complexity[34], 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 insignificant[35]. That said though, the difference in cost overruns measured for Design-Bid-Build and Design-Build projects was also very small[36].

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[33] 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.

[34] 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.

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

[36] 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 found 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.

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 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 auction procured Design-Bid-Build delivery model.

The nature how renegotiations can occur though is different than in the Design-Bid-Build contracts. 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 the asset to perform. In consequence changes are still required during construction. This point finds support in a study of 45 major Design-Build road projects in the Netherlands[37] (Verweij, van Meerkerk, and Korthagen 2015)[38], with the mean project value of EUR190 million. The authors found that on average 50% of the cost growth could still be attributed to scope changes[39]. The root causes for this phenomenon are beyond the scope of this paper, although the project management literature does offer some ideas, starting with Flyvbjerg, Holm, and Buhl's (2002), optimism bias or strategic misrepresentation.

[37] 38 of these were road projects.

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

[39] 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%).

7.2.2 Engineering-Procurement-Construction contracts

In the Design-Build contract an outline design is commonly made available during the bidding. This is not the case 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)[40]. 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-Procurement-Construction contract alongside a range of incentives against non-performance[41]. 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 PPPs[42]. 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 and not the performance of the project company. 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 runs[43], and 54 projects exactly on cost (Figure 5).

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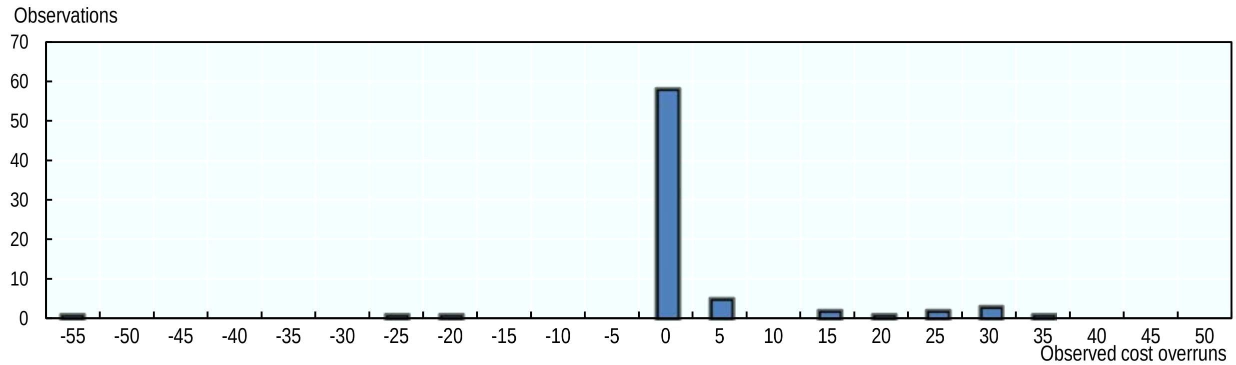
[40] PPPs are also referred to through one of their many variants, most commonly as Design-Build-Finance-Maintain-Operate (DBFMO) contracts.

[41] 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).

[42] 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%.

[43] 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.

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



Source: Blanc-Brude & Makovsek (2013).

Raisbeck, Duffield, & Xu (2010) collected 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 is 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.

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 far.

Given that Design-Build projects represent a very similar procurement format, with the majority of the design risk transferred to the contractor it is not immediately clear, why the Engineering-Procurement-Construction format or PPPs would perform substantially better. One explanation though is, that the complicated financial and legal structure of PPPs makes changes prohibitively expensive for the public authorities.

8 Do high-powered incentives mix well with complete contracts

Contract theory predicts 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 lump-sum contracts should be used when no or few renegotiations are expected.

As noted during our review of theory though, this proposition does not take into account uncertainties bidders face, when pricing the contract. In our evidence review on the impact of pre-contract information exchange in auctions, substantial effects were measured already in relatively small and by extension simpler projects.

Below we review evidence that provides some insights how much uncertainty bidders face in contract pricing and what the impact of high-powered incentives on cost per physical unit could be.

8.1 Incentive power and performance in small contracts

In cost-plus Design-Bid-Build contracts bids are typically submitted through a bill of quantities, which lists expected quantities for the items and unit prices next to them. Bajari, Houghton, & Tadelis (2014) in their measurement of adaptation cost in such contracts also revealed how much uncertainty bidders face. They found bidders foresaw which items had quantities underestimated and strategically priced them. They increased the prices, where quantities have been underestimated and reduced prices on quantities, which were overestimated to still achieve a lower total.

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 incentive power were to be increased. Their data builds on 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 could 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%[44].

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. Bidders would have to 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 133% more expensive.

On the other hand, the result of Bolotnyy and Vasserman (2019) suggest, even if the objective of contract completeness could be met, uncertainty interfering with the pricing of contract would still lead to significant additional cost. This result does not align well with the predictions of contract theory, which sees adaptation cost as the main challenge to incentive power selection.

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, where the design is not necessarily complete at the time it needs to be priced?

[44] 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.

8.2 Large(r) projects and the relevance of incentive power

The structural models in 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. A single study to date investigated the relative performance of construction cost per physical unit for “traditional procurement” (Design-Bid-Build contracts)[45] and PPPs (Engineering-Procurement-Construction contracts) (Blanc-Brude, Goldsmith, and Välilä 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 work[46], 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 Välilä (2009) sample is also that the projects in question 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 bias[47].

As the study above captured contract cost at or close to award[48] 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 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

[45] 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.

[46] Large bridges were separate projects and were excluded from the sample.

[47] 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.

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

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 hospitals procured through PPPs 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 conclusion[49].

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 or procurement outcomes, the next section looks at how governments procure in practice.

9 How are procurement choices informed today?

Advanced public infrastructure clients ideally have a procurement strategy guidance defined, with more detailed support found in separate documents. The procurement strategy typically begins with a statement of objectives, description of requirements, an analysis of the market and client capability and then moves towards informing the delivery model (e.g. Department of Infrastructure and Regional Development 2008b; FTA 2016; HM Treasury 2016). Bidder selection process and incentive power are in most cases a result of the selected delivery model, whereby the first is strictly regulated by law.

9.1 The bidder selection choices are enshrined in the law

The bidder selection choice is subject to detailed description of the process (e.g. FDOT 2015) and is broadly framed by the procurement legislation in any jurisdiction. In the EU directives on procurement negotiations for simpler projects are to be avoided, if competition can be secured. For more complex projects, when public authorities chose delivery models using an output specification (such as Design-Build), negotiations and competitive dialogue are allowed. Similar bidder selection options are now available in other jurisdictions (e.g. Federal Acquisition Regulation (FAR)[50], 48 CFR in the US, since 2004; Scott 2006).

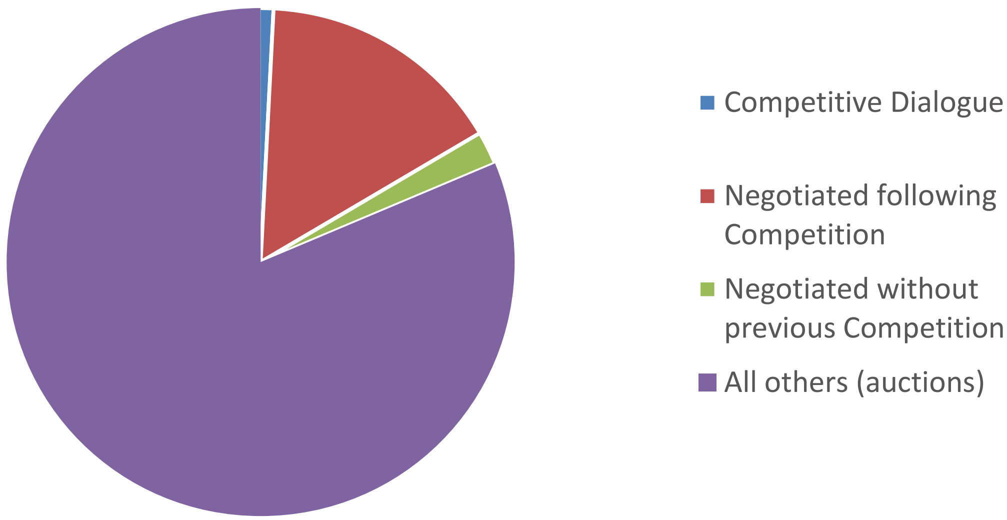
The use of negotiated procedures has been slowly increasing but is (at least in Europe) still limited (figure below 3). In principle the choice of procedure should be heavily related to the choice of the delivery model but there may be other circumstances guiding this choice as well[51].

[49] 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.

[50] FAR in the US regulates procurement with federal funding (https://www.acquisition.gov/browse/index/far). The States themselves also developed procurement legislation, which follows similar basic principles.

[51] E.g. from the perspective of ex-ante information exchange, where the delivery model requires a specification of needs such as with the Design and Build or Engineering-Procurement-Construction models, the competitive

Figure 3. Procurement procedures in the EU market for rail and road projects above EUR 50 million (2006 – 2016; N=1520)



Note: Sourced from TED electronic database, including all projects, where data on the procurement process was available.
Source: Based on data in Roumboutsos (2019).

9.2 The delivery model is chosen through MAUA

A common tool to inform the choice of the delivery model are simple descriptions of the pro's and con's of various delivery models (e.g. FTA 2016). Another widely spread approach is the weighing of perceived attributes of individual approaches in pursuing project objectives (quality, being on time, cost…). This method is called 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; Department of Infrastructure and Regional Development (2008) in Australia).

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. Table 2 below includes an example. The projects too can be subject to straightforward characterisations (e.g. complex, simple) and procurement models designated as to which is best to match which type of project.

negotiation (US)/competitive dialogue (EU) should be a necessity (Kennedy et al. (2018)). That said public clients could face impediments that affect their procedure choice related to e.g. available time to execute the tender, in-house capacity and capabilities to run a competent negotiation etc. There is no systematic evidence showing, whether there is a match between bidder selection procedures and delivery models.

Table 2. Informing the choice of the delivery model - an example of MAUA

Evaluation Criteria	Importance of Criteria	Government funded Design and Construct	Government funded Alliance	Government funded DBOM	Privately funded PPP
Operational Flexibility The extent to which each procurement option enables the Government to retain flexibility in terms of the operational profile.					
Risk Management The extent to which each procurement option provides incentives effectively and efficiently to manage and reduce risks, thereby minimising the whole-of-life cost to the government.					
Time to Deliver The extent to which each procurement option is able to support achieving an operational supply by [X].					
Value for Money The extent to which each procurement option assists in maximising the government's value-for-money from implementing the project. • Design and construction innovation • Other innovation factors • Whole-of-life cost considerations • Risk allocation • Competitive tension • Government development and tender costs and resources • External development and tender costs					
... [other factors]					

Source: Department of Infrastructure and Regional Development (2008).

We should note though that tables, such as the example above asks many (research) questions, which, as seen from our own paper so far, are not well understood. There is a dearth of evidence with regard to procurement outcomes of procurement choices. Most available evidence is predominantly associated with cost overruns, delays, and construction speed. Aspects such as quality or value, cost per physical unit are almost never captured. Empirically, as shown in this paper so far, the trade-offs are not well understood. For more recent (collaborative) methods such as alliancing, there is practically no robust quantitative evidence available.

9.3 The incentive power depends on the delivery model and whether the project is considered to be "simple"

The choice of incentive power to a large extent depends on the choice of the delivery model, i.e. by choosing the delivery model we also determine the payment mechanism. For the Design and Build or Engineering-Procurement-Construction delivery models, the lump-sum payment mechanism is the default choice.

As regards the use of the lump-sum mechanism in relation to Design-Bid-Build delivery model, the guidance road agencies use tends to be prescriptive. Lump-sum contracts are only allowed to be used on very simple projects. For example, the US Florida Department for Transportation (road) Design Manual specifically notes (FDOT 2019):

"Lump Sum Projects should be identified during the scope development process, rather than during or after the design process... Lump Sum contracting should be used on simple projects. 'Simple' is defined by the work activity, not by the project cost."

The manual also provides examples of projects that may be good Lump Sum contracting candidates: (1) Bridge painting (2) Bridge projects (3) Fencing (4) Guardrail… Interestingly, Design and Build projects are also considered to be simple, because the manual assumes they have a well-defined scope for all parties and because they are thought to have a low possibility for change during all phases of work.

The use of other payment mechanisms, when these are not a consequence of a particular delivery model, professional judgment is applied.

9.4 Recent advances

In recent years advances in the area of procurement in UK and Australia signal a departure from the traditional perception of what a "procurement strategy" should entail.

The UK has rolled out a series of initiatives with the aim of increasing the efficiency of procurement of infrastructure and in general. Specifically related to informing procurement choices however, the new guidance moves beyond the core procurement choices pursued in this paper. The newly deployed functional standards in relation to procurement identify the make-or-buy decision as the first choice to be made (HM Government 2019). The Project Initiation Route Map (HM Treasury 2016) explicitly introduces a step called project "packaging" alongside other, softer procurement dimensions (e.g. communication). The packaging concerns the question whether a (larger) project should be broken down into multiple contracts and where should the boundaries between them lie.

These two steps require a mindset that sees any project as a set of activities. They precede the procurement choices pursued in this paper and importantly predetermine the procurement outcomes. For example not insourcing an activity, which we frequently need but is being produced by a single supplier will lead to an inefficient final procurement outcome, regardless of our choice of delivery model or incentive power. An example of bad "packaging" would be to procure a large project as a single contract in which out of many, one activity has only two suppliers. As a consequence two consortia would form around the two suppliers and the competition benefits for all other activities would be reduced as well.

Both questions – the make-or-buy and packaging – go out of the purview of auction and contract theory and move into the realm of the theory of the firm and new institutional economics. While the recent UK guidance asks these questions be considered it does not yet offer a tool of how to address them. To date in infrastructure procurement such decisions were left to professional judgment.

A tool that seeks to use economic theory to address the two questions above and the three procurement choices we have dealt with in this paper is currently being trialed in Australia and is briefly explained below.

9.4.1 Expanding the concept of procurement strategy

The method proposed by Bridge and Tisdell (2004), applied in Bridge and Bianchi (2014) and Teo (2014) rejects MAUA as tautological because it 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). In consequence, MAUA simply points to the choice of the model which aligns with the preferred result of the buyer. It does not scientifically inform what the best procurement approach would be, given the nature of the project, where a simple broad description (e.g. it is complex) is insufficient.

The first step in the Australian model is to identify the activities in the project that concern design, construction, maintenance, and operation of the project. Each activity must be technologically bounded (distinct knowledge and/or skill set) and correspond to the highest level of firm specialization available on the market. Figure 4 represents an activity break down for a major road project case study.

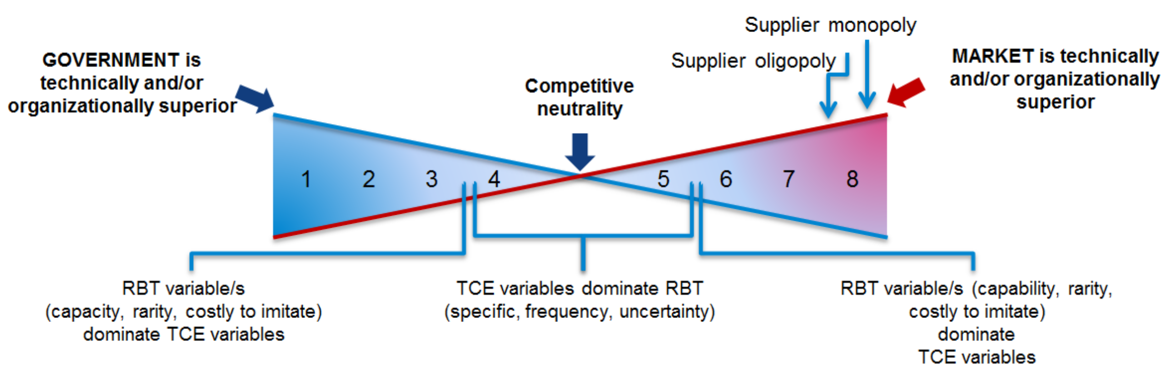
Figure 4. Activity Analysis

Design	Construction	Operations & Maintenance
Design of construction 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 *Design of performance specification of maintenance* 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	*Cut and cover tunnels* 9. Relocation of existing public utility plant, 10. Remova 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 *Driven tunnel* 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 *Road at grade* 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 *Bridge, ramps, median, walkway and bikeway structures* 40. Traffic management, 41. Earthworks, 42. Pile foundation, 43. Structural works, 44. Precast concrete: barriers, kerbs *Bus stations* 45. Water and stormwater, 46. Electrical and communication, 47. Pile foundations, 48. Cast insitu 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 *Remaining construction activities in multiple parts of the project*	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

Source: Teo (2014).

In the second step, 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). The assessment allocates the activities into 8 brackets – competitive states (Figure 5), which serve to predict, which activities might lead to ex-ante contract failures (low competition) or ex-post contract failures (e.g. hold-up).

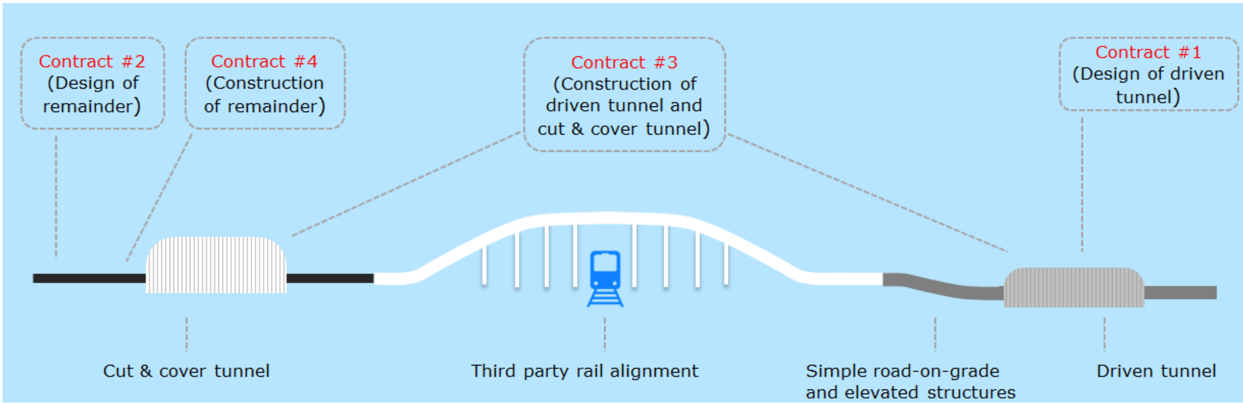
Figure 5. Make-or-Buy Analysis



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. For example, in pattern 8 the characteristics of variables 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 number of potential bidders (Teo 2014).

In the third step the model guides the user to explore bundling of activities – it informs whether the project should be split into multiple contracts and which contract should particular activities be. At the risk of oversimplifying the process, the aim is to create bundles of activities that have a solid potential to attract many competitors and filter out those that do not, contracting them separately. This step corresponds to the "packaging" question in the recent UK procurement guidance introduced above. An actual major road project in Australia that was procured as a single alliancing contract was assessed by this model in Figure 6 (Teo 2014).

Figure 6. Bundling Analysis



Source: Based on Teo (2014).

The analysis showed that contracts 2# and #4 would have been most efficiently procured with a lowest price competition. Only for contracts #1 and#3 could alternative contracting methods such as alliancing be considered, which rely on negotiations and do not derive their efficiency incentives from competition.

The model involves further steps to deal with other procurement dimensions, such as contract power. At time of the case study above it did not yet acknowledge an important issue raised in this paper – the role of uncertainty not only as a source of opportunistic behaviour but also as a source of ex-ante risk pricing failures. 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. For major projects, important decisions that will strongly affect procurement outcomes will have already been made by that point.

10 Discussion – the opposing forces in contracts

The objective of this paper to provide an overview over what we know about how procurement choices affect procurement outcomes. Albeit our scope was limited to a few well established delivery models, which received most of the attention from the researchers, robust quantitative analysis that involves competent authorities in advanced economies is rare.

Where empirical evidence seems to depart especially vividly from the predictions of the economic theory is the expectation that project phase bundling will reduce the need for renegotiations and that the latter is the primary challenge for the use of high-powered incentives or lump-sum contracts in our case.

The available evidence does not support the expectation that negotiations and bundling lead to less renegotiation per se. This seems to be the case for road projects up to several hundred USD million. The issue is that cost overruns in Design-Bid-Build projects are not very large, hence even if Design-Build projects could yield better results (and Engineering-Procurement-Construction contracts actually do) it would be a few percentage points. Aa marginal gain in cost (and time) certainty however yields a disproportionate cost premium.

In our discussion we first focus on this latter issue, why are high-powered contracts disproportionately more costly.

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, recent developments suggest 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.

10.1 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 with cost-plus Design-Bid-Build contracts will experience systematic cost overruns in a single digit percentage and therefore adaptation cost.

As regards uncertainty the bidders face, 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 of 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 do[52]. 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 contractor[54]. 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

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[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 (Vincentsen 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 (Roumboutsos 2019). The potential of these methods though is not a given, but must be exploited and public clients could significantly increase their efforts in identifying and sharing risk related information (Kennedy et al. 2018).

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 incentive 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.

The above also implies that characteristics of PPPs, such as bundling and the high-power of incentives, face trade-offs that could more than offset the potential benefits of the model. To date though, no study managed to secure the data to allow a comparisson of life-cycle cost with an adequate public counterfactual[55].

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.

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.

10.2 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

[55] In a comparison of a public road agency, which is funded from the general budget and dependent on annual budgetary discussions and a PPP, the latter would likely win. Such comparisons though are deceptive. The PPPs do not make road tolling possible. The introduction of tolling is a political challenge. If tolling can be introduced, the road infrastructure manager can be public or a PPP. Hence, an adequate comparison would involve a state-owned road company (such as those in Austria, Slovenia, etc), which is funded through tolls and a toll funded PPP.

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, why[56]. 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 2019[57]. Australia has been pursuing infrastructure benchmarking for several years.[58] A comprehensive road asset management standard is also developed in multiple countries, though it does not yet extend to procurement choices and outcomes[59]. 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 basis 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. This is the state of the art in an era where a transition is slowly occurring from the traditional procurement, where the lowest price competition was the backbone to delivery models which forfeit price competition in favour of collaboration and are based on negotiation. Against the increased repertoire of different project delivery models it seems to be even more pertinent to pursue decision support tools, which will

[56] The UK tried to benchmark with the Netherlands several years ago with very limited success (IUK 2010)
[57] https://www.gov.uk/government/publications/best-practice-in-benchmarking
[58] https://www.bitre.gov.au/data_dissemination/priority_projects/cost_benchmarking_infrastructure_investments.aspx
[59] The Australian example is available here: https://austroads.com.au/publications/asset-management/ap-t334-18

comprehensively inform what should we buy from the market, how should we break down the projects into contracts, and on which contract should we apply which bidder selection, delivery model, and incentive power choices.

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.

Table 3. 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 least 3 candidates to a dialogue in which the final

Procedure	Description
	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 4. 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 5. 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 6. 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 rely on bill of quantities payment mechanism. Lump-sum tends to be used only in smaller/simple contracts.
DB (Design&Build)	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 client procures professional services on a qualifications or best-value basis from a construction manager. During the design phase the contractor acts as a consultant to the client to offer suggestions on innovations, cost and schedule savings, and constructability issues. Upon completion of the design or individual design packages, the contractor and client 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 gaining prominence 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 7. 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. This method is rarely used and is prohibited in some jurisdictions ((FTA 2016).
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. A target price contract relies heavily on the ability of the procurement authority to competently engage with the private party in a collaborative fashion. It also assumes open book principles, i.e. the procuring authority should be able to monitor progress and actual costs incurred by the contract effectively.

Source: Klee (2018).

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

Table 8. 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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