

Contract Enforcement and Productive Efficiency: Evidence from the Bidding and Renegotiation of Power Contracts in India*

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Abstract

Weak contract enforcement may reduce the efficiency of investment in developing countries. I study how contract enforcement affects efficiency in procurement auctions for the largest power projects in India. I gather data on bidding and ex post contract renegotiation and find that the renegotiation of contracts in response to cost shocks is widespread, despite that bidders are allowed to index their bids to future costs like the price of coal. Connected firms choose to index less of the value of their bids to coal prices and, through this strategy, expose themselves to cost shocks to induce renegotiation. I use a structural model of bidding in a scoring auction to characterize equilibrium bidding when bidders are heterogeneous both in cost and in the payments they expect after renegotiation. The model estimates show that bidders offer power *below* cost due to the expected value of later renegotiation. The model is used to simulate bidding and efficiency with strict contract enforcement. Contract enforcement is found to be pro-competitive. With no renegotiation, equilibrium bids would rise to cover cost, but markups relative to total contract value fall sharply. Production costs decline, due to projects being allocated to lower-cost bidders over those who expect larger payments in renegotiation.

1 Introduction

There are many investments firms will make only if they can sign a contract to protect their returns (Klein, Crawford and Alchian, 1978; Hart and Moore, 1990). Countries that enforce contracts strictly therefore invest and produce more in industries that rely on such relationship-specific investments (Acemoglu, Johnson and Mitton, 2009; Nunn, 2007).

Countries that enforce contracts imperfectly, to the contrary, may bear economics costs. The size and even existence of these costs are not obvious, though, since it is hard to know how firms' investment decisions respond to weak contracts. Suppose, for example, that some firms are connected to the government and can hold up the government or other counterparties, and

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that this hold up power allows them to invest at a lower price. Weak contract enforcement will reduce competition and transfer rents to these connected firms. It may also have an economic cost, if connected firms displace other firms that would—under strong contracts that leveled the competitive field—be able to invest or produce more efficiently. Connected firms profit from their connections (Fisman, 2001; Faccio, 2006). The mere fact that connected firms profit, however, is not enough to establish an efficiency cost of weak contracts. It may be that connected firms are just as efficient at investing and producing as other firms and their rents are transfers.

This paper studies the efficiency costs of weak contract enforcement in the Indian power sector. Power generation requires large and specific investments that in India were traditionally made under complete public ownership and vertical integration. Structural reforms in the 2000s moved the power generation segment from integration toward private investment (Kumar and Chatterjee, 2012). As part of this reform, the government set up power procurement auctions for state utilities to buy power from private companies that would invest in building and running new plants.

Several features of these auctions make them a good setting to study how contract enforcement affects equilibrium rents and productive efficiency. First, because the regulatory institutions in the power sector are new, the enforcement of power procurement contracts is imperfect. Second, power remains a regulated sector, which means the renegotiation of contracts set at auction must be recorded and is therefore observable. Third, the bids used for these auctions are rich, and include not only a total price but also the separate parts that make up each bid. With these bid parts, I show that it is possible from bidding strategies to infer how much bidders anticipated contract renegotiation.

The auctions studied are also important in their own right. This mechanism, as the main way states bought power from new plants after the structural reforms, contributed to the rapid growth of private investment in the Indian power sector (Figure 1). The average investment in these power projects is USD 553 million per plant and the largest projects of this generation, so-called Ultra-Mega Power Plants, demand USD 2.5 billion of capital. I calculate the total capacity procured through the auction mechanism studied to be 45% of the generation capacity in India when the auction rules were put in place.

I gather a new data set on bidding, contracting, investment and contract renegotiation in

power procurement auctions in a range of Indian states. In each auction a state, or group of states, seeking to buy power offers a long-term contract to purchase from a private seller. The seller offering the lowest price of power wins the contract to supply. Each contract runs for twenty-five years, so there is a huge risk that cost shocks, particularly to coal prices, will change the cost of production during the life of a contract. The auction bidding therefore allows that bidders can choose how much to index their selling price in future years to the future price of coal. The electricity regulators approve as power purchase agreements the contracts set at auction.

I study contract enforcement in these auctions using both a reduced-form analysis and a structural model. The reduced-form part describes the extent and causes of contract renegotiation. The structural part builds these forces into a model of renegotiation to study how contract enforcement affects equilibrium rents and efficiency.

There are three main reduced-form findings. First, renegotiation of contracts is widespread. Of the auction winners for whom contract outcomes can be found, half petition the regulator that approved the contract to change its terms. Of those that petition, about one-third are successful in winning some formal change to the contract. Second, renegotiation responds to cost shocks for firms exposed to the price of coal. Petitions typically seek an increase in the unit price, or a “compensatory” tariff, to offset a cost shock. Projects that see a jump in coal prices after they are bid out are far more likely to renegotiate, especially if they rely on imported coal, which has the most volatile prices. The large effects of cost shocks on renegotiation are surprising given that the auction mechanism allowed bidders to index their bids to the price of coal. Bidders can offer several different bid components, including fixed charges, energy charges, and energy charges indexed to future coal prices, and have complete flexibility over how they break down their bid across these components. Bidders therefore could have insulated themselves against coal shocks entirely, if they wished, by indexing all of their energy costs to the price of coal.

The third and main finding of the reduced-form analysis is that politically connected firms index less of the value of their bids to coal prices, exposing themselves to fuel price risk. A documentary case study of the Mundra Ultra Mega Power Plant, a prominent project, shows that not indexing is a strategy that bidders used deliberately to lower their bids by lowering their offered prices late in the life of a contract. This bidding strategy makes bids appear

lower up front but increases the risk of renegotiation and therefore payments to firms ex post. To show that the lesson of this case applies generally, I develop a new measure of firm connectedness based on the government’s allocation of free coal to power companies in the “coalgate” scandal.¹ I deem the companies that received coal in the coalgate scandal to be politically connected in the sense of having greater influence over the government. I then link the connected firms, from coalgate, to the companies bidding to supply power in power procurement auctions, to measure the effect of connectedness on bidding strategies. I show that connected firms index less of the value of their bids in power auctions, conditional on the overall present discounted value of the bid and firm and auction controls. This evidence is consistent with connected firms being more willing to bear fuel price risk, because they can hold up the government ex post if they are subject to a cost shock.²

Renegotiation, therefore, is due *both* to exogenous coal price shocks *and* to the endogenous choices of bidders, particularly connected bidders, to bear this coal price risk. Motivated by these findings, I build a model that captures the important features of the auction environment with contract renegotiation. Bidders in the model bid to supply power over twenty-five years. They choose both the level of their bid and the level of indexation of their bid to future coal prices. Bids are scored based on the expected present discounted value of offered prices for power. The model allows bidder types to differ in two dimensions. First, bidders differ in *heat rate*, the quantity of coal energy input they need to generate a unit of electricity (the key determinant of variable cost in thermal power generation). Second, bidders differ in *bonus*, the per unit additional tariff they expect to receive if their contract is renegotiated. The variation in bonus across bidders is meant to capture heterogeneity in the connectedness or influence of firms with the government. Renegotiation depends on both exogenous coal price shocks and on the endogenous indexation choice of the winning bidder. If a bidder bid a very low price, without indexation, then it takes a smaller cost shock to wipe out their variable profits and

¹This scandal was independent from, but roughly contemporaneous with, the power procurement auctions I study. The Indian government has a monopoly over coal production, but in the 1990s and 2000s a government committee gave away the rights to many coal mines to private firms with “no clearly spelt out criteria” for allocation. The Comptroller and Auditor General of India issued an audit report on this allocation process and found that the windfall gain to companies that received coal was \$214 billion (Comptroller and Auditor General of India, 2012). This report launched a national scandal, “coalgate,” and led to the Supreme Court in 2014 overturning the coal awards.

²An alternative interpretation is that receiving coal in coalgate directly provides a hedge against input cost shocks and therefore need not measure the effect of connectedness per se. I consider this alternative explanation at length, through several tests of whether coalgate had a direct effect on costs or hedging, and reject these alternatives in favor of a direct connectedness effect independent of costs.

make a threat to exit the project credible. Firms are risk averse and wish to maximize their profits, including the value of renegotiation, while not taking on too much fuel price risk.

Renegotiation has effects on both the level and composition of bids in the model. Without renegotiation, bidders fully index their bids, because they dislike risk. Bidders earn markups by adjusting the fixed component of their bids. With renegotiation, bidders no longer fully index their bids. Low-cost bidders are somewhat less concerned with cost shocks, because even if the price of coal increases, they need less coal than a high-heat-rate plant to generate the same amount of power. Additionally, given a level of cost, these connected bidders, with a high bonus, will choose to index a lesser share of their bid, since they expect higher payments in renegotiation after a cost shock. Because those higher payments are not accounted for in the auction score *ex ante*, this strategy makes the bids of those who expect renegotiation artificially competitive. Bidders take on risk to endogenously increase the likelihood of renegotiation. In equilibrium with renegotiation, these distortions in bidding strategy imply that firms with a high bonus are strong bidders and may underbid firms with the lowest cost of production.

I prove that bidder types are identified in the model from the level and composition of bids. The proof of identification is in two steps. First, while bidder types are two-dimensional, these types can provisionally be reduced to a one-dimensional pseudo-type that measures a bidder's overall strength (Asker and Cantillon, 2008). Bid scores can therefore be inverted to recover one dimensional pseudo-types as in a standard first price auction (Guerre, Perrigne and Vuong, 2000). Second, given pseudo-types, the mapping from bidders' two-dimensional types to the pair made up of the level of their bids and the part of their bid indexed to coal prices is invertible. The intuition for this result is that, conditional on a level of heat rate and thus cost, the bonus a bidder expects in renegotiation will determine how much they choose to index their bid to future coal prices, which choice is observed in the data. Identification does not require imposing a parametric form on the joint distribution of bidder types.

I estimate the model to recover the joint distribution of types and to characterize equilibrium bidding. The structural analysis offers a pair of striking findings about the equilibrium with weak contract enforcement. First, the joint distribution of types suggests that low heat rate (thus low cost) firms tend to have somewhat higher bonuses. This means that the firms that are best at producing power are also estimated to be relatively connected to the government, in terms of their expected value of renegotiation. Second, in equilibrium, markups for

winning bidders are 18% above pseudo-types (the relevant one-dimensional measure of apparent cost) but marginally (3%) below production cost. This finding means that bidders bid below cost in equilibrium in order to win the contract and then recover part of the anticipated contract value in renegotiation.

With the structure of the model it is possible not only to characterize the equilibrium but also to consider counterfactual equilibria under different enforcement regimes. The leading case of interest is a regime with perfect contract enforcement and therefore zero expected value of renegotiation for all bidders. I model this counterfactual as a first-price auction where bidders have a one-dimensional cost type due to the marginal distribution of heat rates alone. That is, bidder bonuses are rendered meaningless in the counterfactual, as they will never be paid out, so the type collapses to a single dimension. I run this counterfactual solving the optimal first-price auction bid given the estimated non-parametric distribution of heat rates.

The counterfactual shows that strict contract enforcement is pro-competitive and increases efficiency, but also raises prices. In the counterfactual regime it is no longer possible for bidders to underbid in expectation of future renegotiation payments. Therefore, equilibrium bids under perfect enforcement rise 16% and equilibrium winning bids rise 9%. Bidder markups are now above production cost, but the margins of winners are cut by one-third, down to 13% relative to cost in the counterfactual (as compared to 18% above pseudo-types in the equilibrium with renegotiation). This result is due to a compression of the type distribution; when types are one-dimensional, bidders with low costs and high bonuses cannot be as sure that they will not lose if they markup their bids, which brings down equilibrium markups. Even as bid prices rise, production costs for winning bidders in the counterfactual decline by nearly ten percent. This decline in production costs indicates that stronger contract enforcement would improve productive efficiency by allocating power projects to lower-cost firms. The size of the reduction in costs in the model depends on competition and the correlation between connectedness and cost. Because the bonus is estimated to be negatively correlated with cost, there are relatively few high-cost but high-bonus firms able to win contracts over lower-cost firms in the present equilibrium. Had this correlation been positive the efficiency gains would be even larger. The structure of the joint distribution of types, which is the focus of the identification argument, is therefore central to measuring the efficiency costs

of renegotiation.

This paper contributes to disparate literatures on firm connectedness and how contract enforcement affects efficiency, in development economics, and on empirical auctions, in industrial organization.

On firm connections, Fisman (2001) shows that political connections increase Indonesian firms' stock market value, a finding that has been replicated broadly (Faccio, 2006). Few papers approach the question of whether the profits earned by connected firms have a real efficiency cost. Khwaja and Mian (2005), a notable exception, find that public banks in Pakistan lend more to politically connected firms and these politically-motivated loans are more likely to default. They bound efficiency costs with assumptions on the alternative use of the capital spent on bad loans.³ This paper not only shows that firm connectedness changes profits (markups) but also traces the mechanism through equilibrium changes in firm bidding *strategies*; connected firms behave differently, and that is how they earn rents. I then build a structural model to estimate the how weak contract enforcement changes the equilibrium efficiency of the market.

On contract enforcement and efficiency, there is a very rich empirical literature in development using *de facto* variation in property protections or contract enforcement to study how contracting affects investment, trade and efficiency. Micro-empirical work aims to measure the channels through which contract enforcement matters for real outcomes (Field, 2007; Goldstein and Udry, 2008; Pande and Udry, 2005; Besley and Ghatak, 2010). There is relatively little work on how contract enforcement affects investment in the commanding heights of developing economies, such as power, transportation and infrastructure, though it is widely understood that weak contract enforcement is a barrier to investment. The energy supply industry, which is built of specific assets, has provided examples both of how contracts adapt to specificity and how limited commitment can undermine contracting (Joskow, 1987; Bettauer, 2009; Stroebel and Van Benthem, 2013).

On procurement auctions, weak contract enforcement may dissipate efficiency gains from public-private partnerships and other procurement mechanisms (Engel, Fischer and Gale-tovic, 2014). Most papers in the empirical auctions literature ignore ex post performance

³Estimates of efficiency costs are scarce even in the broader empirical literature on corruption (Olken and Pande, 2012). Corruption is hard to quantify and leading work estimates the loss to corruption using measures of transfers, such as the share of work not done or project funds missing (Olken, 2007; Ferraz and Finan, 2011).

altogether. The closest precedents to this paper are several innovative studies of how ex post performance concerns affect bidding in highway procurement (Lewis and Bajari, 2011, 2014; Bajari, Houghton and Tadelis, 2014).⁴ This paper makes several contributions relative to this frontier. First, in my model and setting, ex post renegotiation depends not only on exogenous shocks, as in Bajari, Houghton and Tadelis (2014), but also on endogenous bidder actions. Renegotiation happens in part because bidders induce it by taking on more price risk, a mechanism I validate in the data. Second, several studies emphasize the efficiency consequences of moral hazard for contract performance ex post, whereas in my model the prospect of renegotiation generates potential ex ante misallocation of the contract. Third, with the structure of bids in my context, I am able to identify and estimate the key structural object, the joint distribution of bidder types, which other analysis has circumvented. My analysis estimates markups and runs counterfactuals without imposing any assumptions on the type distribution.

The rest of the paper runs as follows. Section 2 describes the context of Indian power sector reform and the data. Section 3 provides both documentary and econometric evidence of the extent and causes of renegotiation. Section 4 lays out the model and identification argument and Section 5 describes how the model is estimated. Section 6 presents the structural estimates of the joint distribution of types, equilibrium costs and markups and counterfactual bidding and production costs under strict contract enforcement. Section 7 concludes.

2 Context and Data

a Ownership and regulation of electricity generation in India

The classical solution to hold-up is integration. After independence, the Indian power sector was mostly publicly owned and run for more than forty years. The Electricity (Supply) Act of 1948 established State Electricity Boards in each state as public monopolies vertically integrated across generation, transmission and distribution. The Central government invested more in transmission and generation over time, in particular with the creation of a large central generating company in the 1970s, in response to an energy crisis and flagging investment by

⁴In common with Lewis and Bajari (2011), this paper uses the theoretical results of Asker and Cantillon (2008) on scoring auctions to build a model with multi-dimensional types. In common with Bajari, Houghton and Tadelis (2014), I study how ex post shocks affect bidding. Bhattacharya, Ordin and Roberts (2018) study how the form of auction bidding affects later investment effort in the context of oil drilling.

the states.

A sweeping economic liberalization in the early 1990s opened power generation to private firms, and the Indian government solicited investment, including from foreign companies. This liberalization, which lifted tariffs and deregulated manufacturing, is considered a triumph for trade, productivity and growth (Topalova and Khandelwal, 2011; Aghion et al., 2008; Rodrik and Subramanian, 2005). For the power sector specifically, though, the 1990s liberalization was a failure. Because the deregulation of entry in generation was not paired with any deeper structural reform, potential private entrants still faced monopsony buyers, the State Electricity Boards, in every state, and were therefore reluctant to invest (Mathavan, 2008; Kundra, 2008).

Figure 1 shows the generation capacity in the Indian power sector from 1947 to the present, with total capacity up to 1992 and capacity by ownership (state government, central government, private) thereafter. The power sector, in the decade after the 1990s liberalization, is open to private investment, but the privately-owned share of capacity is low and slow-growing during this time. Fear of hold-up, in the absence of strong contract enforcement, is a plausible explanation for slow private investment in power in the 1990s. A gas-fired power plant in Dabhol, Maharashtra, built during this period by a consortium led by Enron, became a cautionary example of hold-up in the power sector.⁵

The failure of this generation of private projects and power rationing built up pressure for deeper reforms. The Electricity Act of 2003 (and its predecessor, the Electricity Regulatory Commissions Act of 1998) undertook structural reforms that recognized the natural monopoly nature of much of the power sector (Kumar and Chatterjee, 2012). Under these laws, the State Electricity Boards were separated into component parts, for generation, transmission and distribution. Independent regulators were established to rule on power contracts and tariffs. Markets for power, though initially a small share of the sector, provided an outside option for private entrants to sell power (Ryan, 2017). Each of these measures served to reduce the hold-up power of the former Boards and therefore the political risk faced by private entrants.

⁵The company negotiated and signed a power purchase agreement with the Maharashtra State Electricity Board that was guaranteed by both the State of Maharashtra and the Government of India. The Board renegotiated the price of power downwards before the plant opened, and after a year of plant operation, the Board defaulted on the contract anyways (Bettauer, 2009). Project partners sought compensation through international arbitration and expropriation insurance, but largely failed (Kundra, 2008). After a settlement the project was nationalized by the Central government.

b Auction mechanism for power purchase agreements

The auctions studied here were meant to take advantage of the new structure of the power sector and give private investors a way to invest. The National Tariff Policy (2006), issued under Section 63 of the Electricity Act (2003), mandated that state procurement of power must be done through a competitive bidding process (Ministry of Power, 2006). To implement this policy, the Ministry of Power issued standard bidding documents saying how power auctions should be run.

The procurement auctions, critically for the present analysis, allow a high degree of flexibility in how bidders structure their bids. The model and empirical analysis will use bidders' decisions about the degree of indexation in order to study how the prospect of renegotiation affects bids. The bidding guidelines say that bids will be set in multi-part tariffs allowing both capacity (fixed) and energy (variable) charges. For any given charge, bidders may further break the charge down into escalable (i.e., indexed) and non-escalable bid components.⁶ Therefore, a bidder can offer a bid wherein the payments for energy production are an affine function of the future price of coal. Appendix A, Figure A1 gives an example of a bid with energy and capacity charges, both indexed and not indexed, over twenty-five years.

A bid's *score*, called the levelized tariff, is the expected present discounted tariff across all bid components using an interest rate for discounting and assumed growth rates for each escalable bid component. Section 2 c discusses the structure of bids in more detail and Section 5 bid scoring.

The bidding guidelines split projects into two types based on the specificity of assets to be used in generation. In non-specific asset projects, the procurer specifies an amount of power they want to buy, at a particular point in the transmission network, and that can be supplied by any new or existing plant. In specific-asset projects, the procurer specifies the location and source of fuel to be used for a new plant; for example, a plant might be intended to be set up at a mine and to use that mine as a captive source of fuel, or a plant might be set up at a port upon state-owned land to use imported coal.⁷

⁶Bidders can use additional sundry charges, including charges for the transportation of fuel, the handling of fuel and the transmission of electricity. Bidders can also in many auctions index not only energy charges but also other charges such as capacity charges and transportation charges (to pre-specified components of the wholesale price index). However, energy charges are by far the largest and most volatile component of costs, so in the analysis I will map all bids to three parts: capacity charges, variable charges not indexed to energy costs, and variable charges indexed to energy costs.

⁷The terminology used for these projects is Case 1 (non-specific asset) and Case 2 (specific asset). The

The flagships of this second generation of power projects were specific asset (Case 2) projects called Ultra-Mega Power Projects (UMPPs), to distinguish them from the Mega Power Projects (MPPs) of the failed prior generation. There were intended initially to be sixteen UMPPs but only four have been bid out. These projects are distinct for first, their namesake scale, typically about 4,000 MW at an investment of USD 2.5 billion apiece, and second, the fact that the procurement process was run centrally by the Government of India, which helped arrange the specific assets involved (land, coal mine). Despite this central process, the power from these projects was still bought by state utilities. In these large projects, states joined consortia of five or more buyers and each bought a share of the power to be generated.

The auction results are formalized in a power purchase agreement (PPA), a contract for the procurement of power that is written at the price set by the auction and reviewed and approved by the electricity regulator. The relevant regulator is the Central Electricity Regulatory Commission (CERC), for projects with central procurement, or the State Electricity Regulatory Commission (SERC), for projects run by the states themselves. Each auction winner signs a PPA with the procuring state utility or utilities. The regulatory review of these contracts is universal but pro forma, since the Electricity Act (2003) advises deference to the market process for procurement: “the Appropriate Commission shall adopt the tariff if such tariff has been determined through transparent process of bidding in accordance with the guidelines issued by the Central Government” (Ministry of Law and Justice, 2003).

Several features of this procurement process tilt the balance of bargaining power in favor of private power sellers and away from the distribution companies buying power. First, the existence of Electricity Regulatory Commissions to approve contracts and arbitrate disputes. Second, the principle of contracts being revealed at auction, which may lower contract prices and increase the transparency of price setting. Third, the deference of the institutions now involved to the market process of setting prices. Fourth, the specific assets that sellers may obtain if they win an auction, and in general the large amount of power they are supplying, which may make them difficult to replace in the short term. Fifth and finally, the fact that the buy side consists of consortia of state bidders for large projects, which diversifies the political

official descriptions of each type literally turn on asset specificity, with the full name of Case 1 “Tariff Based Bidding Process for Procurement of Power on Long Term Basis by Setting up Power Stations where Location or Fuel is not specified” and Case 2 “Tariff Based Bidding Process for Procurement of Power on Long-Term Basis from Power Stations to be set up at Specified Location (and/or operating on Specified Fuel).”

risk faced by sellers.

There was a large wave of private investment in power in response to the deeper structural reforms in the electricity sector and under the new bidding rules. The rules took effect in 2006 but the new projects built under these rules typically had a five-year lag, meaning that they came online in 2011. Returning to Figure 1, we see a rapid increase in private generation capacity during this period, as shown by the top (light grey) area of the figure, such that by 2017 private generation capacity was a plurality of total capacity, greater than that owned by either the states or the central government.

c Data on bidding and renegotiation

The data have been gathered from an array of administrative sources and together form the first dataset on this large wave of private investments in power. The population of interest is the auctions for long-term power procurement run under the bidding rules in effect from 2006 through 2012, after which the bidding rules were revised. I obtain data on the characteristics of auctions, the bids offered under auctions, the contracts signed for winning bids and any subsequent revisions of those contracts. Appendix A describes the data sources in more detail.

Central Electricity Regulatory Commission, State Electricity Regulatory Commissions. The Forum of Regulators, a joint body of the Central and State commissions, gathered an inventory of auctions which I used as the basis for the population and supplemented with additional projects. The CERC and SERCs review Power Purchase Agreements (PPAs), the contracts signed after an auction, and approve tariff orders. I gathered these contracts from CERC and SERCs. In some cases SERCs would include bids as part of tariff orders. The respective ERC that notified the original tariff order for a project also records any subsequent changes or revisions to that contract.

Distribution companies, Power Finance Corporation. Additional bids were gathered from the distribution companies that procured power under the auctions. Whether the bids were publicly available or privately available varied across states. I obtained most bids from the major states with the most procurement under the bidding rules, including Gujarat, Maharashtra, Madhya Pradesh, Punjab, Rajasthan and Uttar Pradesh. Bids for Ultra-Mega Power Projects were obtained from the Power Finance Corporation, which ran the Central Government's procurement process.

The data set consists of 199 bids from 31 auctions. The main limitation of the data is that I could not obtain the individual bid components in each year of the contract for all bids. The sample for the structural analysis is restricted to the long-term (25-year) contracts for which bid components are available: there are 162 bids with scores and 121 bids with both scores and the component parts of the bid. I take the approach of using all available data to estimate the model in each estimation step. In Section 6 I check that this is reasonable by comparing the levels of bids and markups between bids that have all component parts available and bids that have only the final score. I find that bids in the full sample and in the restricted sample with components available are similar.

d Data on firm connectedness

This subsection describes a measure of firm connectedness to the Government of India. The goal of the measure of connectedness is to test using observable characteristics of firms whether firms with influence over the government change their bidding strategies. I denote a firm as connected if it received coal at below-market prices from the Government in the “coalgate” scandal, described below.

The Government of India, by law, has a monopoly on coal production in the country. However, under pressure to increase output, the government allocated coal mines to private companies in energy-intensive sectors such as power, iron and steel to use for their own production. The Ministry of Coal has a Screening Committee that decides what companies get coal. From 1993 to 2005, this committee had “no clearly spelt out criteria” for the award of coal blocks (Comptroller and Auditor General of India, 2012). In 2005, the Ministry of Coal proposed to auction off coal instead of awarding by committee, but this proposal died and the Screening Committee continued to pick and choose what companies would get coal blocks.⁸

Comptroller and Auditor General (CAG). The Comptroller and Auditor General of India (CAG) audited the coal allocation process to see if it was meeting the goal of increasing production in the country. In March 2012, a draft of the CAG report was leaked to the press

⁸After 2005 the stated criteria for award were written down. The Committee based its decisions on “the techno-economic feasibility of the end use project, status of preparedness to set up the end use project, past track record in execution of projects, financial and technical capabilities of the applicant companies, recommendations of the State Governments and Administrative Ministry concerned.” (Comptroller and Auditor General of India, 2012)

and incited a national scandal later known as “coalgate” (Dutta, 2012). The draft report concluded that the difference between the value of the coal given away by the Government and the cost of extraction, the “windfall” gain to the companies receiving coal, was INR 11 trillion (USD 214 billion). The appendix of the draft report painstakingly details the value of the coal received by a large number of private and government-owned industrial companies in the power and manufacturing sectors (See Appendix A). The report also concludes that few companies actually started coal production with their coal blocks; instead, they largely sat on them as coal prices rose.

To form a measure of firm connectedness, I match the private companies named in the draft report to the bidders in power procurement auctions. The idea is that to get a coal block for free a company must have influence with the Government. Both bidders and coal awardees include many of the largest industrial companies in India. I find that 90 out of 162 bids (56%) were offered by parent companies that received free coal through coalgate, including titans like Tata Group, Jindal Steel and Power, Essar Group and Adani Power. A plausible limitation of coal block allocation as a measure of connectedness, for my purposes, is that receiving a coal block may also affect firm costs of production and therefore bidding strategies directly. I discuss this alternative interpretation with the empirical analysis.

3 Renegotiation of power auctions

This section provides case study and reduced-form evidence that renegotiation is common and studies the determinants of renegotiation to provide empirical grounding for the model.

a Case study of Mundra Ultra Thermal Power Project

This section considers contract renegotiation in the Mundra Ultra Mega Power Project. This project is not meant to be representative of the sample, as it is a flagship UMPP. Yet the process of renegotiation in Mundra is emblematic of how contract enforcement works under the new post-reform structure of the power sector.

i Bidding

Mundra is a port in Gujarat in the west of India. The Mundra UMPP was an asset-specific project that included the right to build a power plant on a large plot of land in the port as well as a power purchase agreement, with the plan that the plant would rely on coal imported from overseas. The project was bid out in late 2006 with the winning bidder responsible to build the plant and supply 3800 MW of power over twenty-five years.

The auction was won by Tata Power, part of the storied Indian industrial house, at an expected discounted price of INR 2.26 per kWh (Central Electricity Regulatory Commission, 2003). Figure 2, panel A shows the time path of all the bids in the auction, ranked from L1 (the winning bidder) to L6 (the highest bidder) in terms of their expected discounted nominal tariff (the *score* of the auction). Each curve shows the tariff offered by each bidder in each year of the contract from one to twenty-six (contracts are 25 years long but often span 26 calendar years). These future offered tariffs are expectations, because, for bids indexed to future prices, like the price of coal, the realized value of future tariffs will depend on the realizations of those prices.

Figure 2, panels B, C and D then break down the overall tariffs for the L1, L2 and L6 bidders into their component parts. In each of these three panels, there are three curves. The lowest, dashed curve shows the nominal tariff for capacity (i.e., fixed) charges. The middle, dotted (red) curve shows the tariff for all parts of the bid not indexed to coal prices. It is therefore the sum of the dashed curve and other charges like energy charges not indexed to coal prices. The topmost, solid (black) curve shows the total tariff in a year. The gap between the solid (black) and dotted (red) curves is therefore the part of the bid indexed to fuel prices.

These figures show, of course, that Tata's bid was the lowest in expected discounted value terms (panel A). They also show two features of the bid that bear on Tata's prospects for later renegotiation. First, in panel A, although Tata was the winning bid, there are several other bids that are very close. In particular, in the initial years of the contract, Tata, the L2 and the L4 bidders offer nearly identical prices for power. It is only in later years that these bids rise and Tata, by keeping its bid low, wins the lowest expected discounted tariff. Second, in panel B, we see that even in the final years of the bid, most (about three-quarters) of Tata's winning bid was not indexed to future coal prices. This project used imported coal and the level of coal prices in twenty-five years is uninsurable on financial markets. Losing

bidders tended to increase their bids more over time and to index more of their bids to future prices. In panel C, the L2 bidder increases its bid more at the end of the contract and indexes about half of the value of its tariff in the last year to coal prices. In panel D, we see that the bidder offering the highest price increases its bid still more steeply over time.

Therefore Tata's expected discounted bid is low due mainly to low prices offered towards the end of the contract. Other bidders indexed a greater share of their bids; by the scoring of the auction, this implied that their expected energy charges to the procurers would grow in nominal terms over time.

ii Renegotiation

The structure of Tata's bid was central to later renegotiations of Tata's contract.

The first units of the Mundra UMPP were commissioned and began working in mid-2012 roughly on schedule. However, in the interim between bidding and the plant starting up, coal prices had spiked dramatically, then receded only partway to their former level. Figure 3 shows the time series of the relevant coal price index for imported coal (solid black line), with the gray histogram in the background showing the number of bids received in sample auctions in each year. The Mundra project, having been bid in 2006, was followed by a steep increase in coal prices. The imported coal price was around USD 50 per ton in the years preceding bidding and moved sharply upwards, to a level around USD 100 per ton in the year the plant started running.⁹

In September 2012, Tata applied to the Central Electricity Regulatory Commission for an increase in the tariff set by the auction (Central Electricity Regulatory Commission, 2012). Their legal argument was that the price increase was unexpected and due in part to changes in foreign law, which should be considered *force majeure* to revise the contract.¹⁰ A majority of members of the CERC accepted this argument and granted Tata a "compensatory tariff" of INR 0.53 per kWh, or roughly a quarter of the tariff from the auction, among other additional compensation.

The consideration of the case turned on the question of whether a prudent bidder should

⁹Observers attributed this increase in part to the fundamental shift of China rapidly moving from a net exporter to a net importer of coal.

¹⁰Tata specifically argued they had tried to hedge by buying part of a coal mine in Indonesia. The Government of Indonesia revised its rules on foreign ownership of mines which changed the terms on which Tata could export coal. However, the claimed hedge was not even close to the full quantity or duration of contract needed to fully supply the Mundra plant.

be expected to index the price of power to the price of coal. In the ruling granting the added tariff, one dissenting member of CERC argued that Tata should be held to their bid:

[B]y not factoring in the market price of coal and not quoting the escalable energy charges in full has helped it in winning the bids. The petitioner . . . cannot renege on its commitment and seek restitutionary remedy in the form of additional tariff The petitioner being in business for a pretty long time is expected to factor in the possible market variation, while quoting for a period of more than 25 years. (Central Electricity Regulatory Commission, 2012)

This argument, in rough terms, sustained several stages of appeal. The Supreme Court of India ruled against the grounds for the compensatory tariff and legal disputes continued. Tata proposed to sell the plant back to the procurers, and as of writing the Government of Gujarat is apparently considering this offer.

The ex ante and even ex post result of this renegotiation is hard to value for Tata and other bidders. Tata was granted a compensatory tariff for a brief time and is now in renegotiation for the sale of its plant. In other cases, such renegotiation has allowed private parties to earn compensation or to exit money-losing plants. For example, Reliance Power sold the Tilaiya UMPP off to the state utility of Jharkhand for a positive amount, at a time when the net present value of that project, on the contract set at auction, ran billions of dollars into the red.¹¹ The main import of this case for the analysis that will follow is that (a) some bidders had a founded expectation they may be able to revise terms to increase the value of their contracts as bid (b) the prospects for renegotiation depend on exogenous shocks to input costs.

b Reduced-form evidence on mechanisms for renegotiation

This subsection provides evidence that the mechanism of renegotiation in the Mundra case was common to other projects of this generation. I establish three facts. First, renegotiation is widespread. Second, firms renegotiate in response to cost shocks. Third, firms that are more connected to the Government of India index less of their bids to the price of coal. This change in bid strategy differentially exposes connected firms to cost shocks.

¹¹Using the Tilaiya bid and contract, I estimate that the NPV of the project at the time of exit was negative. The increase in tariff required to make the project whole at the time of exit was INR 0.38 per kWh, or 21% of the tariff as bid.

i Renegotiation is widespread

Table 1 summarizes auction outcomes at the bid level. The rows of the table represent different years in which contracts were auctioned. The columns give the number of bids and winners, then whether a petition for revision of the tariff at auction was filed (column 4) and granted (5), as well as the initial tariff and capacity on average across winners (columns 6 and 7).

Renegotiation is very common. Of 39 (column 4) auction winners for which the status of renegotiation can be found, 20 (column 5) file a petition with the regulator for a revision of the tariff revealed at auction and 7 (column 6) are successful. Thus roughly half of projects have some kind of renegotiation, even if all do not yield a payoff. The rate of petition filing is highest in the initial auction years of 2006 through 2009, in which a staggering 17 out of 23 auction winners filed a petition for tariff revision. The tariffs bid by winners in these early auction years, in particular 2006 and 2007, are much lower than later years of the sample, after coal prices had risen (Figure 3).

ii Renegotiation responds to cost shocks

The tendency to renegotiate should differ across projects. Projects bid early in the sample saw greater coal price shocks than those bid later. Projects also differ in their asset-specificity and in their fuel type. Some projects use imported fuel exposed to market prices, whereas others use a domestic or captive source for fuel and so are less exposed to coal price shocks. I test these factors with a linear probability model

$$R_{it} = \gamma_0 + \gamma_1 CoalShock_t + \gamma_2 CoalShock_t \times CoalImported_i + \gamma_3 UMPP_i \\ + \gamma_4 CoalImported_i + \gamma_5 CoalDomestic_i + \epsilon_{it}.$$

Here R_{it} is a dummy for filing a petition to change one's tariff, $CoalShock_t$ is the change in average coal prices from five years before the auction to five years after, $CoalImported_i$ and $CoalDomestic_i$ are dummies for fuel source, with the omitted category being captive coal, and $UMPP_i$ is a dummy for whether a project is an Ultra-Mega Power Plant. The coal shock is measured in units of INR per kWh to represent the change in generating cost caused by changes in coal prices for a typical plant.¹² A one unit coal price shock would therefore

¹²I assume a calorific value of coal of 6,300 kcal per kg and a plant heat rate of 11,615 btu per kWh for this conversion.

change output prices by 1 INR per kWh, about one-quarter of the average bid (Table 1). The five-year lead and lag are set since most projects have a five-year lead before they start producing power.

The results of the regression are reported in Table 2. The specification in column 1 shows that projects that experienced a one INR per kWh increase in cost are 0.288 (standard error 0.099) more likely to renegotiate, on a base of about half. Column 2 shows that the coal price shock remains after controlling for asset-specificity (the *UMPP* dummy). In column 3, we drop the coal price shock. In this specification, UMPPs are much more likely (coefficient 0.571, standard error 0.167) to renegotiate than other projects, consistent with an effect of asset specificity. Imported and domestic coal projects, which are exposed to market prices, are also much more likely to renegotiate, relative to the omitted category of projects using captive fuel. Finally, in column 4, I interact the coal price shock with the use of imported fuel. The interaction effect is 0.403 (standard error 0.158), which is a large and statistically significant effect. In column 4, having controlled for the coal price shock, the *UMPP* dummy is no longer statistically different from zero, though it remains fairly large (point estimate 0.202).

The regressions suggest that fuel price shocks are an important cause of renegotiation. In the full column 4 specification, a UMPP using imported coal hit by a one INR per kWh fuel price shock would be 60 percentage points more likely to renegotiate than a captive, non-UMPP project.

iii Connected bidders index less of their bids

It is striking that cost shocks have a large effect on renegotiation despite that the auction rules allowed complete coal price indexation. One view of this finding is that cost shocks are inevitable and renegotiation must occur for a large enough shock. Another view, which is informed by the Mundra case and not mutually exclusive, is that bidders may choose to expose themselves to cost shocks to gain a competitive advantage. I expect that bidders that are more connected to the Government of India may be more confident in their prospects for renegotiation. Therefore, for a given level of aversion to coal price risk, these bidders will index less of the value of their bids to the price of coal.

In order to test this hypothesis, I regress bidding strategies in power procurement auctions

on whether bidding firms were given a coal block in the “coalgate” scandal (Section 2 d). The specification for bidder i in auction a is:

$$FractionIndexed_{ai} = \beta_0 + \beta_1 ConnectedFirm_i + \beta_2 BidPrice_{ai} + \beta'_3 X_i + \beta'_4 X_a + \epsilon_{ai} \quad (1)$$

where $FractionIndexed_{ai} \in [0, 1]$ is the share of the present value of a bid that is indexed to coal prices, $ConnectedFirm_i$ is a dummy for receiving coal in coalgate, $BidPrice_{ai}$ is the present discounted value of the power price offered by firm i in auction a , X_i are firm-level controls including a dummy for public ownership and firm age, and X_a are auction-level controls including the source of coal and the price of coal at the time of bidding. Some specifications replace auction-level controls with auction fixed effects. The main coefficient of interest is β_1 , the effect of connectedness on bidding strategies.

Table 3 presents the results of estimating equation 1. Column 1 has no controls, column 2 has firm and auction controls, and column 3 and onwards have firm controls and auction fixed effects. The main finding is that the coefficient on being a connected firm is negative and significant in all specifications. Therefore, given a level of the bid price, connected firms index less of the value of that bid to the price of coal. The effect is economically large. The mean share of the present value of bids indexed to the price of coal is 24%; the effect of connectedness is to reduce indexation by 8.14 percentage points (standard error 3.04 pp) of bid value (column 3), or one-third. This evidence is consistent with connected firms being willing to take on greater fuel price risk when bidding in power procurement auctions.

My preferred interpretation of this result is that connected firms expect that their influence with the government will allow them to change bid prices in the event of a cost shock. There are two plausible alternative interpretations that the regression speaks against. First, connected firms may be larger, more widely held and therefore less risk averse in general. The firm controls (not reported) include both dummies for whether a firm is publicly held and firm age. These variables have small and insignificant effects on bidding strategies and do not change the estimated coefficient on connectedness (comparing column 2 to column 1).

The second alternative explanation for the bidding strategies of connected firms is that connected firms may use the coal they got in the scandal to hedge fuel price risk. There are three reasons why this appears unlikely. First, renegotiation is widespread. If connectedness

were a hedge, instead of a means to renegotiate, then we should not observe contracts being changed. Second, the effect of connectedness is observed even in auctions that came with their own coal sources. Some auctions specifically designate that the winner of the power procurement contract will produce with a specific asset: coal from a mine bundled with the project, or coal imported from a port bundled with the project. In those cases a company having a coal block somewhere else in the country should not affect costs or risk. Yet, the effect of connectedness on bidding is as strong in these auctions as in others (column 4, small and insignificant coefficient on “Connected firm (=1) \times coal tied to auction (=1)”). Third, the effect of connectedness is observed even in auctions bid out *before* the bidders were given any coal blocks in coalgate. Column 5 adds an interaction between “Connected firm (=1) \times auction before coal awarded (=1)”, where the latter variable equals one if the power procurement auction was run prior to the company receiving any coal via coalgate. The small and insignificant coefficient on this interaction indicates that connected firms behave like they are connected even *prior* to being awarded any coal. I interpret these findings as showing that the mechanism through which connectedness affects bidding strategies is not a direct impact on costs, but rather through the confidence of connected firms in their ability to renegotiate.

4 A model of renegotiation

The theoretical model follows the reduced-form evidence by letting renegotiation depend on both exogenous shocks and endogenous bidder indexation decisions.

a Environment

A number N of firms i bids at $t = 0$ to supply one unit of electricity in $t = 1$. Each firm has a two-dimensional type $\theta_i = \{h_i, \Delta_i\}$ consisting of their heat rate, the energy of coal input per unit of electricity output (btu per kWh), and a return to renegotiation Δ_i described below. The types of bidders are assumed to be independently and identically distributed.

A bid consists of two components $\beta_i = (\beta_{Fi}, \beta_{ci})$. The firm or firms bidding the $W \geq 1$ lowest total scores $S(\beta_i)$ are awarded the contract. The score for a bid β_i is

$$S(\beta_i) = \beta_{Fi} + \beta_{ci}\mathbb{E}[p].$$

where p is the coal price in INR per btu. The price $p \sim H$ of coal is uncertain at the time of bidding. The payment to the firm in $t = 1$, after the price is realized and net of the cost of production, is

$$\pi(\beta_i, \theta_i) = \beta_{Fi} + (\beta_{hi} - h_i)p.$$

Hence the firm's realized marginal cost is $c_i = h_i p$ INR per kWh.

b Renegotiation

Renegotiation occurs if net variable payments are less than some V_0 . The fixed component of bids and profits cannot trigger renegotiation, since the uncertainty about fixed costs is very small relative to the uncertainty about variable costs. We may also imagine that fixed investments are sunk by the time the price shock is realized, and therefore the only threat the firm has in renegotiation is to walk away from operating the plant and earning its variable profits. This threat is credible if variable profits are low.

The event of renegotiation is therefore

$$\begin{aligned} R(\beta_i, \theta_i) &= \mathbf{1}\{(\beta_{hi} - h_i)p < V_0\} \\ &= \mathbf{1}\{p > V_0/(h_i - \beta_{hi})\} \end{aligned}$$

where we assume that $h_i > \beta_{hi}$ so that bidders index less than their marginal cost. Bidders can still earn markups through the fixed component of bids. This event sets a threshold price

$$\bar{p}(\beta_i, \theta_i) = \frac{V_0}{h_i - \beta_{hi}}$$

such that renegotiation occurs if the realized price is higher than the threshold. The greater is the indexation of bids, as $\beta_{hi} \uparrow h_i$, the higher the coal price shock has to be in order to induce renegotiation. Thus renegotiation depends on both the shock and the bid that the auction winner offered.

In the event of renegotiation, we assume the bidder gets an additional payment Δ_i per

unit. Therefore net payments are

$$\pi(\beta_i, \theta_i) = \beta_{Fi} + (\beta_{hi} - h_i)p + \Delta_i R.$$

accounting for renegotiation. The heterogeneity in Δ_i , the INR per kWh return to renegotiation or *bonus*, is meant to reflect that some firms may have greater bargaining power with the government and therefore be able to extract a higher price in response to a given cost shock ex post.

c Preferences

The firm is risk averse. The firm is assumed to value a payment as

$$V(\pi) = \mathbb{E}[\pi + \Delta_i R] - \eta \text{Var}[\pi].$$

These preferences are close to mean-variance preferences, as arise from a constant absolute risk aversion model with normally distributed shocks. I deviate from strict mean-variance preferences by assuming that the firm does not account for variance induced by renegotiation. This assumption greatly simplifies the bidding problem and does not have a large effect on optimal indexation choices.¹³

d Equilibrium

First consider the choice of bid components conditional on a score S_i . The firm will choose bid components $\beta_i = (\beta_{Fi}, \beta_{hi})$ to maximize value conditional on meeting the score

$$\begin{aligned} \max_{(\beta_{Fi}, \beta_{hi})} \quad & \mathbb{E}[\pi(\beta_i, \theta_i)] - \eta \text{Var}[\pi(\beta_i, \theta_i)] \\ \text{subject to} \quad & S_i = \beta_{Fi} + \beta_{hi} \mathbb{E}[p]. \end{aligned}$$

¹³The practical deviation from strict mean-variance preferences is small for reasonable parameter values, because the omitted variance term from renegotiation is roughly offset by the fact that renegotiation positively covaries with prices, and this covariance reduces the volatility of payments net of renegotiation.

We can substitute for the fixed charge in the objective function for

$$\begin{aligned} \max_{\beta_{hi}} \mathbb{E}[S_i - \beta_{hi}\mathbb{E}[p] + (\beta_{hi} - h_i)p + \Delta_i R] - \eta \text{Var}[\pi(\beta_i, \theta_i)] \\ \max_{\beta_{hi}} S_i - c_i \mathbb{E}[p] + \Delta_i \mathbb{E}[R] - \eta \text{Var}[\pi(\beta_i, \theta_i)]. \end{aligned}$$

The key features that this scoring model satisfies are that (i) the score is linear in β_F (ii) the optimal β_{hi} is independent of the desired score. A bidder can always pick the right level of risk indexation and then meet a desired score by adjusting the fixed charge.

Given these features, the firm's two-dimensional type can be summarized by a one-dimensional pseudo-type, a summary measure of bidder strength (Asker and Cantillon, 2008). The correct definition of pseudo-type is the firm's contribution to apparent social surplus

$$k(\theta_i) = \max_{\beta_{hi}} \{-h_i \mathbb{E}[p] + \Delta_i \mathbb{E}[R(\beta_i, \theta_i)] - \eta \text{Var}[\pi(\beta_i, \theta_i)]\}. \quad (2)$$

The pseudo-type gives the maximum level of apparent surplus that the firm can generate and thus omits any transfer payments in the auction. We expect that firms with higher heat rates, and thus costs, will have lower pseudo-types (the first term) and that firms with higher bonuses will have higher pseudo-types (the second term); however, a firm's pseudo-type will also affect the likelihood of renegotiation and, through indexation choices, the variance of profits, so this result is not immediate.

The optimal indexation conditional on the score is the solution to the above

$$\beta_{hi}^* \in \arg \max_{\beta_{hi}|\theta_i} \{-h_i \mathbb{E}[p] + \Delta_i \mathbb{E}[R(\beta_i, \Delta_i)] - \eta \text{Var}[\pi(\beta_i, \theta_i)]\}. \quad (3)$$

The optimal fixed charge is then inferred as $\beta_{Fi}^* = S_i - \beta_{hi}^* \mathbb{E}[p]$ for any desired score.

Now consider i 's choice of an optimal score. Let $S_{j(W)}$ denote the W th order statistic, in ascending order, of scores for bidders $j \neq i$. The bidder i , in an auction with W winners, solves

$$\max_{S_i} V(S_i|\theta_i) \text{Pr}(S_i < S_{j(W)}) = \max_{S_i} (S_i + k(\theta_i)) \text{Pr}(S_i < S_{j(W)})$$

where the right side follows from the definition of the pseudo-type. The pseudo-type and score

are separable because the pseudo-type is independent of the desired score. Let $G(\cdot|X_a)$ give the marginal distribution of equilibrium scores conditional on the observable characteristics X_a of an auction, such as the number of bidders. The firm solves

$$\max_{S_i} (S_i + k(\theta_i)) (1 - G(S_i|X_a))^{N-W}.$$

Taking the first-order condition with respect to S_i and solving for $k(\theta_i)$ yields

$$k(\theta_i) = \frac{1}{N-W} \frac{1 - G(S_i|X_a)}{g(S_i|X_a)} - S_i. \quad (4)$$

This expression gives the pseudo-type as a function of the number of bidders, the distributions of bids and the bidder's own score. Bidders in the same auction that offer a higher score S_i are inferred to have lower pseudo-types $k(\theta_i)$, hence indirectly to have a combination of higher costs of production or lower payments in renegotiation.

e Identification

The bidder type is distributed as $\theta_i \sim \mathcal{F}$ on \mathbb{R}_+^2 and the distribution of these types is the main structural estimand of interest. The observables $X_i = \{S_i, \beta_{Fi}, \beta_{hi}\}$ include each bidder's score and the components of the bid. The distribution of prices is also known.

The identification argument depends on the bidder's indexation problem, as characterized by the following lemmas (Appendix B has the proofs).

Lemma 1. *The optimal indexation is increasing and pseudo-type decreasing in heat rate.*

This result formalizes the intuition that inefficient (high heat rate) bidders have worse pseudo-types and are therefore weaker bidders, who will index a greater part of their bids to protect against cost shocks.

Lemma 2. *The optimal indexation is decreasing and the pseudo-type increasing in the renegotiation bonus.*

The renegotiation bonus and indexation are strategic substitutes, as a bidder confident of a return to renegotiation will not feel compelled to index as insurance against high input prices.

Proposition. *Assume that parameters (η, V_0) other than the bidder's type are known, and that the chosen indexation β_{hi}^* is interior. Then θ_i is non-parametrically identified from X_i .*

The proof is in two steps. First we recover the bidder's pseudo-type from the score in the auction (Guerre, Perrigne and Vuong, 2000). Then we show that the mapping from bidder types to the pseudo-type and optimal indexation is injective.

Proof. The optimal bidding condition (4) describes a first-price auction, hence we can recover the pseudo-type for each bidder $k(\theta_i)$ non-parametrically (Guerre, Perrigne and Vuong, 2000). The right-hand side of (4) is observed since S_i , the score of i 's bid, is observable and $G(\cdot|X_a)$ is the distribution of these scores.

Consider the mapping Γ from types $\tilde{\theta}_i = \{h_i, -\Delta_i\}$ to bids $\Gamma(\theta_i) = \{\beta_{hi}, -k_i\}$ where the pseudo-type in the bid is observed from the first step. The optimal level of indexation β_{hi} is increasing in h_i and the pseudo-type k_i is decreasing in h_i , thus both elements of Γ are increasing in h_i (Lemma 1). The optimal level of indexation is decreasing and the pseudo-type is increasing in Δ , thus both elements of Γ are increasing in $-\Delta_i$ (Lemma 2). By this strict monotonicity in both arguments Γ is inverse isotone and therefore injective (Rheinboldt, 1970). \square

The second part of the identification argument is similar to that of Berry, Gandhi and Haile (2013), where monotonicity comes from the sign of price elasticities in a demand system. Here, monotonicity comes from the indexation decision of a bidder given their type.

The intuition for the identification result is illustrated by Figure 4, which plots the pseudo-type $k(\theta)$ of a bidder against that bidder's chosen level of indexation β_h . In this figure, the gray curves represent the bidder value functions for three different heat rates, and a fixed bonus, at different levels of indexation along the horizontal axis. The highest gray curve is the value function for a relatively low heat rate (equivalently, low cost) bidder. The bidder, despite being risk averse, does not wish to use a high level of indexation, since that would eliminate the prospect of a bonus; however, at low levels of indexation the bidder is exposed to too much price risk. Point A is the optimal level of indexation for this type. The iso-bonus locus from point A through points B and C shows how the optimal indexation and pseudo-type change linearly if we increase the heat rate (as proven in Lemma 1). Higher cost bidders have lower pseudo-types. An analogous iso-cost locus can be found by fixing the heat rate

and varying the bonus. Increasing Δ , we move from southeast to northwest along the dashed line, reducing indexation and raising the bidder’s pseudo-type or bidding strength. Bidders that have a larger bonus bid more aggressively (i.e., index less) and have higher pseudo-types.

The identification result shows that the intersection of iso-cost and iso-bonus loci, which is observed at a point such as B, can be uniquely inverted to recover a bidder’s underlying type. Thus the data can break the strength of bidders down into its component parts: cost and renegotiation payoffs. The intuition for identification is that, since we observe both the level of the bid and its division into indexed and not-indexed parts, we can use bidding strategies to recover a two-dimensional bidder type.

5 Estimation

This section maps the theoretical model to the empirical model. The empirical model stays very close to the theory but is enriched in a few directions for realism. I make a parametric assumption on the distribution of scores, which can be judged against the observed empirical distribution of scores, but non-parametrically identify the unobserved distribution of types, using the result above.

The three steps in estimation are: (1) estimate the distribution of equilibrium scores; (2) use the first-order condition for optimal bidding to invert the score distribution and recover bidder pseudo-types; (3) use the bidder’s optimal indexation problem to invert the pair of pseudo-type and indexation choice for the two-dimensional bidder types. I now discuss these steps in turn.

a Equilibrium score distribution

The first object of interest is $G(S_i|X_a)$, the equilibrium distribution of scores for an auction with observable characteristics X_a . I parameterize $G(\cdot)$ as a log-normal cumulative distribution function. I specify the mean and the log variance of the score distribution as linear functions of a set of observables that should affect equilibrium scores. These observables are: the price of coal at the time of bidding, dummies for whether a project is an Ultra-Mega Power Plant, whether coal is imported, and whether coal is domestic (the omitted category being a captive source of coal), and the number of bidders. The coal price series used varies

by coal source as described in Appendix A.

I fit the distribution of scores by maximum likelihood. With the distribution of scores, the number of bidders, the number of winners, and each bidder's score S_i , I then invert equation 4 to recover bidder pseudo-types (Guerre, Perrigne and Vuong, 2000).

b Type distribution

There are two main ways in which the theoretical model is enriched to match the empirical setting in the estimation of types. First, prices are not realized in a single second period, as in the theory, but as a price path over 25 years. Second, bidders may have different price expectations than those used in the auction scoring. This difference in expectations is important to account for since it could form an alternative rationale for low indexing.

The discussion below is a summary of the detailed steps to map theory to data laid out in Appendix C. To account for the time-series nature of prices, we simulate possible coal price paths, for each coal price series and for each bidding year. This yields expected present values of future prices as of year t of $\mathbb{E}[\tilde{P}_t]$. For the purposes of estimating renegotiation probability, we model the price series as a geometric random walk with a log-normal distribution and then calculate the expected discounted present number of future renegotiation events $\mathbb{E}[\tilde{R}_t]$ using the probability of price shocks large enough to induce renegotiation.

With these modifications, the bidder's pseudo-type is

$$k(\theta_i) = \max_{\beta_{hi}} \beta_{hi} \left(\mathbb{E}[\tilde{P}_t] - \tilde{P}_0 \right) - h_i \mathbb{E}[\tilde{P}_t] + \Delta_i \mathbb{E}[\tilde{R}_t] - \eta(\beta_{hi} - h_i)^2 \text{Var}[\tilde{P}_t]. \quad (5)$$

The problem is analogous to (2) with two modifications. First, price expectations are now over price paths. Second, I allow price expectations to differ from the price expectations \tilde{P}_0 used by the auctioneer. That is, bidders, based on the history of prices, may expect prices to rise more or less than is assumed in the scoring of the auction. This feature allows that, for example, a bidder may not index, even if they do not expect to renegotiate, because they believe that the auctioneer has assumed prices will rise too quickly. In that case, the first term of the pseudo-type will be negative, because the bidder's contribution to surplus will decline the higher is β_{hi} . This force will drive bidders to index *less* than if they had common beliefs with the auctioneer (or more, if bidders expect prices to rise more quickly).

The optimal indexed bid conditional on the score is the solution to the above problem

$$\beta_{hi}^* \in \arg \max_{\beta_{hi}} \left(\mathbb{E} [\tilde{P}_t] - \tilde{P}_0 \right) - h_i \mathbb{E} [\tilde{P}_t] + \Delta_i \mathbb{E} [\tilde{R}_t] - \eta (\beta_{hi} - h_i)^2 \text{Var} [\tilde{P}_t].$$

The first order-condition for this problem is

$$\frac{dk(\theta_i)}{d\beta_h} = \left(\mathbb{E} [\tilde{P}_t] - \tilde{P}_0 \right) + \Delta_i \frac{d\mathbb{E} [\tilde{R}_t]}{d\beta_h} + \eta 2(h_i - \beta_{hi}) \text{Var} [\tilde{P}_t] = 0. \quad (6)$$

In addition to the type, the system consisting of (5) and (6) has two unknowns, V_0 and η . I calibrate these based on documentary evidence, from the Mundra case and others, and bid indexation choices, and hold them fixed across all bidders. These parameters therefore help fit the level of bids but play no part in fitting heterogeneity across bids. The parameter V_0 may be called the tolerable loss—the amount, in INR per kWh, that the regulator will allow a project to lose in variable profits per unit before permitting renegotiation. I set $V_0 = 0.30$ INR per kWh, which is about ten percent of a typical bid. The parameter η is risk aversion, the relative weight the bidder puts on variance in expected payments relative to the expected value of payments. I calibrate the level of risk aversion in the model such that a bidder of median heat rate from Chan, Cropper and Malik (2014) would, using imported coal in 2010, index approximately one-quarter of their bid to coal prices, as is observed on average in the data. This results in $\eta \approx 1$ so I take $\eta = 1$ as the base case. Appendix D considers the robustness of the estimated type distribution to other values of the calibrated parameters.

I now can solve the system consisting of (5) and (6) to recover each bidder’s pseudo-type. For a given bid, the system is solved exactly to recover the pseudo-type pairs $\{\hat{h}_i, \hat{\Delta}_i\}$ for each bidder.

c Counterfactual bids under strict contract enforcement

The main counterfactual of interest is to consider a world where all contracts are strictly enforced. I interpret this to mean that $R_t = 0$ for all bidders and years, regardless of price shocks. Therefore bidders with higher bonus Δ_i will not receive any advantage, since renegotiation will never occur.

I model this counterfactual as a first-price auction with independent private values given

by the bidder heat rates. The estimated two-dimensional bidder type collapses, in this counterfactual, to a one-dimensional type, since Δ_i is not payoff-relevant. For a given bidder I set $c_i = \mathbb{E} \left[\tilde{P}_t \right] h_i + F + T$ for estimated heat rate h_i , fixed costs F and transportation costs T , which are common by year and project type. Therefore all heterogeneity across bidders comes from differences in production efficiency and thus variable costs.

The distribution of average costs c_i is an affine shift of the estimated distribution of heat rates h_i . Considering a first-price procurement auction with N bidders and W winning bidders, the optimal bid function can be solved as

$$S(c_i) = c_i + \frac{\int_{c_i}^{\bar{c}} (1 - F(\tilde{c}))^{N-W} d\tilde{c}}{(1 - F(c_i))^{N-W}}. \quad (7)$$

Here $F(\cdot)$ is the distribution of costs. The markup term is the probability of winning at a bidder's cost c_i over the marginal change in the probability of winning with respect to cost, evaluated at the same point in the cost distribution.

For the empirical implementation of F I smooth over the cumulative distribution of heat rates using a bandwidth of 1,000 btu per kWh and a normal kernel. For the numerator of the above expression, I use Gauss-Legendre quadrature to numerically integrate the appropriate function of the cost CDF over the relevant range of the cost distribution, which differs bidder by bidder. I can therefore both recover the type distribution and solve the above condition for counterfactually optimal bidding without making any parameteric assumptions on the form of the type distribution.

6 The value of strict contract enforcement

This section discusses the empirical estimates of the structural model. The first subsection presents the estimates of the score and type distributions. Then, I use these distributions to estimate production costs and bidder markups in the present equilibrium. Finally I compare these estimated costs and markups to the counterfactual costs and markups that would be achieved if there was no renegotiation of contracts as bid.

a Model estimates

i Score distribution

To give a better sense of the fit of the score model, Figure 5 plots the equilibrium score distribution and the residual of the score distribution. Panel A plots the equilibrium scores (expected discounted tariffs) in the raw data. Panel B plots the residual scores. I calculate residuals by subtracting the predicted mean score in each auction and dividing by the standard deviation. I then reflate residuals to the original units, INR per kWh, by using the average μ_{it} and σ_{it} across auctions. Panel B therefore shows what bidders would have bid, if they all bid in an auction with the same observable characteristics.

The observable characteristics used have strong explanatory power for bid scores. The unconditional score distribution is broad, with a variance of 1.49 INR per kWh squared. The residual score distribution is much narrower, with a variance of 0.33 INR per kWh squared, 22% as large. I overlay the log-normal distribution fit on the residual score distribution. The parametric log-normal distribution has a good fit and in particular matches the slight right-skewness of the distribution of residual scores.

ii Type distribution

The score distribution is an equilibrium object that depends on bidder types—their heat rates and bonuses—but also on coal prices, project types and other characteristics. I now present and discuss the type distribution that underlies these equilibrium bids.

Figure 6 shows the joint density of the type distribution. The density is oriented to provide a view of the relation between heat rates and bonuses. The horizontal (lower right) axis shows the heat rate h_i in btu per kWh, decreasing from left (high heat rate, inefficient plants) to right (low heat rate, efficient plants). The horizontal (lower left) axis shows the bonus Δ_i , increasing from upper left (low bonus plants) to lower right (high bonus plants, that expect to receive high payments in renegotiation).

There are two features of the joint distribution of types of interest. First, it is sharply peaked, with most bidders having heat rates around 10,000 btu per kWh and bonuses of less than INR 0.5 per kWh (I discuss the reasonableness of the levels of these types below). Second, the orientation of the mass of the joint distribution suggests that the plants with the

lowest heat rates have higher bonuses. The correlation of the two parts of the type is -0.20, because the foothills of the joint distribution move from the upper left towards the lower right, with few plants in the lower left (which would indicate high costs and high bonuses). This feature of the joint distribution is important, since it implies that there will be few very high cost bidders who win auctions because they have countervailingly high bonuses, and are therefore willing to bid low prices despite their high costs.

The counterfactual will use the marginal distribution of heat rates. Figure 7 plots this marginal distribution. Panel A shows the probability density function and Panel B the cumulative distribution function. The modal heat rate is slightly below 10,000 btu per kWh, with the 25th percentile at 8,192 btu per kWh and the 75th at 12,546 btu per kWh. This distribution has a similar central tendency, but broader dispersion, than the distribution of operating heat rates reported for Indian plants from engineering estimates (Cropper et al., 2012). Figure 7, Panel B plots the median engineering estimate of heat rates for operational Indian plants on the estimated distribution; the engineering median is at about the 60th percentile of the estimates. Since sample plants are newer than the average plant we would expect them to be slightly more efficient, as is observed.

b Counterfactual allocation without renegotiation

This section considers the effects of renegotiation on equilibrium markups and the counterfactual effects of strict contract enforcement on bidding and production costs.

Figure 8 shows optimal bid functions calculated by applying equation 7 to the estimated cost distribution for two auctions, one with three bidders (panel A) and another with six (panel B). The optimal markup in a first price auction is the ratio of the probability of winning to the change in the probability of winning if a bidder changes their bid. The markup is therefore generally higher for low-cost bidders, that are more likely to win, as seen by the decline in the gap between the bid and cost for higher costs in both panels. The markup is also smaller in more competitive auctions (panel B as compared to panel A).

Table 4 presents both the equilibrium estimates and the counterfactual results in parallel. The first four columns show estimates describing the current equilibrium bidding. The last two columns show counterfactual simulations. The statistics in the table are reported for two samples. The first pair of columns applies to the entire sample with bids, i.e. equilibrium

scores. The second and third pairs of columns, columns three through six, apply to only bids that have their component parts, such as the indexed energy charge, in the data set. Equilibrium scores are sufficient to infer pseudo-types for all bids. The sample restriction from column three onwards is needed because only for bids with component parts is it possible to infer underlying types and therefore to run counterfactuals. Within each pair of columns, the first column reports the mean for all bids and the second the mean for winning bids only.

Each column of the table reports statistics that describe bidding. These are the equilibrium or counter-factual bid; the pseudo-type; the margin of the bid over the pseudo-type; the cost of supply, using the estimated heat rate and the coal price applicable to each auction; the margin over cost; the estimated bidder bonus Δ_i ; and finally the value of renegotiation, which is equal to the bonus times the expected discounted number of times renegotiation will occur evaluated at the time of bidding. I report the pseudo-type and bonus for the counter-factual scenario, even though they have no effect on auction outcomes, in order to understand the selection of winners in the counterfactual. I bootstrap equilibrium outcomes and counterfactual outcomes by re-drawing bidders, within clusters at the level of bidding year, fuel source, and data availability (i.e., whether a bid has component parts or not). On each bootstrap iteration, I redraw bids, estimate the score distribution, invert scores for pseudo-types, solve pseudo-types for types and, in counterfactuals, use the inferred types to solve the counterfactual model. Standard errors across 200 bootstrap samples are reported in parentheses.

Bidders earn decent markups relative to their pseudo-types. First consider Table 4, columns 1 through 4, which characterize equilibrium bids. The mean bid across all bidders is INR 3.68 per kWh (all bids are in expected present nominal values at the time of bidding) and the mean bid among winners slightly lower at INR 3.41 per kWh. Relative to the pseudo-type, this implies that winning bidders earn a markup of 16.61% (column 2). The levels of bids and pseudo-types are similar in the sample of bids with component parts available compared to the whole sample, with differences less than one standard error (columns 3 and 4 as compared to columns 1 and 2). Winning bidders earn a slightly higher markup in the restricted sample of 18.36% (standard error 2.75%), but this is not significantly different from the markup in the full sample.

Markups with respect to cost, unlike markups with respect to pseudo-types, are estimated

to be negative or zero. In the sample of bidders with types, in columns 3 and 4, we can compare bids to the cost of supply. The mean cost of supply is estimated at INR 3.97 per kWh and the mean amongst winners at INR 3.72 per kWh. These costs imply that bid markups are -3.88% (standard error 1.76%) on average and -2.81% (standard error 2.94%) for winners. A negative markup means that bidders, because they expect to earn more in ex post renegotiation, bid below cost at the start. Consistent with these estimates, market analysts at the time of some auctions puzzled over how such low bids could cover firm costs.¹⁴

The mean bonus across all bidders is INR 0.29 per kWh and across winning bidders INR 0.31 per kWh. There is therefore selection into winning an auction on the dimension of cost but little on the dimension of bonus. The bonus represents the value of renegotiation when it occurs. The expected present value of renegotiation at the time of bidding, taken across future years, is INR 0.24 per kWh for winning bidders. The value of renegotiation is therefore 7% of the value of the initial winning bid ($= 100 \times 0.24/3.39$), on average.

Now consider Table 4 columns 5 and 6, which characterize the counterfactual equilibrium where bidding is based only on costs. In this new equilibrium, where bidders do not get any bonus from renegotiation, the mean bid across all bids rises to INR 4.20 per kWh (a 16% increase) and the mean winning bid to INR 3.70 per kWh (a 9% increase). Bidders increase their bids to insulate themselves against cost shocks, now that renegotiation will not do so. The margins over bidder's pseudo-type (as estimated in equilibrium and held fixed) rise to 29% for all bidders and 22% for winners (columns 5 and 6); however, these margins are no longer relevant to bidders as the pseudo-type includes the expected value of renegotiation, which the bidders do not obtain in the counterfactual.

The large increase in bid prices comes despite a decline in production costs for winning bidders, from INR 3.72 (standard error 0.11) in the estimated equilibrium to 3.36 per kWh (standard error 0.10; a 9.7% decrease) in the counterfactual. This decline in production cost is close to a sufficient statistic for welfare gains in the model. If aggregate power demand is inelastic and we neglect bidder's risk aversion the change in production costs is the change in surplus. With their higher bids and lower costs, winning bidders now earn markups of positive

¹⁴For instance, an article in the Business Standard from 2006 quotes an analyst describing bids in the Mundra and Sasan projects as "aggressive, but realistic", on the grounds that "Otherwise the gap between the highest and the second highest bidder would not have been so narrow." (See <http://www.rediff.com/money/2006/dec/19lanco.htm>). If multiple bidders expect some bonus in renegotiation, then the gap between bidders is no longer informative about the relation of bids to costs.

12.81% (standard error 1.91%) relative to cost in the counterfactual (column 6). Nonetheless, this markup over cost is about one third smaller than the markup they previously earned relative to pseudo-types. This result may be due to a compression of the type distribution; when types are one-dimensional, bidders with low costs and high bonuses cannot be as sure that they will not lose if they markup their bids, which brings down equilibrium markups.

The counterfactual results show that strict contract enforcement would transform the pattern of bidding. Contract enforcement is pro-competitive, since barring renegotiation would force bids ex ante sharply upwards and compress margins. It also decreases productive costs. The size of the change in costs due to contract enforcement depends on both the competitiveness of auctions and the correlation of bonuses with cost. The structure of the joint distribution of bonuses and costs implies that there are not many inefficient but well-connected firms that expect large enough bonuses to out-bid more efficient firms at the start. In general, the more positive the correlation of cost and bonus, the structural measure of firm connectedness, the larger would be the cost savings from strict contract enforcement.

7 Conclusion

This paper studies the effect of contract enforcement on equilibrium prices and efficiency in the market for long-term power procurement contracts in India. I show that these contracts are subject to widespread renegotiation, in particular in response to cost shocks. I argue that the auction mechanism allowed bidders to insulate themselves against these shocks, but that connected bidders endogeneously chose not to, in order to increase their value due to ex post renegotiation.

The analysis has a few novel features. First, I provide evidence that connectedness changes firms' strategies, and that this change is the mechanism by which connected firms win contracts and earn rents. Second, the model allows for the channel of bids affecting renegotiation, and therefore the prospects of renegotiation causing endogenous changes to bidding in equilibrium. Third, the model is specified, identified and estimated with no parametric restriction on the joint distribution of bidder types. This approach allows an especially direct and transparent counterfactual analysis of bidding under strict contract enforcement.

The combination of structural analysis and bidding data, in an environment with weak

contracting, can be useful to measure the normative effects of institutions. Most cross-country and aggregative tests of property rights theory test a positive implication of the theory, such as when integration is more likely to be observed. Micro-economic analysis can provide measures of how weak property rights, renegotiation or corruption affect efficiency (Goldstein and Udry, 2008; Weaver, 2018). This line of work is important because large effects on positive outcomes, such as changes in market prices, can be consistent with small effects on efficiency.

A broader question is how procurement should be designed when contracting is imperfect. Auctions are a transparent procurement mechanism but often do not account for expected contract performance. Ironically, the use of auctions to remove all discretion from procurement, to stamp out corruption, can exacerbate renegotiation by forcing governments to pick low bidders, even when those bidders are not reliable (Decarolis, 2014). Therefore auctions may be scored to account for performance risk. Che (1993) studies scoring auctions and finds that without commitment, the only viable scoring rule in an auction is the utility function of the buyer. In the Indian power sector the rules of auctions were changed in 2013, as a result of the renegotiation studied here, in order to force bidders to index their bids to energy prices and thereby to rule out renegotiation. This change in auction design, to use a simpler scoring rule, can be seen as an example of Che's result: the government, buying power, cares about productive efficiency, and not about the insurance or risk properties of the price path that a fully flexible bid yields. Therefore forcing bidders to bid heat rates may be better than allowing bids to be more flexible functions of future costs. The general lesson would be that the sophistication of a procurement mechanism should not outstrip what can be enforced.

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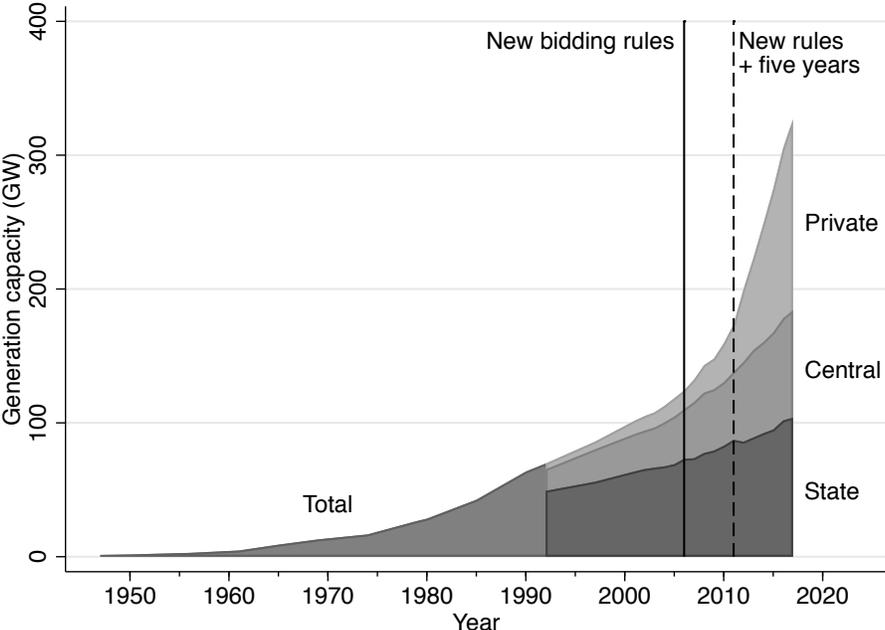
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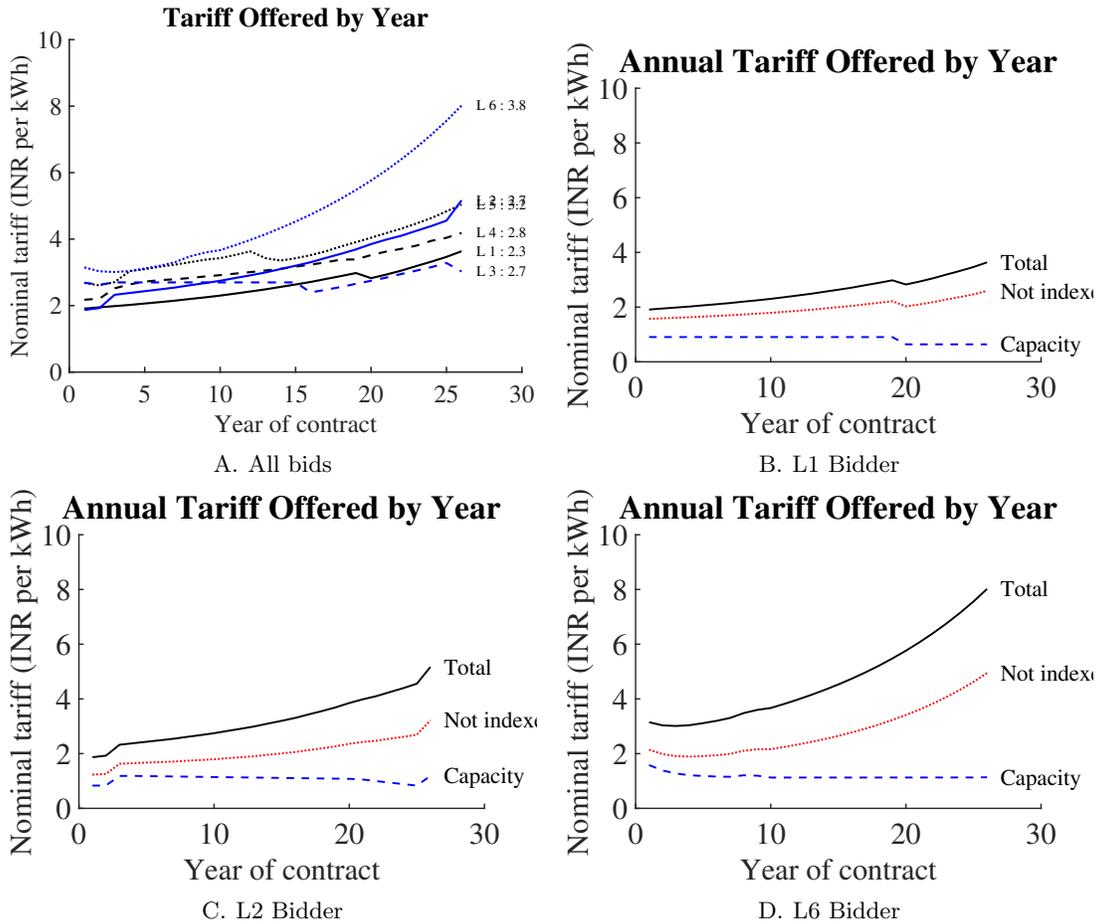
8 Figures

Figure 1: Growth in Capacity by Ownership



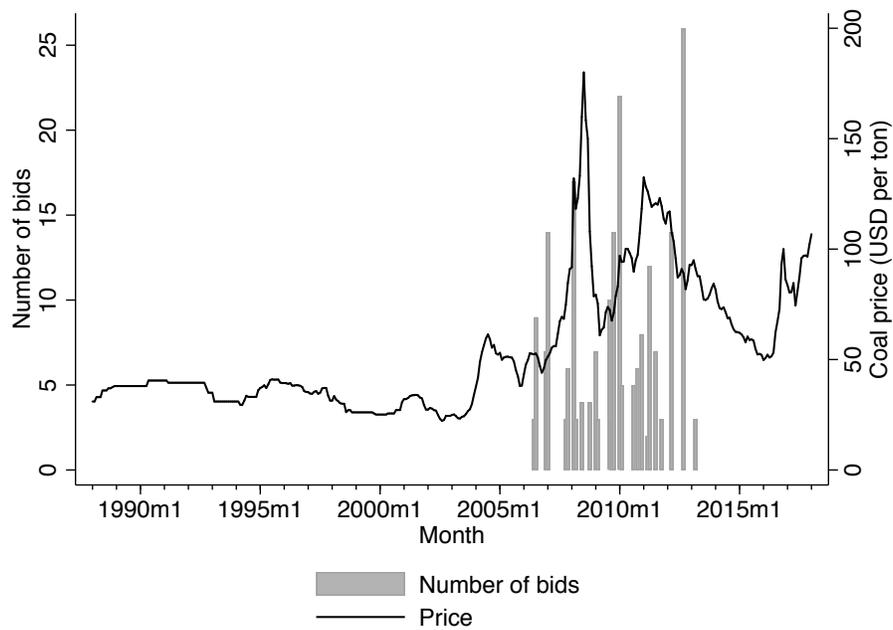
The figure displays the division of generation capacity between the state, central, and private sectors in India from 1947 to 2017. The National Tariff Policy, which introduced new competitive bidding guidelines under the Electricity Act of 2003, was issued in 2006 (indicated by the vertical line). Only the combined generation capacity is available prior to 1992. The data from 1947 to 1992 and from 2001 to 2017 is from the report “Growth of Electricity Sector in India from 1947-2017” from the Central Electricity Authority of the Government of India. The data from 1992 to 2001 is from the Ninth Plan and Tenth Plan reports by the Planning Commission of the Government of India.

Figure 2: Bidding for the Mundra Ultra-Mega Power Project



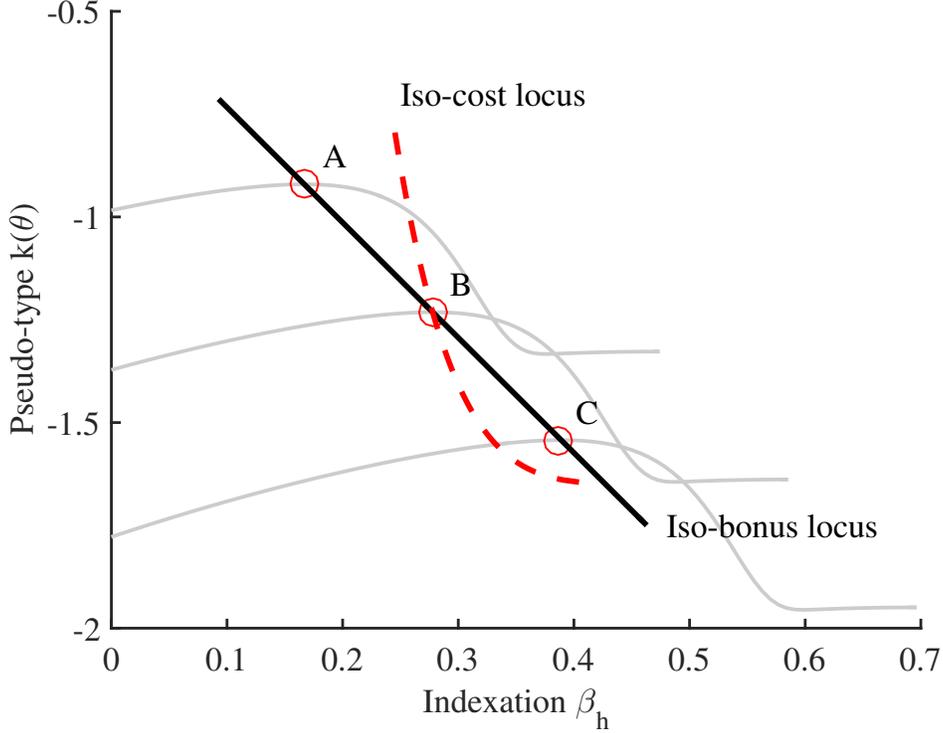
The figure shows bids from the Mundra Ultra-Mega Power Project, which was bid in 2006 for delivery starting in 2012. Panel A shows the time path of all the bids in the Mundra UMPP auction, ranked from L1 (the winning bidder) to L6 (the highest bidder) in terms of their expected discounted nominal tariff (the *score* of the auction). Each curve shows the tariff offered by each bidder in each year of the contract from one to twenty-six (contracts are 25 years long but often span 26 calendar years). These future offered tariffs are expectations, because, for bids indexed to future prices, like the price of coal, the realized value of future tariffs will depend on the realizations of those prices. Panels B, C and D then break down the overall tariffs for the L1, L2 and L6 bidders into their component parts. In each of these three panels, there are three curves. The bottom, dashed (blue) curve shows the nominal tariff for capacity (i.e., fixed) charges. The middle, dotted (red) curve shows the tariff for all parts of the bid not indexed to coal prices. It is therefore the sum of the dashed curve and other charges like energy charges not indexed to coal prices and transportation charges. The topmost, solid (black) curve shows the total tariff in a year. The gap between the solid (black) and dotted (red) curves is therefore the part of the bid indexed to coal prices.

Figure 3: Timing of Power Procurement and Coal Price Shocks



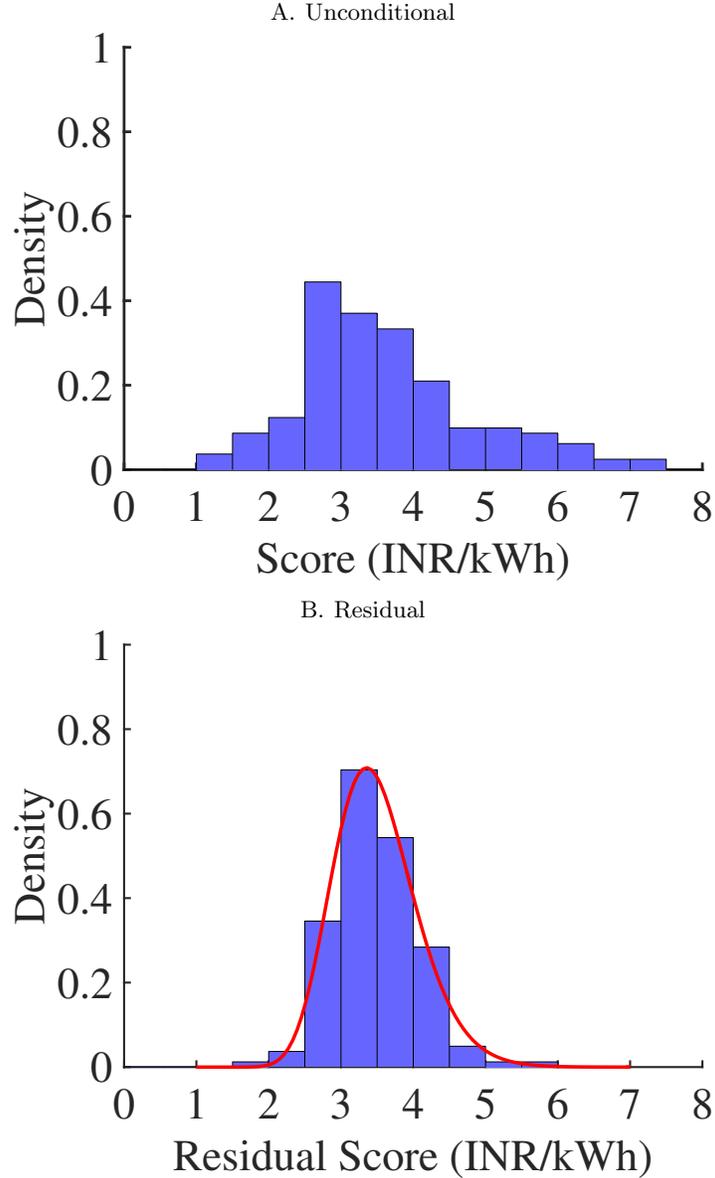
The figure shows the number of bids in sample power procurement auctions (gray bars, against left axis) and the time series of imported coal prices (solid black line, against right axis). The coal price is the Newcastle coal index, formerly the Barlow-Jonkers index, which gives the price of one ton of coal with net calorific value of 6,000 kcal per kg. This benchmark price, out of Australia, is used as a reference price for international coal for the indexation of Indian power purchase auctions.

Figure 4: Illustration of Model Identification



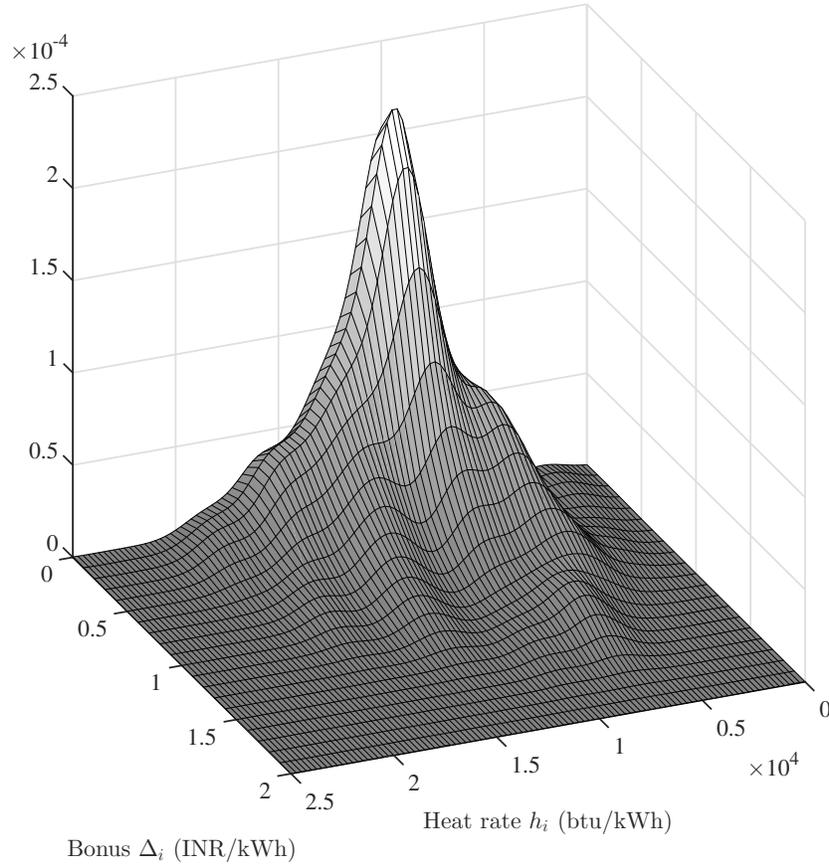
The figure illustrates the identification of the model by tracing out the iso-cost and iso-bonus loci for a calibrated set of model parameters. The figure plots the pseudo-type $k(\theta)$ of a bidder against that bidder’s chosen level of indexation β_h . In this figure, the gray curves represent the bidder value functions for three different heat rates, and a fixed bonus, at different levels of indexation along the horizontal axis. The highest gray curve is the value function for a relatively low heat rate (equivalently, low cost) bidder, who therefore has a high pseudo-type (since this is a procurement auction pseudo-type is by convention negative so that high values represent lower costs). The bidder, despite being risk averse, does not wish to use a high level of indexation, since that would eliminate the prospect of a bonus; however, at low levels of indexation the bidder is exposed to too much price risk. Point A, the maximum of the gray curve, is the optimal level of indexation for this type. The solid (black) iso-bonus locus from point A through points B and C shows how the optimal indexation and pseudo-type change linearly if we increase the heat rate (as proven in Lemma 1). Higher cost bidders have lower pseudo-types. An analogous iso-cost locus can be found by fixing the heat rate and varying the bonus. Increasing Δ , we move from southeast to northwest along the dashed (red) curve, reducing indexation and raising the bidder’s pseudo-type or bidding strength.

Figure 5: Distribution of Equilibrium Scores



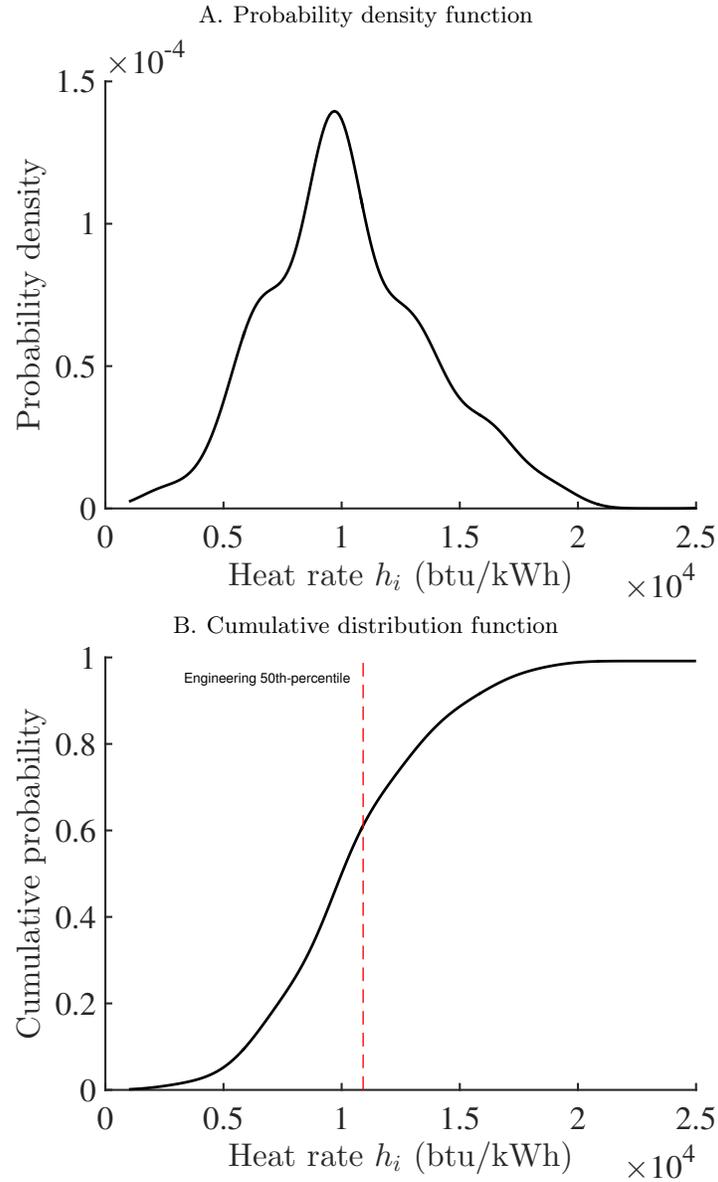
The figure shows the distribution of equilibrium bid scores. The score of a bid is the expected present discounted tariff (i.e., “levelised tariff”) of a bid over the life of a contract in INR per kWh. Panel A shows the unconditional distribution of scores. Panel B shows the distribution of residual scores. Let $\hat{\mu}_{jt}$ be the estimated mean of the log score distribution in auction j in year t and likewise $\hat{\sigma}_{jt}$ the estimated standard deviation. The residual score is then defined as $\epsilon_{ijt} = (\log S_i - \hat{\mu}_{jt}) / \hat{\sigma}_{jt}$. The residuals plotted are scaled up as $\tilde{\epsilon}_{ijt} = \exp(\hat{\sigma}_{jt} \epsilon_{ijt} + \hat{\mu}_{jt})$ to represent the residual variance in an average auction. The red curve overlaid on the histogram is the log-normal fit for such an auction.

Figure 6: Joint Distribution of Types



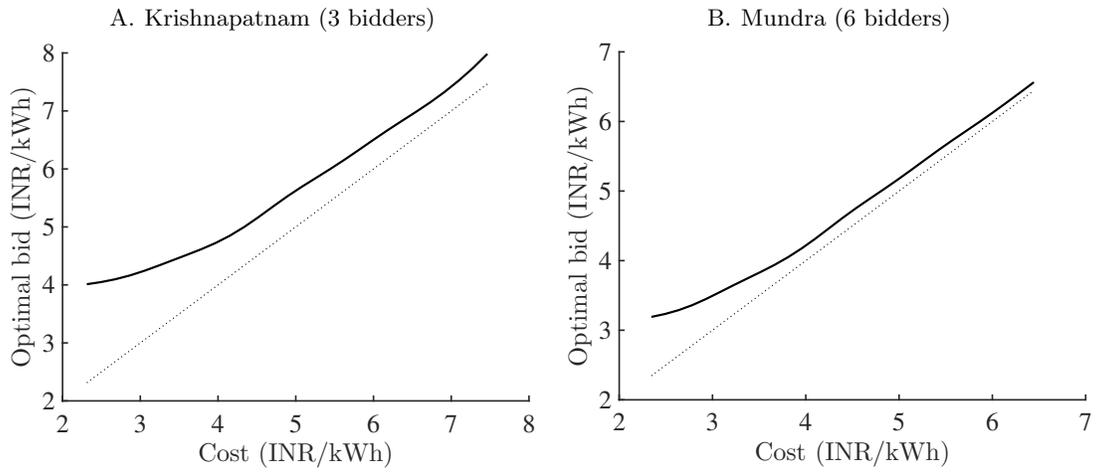
The figure shows the joint density of the type distribution. The density is oriented to provide a view to the relation between heat rates and bonuses. The horizontal (lower right) axis shows the heat rate h_i in btu per kWh, decreasing from left (high heat rate, inefficient plants) to right (low heat rate, efficient plants). The horizontal (lower left) axis shows the bonus Δ_i , increasing from upper left (low bonus plants) to lower right (high bonus plants, that expect to received high payments in renegotiation). The density is kernel-smoothed in both dimensions using a normal kernel and bandwidths of 1,000 btu per kWh in the heat rate dimension and INR 0.2 per kWh in the bonus dimension.

Figure 7: Marginal Distribution of Heat Rates



The figure plots the marginal distribution of heat rates estimated in the model and used for counterfactual simulations of optimal bidding. Panel A shows the probability density function and panel B the cumulative distribution function. The PDF and CDF are kernel-smoothed using a normal kernel and a bandwidth of 1000 btu per kWh.

Figure 8: Counterfactual Bid Functions



The figure plots the counterfactual bid functions from equation 7 for two example auctions. The horizontal axis is the cost of the bidder and the solid black line is the optimal bid of a bidder with that cost. The gap between the dotted forty-five degree line and the black optimal bid line shows the markup at each level of cost.

9 Tables

Table 1: Summary of Bids and Renegotiation

Year	Bids	Winners	Petition status			Mean	
			Known	Filed	Granted	Tariff (INR/kWh)	Capacity (MW)
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
2006	18	3	3	3	2	2.1	3465
2007	23	10	8	4	0	2.9	1043
2008	26	6	4	3	1	3.1	350
2009	34	11	8	7	3	3.5	913
2010	36	5	4	0	0	3.8	365
2011	22	7	3	1	1	4.7	259
2012	40	12	9	2	0	5.7	340
Total	199	54	39	20	7	3.9	836

The table summarizes the outcomes of power procurement auctions in the sample. The rows of the table represent different years in which contracts were auctioned. The columns give the number of bids (column 2) and winners (column 3), then the number of winners for which contract status is known (column 4), for which a petition for revision of the tariff at auction was filed (column 5) and granted (6), as well as the initial tariff and capacity on average across winners (columns 7 and 8). Columns 5 and 6 are restricted to only the auction winners for which the petition status is known, as shown by the column 4 entry.

Table 2: Cost Shocks and Renegotiation

	Dependent variable: Dummy for renegotiation			
	(1)	(2)	(3)	(4)
Coal price shock (Rs/kWh)	0.288*** (0.0999)	0.258** (0.113)		0.191 (0.139)
Coal imported (=1) × coal price shock (Rs/kWh)				0.403** (0.158)
Ultra-mega power plant (=1)		0.247 (0.148)	0.571*** (0.167)	0.202 (0.195)
Capacity missing (=1)				
Coal imported (=1)			0.429** (0.167)	0.150 (0.185)
Coal domestic (=1)			0.357** (0.164)	0.260 (0.187)
Constant	0.541*** (0.0753)	0.521*** (0.0841)	0.143 (0.118)	0.275* (0.154)
Observations	37	37	37	37

The table shows linear probability models for whether an auction winner filed a petition for renegotiation of tariffs. The explanatory variables are the shock to coal prices around the time of bidding, a dummy for whether a plant is an ultra-mega power plant (large, asset-specific projects) and dummies for the source of fuel used by the plant. The coal price shock is measured as the difference in coal prices in a five-year moving period after the auction date relative to a five-year moving period before the auction. The units for the coal price shock are converted from USD per ton, the original price of the coal price index, to INR per kWh, by assuming a gross calorific value of coal of 6,300 kcal per kg and a plant heat rate of 11,615 btu. Hence a one unit change in coal prices is the change in coal prices that would cause a plant with this efficiency and using this grade of coal to experience a one INR per kWh increase in the marginal cost of power generation. The coal price shock has been demeaned. Robust standard errors in parentheses with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 3: Firm Connectedness and Bidding Strategies

	Dependent variable: Fraction of bid indexed to coal				
	(1)	(2)	(3)	(4)	(5)
Connected firm (=1)	-0.0694** (0.0297)	-0.0803*** (0.0296)	-0.0814*** (0.0304)	-0.0774** (0.0347)	-0.0802** (0.0316)
Bid price (Rs/kWh)	0.0589*** (0.0108)	0.0268 (0.0295)	0.0558** (0.0258)	0.0543** (0.0267)	0.0552** (0.0259)
Connected firm (=1) × coal tied to auction (=1)				-0.0216 (0.0645)	
Connected firm (=1) × auction before coal awarded (=1)					-0.00854 (0.0698)
Firm controls		Yes	Yes	Yes	Yes
Auction controls		Yes			
Auction fixed effects			Yes	Yes	Yes
Mean dep. var.	0.24	0.24	0.24	0.24	0.24
Observations	121	121	121	121	121

The table shows estimates of linear regressions of bidding strategies on firm connectedness. The dependent variable is the fraction of the expected present discounted value of a bid that is indexed to the price of coal. The main independent variable of interest is “Connected firm (=1)”, which is a dummy variable equal to one if the firm bidding was allocated a coal block during the coalgate scandal. All regressions control for “Bid price (Rs/kWh)”, the present discounted value of the bid. Firm-level controls are the firm age at bidding and whether the firm is publicly owned. Auction controls include a set of dummies for the source of fuel and the price of coal at the time of bidding. See the text for a description of the interaction variables. Robust standard errors in parentheses with * $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$.

Table 4: Equilibrium and Counterfactual Bids, Costs and Mark-ups

<i>Sample:</i>	Equilibrium				Counterfactual	
	With bid		With type		With type	
<i>Bids:</i>	All	Winning	All	Winning	All	Winning
	(1)	(2)	(3)	(4)	(5)	(6)
Bid (INR/kWh)	3.68 (0.05)	3.41 (0.05)	3.62 (0.05)	3.39 (0.05)	4.20 (0.10)	3.70 (0.09)
Pseudo-type (INR/kWh)	3.46 (0.06)	3.03 (0.08)	3.38 (0.07)	2.98 (0.10)	3.38 (0.07)	3.27 (0.11)
Margin over pseudotype (%)	9.16 (1.01)	16.61 (2.19)	10.07 (1.28)	18.36 (2.75)	29.07 (2.95)	21.87 (4.87)
Cost of supply (INR/kWh)			3.97 (0.10)	3.72 (0.11)	3.97 (0.10)	3.36 (0.10)
Margin over cost (%)			-3.88 (1.76)	-2.81 (2.94)	7.73 (0.95)	12.81 (1.91)
Bonus Δ (INR/kWh)			0.29 (0.02)	0.31 (0.05)	0.29 (0.02)	0.33 (0.05)
Value of renegotiation (INR/kWh)			0.22 (0.02)	0.24 (0.04)		

The table presents both the equilibrium estimates and the counterfactual results in parallel. The first four columns show estimates describing the current equilibrium bidding. The last two columns show counterfactual simulations. The statistics in the table are reported for two samples. The first pair of columns applies to the entire sample of bids. The second and third pairs of columns, columns three through six, apply to only bids that have their component parts, such as the indexed energy charge, in the data set. Within each pair of columns, the first column reports the mean for all bids and the second the mean for winning bids only. Each column of the table then reports the means of several bidder-level variables. These are the equilibrium or counter-factual bid; the pseudo-type; the margin of the bid over the pseudo-type; the cost of supply, using the estimated heat rate and the coal price applicable to each auction; the margin over cost; the estimated bidder bonus Δ ; and finally the value of renegotiation, which is equal to the bonus times the expected discounted number of times renegotiation will occur evaluated at the time of bidding. I bootstrap equilibrium outcomes and counterfactual outcomes by redrawing bidders within clusters of bidding year, fuel source, and data availability (i.e., whether a bid as component parts or not). Standard errors across 200 bootstrap samples are reported in parentheses.

A Appendix: Data (Not for Publication)

The paper uses original data on: (a) bidding in power auctions, (b) the contracts that result from those auctions and the renegotiation of those contracts, and (c) firm connectedness to the government. We also use data on (d) coal prices and investment. The subsections below describe the sources of data.

a Bidding

The sample consists of bids in long-term power procurement auctions following the bidding guidelines notified by the Government of India (Ministry of Power, 2006). These guidelines were in force from 2006 through 2012 and were then revised in 2013. There is no central database of bids, which are kept by the distribution companies that procured power, consultants or financial bodies that assisted in scoring the auctions, and sometimes the relevant regulatory commission that approved the power contract resulting from an auction (Central Electricity Regulatory Commission, CERC, or State Electricity Regulatory Commission, SERC). I obtained bids from the following bodies: Bihar Electricity Regulatory Commission, Central Electricity Regulatory Commission, Power Finance Corporation Ltd., Gujarat Urja Vikas Nigam Ltd., Haryana Electricity Regulatory Commission, Karnataka Electricity Regulatory Commission, Maharashtra Electricity Regulatory Commission, Madhya Pradesh Electricity Regulatory Commission, Punjab State Power Corporation Ltd., Rajasthan Rajya Vidyut Prasaran Nigam Ltd., Uttar Pradesh Electricity Regulatory Commission.

Figure A1 gives an example of a bid. The bidding guidelines say that bids will be set in multi-part tariffs allowing both capacity (fixed) and energy (variable) charges. Additional sundry charges are often specified in auctions including charges for the transportation of fuel, the handling of fuel and the transmission of electricity. For any given charge, bidders may further break the charge down into escalable (i.e., indexed) and non-escalable bid components. Therefore, a bidder can offer a bid wherein the payments for energy production are an affine function of the future price of coal. This example bid has energy and capacity charges, both indexed and not indexed, over twenty-five years. The component of a charge that is not indexed is specified separately for each year. A charge that is indexed is specified only in the initial year, and is thereafter determined by the initial year's charge inflated by the

Figure A1: Example of Bidding Data

Contract Year Number	Financial Year	Commencement Date of Contract Year	End Date of Contract Year	Quoted Non-Escalable Capacity Charges (Rs./kwh)	Quoted Escalable Capacity Charges (Rs./kwh)	Quoted Non Escalable Fuel Energy Charge (Rs./kwh)	Quoted Escalable Fuel Energy Charge (Rs./kwh)
1	2011-12	Scheduled Commencement of Supply	31-Mar	1.3747	0.2403	0.2484	0.2084
2	2012-13	01-Apr	31-Mar	1.3198	Same as Above	0.2498	Same as Above
3	2013-14	01-Apr	31-Mar	1.2843	Same as Above	0.2513	Same as Above
4	2014-15	01-Apr	31-Mar	1.2489	Same as Above	0.2529	Same as Above
5	2015-16	01-Apr	31-Mar	1.2136	Same as Above	0.2546	Same as Above
6	2016-17	01-Apr	31-Mar	1.1786	Same as Above	0.2564	Same as Above
7	2017-18	01-Apr	31-Mar	1.1437	Same as Above	0.2583	Same as Above
8	2018-19	01-Apr	31-Mar	1.1090	Same as Above	0.2604	Same as Above
9	2019-20	01-Apr	31-Mar	1.0745	Same as Above	0.2626	Same as Above
10	2020-21	01-Apr	31-Mar	1.0402	Same as Above	0.2650	Same as Above
11	2021-22	01-Apr	31-Mar	1.0671	Same as Above	0.2675	Same as Above
12	2022-23	01-Apr	31-Mar	1.0332	Same as Above	0.2702	Same as Above
13	2023-24	01-Apr	31-Mar	0.9101	Same as Above	0.2731	Same as Above
14	2024-25	01-Apr	31-Mar	0.6651	Same as Above	0.2762	Same as Above
15	2025-26	01-Apr	31-Mar	0.6703	Same as Above	0.2795	Same as Above
16	2026-27	01-Apr	31-Mar	0.6757	Same as Above	0.2830	Same as Above
17	2027-28	01-Apr	31-Mar	0.6814	Same as Above	0.2868	Same as Above
18	2028-29	01-Apr	31-Mar	0.6875	Same as Above	0.2908	Same as Above
19	2029-30	01-Apr	31-Mar	0.6939	Same as Above	0.2952	Same as Above
20	2030-31	01-Apr	31-Mar	0.7007	Same as Above	0.2998	Same as Above
21	2031-32	01-Apr	31-Mar	0.7079	Same as Above	0.3047	Same as Above
22	2032-33	01-Apr	31-Mar	0.7155	Same as Above	0.3100	Same as Above
23	2033-34	01-Apr	31-Mar	0.7235	Same as Above	0.3156	Same as Above
24	2034-35	01-Apr	31-Mar	0.7320	Same as Above	0.3217	Same as Above
25	2035-36	01-Apr	31-Mar	0.7410	Same as Above	0.3281	Same as Above
	2036-37	01-Apr	25 th anniversary of the Scheduled COD of first Unit	0.7281	Same as Above	0.3350	Same as Above
26							

realization of the cost index. Therefore this bid, which is of the minimal possible complexity, has $26 \times 2 + 2 = 54$ charges that can be independently set.

b Contracts and renegotiation

Winning bidders sign contracts with buyer called power purchase agreements (PPAs). These PPAs have to be reviewed and approved by the appropriate regulatory commission (Central or State), as do any revisions to the PPA after adoption. I gathered PPA documents and revisions from the respective regulatory commissions' websites. I code renegotiation as happening if the firm filed any petition for a change to the original PPA with the appropriate regulatory commission. I could not find the contract status for all auction winners. Table 1 shows the numbers of winning bidders and the number of winning bidders with contract status.

c Connectedness (Coalgate)

The measure of firm connectedness comes from an audit report on the "coalgate" scandal. The Comptroller and Auditor General (CAG) finished its audit of the Ministry of Coal in February 2012 and on March 22nd, 2012, the press reported on a draft of the CAG audit report (Comptroller and Auditor General of India, 2012). The report describes the process of

coal allocation and in Annexure 1B tabulates the private companies given coal blocks, how much coal they were given and the difference between the value of that coal and the estimated cost of extraction.

Figure A2: Example of Coalgate Data

Sl. No.	Company Name	Block Name	Date of Allotment	Sector	GR in MT	GR (90%) in MT	Grade	Grade Considered	Basic Price (Notified Price)	Cost Price of respective Grade for respective Year	Net Revenue (Per Tonne)	Total Benefit extended (in Rs. Million)	Total Benefit extended (in Rs. Crore)
a	b	c	d	e	f	$g = f * 0.9$	h	i	j	k	$l = j - k$	$m = g * l$	$n = m / 10$
35	SKS Ispat Ltd.	Rawanwara North	29-May-07	Sponge Iron	170.00	153	A - F	F	868.53	669.98	198.55	30378	3038
36	Prism Cement Ltd.	Sial Ghoghri	29-May-07	Cement	9.06	8.154	D	F	868.53	669.98	198.55	1619	162
37	Pushpa Industries	Brahampuri	16-Jul-07	Sponge Iron	55.00	49.5	A - F	F	868.53	669.98	198.55	9828	983
38	Hindalco & TATA Power Ltd.	Tubeid	1-Aug-07	Power	189.00	170.10	F	F	520	224	296	50350	5035
39	Jayaprakash Associates Ltd.	Mandla (N)	17-Sep-07	Cement	195.00	175.5	D-E	E	868.53	669.98	198.55	34846	3485
40	AES Chhattisgarh Energy Pvt. Ltd	Sayang	6-Nov-07	Power	150.00	135.00	D - E	E	600	204.48	395.52	53395	5340
41	DB Power Ltd.	Durgapur II/ Sariya	6-Nov-07	Power	91.67	82.50	F	F	470	377.32	92.68	7647	765
42	BALCO	Durgapur II/ Taraimar	6-Nov-07	Power	211.37	190.23	C - G	F	470	377.32	92.68	17630	1763
43	Essar Power Ltd.	Ashok Karkata Central	6-Nov-07	Power	110.00	99.00	E - F	F	520	224	296	29304	2930
44	Bhusan Power & Steel Ltd.	Patal East	6-Nov-07	Power	200.00	180.00	NA	F	520	224	296	53280	5328
45	Adani Power Ltd.	Lohara West Extn.	6-Nov-07	Power	169.83	152.847	D - E	E	900	707.48	192.52	29426	2943
46	Sova Ispat & Jai Balaji Sponge Ltd.	Ardhagram	6-Dec-07	Sponge Iron	109.60	98.64	A - G	F	690	655.74	34.26	3379	338
			2007 Total		1940.71							382838	38284
47	Monnet Ispat & Energy Ltd, Tata	Mandakini -A	9-Jan-08	Power	290.52	261.47	B to G	F	440	394.98	45.02	11771	1177

The measure of connectedness in the bidding data is whether the parent company of a power procurement auction bidder received coal in the coalgate scandal, according to Annexure 1B of the Draft CAG report. Figure A2 gives an example page from the Annexure with coal block level data. The main variables used in the empirical analysis are the company name (column b), the date of allotment (column d), the sector of the company (column e) and the quantity of coal (column f). The CAG also calculated a measure of the value of coal relative to the cost of extraction (column n); however, I do not use this measure as it is nearly collinear with the quantity of coal (the only difference being the quality grading and therefore price of different coal blocks).

d Coal prices and investment

The data source on coal prices differs by the origin of the coal. Coal India Limited is a public sector monopoly on domestic coal supply in India. I obtain domestic coal prices from the price notifications of Coal India, using the price of Grade B thermal coal for the power sector. Because these notifications are published at irregular intervals it is useful to interpolate this series. I use the Wholesale Price Index (WPI) for Non-coking Coal, indexed to the level of Coal India prices, to compute the inflation rate of domestic coal between Coal India notifications.

For international coal I use the Newcastle Coal Price Index (NEWC), formerly the Barlow-Jonkers Index. The Newcastle Index reflects the spot price of one ton of coal with a net calorific value of 6,000 kcal per kg free on board at the Newcastle Coal Terminal in Australia. This index is the primary benchmark for coal prices in Asia and is used, in particular, for indexation of coal prices in sample auctions that use imported coal.

For investment and capacity figures I gather monthly and quarterly reports from the Central Electricity Authority (CEA). For the characteristics of bidding firms I use data on ownership from the Centre for Monitoring the Indian Economy's (CMIE) Prowess database.

B Appendix: Model (Not for Publication)

This appendix contains parts of the proof of model identification.

Proof. (Lemma 1). The bidder's problem yields first-order condition

$$\frac{dk(\theta_i)}{d\beta_h} = -\Delta h \left(\frac{V_0}{h - \beta_h} \right) \frac{V_0}{(h - \beta_h)^2} + \eta 2(h - \beta_h)\sigma_p^2 = 0.$$

The indexation choice β_h appears only as a difference with heat rate (including within \bar{p}). Thus if we fix all other parameters and vary h , optimal levels of interior indexation satisfy $h - \beta_h = C$ for some constant, and β_h^* must be linear and increasing in cost with a slope of one. By observation of the pseudo-type (2), the constant level of indexation net of cost $h - \beta_h^* = C$ implies that the right-hand two terms are constant for all possible h_i , and therefore the pseudo-type as a whole is decreasing linearly in h_i with a slope of $-\mathbb{E}[p]$, following the first term. \square

Proof. (Lemma 2). Take the second part first. By the envelope theorem

$$\frac{dk(\theta_i)}{d\beta_h} = (1 - H(\bar{p})) \geq 0$$

for interior β_h . The inequality is strict provided the support of $H(\cdot)$ is sufficiently broad that renegotiation may occur for all levels of indexation (e.g., there is some possibility of very high prices that induce renegotiation even for a conservative bid). The optimal choice of β_h depends on the cross derivative

$$\frac{d}{d\beta_h} \frac{dk(\theta_i)}{d\beta_h} = \frac{d}{d\beta_h} (1 - H(\bar{p})) = -h \left(\frac{V_0}{h - \beta_h} \right) \frac{V_0}{(h - \beta_h)^2} \leq 0$$

where the inequality is again strict if there is some density at high prices. This implies that increases in Δ decrease the marginal value of β_h and thus the optimal β_h is decreasing in Δ . \square

C Appendix: Estimation (Not for Publication)

The model has two periods. In the data, the second period is in fact a sequence of twenty-five years, over which the series of coal prices is realized. This subsection maps the multi-period objects observed in the data to the simpler structure of the model. It also shows robustness checks for the estimated type distribution under different assumptions on the calibrated parameters of risk aversion η and the regulator's tolerance for firm losses V_0 .

i Score and value function

The score of a bid is the present discounted value of the price of electricity that the bidder offers (i.e., the levelized tariff, in INR per kWh). The score is calculated with an interest rate r for discounting and an assumed growth rate of coal prices r_p . The score is therefore

$$\begin{aligned}
 S(\beta) &= \sum_{t=1}^T \frac{1}{(1+r)^{t-1}} (\beta_{ft} + \beta_{et} + \beta_h(1+r_p)^{t-1}p_0) \\
 &= \underbrace{\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} (\beta_{ft} + \beta_{et})}_{\tilde{\beta}_f} + \beta_h \underbrace{\sum_{t=1}^T \left(\frac{1+r_p}{1+r}\right)^{t-1} p_0}_{\tilde{P}_0} \\
 &= \tilde{\beta}_f + \beta_h \tilde{P}_0.
 \end{aligned}$$

where β_{ft} is the fixed charge in a given year, β_{et} is the energy charge not indexed to coal prices in a given year, and β_h is the energy charge indexed to coal prices. Therefore the score is the same as in the model where the fixed component of the bid is the cumulative present value of the components of the bid not indexed to fuel prices, the indexed component of the bid is as in the data, and the coal price is the cumulative present value of future coal prices assumed in the auction scoring. The initial level of prices, p_0 , is observed at the time of bidding.

The above pertains to the auction scoring. Bidders care about risk and bidder valuations will therefore differ from the score, as in the model. In a given year the bid pays

$$\pi(\beta_t, p_t) = \beta_{ft} + \beta_{et} + \beta_{ht}p_t + \Delta_i R_t(\beta_t, p_t).$$

The value of the stream of payments at the time of bidding is therefore

$$\begin{aligned}
V(\beta) &= \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} (\beta_{ft} + \beta_{et} + (\beta_h - h_i)p_t + \Delta_i R_t) \right] \\
&\quad - \eta \text{Var} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} (\beta_{ft} + \beta_{et} + (\beta_h - h_i)p_t) \right] \\
&= \sum_{t=1}^T \frac{1}{(1+r)^{t-1}} (\beta_{ft} + \beta_{et}) + (\beta_h - h_i) \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} p_t \right] + \Delta_i \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} R_t \right] \\
&\quad - \eta (\beta_h - h_i)^2 \text{Var} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} p_t \right] \\
&= \tilde{\beta}_f + (\beta_h - h_i) \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} p_t \right] + \Delta_i \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} R_t \right] \\
&\quad - \eta (\beta_h - h_i)^2 \text{Var} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} p_t \right] \\
&= \tilde{\beta}_f + (\beta_h - h_i) \mathbb{E} [\tilde{P}_t] + \Delta_i \mathbb{E} [\tilde{R}_t] \\
&\quad - \eta (\beta_h - h_i)^2 \text{Var} [\tilde{P}_t].
\end{aligned}$$

This expression has four terms, which we calculate as follows:

1. $\tilde{\beta}_f$. This term gives the present value of components of bid not indexed to fuel prices, which is observable and deterministic at the time of bidding.
2. $(\beta_h - h_i) \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} p_t \right]$. This term gives the variable component of expected profit.

The expectation is over the cumulative present value of the future stream of coal prices, as of time zero. We calculate this term by simulating possible future price paths using the history of twelve-monthly innovations in log price up to the time of bidding.

- (a) Let $p_0 = 1$.
- (b) Consider a sample of monthly price observations up to the time of bid submission.
- (c) Draw $\log \delta_m = \log p_m - \log p_{m-12}$ randomly from this sample.
- (d) Calculate the simulated time series from p_0 onwards as $p_t = p_{t-1} \delta_m$ for $t = 1 \dots 25$.
- (e) Repeat B times for each starting year in $t_0 \in \{2006, \dots, 2012\}$.
- (f) Calculate the expected value over B draws.

3. $\Delta_i \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} R_t \right]$. This term gives the present value of revenues from renegotiation. It would be possible to simulate this term, however, we choose not to do so, for two reasons. First, unlike the second term, it would be relatively cumbersome to simulate, because R_t is a function of the bid β and type h_i . Second, the derivative of this term will enter the bidder's first-order condition, so it will be useful to have an analytic and thus smooth representation of the function.

Therefore I make additional assumptions on the time series p_t in order to calculate the value of revenues from renegotiation analytically. Assume that $\log p_t \sim N(\mu_t, \sigma_t^2)$ and that p_t follows a geometric random walk. We estimate the drift in this process with a regression

$$\log p_t = \log p_{t-1} + \log(1 + g_p) + \log \epsilon$$

where $\log \epsilon$ is assumed normal. Under this assumption the parameters of the price distribution H_t in any year t are given by

$$\begin{aligned} \mu_t &= \mu_0(1 + g_p)^t \\ \sigma_t &= \sigma_\epsilon \sqrt{t}. \end{aligned}$$

With these parameters, we can therefore calculate the log-normal distribution of prices in any future year. The expected value of renegotiation is then

$$\begin{aligned} \mathbb{E} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} R_t \right] &= \sum_{t=1}^T \frac{1}{(1+r)^{t-1}} \mathbb{E}[R_t] \\ &= \sum_{t=1}^T \frac{1}{(1+r)^{t-1}} (1 - H_t(\bar{p}(\beta, \theta))) \\ &= \sum_{t=1}^T \frac{1}{(1+r)^{t-1}} \left(1 - H_t \left(\frac{V_0}{h - \beta_h} \right) \right). \end{aligned}$$

This expression can be evaluated analytically with the assumed form for $H_t(\cdot)$. The point of evaluation for renegotiation is the same in all years. However, because the variance of the time series of prices increase over time, we are evaluating a broader distribution H_t at a given point; thus the mass below the threshold price will fall and

the likelihood of renegotiation rise in later years, in expectation.

4. $\eta(\beta_h - h_i)^2 Var \left[\tilde{P}_t \right]$. This term gives the present value of price risk. I simulate this term using the same procedure as for the second term, but calculating the variance in the last step.

The above four terms complete the specification of the value function with long-lived bids. The main difference between the model objects and the empirical objects is that the empirical objects represent statistics calculated over the future stream of prices, rather than a single price realization. In the new notation of the empirical model, the bidder's problem is written

$$\begin{aligned} \max_{(\tilde{\beta}_f, \beta_{hi})} \quad & \tilde{\beta}_f + (\beta_h - h_i) \mathbb{E} \left[\tilde{P}_t \right] + \Delta_i \mathbb{E} \left[\tilde{R}_t \right] - \eta(\beta_h - h_i)^2 Var \left[\tilde{P}_t \right] \\ \text{subject to} \quad & S_i = \tilde{\beta}_f + \beta_h \tilde{P}_0. \end{aligned}$$

Substitute the score into the bidder's indexation problem for

$$\begin{aligned} \max_{(\tilde{\beta}_f, \beta_{hi})} \quad & S_i - \beta_h \tilde{P}_0 + (\beta_h - h_i) \mathbb{E} \left[\tilde{P}_t \right] + \Delta_i \mathbb{E} \left[\tilde{R}_t \right] - \eta(\beta_h - h_i)^2 Var \left[\tilde{P}_t \right] \\ \max_{(\tilde{\beta}_f, \beta_{hi})} \quad & S_i + \beta_h \left(\mathbb{E} \left[\tilde{P}_t \right] - \tilde{P}_0 \right) - h_i \mathbb{E} \left[\tilde{P}_t \right] + \Delta_i \mathbb{E} \left[\tilde{R}_t \right] - \eta(\beta_h - h_i)^2 Var \left[\tilde{P}_t \right]. \end{aligned}$$

This expression is very similar to the expression in the two-period case. The main change is that, instead of expectations or variances of a single realization of price, the uncertain parts of the value are functions of the path of prices. The expression also allows that the expected present value of prices $\mathbb{E}[\tilde{P}_t]$ may differ from the present value used in the auction scoring \tilde{P}_0 . If bidders agree with the auctioneer's expectation then the second term is zero and does not change indexation decisions. If instead bidders expect greater price appreciation than the auctioneer, then the second term in the value will be positive, and optimal indexation will be higher.

ii Pseudo-type

The pseudo-type is the bidder's contribution to apparent social surplus

$$k(\theta_i) = \max_{\beta_{hi}} \beta_{hi} \left(\mathbb{E} \left[\tilde{P}_t \right] - \tilde{P}_0 \right) - h_i \mathbb{E} \left[\tilde{P}_t \right] + \Delta_i \mathbb{E} \left[\tilde{R}_t \right] - \eta(\beta_{hi} - h_i)^2 Var \left[\tilde{P}_t \right]. \quad (8)$$

The optimal indexed bid conditional on the score is the solution to the above problem

$$\beta_{hi}^* \in \arg \max_{\beta_{hi}} \left(\mathbb{E} [\tilde{P}_t] - \tilde{P}_0 \right) - h_i \mathbb{E} [\tilde{P}_t] + \Delta_i \mathbb{E} [\tilde{R}_t] - \eta (\beta_{hi} - h_i)^2 \text{Var} [\tilde{P}_t].$$

The first order-condition for this problem is

$$\frac{dk(\theta_i)}{d\beta_h} = \left(\mathbb{E} [\tilde{P}_t] - \tilde{P}_0 \right) + \Delta_i \frac{d\mathbb{E} [\tilde{R}_t]}{d\beta_h} + \eta 2(h_i - \beta_{hi}) \text{Var} [\tilde{P}_t] = 0.$$

The second term is

$$\begin{aligned} \frac{d\mathbb{E} [\tilde{R}_t]}{d\beta_h} &= \frac{d}{d\beta_h} \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} \left(1 - H_t \left(\frac{V_0}{h - \beta_h} \right) \right) \right] \\ &= \left[\sum_{t=1}^T \frac{1}{(1+r)^{t-1}} \left(-h_t \left(\frac{V_0}{h - \beta_h} \right) \frac{V_0}{(h - \beta_h)^2} \right) \right]. \end{aligned}$$

The derivative is therefore the sum of the change in the probabilities of renegotiation over the life of the contract.

D Appendix: Additional Results (Not for Publication)

a Score distribution parameter estimates

Table D1 reports the maximum likelihood estimates of the parameters of the distribution of equilibrium scores. Since the distribution is assumed log-normal the parameters μ_{it} and σ_{it} are the mean and standard deviation of the distribution of log scores; the two columns of the table report the coefficients on observables from linear specifications for μ_{it} and $\log \sigma_{it}$.

The parameters of the distribution are precisely estimated and marginal effects on the mean of the distribution have the expected signs. Since the same variables change both the mean and dispersion of the distribution I use the coefficients in the table to calculate marginal effects (or the discrete effects of switching indicator variables from zero to one). The mean of the score distribution is higher for projects reliant on imported or domestic coal than for captive coal projects. For example, applying the estimated parameters to a project with four bidders and the mean coal price, if we change a project from a captive Ultra-Mega Power Plant to a plant using domestic coal, this raises the mean of the score distribution by INR 1.82 per kWh (the mean of the score distribution in the data is INR 3.68 per kWh, so this is a large effect). This jump in prices is to be expected since a captive UMPP has the lowest cost structure of any type of plant. The mean of the score distribution is also increasing in the coal price. The price effect is large and precisely estimated. A one standard deviation (INR 519 per ton) increase in coal price raises the mean score by INR 0.55 per kWh. A two standard deviation price change therefore has the same effect as moving a project from using domestic to imported coal.

b Robustness of type distribution estimates

Table D2 studies the robustness of the estimated type distribution to alternative assumptions on the calibrated parameters. The baseline values of the calibrated parameters are $\eta = 1.0$, for firm risk aversion, and $V_0 = 0.30$ (INR per kWh), for the regulator's tolerance for a firm's loss in variable profits before permitting renegotiation. Column 1 shows statistics on the type distribution under the baseline values of these parameters and the other columns show the same statistics on the estimated type distribution under different values of the calibrated parameters, as indicated by the column headers.

Table D1: Estimates of equilibrium score distribution

	μ_{jt} (1)	$\log \sigma_{jt}$ (2)
Coal price (USD/ton)	0.027 (0.0017)	-0.010 (0.0082)
Ultra-mega power plant (=1)	0.274 (0.0863)	0.337 (0.4268)
Coal imported (=1)	0.666 (0.0952)	-0.418 (0.3119)
Coal domestic (=1)	0.968 (0.1140)	-0.127 (0.4833)
Number of bidders	0.000 (0.0037)	-0.012 (0.0166)
Constant	0.334 (0.1102)	-1.619 (0.4638)
N		162
$\log \mathcal{L}$		-135.88

The table provides estimates of the parameters of the marginal distribution of equilibrium bid scores. The first column gives coefficients on variables affecting the mean score for auction j in time t and the second column coefficients on variables changing the variance. Number of bidders is the maximum of the number of bidders in an auction and six. An asset-specific project is a project where land or coal is given to the winning bidder. Ultra-mega power plant is a large projects of nearly 4,000 MW capacity for which the Central government ran procurement. Coal source not captive refers to projects using domestic or imported sources of coal and therefore exposed to coal price fluctuations. The coal price is the 5-year trailing average of the Newcastle (imported) coal price as of the year prior to bidding in the auction. Estimates are by maximum likelihood with standard errors in parentheses.

The estimates of the type distribution are not sensitive to reasonable changes in the values of the calibrated parameters. For example, the mean heat rate in the baseline case with $\eta = 1.0$ is 10,433 btu per kWh (standard error 306 btu per kWh) and the median is 9,876 btu per kWh (standard error 159 btu per kWh). If we cut risk aversion by half, to $\eta = 0.50$, the mean heat rate rises to 10,602 btu per kWh (standard error 307 btu per kWh) and the median to 10,046 btu per kWh (standard error 180 btu per kWh). These are small changes both economically and statistically. Cutting risk aversion in the same way decreases the estimated mean bonus Δ from 0.29 INR per kWh to INR 0.26. There are similarly small changes in the moments of the estimated heat rate and bonus distributions from changing the regulatory tolerance for firm losses (columns 4 and 5). Nor does varying the calibrated parameters change the

Table D2: Robustness of Type Distribution Estimates to Calibrated Parameters

	Calibrated parameter values				
	$\eta = 1.0$ $V_0 = 0.30$	$\eta = 0.5$ $V_0 = 0.30$	$\eta = 1.5$ $V_0 = 0.30$	$\eta = 1.0$ $V_0 = 0.15$	$\eta = 1.0$ $V_0 = 0.45$
	(1)	(2)	(3)	(4)	(5)
Mean h (btu/kWh)	10433 (306)	10602 (307)	10199 (316)	10263 (304)	10500 (316)
Median h (btu/kWh)	9876 (159)	10046 (180)	9787 (201)	9926 (192)	9974 (187)
Standard deviation of Δ (btu/kWh)	3635 (373)	3674 (365)	3706 (374)	3767 (381)	3702 (378)
Mean Δ (INR/kWh)	0.29 (0.023)	0.26 (0.021)	0.31 (0.027)	0.25 (0.021)	0.31 (0.026)
Median Δ (INR/kWh)	0.15 (0.021)	0.14 (0.015)	0.15 (0.022)	0.12 (0.014)	0.17 (0.024)
Standard deviation of Δ (INR/kWh)	0.33 (0.024)	0.29 (0.023)	0.36 (0.030)	0.29 (0.024)	0.35 (0.026)
Correlation of h and Δ	-0.20 (0.076)	-0.15 (0.079)	-0.20 (0.074)	-0.19 (0.073)	-0.15 (0.077)

The table shows summary statistics on the estimated type distribution under different assumptions on the calibrated parameters in the model. The calibrated parameters are the bidder risk aversion η and the regulatory threshold V_0 for granting a contract revision. Column 1 shows the baseline estimates and the other columns vary the values of η and V_0 . The standard errors are bootstrapped over $B = 200$ iterations. In each column the row statistic is calculated on each iteration and the standard error is the standard deviation of the statistic across iterations.

conclusion that there is a negative and significant correlation of around -0.20 between the two dimensions of the type (final row, comparing across columns).

The robustness checks illustrate the logic of the trade-off in the model between risk and renegotiation. In particular, when firms are more risk averse, we estimate a combination of lower heat rates and higher bonuses. This result can be understood via how the model rationalizes bidding patterns. Given the data that shows the firm's bid and its indexation choice, if the same firm is supposed to be more risk averse, then to have chosen the observed bid it must have had either lower heat rates or a higher bonus. Lower heat rates, *ceteris paribus*, since a more risk averse firm faces lesser risk from fuel prices if it is more efficient and therefore uses less coal per unit output. A higher bonus, *ceteris paribus*, since a more risk averse firm is willing to bear risk only if it expects a greater payoff to renegotiation.