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

Nicholas Ryan†

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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 power procurement auctions covering the largest projects in India. I gather data on bidding and *ex post* contract renegotiation and find that the renegotiation of contracts in response to input cost shocks is widespread. 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 winning bidders offer power *below* cost due to the expected value of later renegotiation. The model is used to simulate bidding with strict contract enforcement. With no renegotiation, equilibrium bids would rise to cover cost, but mark-ups relative to total contract value fall by more than half. Production costs decline modestly, due to projects being allocated to lower-cost bidders over those who expect larger payments in renegotiation.

1 Introduction

The enforcement of contracts affects what investments firms are willing to make (Klein, Crawford and Alchian, 1978; Hart and Moore, 1990). The investments that are contractible, in practice, depend on the enforcement institutions in a given country at a point in time. Comparisons of market structure and exports across countries find that strong contract enforcement encourages relationship-specific investments.[1]

The framework of property rights theory explains why many investments that would be made by private firms, in countries with strong contract enforcement, are in developing countries made by the state. Power generation, for example, requires large and specific investments.

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†Department of Economics, Yale University, Box 208269, New Haven, CT 06520-8269 (e-mail: nicholas.ryan@yale.edu.)

[1] In countries with higher contracting costs, and sufficiently deep financial markets, capital-intensive firms are more likely to avoid contracting through integration (Acemoglu, Johnson and Mitton, 2009). Countries with stronger contract enforcement, by contrast, have a comparative advantage in the export of goods that depend on relationship-specific investments (Nunn, 2007).

In India, a power plant must sell into a grid owned and run by the state, to state-owned distribution monopolies. If investments in generation are not contractible they will be made only under integration. Therefore from independence in 1947 through the 1990s, India managed the problem of relationship-specific investments in power through vertical integration, with both the national and state governments owning and running their own plants to generate power. Structural reforms in the 2000s, such as the establishment of regulators and power markets, moved the sector from integration towards contracting, encouraging private investment in power (Kumar and Chatterjee, 2012).

This paper studies how contract enforcement affects equilibrium prices and efficiency in the first post-reform generation of power procurement auctions. These auctions provide a useful test for how contract enforcement may affect market prices and productive efficiency for several reasons. First, because the regulatory institutions in the power sector are new, the enforcement of power procurement contracts is imperfect. Second, power remains a highly regulated sector, which means the renegotiation of contracts is reviewed by regulators and therefore observable. Third, the bids used for these auctions are rich, and include not only a final bid price but also the separate parts that make up each bid. With these bid parts, it is possible from bidding strategies to infer how much bidders anticipate contract renegotiation.

The auctions studied are also important in their own right. This mechanism, as the main way states bought power from new plants in the immediate post-reform period, 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 56 gigawatts, or 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 *ex post* renegotiation in power procurement auctions in a variety of Indian states. The population is of auctions conducted by states under power procurement rules that were in force from 2006 through 2012. In each auction a state, or group of states, seeking to buy power offers a long-term contract to purchase from a private seller. Each contract runs for twenty-five years, so there is considerable risk that cost shocks, such as 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 prices of coal. Contracts that are procured at auction are approved as power purchase agreements by the state electricity regulator.

I analyze data from these auctions first to describe contract enforcement. Renegotiation of contracts is widespread. Of the auction winners for whom contract outcomes can be found, fully 48% petition the State Electricity Regulatory Commission that approved the contract to change its terms. Of those that petition, 35% are successful in winning some formal change to the contract.[2] These petitions typically seek an increase in the unit price, or a "compensatory" tariff, to offset a cost shock. I show that petitions respond to cost shocks for firms exposed to the price of coal. During and after the initial wave of auctions, the price of coal was extremely volatile. Projects bid out before a jump in coal prices are far more likely to renegotiate, especially if they rely on imported sources of coal. A subset of projects are connected to mines as captive fuel sources. These captive projects, which face no fuel price risk, are less likely to renegotiate their contracts and do not respond to coal price shocks.

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 a variety of different bid components, including fixed charges, energy charges, and energy charges indexed to future coal prices, and had 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. I show through a documentary case study of the Mundra Ultra Mega Power Plant, a prominent project, that not indexing is a strategy that bidders used deliberately to lower the present value of their bids by lowering their offered prices late in the life of a contract. This strategy is common in many other auctions beyond the case considered. This descriptive analysis shows, therefore, that renegotiation is due both to exogenous coal price shocks and to the endogenous choices of bidders to bear this 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

[2]These numbers are the number of petitions and successful petitions at the initial stage. Rulings that change in contract at the initial stage, at the level of the state regulator, may be overturned on appeal. I discuss the stages of renegotiation in Section 2.

of their bid to future coal prices. Bids are scored based on the expected present discounted value of offered prices for power, as in the data. 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 government regulators. 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 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 mark-ups 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, 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 artifically 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. While bidder types are two-dimensional, these types can be reduced to a one-dimensional pseudo-type that measures a bidder's overall strength (Asker and Cantillon, 2008). The proof of identification is in two steps. First, bid scores can be inverted to recover pseudo-types (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. Identification does not require imposing any 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 as observed, with renegotiation. There are several key findings from the structural model that would not have been possible to characterize with a reduced-form description of bidding. 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 or influential with the government, in terms of their expected value of renegotiation. (The marginal distributions of both structural parameters are also consistent with external sources of evidence on these parameters, where available.) Second, in equilibrium, mark-ups for winning bidders are 25% above pseudo-types (the relevant one-dimensional measure of apparent cost) but 12% *below* production cost. This finding means that bidders actually bid below cost in equilibrium in order to win the contract and recover part of the anticipated contract value in *ex post* renegotiation. Third, we observe selection into winning an auction on the second dimension of bidder type, the bonus, meaning that bidders with greater prospects for renegotiation do gain a competitive advantage in these procurement auctions.

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 enfocement 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 by non-parametrically solving the optimal first-price auction bid given the estimated distribution of heat rates.

The counterfactual shows that renegotiation of contracts has large effects on equilibrium bidding but leads to only a modest decline in efficiency, as measured by the production cost of winning bidders. 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 25% and equilibrium winning bids rise 20%. Bidder mark-ups are now above production cost, but the margins of winners are squeezed, down to 9% relative to cost in the counterfactual (as compared to 25% 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 mark-up their bids, which brings down equilibrium mark-ups. The large increase in bid prices comes despite a modest decline in production costs for winning bidders in the counterfactual. This decline in production costs indicates that stronger contract enforcement would improve productive efficiency by allocating power projects to lower-cost firms. The effects are modest, however, because the bonus is negatively correlated with cost. Therefore there were relatively few high-cost but high-bonus firms able to win contracts over lower-cost firms in the present equilibrium. The structure of the joint distribution of types is therefore central to measuring the efficiency costs of renegotiation.

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

On procurement auctions, Engel, Fischer and Galetovic (2014) discuss how renegotiation affects the trade-offs between integration and ownership in procurement. They argue, in particular, that weak contract enforcement may dissipate efficiency gains from public-private partnerships and other procurement mechanisms.[3] Most papers in the auction literature ignore *ex post* performance entirely. 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 endogeneous bidder actions. Renegotiation happens in part because bidders induce it by taking on more price risk. 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

[3]As a recent empirical example, Decarolis (2014) finds that moving to first-price auctions for procurement in Italy led to much lower bids, but half of the cost savings were given back to renegotiation.

[4]In 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.

my sample, I am able to identify and estimate the key structural object, the joint distribution of bidder types, which other analysis has circumvented (Lewis and Bajari, 2011). This allows my analysis to estimate mark-ups and even to run counterfactuals without imposing any assumptions on the type distribution.

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. This literature ranges in scale from cross-country studies, such as those cited above, to micro-empirical work that aims to measure the channels through which contract enforcement matters for real outcomes. For example, there is sharp evidence on how the security of property rights changes labor supply and agricultural investment (Field, 2007; Goldstein and Udry, 2008). See Pande and Udry (2005) and Besley and Ghatak (2010) for reviews of micro-economic evidence. There is relatively little micro-empirical 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.[5] I interpret this lack of work as due to a clear prediction of the property rights theory: that if specific investments are not contractible, they will not be made by private firms, leaving few investments to study.

The article also contributes to a literature in development and trade on the consequences of India's economic liberalization (Aghion et al., 2008; Goldberg et al., 2010; Topalova and Khandelwal, 2011; De Loecker et al., 2016; Martin, Nataraj and Harrison, 2017). This literature uses India's changes in policy towards trade, labor or industry to measure positive and normative consequences of reform across a wide set of industries. I study contract enforcement rather than *de jure* changes in regulation or tariffs. The focus here on a single critical industry, power generation, allows great precision in modeling how contract enforcement changes the market equilibrium and production costs.[6]

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 econometric and documentary evidence of the extent and causes of renegotiation. Section 4 lays out the model and identification argument

[5] A prior generation of private contracting in India failed due to government expropriation (Bettauer, 2009). I discuss this episode in the next section. Stroebel and Van Benthem (2013) estimate how price shocks affect expropriation in the oil industry.

[6] Ryan (2017) studies how infrastructure constraints affect the efficiency of short-term wholesale power markets established by the Indian power sector reform. Prior studies of this reform are largely descriptive (Kumar and Chatterjee, 2012; Chan, Cropper and Malik, 2014).

and Section 5 describes how the model is estimated. Section 6 presents the structural estimates of the joint distribution of types, equilibrium costs and mark-ups 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 the perception that states were not investing enough on their own.

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 generally 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. The 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.

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 unique, 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.

(b) Auction mechanism for power purchase agreements

The auctions studied here were meant to take advantage of the new structure of the power sector to give greater incentives for private investors. 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.[7] For any given charge, bidders may fur-

[7]In practice additional sundry charges are often specified in auctions including charges for the transportation

ther 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. Appendix A, Figure A1 gives an example of a bid with energy and capacity charges, both indexed and not indexed, over twenty-five years. Bidders, indeed, can 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 consider map all bids to three parts: capacity charges, variable charges not indexed to energy costs, and variable charges indexed to energy costs.

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 particularly 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.[8]

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 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

of fuel, the handling of fuel and the transmission of electricity.

[8]The terminology used for these projects is Case 1 (non-specific asset) and Case 2 (specific asset). The 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)."

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 Commision (SERC), for projects run by the states themselves. The PPA is the contract between the winning bidder, the supplier that offered the lowest score, and the procuring state utility or utilities. The regulatory review of these contracts is universal but largely 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 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 sources

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, any subsequent revisions of those contracts, and the later expenditures to set up plants.

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.

Central Electricity Authority. The Central Electricity Authority tracks the physical progress and expenditure in power projects regardless of whether they are publicly owned (Central Electricity Authority, 2016). This data is used to measure investment.

The data set consists of 142 bids from 42 auctions. The main limitation of the data is that complete information on bids, including the individual bid components in each year of the contract, is only available for 98 bids.[9] For the remaining bids, SERCs did not include the

[9] The full data set as gathered includes 119 bids. However, some of these are from auctions for medium-term procurement, with contracts 3-7 years. I restrict the sample to only long-term contracts since medium-term contracts are not bid in component parts.

complete bid information in PPAs and I have been unable to obtain the bids from distribution companies directly.[10] Some bids may be complete but not have complete outcomes on contract renegotiation. I take the approach of using all available data to estimate the model in each step. In Section 6 I check that this is reasonable by comparing the levels of bids and mark-ups between bids that have all component parts available and bids that have only the final score. I find that these types of bids are quite similar but bids with component parts available tend to be slightly lower than other bids.

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 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

[10] In some states distribution companies themselves appear not to have retained the records on individual bid components after scoring the auction.

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, solid (red) curve shows the tariff for all parts of the bid *not* indexed to coal prices. It is therefore cumulative of the dashed curve and other charges like energy charges *not* indexed to coal prices. The top-most, solid (black) curve shows the total tariff in a year. The gap between the solid (black) and solid (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. 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 we see that 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. Losing bidders also tended to increase non-indexed prices more 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.[11]

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.[12] 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 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)

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

[12]Tata 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 . However, the claimed hedge was never close to the full quantity of coal or duration of contract needed to fully supply the Mundra plant.

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 as bid ran billions of dollars into the red.[13] 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) Renegotiation and cost shocks

Renegotiation occurred commonly in this generation of power projects. Here I provide evidence that the causes of renegotiation in the Mundra case, which was particularly high profile, applied for other projects also.

Table 1 summarizes the outcomes of 42 auctions containing 135 bids, for which I have complete data on the auction winner and any contract revisions. 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 42 (column 3) auction winners, 20 (column 4) file a petition with the regulator for a revision of the tariff revealed at auction and 7 (column 5) 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 22 auction winners filed a petition for tariff

[13] Using 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.

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).

The tendency to renegotiate should differ across projects. As noted, projects bid early in the sample saw greater coal price shocks than those bid later. In addition, projects differ in their asset-specificity and in their fuel type. Some projects use imported fuel exposed to market prices, whereas others use a captive mine for fuel and so are fully insured against coal shocks. I test these factors with a linear probability model

$$\begin{aligned} R_{it} &= \gamma_0 + \gamma_1 CoalShock_t + \gamma_2 CoalShock_t \times CoalImported_i + \gamma_3 UMPP_i + \\ &= \gamma_4 CoalImported_i + \gamma_5 CoalDomestic_i + \epsilon_i t. \end{aligned}$$

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 (i.e., about one-quarter of the average tariff bid, from Table 1).[14] 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. 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, as in the specification above. 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

[14]I 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.

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 based on 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.

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. The theoretical model will allow that renegotiation depends on *both* exogenous shocks *and* endogenous bidder indexation decisions.

4 A model of renegotiation

(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 $\beta_i = (\beta_{Fi}, \beta_{hi})$. The firm bidding the lowest total score $S(\beta_i)$ is 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 ex ante 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 mark-ups through the fixed component of bids. This event sets a threshold price

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

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 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 cost shock ex post.

(c) Preferences

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

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

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.[15]

(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 that score

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

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

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

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

[15] The 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.

definition of pseudo-type is the firm's contribution to apparent social surplus

$$k(\theta_i) = \max_{\beta_{hi}} \left\{ -h_i \mathbb{E}[p] + \Delta_i \mathbb{E}[R(\beta_i, \theta_i)] - \eta Var[\pi(\beta_i, \theta_i)] \right\}. \tag{1}$$

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

$$\beta^*_{hi} \in \arg\max_{\beta_{hi}|\theta_i} \left\{ -h_i \mathbb{E}[p] + \Delta_i \mathbb{E}[R(\beta_i, \Delta_i)] - \eta Var[\pi(\beta_i, \theta_i)] \right\}. \tag{2}$$

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. The bidder solves

$$\max_{S_i} V(S_i|\theta_i) Pr(S_i < S_j, \forall j \neq i)$$
$$\max_{S_i} (S_i + k(\theta_i)) Pr(S_i < S_j, \forall j \neq i)$$

where the second line 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 $G(\cdot|N)$ give the marginal distribution of equilibrium scores conditional on the number of bidders in an auction. The firm solves

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

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

$$k(\theta_i) \quad = \quad \frac{1}{N-1} \frac{1 - G(S_i|N)}{g(S_i|N)} - S_i. \tag{3}$$

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.

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

Proof. 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 $\overline{p}$). 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 (1), 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. □

This result formalizes the intuition that inefficient (high heat rate) bidders have worse pseudo-types and are therefore weaker bidders, who in equilibrium 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.*

Proof. Take the second part first. By the envelope theorem

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

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

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

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. □

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 other than the bidder's type (η, V_0) 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 (3) 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 (3) is observed since S_i, the score of i's bid, is observable and $G(\cdot|N)$ 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). □

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, but identify the distribution of types non-parametrically 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 $G(S_i|N, X_a)$, the equilibrium distribution of scores for an auction with N bidders and 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 number of bidders, 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 price of coal at the time of bidding. The price series used varies by coal source as described in the data sources.

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 (3) 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 B. 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 $\mathbb{E}\left[\tilde{P}_t\right]$. 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 $\mathbb{E}\left[\tilde{R}_t\right]$ using the probability of price shocks large enough to induce renegotiation.

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

$$k(\theta_i) = \max_{\beta_{hi}} \beta_{hi}\left(\mathbb{E}\left[\tilde{P}_t\right] - \tilde{P}_0\right) - h_i\mathbb{E}\left[\tilde{P}_t\right] + \Delta_i\mathbb{E}\left[\tilde{R}_t\right] - \eta(\beta_{hi} - h_i)^2 Var\left[\tilde{P}_t\right]. \quad (4)$$

The problem is analogous to (1) 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

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

The first order-condition for this problem is

$$\frac{dk(\theta_i)}{d\beta_h} = \left(\mathbb{E}\left[\tilde{P}_t\right] - \tilde{P}_0\right) + \Delta_i\frac{d\mathbb{E}\left[\tilde{R}_t\right]}{d\beta_h} + \eta 2(h_i - \beta_{hi})Var\left[\tilde{P}_t\right] = 0. \quad (5)$$

In addition to the type, the system consisting of (4) and (5) 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 renegotation. 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 calibrated the level of risk aversion in the model for a bidder with the median heat rate reported by Chan, Cropper and Malik (2014) and price expectations circa 2006 to index about half of their variable costs. I set $\eta = 1$ through this calibration.

I now can solve the system consisting of (4) and (5) 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 therefore just 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

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

Here $F(\cdot)$ is the distribution of costs. Bidders will have postiive mark-ups and these mark-ups will be larger, the lower they are in the cost distribution. The fact that mark-ups are decreasing in cost can be seen from the bounds of the integral in the numerator of the mark-up term, which range from c_i to $\overline{c}$. Therefore, for lower-cost bidders, this term is integrated over a broader part of the cost distribution and the mark-up will be larger. Intuitively, lower-cost bidders have less of a risk of losing the auction if they increase the price they offer relative to cost, and so offer higher mark-ups.

For the empirical implementation of F we 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 mark-ups in the present equilibrium. Finally I compare these estimated costs and mark-ups to the counterfactual costs and mark-ups that would be achieved if there was no renegotiation of contracts as bid.

(a) Model estimates

i Score distribution

Table 3 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 then report the coefficients on observables from linear specifications for μ_{it} and $\log \sigma_{it}$.

The parameters of the distribution are all precisely estimated and the mean effects generally have the expected sign. The mean of the score distribution is decreasing in the number of bidders and higher for projects reliant on imported or domestic coal than for captive coal projects. The mean of the score distribution is also increasing in the coal price. The price effect is very precisely estimated and large. A USD 50 per ton increase in coal price, as was observed in the sample, has the same effect on the price bid as moving a project from using imported coal to a captive coal mine (thus removing all coal transportation costs and fuel price mark-ups).

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 very broad, with a variance of 0.97 INR per kWh squared. The residual score distribution is much narrower, with a variance of 0.27 INR per kWh squared, 27% as large. I overlay the log-normal distribution fit on the residual score distribution. The parametric log-normal distribution has a very 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, decreasing from lower right (high bonus plants, that expect to receive high payments in renegotiation) to upper left (low bonus plants). The density is kernel-smoothed in both dimensions.[16]

There are two features of the joint distribution of types of interest. First, it is sharply peaked, with most bidders having heat rates around or slightly above 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. That is, 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 above 10,000 btu per kWh, with the tenth percentile at 7,000 btu per kWh and the 90th at 15,000 btu per kWh. This

[16]The smoothing uses a normal kernel in both dimensions, a bandwidth of 1,000 btu per kWh in the heat rate dimension and INR 0.2 per kWh in the bonus dimension.

distribution is similar to the distribution of operating heat rates reported for Indian plants from engineering estimates. Cropper et al. (2012) report a median heat rate of 10,910 btuh per kWh, with a 5th percentile of 9,129 btu per kWh and 95th of 13,860 btu per kWh. The estimated distribution of heat rates is therefore centered in the same place but slightly broader than engineering estimates of the same parameter. The match is nonetheless very good considering the parsimony of the model. One source of residual variation is that some captive coal projects and domestic coal projects may get coal at concessional prices, relative to the common domestic price that I use to form bidder expectations. If the price offered as part of a power procurement auction is below the common domestic price, my model, using the common price, will infer that heat rates must be very low to offer power so cheaply.

(b) Counterfactual allocation without renegotiation

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

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 then 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 counterfactual scenario, even though they have no effect on auction outcomes, in order to understand the selection of winners in the counterfactual. I block bootstrap equilibrium outcomes and counterfactual outcomes by re-drawing bidders clusterered at the level 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.

First consider Table 4, columns one through four, which characterize equilibrium bids. The mean bid across all bidders is INR 3.39 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 3.05 per kWh. Relative to the pseudo-type, this implies that winning bidders earn a mark-up of 21.43% (column 2). The levels of bids and pseudo-types are similar in the sample of bids with component parts available in the data. However, mean bids are slightly lower (column 4) and mean pseudo-types slightly higher, so that in this restricted sample I estimate a mean mark-up for winners of 25% relative to pseudo-types.

In the sample of bidders with types, in columns 3 and 4, we can also compare bids to the cost of supply. The mean cost of supply is estimated at INR 3.82 per kWh and the mean amongst winners at INR 3.46 per kWh. These costs imply that the mean mark-up of winning bids relative to cost is *negative* 12.40%. A negative mark-up means that bidders, because they expect to earn more in ex post renegotiation, bid below cost at the start.[17]

The mean bonus across all bidders is INR 0.32 per kWh and across winning bidders INR 0.45 per kWh. There is therefore selection into winning an auction on both the dimension of efficiency and on the dimension of cost. 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 0.37 per kWh for winning bidders. The value of renegotiation is therefore 12.6% of the value of the initial bid ($= 100 \times 0.37/2.92$). This value of renegotiation is still not enough for mean bids to completely cover costs. The remaining gap between the negative mark-up over cost and the mark-up over pseudo-type is due to bidders expecting slightly lower future price appreciation than the auctioneer, on average.

Now consider Table 4 columns 5 and 6, which characterize the counterfactual equilibrium

[17] Observers at the time noted that the prices for initial power auctions were lower than all precedent and struggled to explain how they were consistent with estimates of cost. For 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.

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 4.01 per kWh (a 25.3% increase) and the mean winning bid to INR 3.53 per kWh (20.9%). 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 40% (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 modest decline in production costs for winning bidders, from INR 3.46 in the estimated equilibrium to 3.28 per kWh (a 5.2% decrease) in the counterfactual. This decline in production cost is close to a sufficient statistic for welfare gains in the model.[18] With their higher bids and lower costs, winning bidders now earn mark-ups of positive 9.0% relative to cost in the counterfactual (column 6). Nonetheless, this is lower than the margin they previously earned relative to pseudo-types. This result may be thought of as 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 mark-up their bids, which brings down equilibrium mark-ups. Because the bonus is negatively correlated with cost (positively correlated with efficiency), there is still a modest degree of positive selection on bonus in the counterfactual, with winners having a bonus of INR 0.37 per kWh (standard error 0.06) against the mean bonus of INR 0.32 per kWh. However, this is smaller than observed in equilibrium, when the bonus actually affected bids, and not statistically significant.

Overall the counterfactual results show that strict contract enforcement would transform the pattern of bidding but have only modest affects on the allocation of plants to suppliers and therefore on production costs. In particular, barring renegotiation would force bids *ex ante* sharply upwards and compress margins, but only modestly decrease productive costs. The result on costs is due both to fairly competitive auctions and to the negative correlation of bonuses with cost. The structure of the joint distribution of bonuses and costs implies that there are few inefficient but well-connected firms that expect large enough bonuses to out-bid more efficient firms at the start.

[18] The decline in production costs neglects that bidders dislike risk, and so higher prices may protect them from fuel price risk to an extent. For the change in production costs to represent the change in surplus we would also need to assume that aggregate power demand is inelastic, which is generally considered realistic.

7 Conclusion

This paper studied 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 bidders endogeneously chose not to, in order to increase their value due to *ex post* renegotiation.

The structural approach here has a few novel features. First, the model allows for the above channel of bids affecting renegotiation, and therefore the prospects of renegotiation causing endogenous changes to bidding in equilibrium. Second, the model is specified, identified and estimated with few parametric restrictions, and in particular no restriction on the joint distribution of bidder types. This approach allows an especially direct and transparent counterfactual analysis of bidding under strict contract enforcement.

At a broader level, 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.[19] 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.

The model simplifies the renegotiation process for the sake of tractability. In the model renegotiation is costless, in order to focus on the effects of renegotiation on *ex ante* bidding and investment. My estimates therefore exclude any transactions costs of the renegotiation process itself, such as hiring lawyers, delaying projects to improve bargaining power, or cancelling projects without agreement when going ahead would be efficient. These adjustment and transactions costs matter in practice and depending on the context may be a main determinant of optimal auction design (Bajari, Houghton and Tadelis, 2014). Larsen (2018) studies the efficiency of bargaining after an auction; with enough data, a similar approach could be applied

[19] Weaver (2018) is a recent example of work in this direction. Weaver (2018) uses an auction model to characterize bidding for public sector jobs. In that seeting, the corrupt allocation of jobs is found to improve efficiency, since rule-based selection without bribes tends to pick weaker candidates than willingness-to-pay for the job.

to contract renegotiation.

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 therefore to rule out renegotiation. Che (1993) studies scoring auctions and finds that without commitment, the only viable scoring rule in a scoring auction is the utility function of the buyer. The change in auction design in India, to use a simpler scoring rule, can be seen as an example of this maxim: 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 instead of more flexible functions of future coal prices may be the only enforceable contract. The general lesson would be that the sophistication of a procurement mechanism should not outstrip what can actually be enforced.

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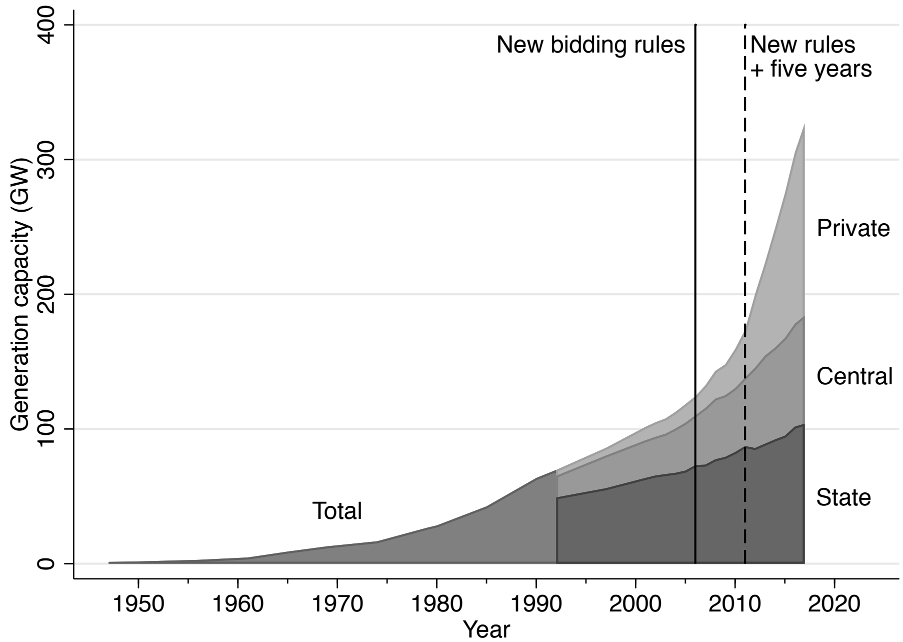
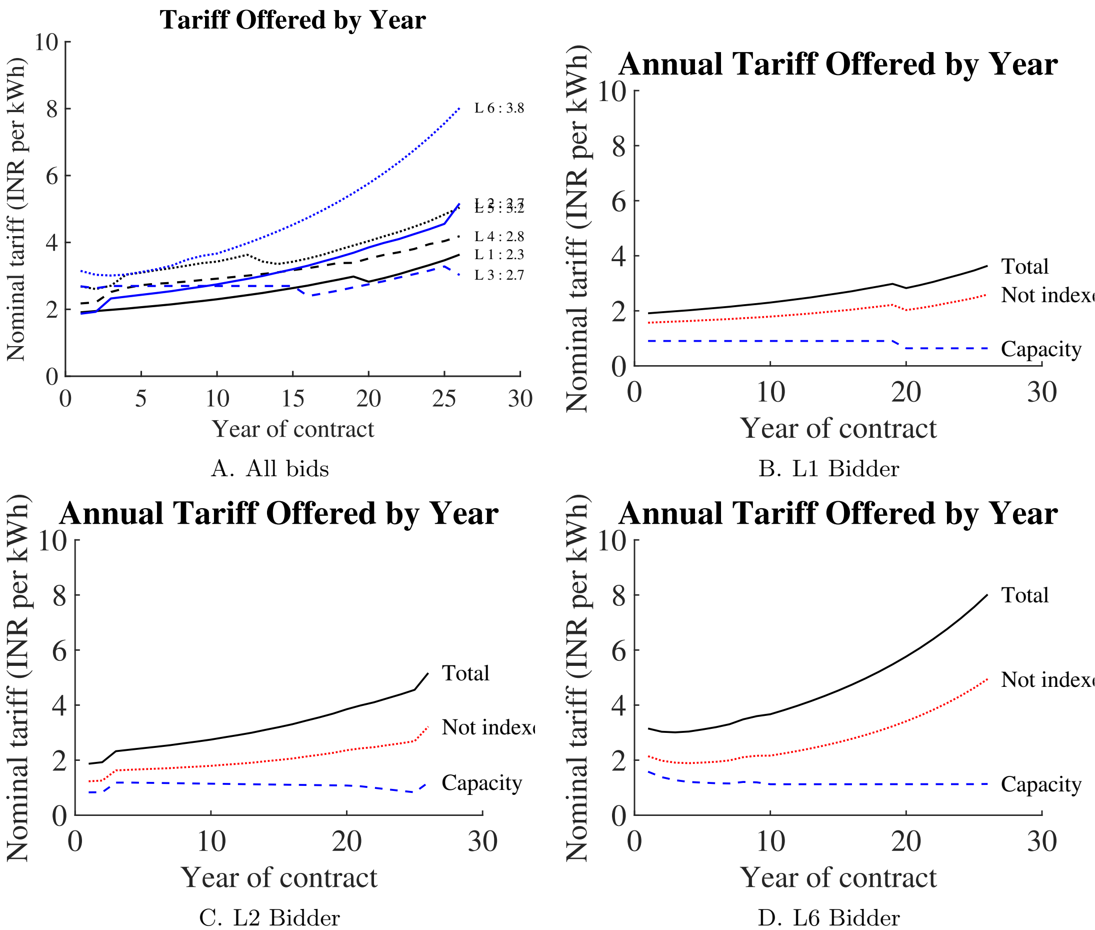
8 Figures

Figure 1: Growth in Capacity by Ownership



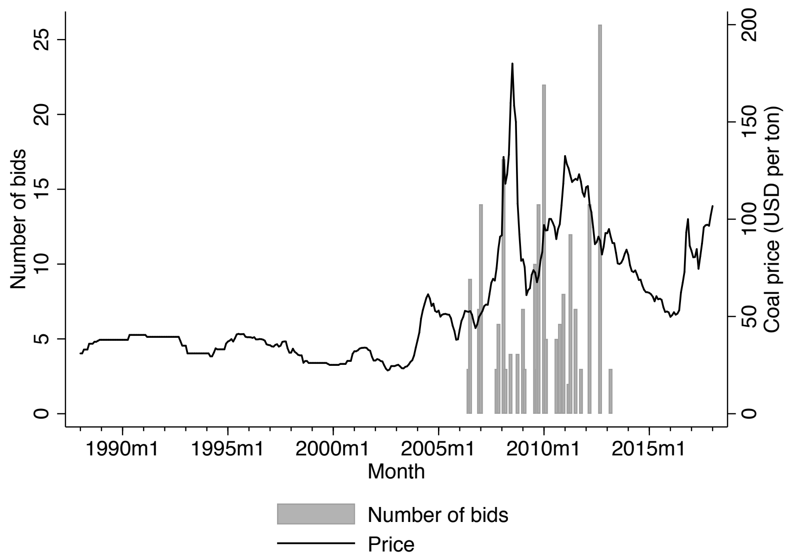
The figure displays the division of generation capacity between the state, central, and private sectors in India from 1947 to 2017. The Tariff Policy under the Electricity Act are issued in 2006 (indicated by the vertical line), which introduced new competitive bidding guidelines. Only the combined generation capacity is available prior to 1992. The data from 1947 to 1992 and from 2001 to 2017 is from 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. Since the reports only provided additional capacity to each of the sectors during each plan (each plan is five years), the generation capacity for 1992 and 1997 were calculated by subtracting the additional capacity from the known capacity for each sector.

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



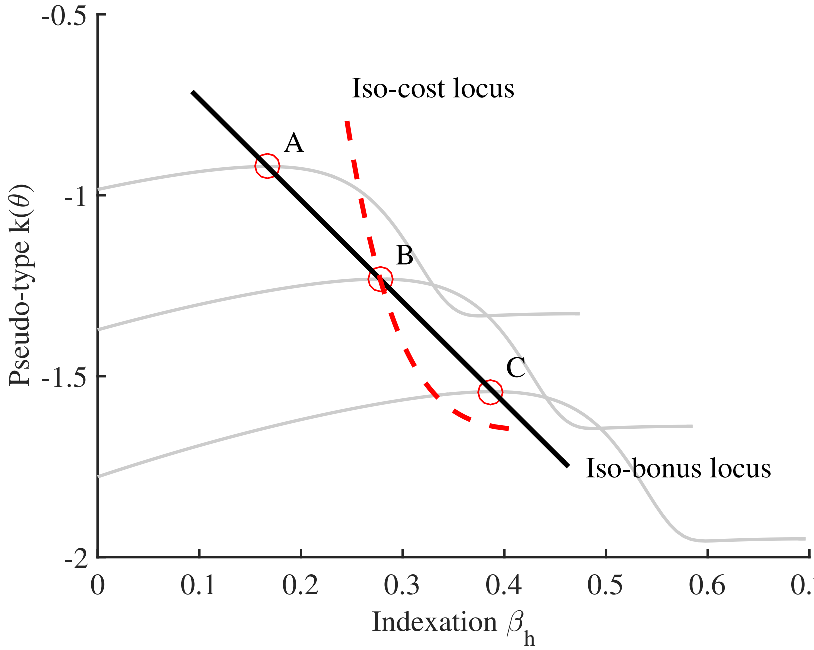
The figure shows bids from the Mundra Ultra-Mega Power Project, which was bid in 2006 for delivery starting in 2012. Panel A shows the time path of all the bids in the Mundra UMPP auction, ranked from L1 (the winning bidder) to L6 (the highest bidder) in terms of their expected discounted nominal tariff (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 lowest, dashed curve shows the nominal tariff for capacity (i.e., fixed) charges. The middle, sold (red) curve shows the tariff for all parts of the bid *not* indexed to coal prices. It is therefore cumulative of the dashed curve and other charges like energy charges *not* indexed to coal prices and transportation charges. The black curve includes charges indexed to prices other than coal, such as capacity charges indexed to the wholesale price index. The top-most, solid (black) curve shows the total tariff in a year. The gap between the solid (black) and solid (red) curves is therefore the part of the bid indexed to coal prices.

Figure 3: Timing of Power Procurement and Coal Price Shocks



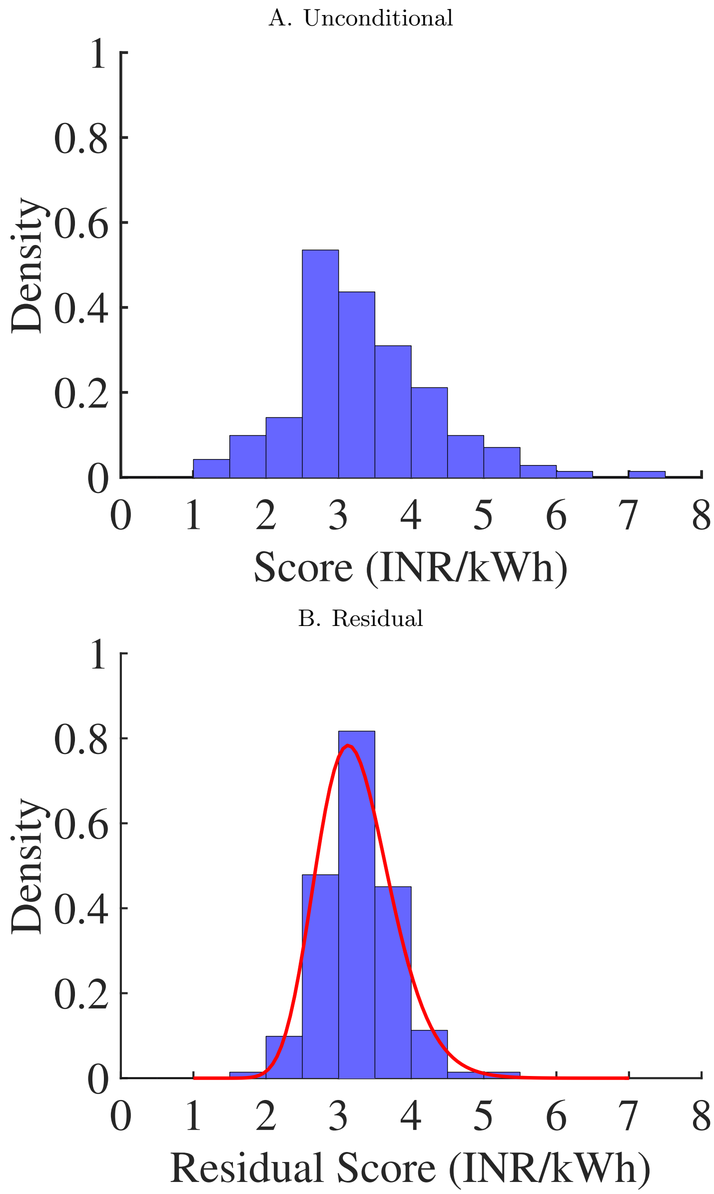
The figure shows the number of bids in sample power procurement auctions (gray bars, against left axis) and the time series of coal prices (solid black line, against right axis). The coal price is the Newcastle coal index, formerly the Barlow-Jonkers index, which gives the price of one ton of coal with gross 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



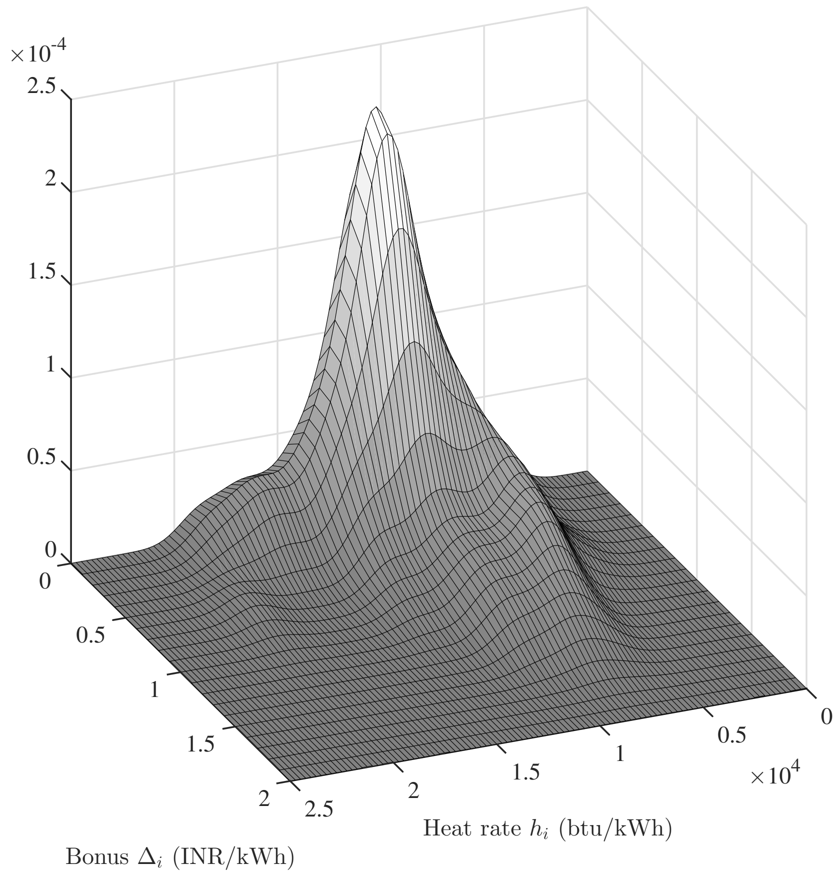
The figure illustrates the identification of the model by tracing out the iso-cost and iso-bonus loci for a calibrated set of model parameters. The figure plots the pseudo-type $k(\theta)$ of a bidder against that bidder's chosen level of indexation β_h. In this figure, the gray curves represent the 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 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 (red) line, reducing indexation and raising the bidder's pseudo-type or bidding strength.

Figure 5: Distribution of Equilibrium Scores



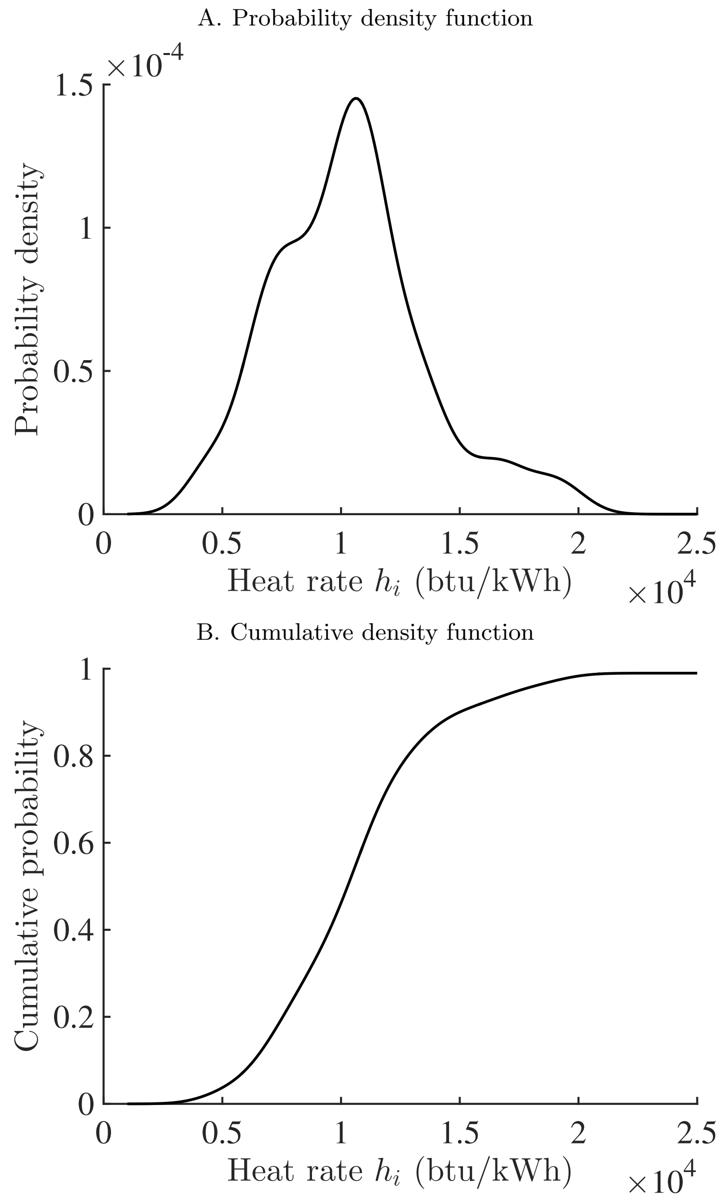
The figure shows the marginal distribution of equilibrium bid scores. The score of a bid is the expected present discounted tariff (i.e., "levelised tariff") of a bid over the life of a contract in INR per kWh. The left panel shows the unconditional distribution of scores. The right panel shows the distribution 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 $\tilde{\epsilon}_{ijt} = \exp(\overline{\hat{\sigma}}_{jt}\epsilon_{ijt} + \overline{\hat{\mu}}_{jt})$ 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, decreasing from lower right (high bonus plants, that expect to received high payments in renegotiation) to upper left (low bonus plants). The density is kernel-smoothed in both dimensions. The smoothing uses a normal kernel in both dimensions, a bandwidth 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 density function. The PDF and CDF are kernel-smoothed using a normal kernel and a bandwidth of 1000 btu per kWh.

9 Tables

Table 1: Summary of Bids and Renegotiation

Year	Bids	Winners	Petition		Mean	
			Filed	Granted	Tariff	Capacity
(1)	(2)	(3)	(4)	(5)	(6)	(7)
2006	10	3	3	2	2.4	3069
2007	19	7	4	0	2.9	1096.6
2008	15	4	3	1	3.1	349.6
2009	13	8	7	3	3.9	481.9
2010	16	4	0	0	3.5	410.7
2011	22	7	1	1	4.7	259.3
2012	40	9	2	0	5.7	339.7
Total	135	42	20	7	4.2	658.5

The table summarizes the outcomes of power procurement auctions for which I have complete data on the auction winner and any contract revisions. 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).

Table 2: Cost Shocks and Renegotiation

	(1)	(2)	(3)	(4)
Coal price shock	0.288***	0.258**		0.191
	(0.0999)	(0.113)		(0.139)
Coal imported (=1) × coal price shock				0.403**
				(0.158)
Ultra-mega power plant (=1)		0.247	0.571***	0.202
		(0.148)	(0.167)	(0.195)
Capacity missing (=1)				
Coal imported (=1)			0.429**	0.150
			(0.167)	(0.185)
Coal domestic (=1)			0.357**	0.260
			(0.164)	(0.187)
Constant	0.541***	0.521***	0.143	0.275*
	(0.0753)	(0.0841)	(0.118)	(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 (the largest 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 calorific value of coal of 6300 kcal per kg and a plant heat rate of 11615 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: Estimates of equilibrium score distribution

	μ_{jt}	$\log \sigma_{jt}$
Constant	0.339	-1.734
	(0.0098)	(0.0415)
Number of bidders	-0.001	-0.015
	(0.0003)	(0.0014)
Ultra-mega power plant (=1)	0.276	0.447
	(0.0076)	(0.0374)
Coal imported (=1)	0.667	-0.355
	(0.0080)	(0.0266)
Coal domestic (=1)	0.897	-0.046
	(0.0096)	(0.0415)
Coal price (USD/ton)	0.019	-0.004
	(0.0001)	(0.0006)
N	142	
$\log \mathcal{L}$	-105.05	

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.

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

	Equilibrium				Counterfactual	
Sample:	With bid		With type		With type	
Bids:	All	Winning	All	Winning	All	Winning
Bid (INR/kWh)	3.39	3.05	3.20	2.92	4.01	3.53
	(0.04)	(0.04)	(0.05)	(0.05)	(0.10)	(0.10)
Pseudo-type (INR/kWh)	3.17	2.64	2.96	2.47	2.96	2.67
	(0.05)	(0.07)	(0.06)	(0.09)	(0.06)	(0.10)
Margin over pseudotype (%)	10.13	21.43	11.76	24.98	41.30	37.94
	(1.53)	(4.22)	(2.08)	(5.85)	(3.99)	(7.44)
Cost of supply (INR/kWh)			3.82	3.46	3.82	3.28
			(0.09)	(0.12)	(0.09)	(0.10)
Margin over cost (%)			-13.39	-12.40	5.90	8.98
			(1.49)	(2.59)	(0.47)	(0.96)
Bonus Δ (INR/kWh)			0.32	0.45	0.32	0.37
			(0.03)	(0.06)	(0.03)	(0.06)
Value of renegotiation (INR/kWh)			0.23	0.37	0.23	0.29
			(0.03)	(0.06)	(0.03)	(0.06)

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 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. 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_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 block bootstrap equilibrium outcomes and counterfactual outcomes by re-drawing bidders clusterered at the level 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)

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
26	2036-37	01-Apr	25th anniversary of the Scheduled COD of first Unit	0.7281	Same as Above	0.3350	Same as Above

The figure gives an example of a bid. Bidding guidelines say that bids will be set in multi-part tariffs allowing both capacity (fixed) and energy (variable) charges. In practice, 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 realization of the cost index. Therefore this bid, which is of the minimal possible complexity, has $26 \times 2 + 2 = 54$ charges.

B Appendix: Estimation (Not for Publication)

The model presented above is in 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.

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

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

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

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

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 last ten years of twelve-monthly innovations in log price.

   (a) Let $p_0 = 1$.

   (b) Consider a sample of monthly price observations for the ten years preceeding 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 $t = 1 \ldots 25$.

   (e) Repeat B times for each starting year in $t_0 \in \{2006, \ldots, 2012\}$.

   (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

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

   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 developed for the empirical model, the bidder's problem is written

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

Substitute the score into the bidder's indexation problem for

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

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

$$k(\theta_i) = \max_{\beta_{hi}} \beta_{hi} \left(\mathbb{E}\left[\tilde{P}_t\right] - \tilde{P}_0\right) - h_i \mathbb{E}\left[\tilde{P}_t\right] + \Delta_i \mathbb{E}\left[\tilde{R}_t\right] - \eta(\beta_{hi} - h_i)^2 Var\left[\tilde{P}_t\right]. \quad (6)$$

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

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

The first order-condition for this problem is

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

The second term is

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

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