

MARKET TRANSPARENCY, RELATIONAL CONTRACTS AND COLLUSION IN THE COLOMBIAN ELECTRICITY MARKET *

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Abstract

In models of collusive behaviour firms deviate from current profit maximization in anticipation of future rewards. As current profit maximization places little restrictions on firms' pricing behaviour, these models are hard to test and collusive conduct hard to infer from pricing behaviour alone. This paper tests for, and quantifies the value of, a collusive arrangement in the Colombia energy sector. We take advantage of the *announcement* of a market transparency reform that potentially made it harder for firms to sustain a collusive arrangement. We show that bids submitted by a subset of firms in the market collapsed immediately after the *announcement*, and before the *implementation* of the reform. We construct several proxies for (potential) cartel membership based on firms' characteristics a priori correlated with incentives and ability to collude. Within an event-study framework, the resulting proxies capture well the observed drop in bids following the announcement. We rule out confounders and provide forensic evidence of how the cartel functioned and how firms might have communicated about it. A calibration of the dynamic incentives compatibility constraints confirms that a collusive arrangement was sustainable before, but not after, the reform. Profits of firms' in the cartel and the equilibrium price fell substantially after the reform. A back-of-the-envelope calculation suggests that the average consumer paid 3% higher energy bills as a result of the cartel.

Keywords: Collusion, Transparency, Regulation, Energy Markets, Relational Contracts.

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No one has the right, and few the ability, to lure economists into reading another article on oligopoly [...] The present paper accepts the hypothesis that oligopolists wish to collude to maximize joint profits. It seeks to reconcile this wish with facts, such as that collusion is impossible for many firms and collusion is much more effective in some circumstances than in others. [...] The reconciliation is found in the problem of policing a collusive agreement, which proves to be a problem in the theory of information. (Stigler (1964), p. 44)

1 Introduction

Often the nature of the transaction prevents parties from having access to formal contract enforcement (Greif (1993); Dixit (2003)). Parties then rely on informal agreements sustained by the future value of the relationship to cooperate (Macchiavello, 2021). While these arrangements are advantageous for their participants, there is no guarantee that they benefit the market as a whole. Horizontally competing firms colluding to raise prices (Green and Porter (1984); Rotemberg and Saloner (1986)) offer perhaps the most prominent example of this.¹ Such arrangements might be particularly frequent in developing countries, where markets are often thinner and more concentrated (Mitton (2008); Leone et al. (2022)), entry barriers protect colluding incumbents (Djankov et al. (2002)) and competition authorities weaker – if at all existent (see, e.g., World Bank (2016); Besley et al. (2020)).

Despite the policy relevance, evidence on cartels in low income countries – and on how they function – remains scarce. Most empirical studies focus on cartels investigated by competition authorities. As those are weaker in developing countries, fewer documented examples exist.² Furthermore, collusive behaviour is notoriously difficult to identify (Chassang and Ortner, 2022). In models of collusive behaviour firms deviate from current profit maximization in anticipation of future rewards. As profit maximization places little restrictions on firms' behaviour, these models are hard to test and collusive conduct hard to infer from pricing behaviour alone.³

This paper tests for, and quantifies the value of, a collusive arrangement in the Colombia energy sector. Access to adequate sources of reliable and cheap energy is a critical engine for development

¹Other prominent examples include buyers and sellers using informal relationships to foreclose markets to rivals (see, e.g., Rey and Tirole (2007)) and organized crime (Gambetta (1993)).

²For example, data from the Private International Cartel database (Connor, 2020) reveal that only 5% of proven cartels are in Africa (and, of those, 72% were proven in South Africa alone), 7% in Latin America and 11% in Asia.

³Formally, there is a close analogy with models of relational contracting – defined as informal arrangements sustained by the value of future interactions (Baker et al., 2002). Those are based on promises about future behaviour that are not observed and that make it hard to rule out confounding explanations (Macchiavello, 2021).

(Greenstone et al. (2014)) and a key determinant of firms’ productivity (see, e.g., Allcott et al. (2016)). Besides its intrinsic relevance, the context of our study offers two advantages to understand how relational contracts are used to support collusive arrangements. First, wholesale electricity markets are inherently incomplete, imperfectly competitive and thus regulated (Wilson (2002)). The Colombian wholesale electricity spot market is no exception and, as many other markets around the world, it functions as a uniform price multi-unit procurement auction.⁴ Detailed data on the bidding behaviour and costs of all market participants are thus available. Second, we exploit a regulatory change for identification. Specifically, we study the effect on bidding behaviour of a change in regulation that delayed the availability of information on other market participants’ bids. Conventional wisdom (see, e.g., Whinston (2008)) holds that such a regulatory change can make collusion harder to sustain by inhibiting cartel members’ ability to “police” the agreement, i.e., detect, and punish, deviating members.

We find evidence that a subset of firms in the market colluded to raise the price of electricity. Critically to our identification strategy, we show that a subset of the firms in the market lowered bids by a number between 47% and 30% immediately after the *announcement* – and well before the actual implementation – of the regulatory change. That is, a subset of market participants reacted in anticipation of *future* market conditions that could (potentially) make a cartel unsustainable. Inter alia, this strategy allows us to rule out several confounders, including the fact that changes in market transparency itself could lead firms to change their bidding behaviour. Besides ruling out confounders, we also provide detailed forensic evidence of how the cartel functioned, uncovering both the incentives to collude and the mechanism through which firms colluded. We calibrate the dynamic incentives compatibility constraints required to sustain the cartel and confirm that they were satisfied before, but not after, the reform. The results, which point at a potentially sizeable welfare loss due to the cartel, also yield much needed evidence on energy market design and, more broadly, a cautionary message to efforts to boost market transparency (e.g., in agriculture, or through e-commerce) in developing countries.

Section 2 provides background information on the Colombia wholesale electricity market, the regulatory change and the data used in the analysis. In this market, generation units declare, once a day, their available supply for each hour and a unique bidding price for the next day.⁵ *XM*,

⁴Other examples of markets that have used the multi-unit uniform auction are the Mexican treasury Bill, Swiss Bonds and Texas and UK electricity sectors.

⁵The 47 units are owned by 15 firms. Since we focus on bids, which are submitted by units, we consider generation units as the relevant unit of analysis. We use information on firms’ ownership of generation units for robustness checks and to gain further insights into the operation of the cartel.

the system operator, minimizes the cost of fulfilling the demand for each hour arranging bids in increasing order. This process generates an hourly *spot* price (the bidding price of the marginal generation unit necessary to fulfill the demand) and gives rise to the *ideal dispatch*. Ensuing constraints to the transmission network, however, induce *XM* to modify the initial production assignment across units, the *real dispatch*. Differences between the *ideal* and *real dispatches* yield positive and negative reconciliations. A generation unit receives a positive reconciliation when the real dispatch allocation is greater than the ideal dispatch, and a negative reconciliation if it is lower. As we describe momentarily, reconciliations play a key role in our analysis.

The market witnessed a significant increase in bidding prices during 2008. During a meeting on January 6th, 2009 (the *announcement* date), the regulator – concerned with the price increase – decided to invite Professor Peter Cramton for advice. At that time, the operator used to disclose all information (bids, availability and allocation) to all market participants with two days delay. While such a transparent market can increase the efficiency of bidding behavior and simplify monitoring and implementation, Cramton had previously advised regulators on how transparency also facilitates collusion and was thus expected to recommend a tightening of the transparency policy. Indeed, Cramton recommended to increase to 90 days the delay to disclose information to market participants during a presentation delivered on January 24th, 2009. The regulator adopted the recommended change on January 30th, 2009, with effect from February 6th, 2009 onward (the *implementation* date).

Section 3 presents the main evidence and rules out potential confounders. The average bid in the market sharply decreased right after the *announcement* date – and before the *implementation* date. We interpret the *announcement* as having altered potential cartel members’ perceptions about their *future* ability to sustain a cartel, leading to its unravelling.⁶ Chassang and Ortner (2022) elucidate the challenges involved in identifying collusive conducts in the data: non-competitive behaviour is not necessarily collusive behaviour (e.g., firms might make mistakes); in dynamic environments, pricing behaviour inconsistent with static profit maximization also need not imply collusive behaviour.⁷ Our test, however, identifies a discontinuous change in behaviour that is the central implication of reward-punishment schemes at the heart of collusive equilibria and arguably overcomes most of these challenges.

⁶The logic of the test doesn’t rely on cartel members perfectly foreseeing the regulatory change. It simply requires them to become sufficiently pessimistic about their future ability to sustain a cartel. Participants might have also updated their beliefs about the likelihood that regulators would begin investigations. We discuss evidence on this in the text.

⁷In our context, the bidding behaviour of hydro units is inherently dynamic as it depends on current and expected availability of water in the reservoir.

Unlike studies that rely on proven cartels (see, e.g., [Porter and Zona \(1993\)](#); [Asker \(2010\)](#); [Igami and Sugaya \(2021\)](#)), we do not know the identity of the firms participating in the collusive arrangement – if one existed. The average decline in bids, however, masks significant heterogeneity: not all units lowered their bids. We construct several proxies for cartel membership to sharpen our empirical test. In our baseline definition, we conjecture that thermal units in the Atlantic region had the incentives and ability to form a cartel.⁸ This classification isolates a group of 14 units – henceforth, the *cartel* – that belong to 5 firms. Using both DID and more flexible event-study specifications, we show that the average bid for cartel units falls by a number between 47% and 30% after the announcement date, and before the implementation of the regulatory change. No fall in bids is detected for the remaining units in the market.⁹

Alongside the baseline DID and event-study specifications, we present several robustness checks and placebos. First, we rule out several potential confounders, e.g., shocks to costs and demand that might have affected units differently. Second, we explore robustness of the results to alternative definitions of the cartel. We use ownership information to explore both more and less restrictive definitions, we use unit characteristics a priori correlated with incentives and ability to collude as well as bidding behaviour in the pre-period to construct several alternative proxies, and also explore placebos. We find that results are very robust.¹⁰

Section 4 conducts forensic analysis to uncover the incentives, and strategies used, to collude. We argue that units in the cartel colluded to increase bids so as to increase profits earned on positive reconciliations. Our argument unfolds in three steps. In the first step, we note that cartel units – which are all thermal – have high production costs and would be unable to win in the ideal dispatch. Given this, these units try to maximize benefits in the only possible remaining way: the positive reconciliation market. In the second step, we confirm that the positive reconciliation market functions as a standard oligopolistic market in which firms have incentives to coordinate price increases. In the third step, we show that increases in the likelihood of positive reconciliations induce firms to submit higher bids and that cartel units coordinated on this behaviour. Units in the cartel increased bids particularly so at times in which other units in the cartel bid low prices and

⁸The rationale for this choice is that thermal units have higher costs and can't make money in the ideal dispatch. We thus hypothesize, and later confirm, that thermal units profit from colluding when awarded positive reconciliations. Because positive reconciliations occurs when there are disruptions to transmission or generation, units are more likely to compete for positive reconciliation with nearby units. This justifies the regional focus of the cartel.

⁹[Connor and Bolotova \(2006\)](#) provides a meta-analysis of cartel overcharges and finds, in a sample of 395 documented cartel episodes for which overcharges are available, a median (average) overcharge of 19% (29%).

¹⁰At any rate, provided our classification is positively correlated with actual membership in the cartel, miss-classification of units into (and out of) the cartel leads to attenuation bias, making it harder for us to detect collusive behaviour (see [Mirenda et al. \(2022\)](#) for a similar argument).

declare unavailability after winning the ideal dispatch, thereby generating positive reconciliations for the high bidders in the cartel. We show that this behaviour exists only for cartel units and ceases after the reform.

Courts require evidence of express agreement and overt communication to declare collusive behaviour illegal (Chassang and Ortner, 2022). Of course, we do not observe whether members of the collusive arrangements explicitly communicated and/or whether they used transfers to share the spoils. We however try to look into both issues. First, we use data from the minutes of the meetings of the Association of Generating Units (CNO in Spanish). The association holds regular meetings to discuss engineering problems (and solutions) related to technical difficulties and constraints on the network. Of course, bidding behaviour is not to be discussed at those meetings. We downloaded the minutes of all the meetings in 2008 (during the cartel) and 2009 (after the announcement date). Within a DID framework, we find that after the reform, units in the cartel stopped sending employees involved in setting bids to the meetings. The meetings of the association might have thus been used to discuss bids and collude. Second, if the forensic analysis is correct, we expect that profits – particularly from positive reconciliations – fall relatively more for cartel units after the end of the cartel. We confirm this to be the case within the baseline DID analysis. Across units in the cartel, however, we find that profits fell for *all* units – regardless of their costs during, and role in, the cartel. Transfers might thus *not* have been needed to sustain the cartel in this case.

Section 5 quantifies the incentive to collude for each unit and the cost of the cartel for consumers. First, we calibrate the optimal static bidding strategy and show that, before – but not after – the announcement date, cartel units could increase static profits by deviating from the collusive agreement. In contrast, non-cartel units would not be able to increase profits by bidding differently. We then embed such deviations into a dynamic incentive compatibility constraint. For reasonable parametrizations of the discount factor, such deviations are not incentive compatible under the old transparency rule but become so under the new rule. This calibration thus lends further support to the DID results in Section 3: the (announcement of the) reform made collusion unsustainable and caused the cartel to unravel.

Counterfactual bids and allocations allow us to provide a lower bound of the excessive costs paid by consumers for electricity in the second semester of 2008. The cartel artificially increased the price paid for electricity in the wholesale market. In particular, the cartel increased by 12% the price paid for positive reconciliations. Positive reconciliations account for approximately 10% of

the electricity procured by the regulator, but since they are paid above the spot price this led to an overall increase in costs of 2.5%. Assuming a full pass-through of the cost increase to consumers, the cartel increased the average monthly bill paid by a Colombian households by 1,100 COP , i.e., around 3%. Finally, Section 6 discusses policy implications of our results.

Related Literature

This paper contributes to three branches of the literature, with a particular focus on developing countries: collusive arrangements, energy markets and relational contracts.

Collusion We hope to contribute to the empirical literature on collusion (see [Asker and Nocke \(2021\)](#) for a recent, comprehensive, review). A first branch of the literature studies known cartels to gain insights into their functioning and quantify associated efficiency losses. Within this branch (see, e.g., [Porter and Zona \(1993, 1999\)](#); [Asker \(2010\)](#)). Studying the international vitamin C cartel, [Igami and Sugaya \(2021\)](#) calibrate the dynamic incentive compatibility constraint associated with the collusive arrangement to perform counterfactual and is thus particularly related to our paper.

A second branch designs empirical tests to detect anti-competitive behavior in contexts in which a cartel has not been proved. [Porter \(2005\)](#) and [Harrington \(2008\)](#) provides overviews of the literature and [Hendricks and Porter \(1988\)](#); [Bajari and Ye \(2003\)](#); [Baldwin et al. \(1997\)](#); [Ishii \(2009\)](#); [Athey et al. \(2011\)](#); [Conley and Decarolis \(2016\)](#); [Chassang et al. \(2022a,b\)](#) examples. [Chassang and Ortner \(2019\)](#) study of procurement in Japan derive a test from the dynamic incentive compatibility constraint and is thus particularly related to our paper. They note that higher minimum prices can make punishment less effective and lead to a drop in the right tail of winning bids. Instead, we exploit the fact that the announcement of a *future* change in market transparency leads to the instantaneous demise of the cartel. [Chassang and Ortner \(2022\)](#) discuss the processes involved in regulating collusion, including the information required not just to mark collusive behaviour as illegal, but even to hear a case and begin investigation. The logic of our empirical test and the combination of forensic approaches are potentially portable to other contexts and might meet the informational hurdle, at least in some cases.

We thus also contribute to the literature on collusion and market transparency. Conventional wisdom holds that transparency facilitates collusion (see, e.g., [Whinston \(2008\)](#); [Perloff and Carlton \(1999\)](#)). A number of notable contributions, e.g., [Genesove and Mullin \(2001\)](#) study of the sugar cartel in the U.S. and [Albæk et al. \(1997\)](#) analysis of the Danish antitrust authority's decision to publish firm-specific transactions prices of ready-mixed concrete in three regions, support this

view. The evidence and theoretical literature on the matter, however, is less conclusive. [Sugaya and Wolitzky \(2018\)](#) argue that transparency can hinder cartels by helping firms devise more profitable deviations and discuss examples in which that appears to have been the case. We thus contribute evidence to the ongoing debate. We do so in a developing country context. This might be particularly valuable given the general perception that cartels are widespread ([World Bank \(2016\)](#)) and the limited available evidence.¹¹

Energy Markets We also contribute to the empirical literature on energy markets in developing countries.¹² The critical role played by the electricity sector in the development process is increasingly appreciated (see, e.g., [Rud \(2012\)](#), [Lipscomb et al. \(2013\)](#), [Greenstone et al. \(2014\)](#) and [Allcott et al. \(2016\)](#)). In a recent review, [Greenstone et al. \(2019\)](#) note that "rigorous evidence from developing countries on market design is lacking" (see also [World Bank \(2019\)](#)). Intrinsic features of electricity markets make them prone to abuse of market power and even collusion – evidence on which policies improve market efficiency is thus particularly valuable. For example, through counterfactual simulations, [Ryan \(2021\)](#) finds that a more integrated grid would increase surplus by 22% in the Indian market.¹³ A few papers study the Colombian electricity market, albeit with a different focus ([Camelo et al. \(2018\)](#) on centralized unit commitment, [Fioretti et al. \(2021\)](#) on substitution between fossil fuels and hydropower, and [Suárez \(2022a,b\)](#) on the interaction of market power and public ownership).

Relational Contracts Markets in developing countries are often characterized as having weaker formal contract enforcement and governance, making the study of relational contracts particularly important (see, e.g., [McMillan and Woodruff \(1999\)](#); [Fafchamps \(2004\)](#) and [Macchiavello \(2021\)](#) for a review).¹⁴ The key difficulty in testing models of relational contracting is that neither the *future* value of the relationship nor the *current* temptations to deviate are typically observed. [Macchiavello and Morjaria \(2015\)](#) tests the implications of a relational contracting model exploiting information on temptations to deviate and an exogenous supply shock in the Kenya flower sector. [Blouin and Macchiavello \(2019\)](#) uses unanticipated increases in temptations to deviate to

¹¹In a recent review of the literature [Asker and Nocke \(2021\)](#) cites only two studies on collusion in developing countries ([Bergquist and Dinerstein \(2020\)](#) on Kenya maize and [Barkley \(2020\)](#) on Mexican insulin).

¹²The literature on energy markets is vast (see, e.g., [Kellogg and Reguant \(2021\)](#) for a recent and comprehensive review). Examples of collusive practices in electricity markets in developed countries include [Fabra and Toro \(2005\)](#) and [Mercadal \(2022\)](#).

¹³[Ryan \(2020\)](#) finds that widespread contract renegotiations induce significant efficiency costs in the procurement of power generation units in India.

¹⁴Relational contracts between firms are important in developed countries as well, see, e.g., [Corts and Singh \(2004\)](#); [Barron et al. \(2020\)](#); [Gil and Zanarone \(2017\)](#); [Gil et al. \(2022\)](#) for examples and reviews.

test for, and quantify, the extent of opportunistic behaviour in relationships between exporters and importers in the international coffee market. We contribute a test for relational contracting that relies on changes in *current* behaviour in anticipation of changes in the *future* value of the relationship – a central implication of relational contracting models.¹⁵

2 Institutional Setting & Background

This section provides an overview of the Colombian wholesale electricity market and details the timeline of the events used in Section 3 to detect the collusive arrangement. The Section concludes describing the data used in the analysis.

2.1 Electricity Demand and Generation

Demand The average daily generated electricity in Colombia was 149.81 GWh in 2009.¹⁶ The energy demand fluctuates at different times of the day with 7 p.m. being the peak hour and 3 a.m. the one with the lowest demand. Given its location in the tropic, demand does not vary significantly across the different months of the year.

Supply (Generation) Electricity sold on the wholesale Colombian market in 2008/2009 was produced by 47 generation units. Among these generation units, 32 units owned by 11 private firms produce about 70% of market output, the rest is produced by publicly owned generation units. According to the Comisión de Regulación de Energía y Gas (CREG), the market was a moderately concentrated oligopoly in 2008/2009 with an Herfindahl-Hirschman index of installed capacity around 1306 (see CREG (2009a)). The 4 largest firms (EMGESA, EPPMM, ISAGEN and GECELCA) accounted for 65% of installed capacity.¹⁷

Bids to supply electricity in the wholesale market are submitted by individual generation units. Most of our analysis therefore considers generation units, rather than firms, as the relevant decision makers. However, we use information on firms' ownership of generation units for robustness checks and to gain further insights into the functioning of the collusive agreement.

¹⁵Ghani and Reed (2022) study how relationships evolved in response to an increase in supply in the Sierra Leone market for ice, Macchiavello and Morjaria (2021) finds that higher competition inhibits relational contracting in the Rwanda coffee chain.

¹⁶For comparison, it was: 1277,15 in Brazil, 340,82 in Argentina, 260,93 in Pakistan, 54.18 in Nigeria, 24.54 in Ghana, 937,02 in the UK and 10822,82 in the US.

¹⁷These values are typical of other developing countries, for instance the HHI index was 3.500 in Kenya, 2,300 in Peru and 677 in Pakistan World Bank (2016)).

Electricity is generated using different technologies. In Colombia, the share of different generation technologies over the installed capacity in 2008 was as follows: 66.7% hydro-power, 32.9% thermal generation (20.4% gas-fired, 7.3% coal-fired and 5.2% other fuels) and 0.4% of other small units (co-generation and wind).

Hydro-power generation relies on availability (head and flow) of water stored in reservoirs (hydroelectric basins). Water availability depends on seasonal rainfall patterns (Colombia has three main rain periods: dry (December to February), wet (April to June) and normal (the other 6 months)) and other meteorological events (e.g., El Niño, during which dry weather conditions lower hydroelectric resources, and La Niña during which the opposite occurs).

Thermal generation relies on gas and coal. The most important source of gas for Colombian producers is the basin Guajira, located on the northern coast of the country. In 2009, 82% of gas consumption for electricity generation came from that source. During the sample period, the Colombian Government set a maximum price for gas from the Guajira basin (gas from alternative sources was not regulated at the time). Colombia was the fourth largest exporter of Coal in 2009.¹⁸ Most coal-fired generation units are located close to large coal mines. Coal is usually transacted through long-term contracts with bilaterally negotiated prices.

2.2 Colombian Wholesale Electricity Market

Market Format and Ideal Dispatch Electricity markets are characterized by volatile demand, prohibitively high storage costs and economies of scale. They are thus incomplete and imperfectly competitive (Wilson (2002)). To improve efficiency, encourage participation and minimize expected payments to generators, many countries trade electricity through auction mechanisms. The Colombian wholesale electricity spot market works as a uniform price multi-unit procurement auction.¹⁹ Once a day, companies submit for each generation unit their availability for each hour and a unique bidding price for the next day. Although only one bidding price is allowed for each unit per day, the Colombian wholesale electricity market clears every hour. The heterogeneity of hourly spot prices within a day is explained by differences in the availability of the units and hourly demand fluctuations. There are not intra-day balancing markets and there is only one pricing node for the whole market, i.e. the same spot price is paid in all the regions.

Once the generation units have submitted their daily bids, XM , the system operator, minimizes

¹⁸See <https://www.iea.org/data-and-statistics/charts/total-coal-exports-by-major-exporters-1978-2020>.

¹⁹Examples of uniform price multi-unit auctions electricity markets studied in the literature include Spain (Fabra and Toro (2005)), Texas (Hortaçsu and Puller (2008)) and U.K. (Crawford et al. (2007)).

the cost of fulfilling the demand for each hour, by arranging in increasing order the submitted bids. This process does not consider transmission network restrictions. For each hour, the price that clears the market, the *spot* price, is the bidding price of the marginal generation unit necessary to fulfill the demand. This process gives rise to the *ideal dispatch*, which establishes for each generation unit, how much and at which hour, it should supply energy to the system. Throughout the sample period, hydro-power units tended to have significantly lower costs than thermal units. For this reason, around three quarters of the times the marginal bidder is a hydro-power unit.

Real Dispatch: Positive and Negative Reconciliations Once the ideal dispatch has been determined, contingencies such as transmission constraints may arise and make infeasible the initial planned allocation. As a consequence, *XM* proposes a different set of production assignments, called the *real dispatch*. Units that were initially called upon to produce but cannot supply electricity to the network do not do it, while units that were not called upon may be called in. To compensate the generators for the differences between the *ideal* and *real dispatches*, the market operator has a scheme called positive and negative reconciliations.

A generation unit receives a *positive reconciliation* when the real dispatch allocation is greater than the ideal dispatch. In that case, the system compensated each energy unit at a price equal to the minimum between a cost-based regulated price and the generation unit's bidding price. In case that two or more units could replace (in terms of transmission network constraints) the production obligations of another unit and be called for positive reconciliations, the system regulator selects the one with the lowest bidding price.

A *negative reconciliation* arises when the real dispatch generation is less than the ideal dispatch generation. In 2009, the system compensated each of those units at a price equal to the average between the spot price and the generation unit's bid. While the ideal generation depends on expected availability, real availability is the actual amount of energy that the unit produced. The actual availability can be lower than the expected availability due to exogenous reasons (e.g., production shocks to the unit) or to strategic decisions (the unit decides to produce less than declared to the regulator ahead of the auction). In the data, we are unable to distinguish between these two motives. Regulators investigate units that declare unavailable frequently.

2.3 Change in Transparency Policy

Figure 1 shows that during 2008 there was a strong increase in the average bid in the wholesale electricity market. The bid increase was at odds with hydro-electricity generators having received

an unusually high level of rainfalls. The electricity market regulator thus began to suspect that, among the potential reasons to explain the sharp increase, anti-competitive practices such as collusion might have been playing a role.²⁰

Figure 2 summarizes the timeline of events leading to the policy change. To deal with the price increase, the authorities held a meeting on January 6th 2009, a date that we label *announcement date*, to discuss measures that could deal with the increases in bids. During this meeting, it was decided to hire Professor Peter Cramton (University of Maryland) as consultant for the case to advise on potential changes to market design, including its transparency policy.

Before the Colombian regulators asked for his advice, Cramton had advised several regulators on auction markets design. In particular, and possibly known by Colombian market participants, Cramton consistently mentioned the importance of considering the relative costs and benefits of a market with full transparency of bids. On the one hand, transparency might improve efficiency, but on the other hand it might facilitate collusion (Klemperer, 2002; Cramton and Wilson, 1998). In those cases where the market is expected to suffer from collusion, Cramton argued against a fully-transparent policy (Cramton and Wilson, 1998; Cramton and Schwartz, 1998a,b).

On January 24th 2009, Cramton recommended changing the bidding disclosure policy. Before the implementation of the policy, day t production schedules (ideal and real dispatches) and bidding prices were released as public information *two* days after (in $t+2$). Cramton recommended revealing all bids only 90 days after the auction took place, instead of 2 days after.

Following his advice, regulators approved a law on January 30, 2009 with effect on February 6th, 2009 (CREG, 2009a). The law mandated that day t production schedules and bidding prices were public information, only ninety days after (in $t + 90$). The spot price for each hour of day t was still available to everyone, two days after. Privately though, each generation unit was informed whether or not they won in the multi-unit auction or they had any type of reconciliations. The measure also mandated that the generating units kept their bidding programs' information secret from other units. The law established that failure to comply with the disclosure policy would be sanctioned. The law did not specify how long the policy would last.

2.4 Data

In this paper we use three main sources of data. The first one, available from the webpage of *XM*, contains detailed information on market variables of the Colombian wholesale electricity market from August 2008 to July 2009. The database has the universe of submitted bidding programs,

²⁰For more details see (Superintendencia de Servicios Públicos, 2008) and CREG (2009a), page 74.

the forward contracts hourly sales of each generation unit, the hourly demand and spot price, the daily water intakes of the reservoirs for each hydro unit, the quantities, and revenues from positive and negative reconciliations and the contingencies of the transmission infrastructure.

The second dataset provides time-varying marginal costs for each generation unit. To construct them, we follow a standard engineering methodology (Green and Newbery, 1992; Wolfram, 1998, 1999; Wolak, 2000; Fabra and Reguant, 2014) that uses technical specifications of each generation unit (i.e. heat rate), fuel prices and transportation costs (see Appendix B for details).

Finally, we hand-collected minutes of meetings of the electricity-generators association and searched for the CV of the attendees of these meetings through LinkedIn. We were particularly interested to know if attendees had a job position in the commercial area, and therefore were likely to be directly involved in setting bids at the time of the meeting.

3 Detecting Relational Collusive Agreement

This Section provides evidence that a cartel was likely operating in the Colombia wholesale electricity market. We begin explaining the logic of our empirical test. We then describe the sudden decrease in bids around the time of the reform. We introduce a proxy for cartel membership and present DID and event-study specifications. Finally, we perform several robustness checks and rule out confounding explanations.

3.1 The Logic of the Test

We now detail the logic of our test for collusive behaviour. The argument has two parts. First, we argue that a central implication of relational contracting models is that shocks to parties *future* relationship value should lead to *instantaneous* changes in behaviour. This highlights the importance of distinguishing between the *announcement* and the *implementation* date of the regulatory change for our test. Second, we review theoretical arguments regarding the role of information in auction markets and its role in facilitating collusion. Although our test doesn't rely on market participants having correctly anticipated, at the time of the announcement, the exact regulatory change that took place, in practice, the reform eventually approved likely reduced parties *future* ability to punish deviations leading to an *instantaneous* unraveling of the cartel.

Testing for Relational Contracting Baker et al. (2002) defines relational contracts as informal arrangements sustained by the value of future interactions. Although we do not observe whether

members of the collusive arrangement explicitly communicated with each other and/or whether they used transfers to compensate each other (we later try to gather some indirect evidence regarding both), the central idea of relational contracting also applies to collusive arrangements. While models of relational contracting differ in many important respects (see, e.g., [Mailath et al. \(2006\)](#) and [Watson \(2021\)](#) for reviews), they all share the common insight that the *future* value of the relationship is needed to deter *current* temptations to deviate. The future value of the relationship is given by the discounted (expected) difference in the payoffs following cooperation and defection respectively. The current temptation to deviate is instead given by the difference in payoff between deviating from the agreement and sticking to it. In the context of cartels, it is *a priori* difficult to know how cooperation and punishment play out in practice ([Ortner et al., 2022](#)). For instance, firms might coordinate on bidding rings, or they might punish each other entering price wars. In most cases, however, defection will take the form of either an increase in quantity sold in the market and/or a lowering of the price.

The key difficulty in testing models of relational contracting is that neither the *future* value of the relationship nor the *current* temptations to deviate are typically observed (see [Macchiavello \(2021\)](#) for a discussion). The former depends, inter alia, on discount rates, on beliefs about other players' future behaviors on- and off-the-equilibrium-path. The latter also depends on the off-the-equilibrium-path payoffs associated with defection. Discount rates are notoriously difficult to estimate, beliefs rarely observed and off-the-equilibrium-path actions (and payoffs) are not meant to be observed in the data.

A key implication of relational contract models, however, is that it is the *future* value of the relationship that deters *current* temptations. The ideal test thus relates anticipated changes to *future* relationship value to *current* behaviour. To the extent that the announcement date induced cartel members to become sufficiently pessimistic about their ability to sustain a collusive arrangement in the future, the logic of the ideal test can be implemented in our context exploiting the difference between the *announcement* and *implementation* dates.

Market Transparency & Collusion Although the announcement date might have made potential cartel members sufficiently pessimistic about their ability to sustain a collusive arrangement in multiple ways, anticipating the change in the transparency policy might have significantly contributed to such pessimism.

A critical aspect of market-design is to determine what type of information, if any, should be

revealed to bidders. As noted above, during the first part of our sample period, i.e., throughout 2008 and the very beginning of 2009, the Colombian market had a fully transparent process. The market operator, *XM*, was revealing all the information (bids and allocations) to all market participants with minimum delay.

Transparency can potentially increase efficiency and simplify implementation (see, e.g., [Cramton and Wilson \(1998\)](#)). First, transparency can increase the efficiency of individual bidding behavior. For example, better knowledge of the residual demand allows hydro units to improve the inter-temporal allocation of scarce water resources. Second, transparency simplifies implementation. The regulator simply needs to release the information, rather than paying the cost to assure that certain information is only communicated to specific units and not communicated between units. Under transparency, the regulator need not worry about regulator's employees or generation units not keeping information secret from other market participants.

Transparency, however, can also facilitate collusion. The conventional wisdom thus holds that the less the information provided on the outcomes of the auction, the more difficult it is for a cartel to operate (see, [Perloff and Carlton \(1999\)](#); [Porter \(2005\)](#); [Kovacic et al. \(2006\)](#); [Whinston \(2008\)](#)). [Cramton and Schwartz \(1998a,b\)](#) discuss concrete examples. For instance, if the regulator reveals the bids of all bidders, then a bidding ring faces a much easier problem in policing its agreement.

For completeness, [Sugaya and Wolitzky \(2018\)](#) theoretically show that cartels can sometime sustain higher profits under *less* transparency because better information can hinder collusion by helping firms devise more profitable deviations. Given the relatively limited evidence on how market transparency impacts collusion (see [Albæk et al. \(1997\)](#) and [Genesove and Mullin \(2001\)](#) for notable exceptions), our empirical analysis thus also contributes empirical evidence to the debate.

The Test A worsening of parties ability to detect defection – e.g., induced, as in our case, by regulatory changes in market transparency – increases the future payoffs associated with defection and lowers the value of the relationship. Holding constant current temptations to deviate, makes it harder to satisfy the dynamic incentive constraint and increases the likelihood of defection. That is, we expect that the change in transparency policy leads to lower bids by firms in the cartel.

In practice, changes in market transparency could potentially influence behaviour through a variety of channels. For example, more information might lead firms to have more precise estimates of their residual demand curve and alter bidding behaviour. In our case, the difference between the *announcement* and the *implementation* date allows us to rule out such confounders:

Test for Collusion: *Units that belong to a cartel sustained by a relational contract lower their bids after the announcement, and before the implementation, of the regulatory change.*

3.2 The Main Fact

Figure 1 shows a large drop in the average bidding price around the policy change described in Figure 2. Zooming in around the time of the events surrounding the regulatory change, Figure 3 reveals that the average bid in the market decreased right after the *announcement* date. The average decline, however, masks significant heterogeneity: not all units lowered their bids. Splitting units into two groups – the ones that we label for simplicity cartel units and the rest – and deferring the explanation of how we assign units to the two groups to the next subsection, Figure 3 shows a sharp decrease in the average bidding price right after the *announcement* date *only* for cartel units. The average price for these firms falls by about 43% – the price for other units barely moves.

3.3 Proxying for Cartel Membership

Unfortunately, we do not know the identity of the firms participating in the collusive arrangement. Yet, such information, or a proxy for cartel participation, would allow us to sharpen our empirical test and investigate mechanisms. We thus construct a proxy for cartel membership. To define a baseline proxy, we put forward two exogenous characteristics of the units that we believe, on a priori grounds, to be correlated with unit’s incentives to enter, and ability to sustain, a collusive arrangement. Specifically, in our baseline definition, we hypothesize that cartel units are those *thermal units located in the Atlantic region*. All but one of the 15 units in the Atlantic region are thermal. Therefore the baseline definition yields 14 units in the cartel (9 private and 5 public) belonging to 5 firms.²¹

It is worth describing the rationale for our baseline choice. First, we focus on thermal units because they have larger marginal costs than hydro units (Knittel and Stango (2003)). Due to these higher costs, thermal units wouldn’t be able to win on the ideal dispatch if they were bidding competitively. We hypothesize, and later confirm, that thermal units might profit from colluding on high bids through the process of positive reconciliations. As explained above, conditional on receiving a positive reconciliation, a unit receives a price that is tightly linked to its bid – potentially strengthening the incentives to collude.

At the same time, because positive reconciliations occurs when there are disruption to units

²¹Barranquilla 3 and 4, Cartagena 1, 2 and 3, Flores 2 and 3, Guajira 1 and 2, Proelectrica 1 and 2, Tebsab and Termocandelaria 1 and 2. They belong to 5 firms.

that won the ideal dispatch and/or the power distribution network, not all units might be able to be called in for positive reconciliations. In the positive reconciliation market, therefore, units are more likely to compete with nearby units. Figure A1 shows that units in the Atlantic region are relatively isolated and might thus be more likely to interact with each other in the positive reconciliation market.²²

We are aware that this parsimoniously constructed proxy might be imprecise and/or *ad hoc*. For this reason, we explore robustness and alternative definitions along several dimensions. First, we note that the baseline definition *does not* rely on the unit’s bidding behaviour around the time of the policy change – there is thus no mechanical correlation between variation used to proxy for cartel membership and bidding behaviour around the time of the reform. We could, of course, exploit information on units’ bidding behaviour in the period before the events summarized in Figure 2, and we will indeed do so in a battery of robustness checks. Second, our proxy might suffer from both type-I and type-II errors. The classification might miss units that did instead belong to the cartel, it can also assign units to the cartel that were not part of it. Provided our proxy is moderately positively correlated with actual membership in the cartel, miss-classification of units into (and out of) the cartel leads to attenuation bias, making it harder for us to detect collusive behaviour (see [Mirenda et al. \(2022\)](#) for a similar argument in the context of organized crime infiltration). Nevertheless, for all these reasons we explore alternative baseline definitions of the cartel proxy, relying both on variation in the factors considered for classification, on information of firm’s ownership of units and on placebos.

Table 1 presents descriptive statistics for the units classified to be in the collusive agreement and the rest for two different periods: before and after the announcement date. Besides providing descriptive statistics, the Table also reveals patterns that are consistent with our classification. As one might have expected, units classified in the cartel (64%) are more likely to be privately-owned relative to other units (48%). Private units maximize profits while public firms might maximize other objective functions ([Barros and Modesto, 1999](#)). We expect private firms to be more likely to enter collusive arrangements than public firms. Units classified in the cartel also have a lower fraction of forward contracts, relative to other units. Firms that have committed a large portion of their capacity in forward sale contracts have a lower incentive to increase prices ([Wolak, 2007](#)). A larger fraction of capacity committed to forward contracts thus reduces incentives to enter a

²²Unfortunately, we do not have detailed records of the transmission network and how it has evolving over the last years. The Atlantic region (composed by the Atlantico, Bolivar, Cesar, Cordoba, Guajira, Magdalena and Sucre states) is generally considered the one with the worst governance and highest corruption in Colombia (see for instance, [Duque \(2014\)](#); [CTpC \(2010, 2017\)](#)).

collusive arrangement.²³

Turning to the comparison between the top and bottom panel, we see that the bids of units classified in the cartel decrease after the announcement of the policy. Furthermore, the average positive reconciliation and the revenue from these reconciliations decrease and the average availability increase.²⁴ In the pre period, non-cartel units have lower bids and earn much less in positive reconciliations than cartel units. These facts are consistent with our classification being positively correlated with actual cartel membership. Of course, Table 1 is only suggestive – we now subject our hypothesis to more rigorous testing.

3.4 Market Transparency, Cartel Membership & Bidding Behaviour

We use a difference-in-differences specification to quantify the differential change in bidding behaviour across the two groups around the time of the reform. We distinguish the announcement and the implementation of the non-transparency policy, controlling for time-invariant heterogeneity across units and time effects. The baseline equation specifies the log bidding price of unit i at date t according to:

$$\ln(b_{it}) = \beta_1 \mathbb{1}\{Cartel\}_i \times \mathbb{1}\{Announ\}_t + \beta_2 \mathbb{1}\{Cartel\}_i \times \mathbb{1}\{Trnsp\}_t + \lambda_i + \mu_t + X_{it} + \epsilon_{it} \quad (1)$$

Where $\ln(b_{it})$ is the logarithm of the bidding price, the dummy variable $\mathbb{1}\{Cartel\}_i$ takes the value of one if i is a unit is classified to be in the collusive agreement group and zero otherwise. That is, in the baseline specification, $\mathbb{1}\{Cartel\}_i = 1$ for thermal units in the Atlantic region. The dummy variable $\mathbb{1}\{Announ\}_t$ take the value of one if t is a date after the announcement date (January 6th, 2009) and zero otherwise, the dummy variable $\mathbb{1}\{Trnsp\}_t$ take the value of one if t is a date after the implementation of the transparency policy (February 6th, 2009) and zero otherwise. λ_i are unit fixed effects and μ_t are date fixed effects, which control for common market conditions (such as demand and input prices). Units with different technologies (e.g., thermal vs. hydro), and units located in different regions, might be exposed to different daily shocks. We

²³Firms must serve forward contracts obligations, independently of the level of the spot price. A firm that has committed a share of production to forward contracts benefits less from an increase in the spot price relative to a firm that only sells in the spot market. If its forward contract obligations are less than its energy production, the firm benefits from higher spot prices only for the portion of sales sold spot. If its forward contract obligations are greater than its energy production, the firm is a net buyer in the spot market, and an increase in the spot price decreases profits (Wolak, 2000, 2007; McRae and Wolak, 2009). Liski and Montero (2006) show that, contrary to the pro-competitive results of finite-horizon models (Allaz and Vila (1993)), forward trading allows firms to sustain collusive profits that otherwise would not be possible. Unfortunately, we only know units' overall forward trading positions, not actual contracts.

²⁴Table A1 shows descriptive statistics of the main controls used. There is no change in the aggregate Demand across periods but it seems to be a decrease in the average level of water intake (rain falls) and the coal price. This decrease in price explains part of the decrease in the marginal cost of cartel firms.

thus also explore specifications in which date fixed effects μ_t vary either by technology type or by region.²⁵ Standard errors are two-way clustered by date and generation unit.

Table 2 presents the regression results. Across a variety of specifications, we find a statistically significant decrease in bidding prices of production units assigned to the cartel after the announcement of the policy. Depending on the exact specification, the estimates range between a drop of 47% and 30% (i.e. $\exp(-0.63) - 1 = -0.47$ and $\exp(-0.36) - 1 = -0.30$). Column (1) reports results without including any fixed effect. Column (2) controls for unit and date fixed effects and finds identical results. Columns (3) and (4) consider in more detail potential confounders from both the demand and the cost side. Column (4) includes unit fixed effects, while column (3) doesn't (date fixed effects can't be included as they absorb the relevant variation in both input controls (rain falls and gas prices) and total demand in the system). Across the board, the estimated coefficients are identical.

It is worth discussing in greater detail the forward contracts and cost confounders that we can explicitly consider. As noted above, the incentives to collude depend on the level of the fixed-price forward contracts obligations signed by the generation unit. Figure A2 plots the daily average ratio forward contracts committed over total availability for cartel units and for other units.²⁶ Two patterns emerge. First, given the differences in levels of contract commitments, cartel firms have more incentives to collude than the rest of the units. Second, the drop in bidding prices of the collusive units is unrelated to a sudden change in the profile of forward contracting around the dates of the transparency policy. In columns (5) and (6) of Table 2 we explicitly control for the levels of forward controls. We still find a significant and negative coefficient for cartel announcement and insignificant and small and negative coefficient for the cartel implementation interaction.

On the cost side, the differential drop in bids could be explained by a sudden change in production costs for cartel thermal units. As a matter of fact, Table 1 shows that the decrease in marginal costs before and after the reform for cartel units was stronger than the decrease for non-cartel units. This hypothesis therefore merits further investigation. Figure A3 presents the time-series of the mark up ($Bid - Mg.Cost$) for the units in the collusive agreement and the rest. This figure shows an abrupt fall in the margin for units in the collusive agreements but not for the rest of the units, on the dates after the announcement. Controlling for measures of costs, however,

²⁵Since all but one unit in the Atlantic region are thermal, we can not let date fixed effects to flexibly vary across combinations of both technology and region.

²⁶As the availability and contracts variables are set for each hour, we simply sum across hours to have a daily measure. We have dropped some outliers (4% of the observations) of this ratio when the denominator was close to zero. We considered as an outlier an observation with a ratio beyond the third quartile plus 3 times the interquartile range or beyond the first quartile minus 3 times the interquartile range.

doesn't change the estimates of interest. Furthermore, Table A2 replicates Table 2 and show that using the earned margin instead of the bidding price provides qualitatively similar results.

In sum, changes in marginal costs and/or positions in the forward market cannot explain the drop in bidding prices of units in the collusive agreement right after the announcement date.

As mentioned above, a potential concern is that time-varying shocks vary across units in ways that are not captured by the common date-fixed effects. For this reason, column (5) allows for the interaction of date-fixed effects with technology fixed effects. The results still yields a negative, and statistically significant coefficient. Column (6) instead introduces the interaction of date-fixed effects with regional dummies, and finds even stronger effects.²⁷

Interestingly, the coefficient for $\mathbb{1}\{Cartel\}_i \times \mathbb{1}\{Trnsp\}_t$ is negative and statistically significant in some specifications, but turns out to be small and statistically insignificant in specifications that more adequately control for potential confounders in columns (5) and (6). This suggests that market transparency didn't further change bidding behaviour differently between units in the cartel (which had already collapsed) and units outside, once we take into account the differential role of shocks (e.g., gas prices and rainfall patterns) across technologies.

Figure 4 reports estimates from a more flexible event-study specification. In particular, we extend the specification in column 2 of Table 2 including interactions between dummies for leads and lags relative to the announcement date and the $Cartel_i$ dummy. First, the specification rules out differences in pre-trends in bidding behaviour between units assigned and not assigned to the cartel. Second, coefficients drop after the announcement and remain negative for the rest of the sample. Similar results are found when we use alternative specifications from Table 2 or when we use – as we do in Figure A4 in the Appendix – margins as dependent variable instead of bids.

The sudden relative decline in bids for units assigned to the cartel immediately after the *announcement* date is thus consistent with a shock to members' perceptions about their ability to sustain collusive behaviour in the future. As noted above, it is not essential for the logic of the test that members exactly anticipated the regulatory change eventually put in place. In practice, the *announcement* date could have also signaled to market participants a tightening of enforcement or regulators' willingness to take action to uncover and prosecute collusive behaviour. Indeed, on January 20th, the Supervisory Authority of Public Services conducted unforeseen *in-situ* inspections to the four biggest electricity generation companies: EMGESA, ISAGEN, EPM and EPSA. The

²⁷We cannot include the interaction date fixed effects with *both* regional dummies and technology type since there is only one non-thermal unit in the Atlantic region. However, in further robustness checks in which we use additional criteria to define the cartel we can include both sets of interactions simultaneously and obtain similar results.

inspections aimed to find information related to potential collusive practices among them. Figure A5 extends the event-study specification in Figure 4 adding the interactions between dummies for leads and lags relative to the *inspection* date for inspected firms. A few interesting patterns emerge. First, the results for the cartel units are virtually unchanged. Furthermore, the bulk of the differential drop in bids for cartel units happens *before* the inspection date. Second, after the inspection, inspected firms do not change much their bids (the point estimates are negative, but very small and not statistically different from zero). The regulator might have misfired inspections at the wrong firms.

Our preferred interpretation is that firms in the cartel were artificially increasing their bids to benefit from higher prices. As in standard oligopolistic markets, lower bids increase expected electricity sales (either by increasing the likelihood of winning the auction or, in the case of thermal units, being called in for positive reconciliations) and constitute a potentially profitable deviation that the cartel has to police. As any relational contract, the collusive agreement rests on the premise that current temptations to deviate are deterred by future punishments. The transparency regime allowed firms in the cartel to police the agreement, by detecting and – if needed – punishing deviations. The *announcement* of the regulatory change altered members’ expectations about their *future* ability to enforce the cartel: even before the regulatory change was implemented, cartel members knew that future punishment was no longer possible and the cartel unraveled.

3.5 Robustness to Alternative Definitions

Before investigating more direct evidence of why, and how, firms in the cartel colluded in Section 4, this subsection explores the robustness of our results. We first explore robustness to alternative definitions of cartel membership.

3.5.1 Robustness in the Cartel Definition: Firms’ Ownership

Our cartel definition has classified units and not firms. To know the extent of which this can bias our results, Figure 5 reports estimated coefficients of the interaction between the dummies for announcement, $\mathbb{1}\{Announce\}_t$, and implementation, $\mathbb{1}\{Trnsp\}_t$, with four alternative definitions of cartel membership: Baseline, Refined, Extended and Placebo units.

The first group comprises the 14 units from the baseline definition. The second group includes only 9 units that belong to firms for which *all* their units were initially classified in the baseline Cartel. The extended units group, with 22 units, includes the baseline units plus other units that also belong to the firms that have at least one unit in the baseline definition of the cartel. Finally,

to conduct the placebo exercise, we randomly allocate some of the units to the placebo cartel and the rest to the control group. In doing so, we keep the same proportion of cartel and non-cartel units as is in our baseline definition. We repeat this procedure 1000 times.

Figure 5 presents the results and shows two main patterns. First, for the refined and extended units groups, both the announcement and implementation coefficients are significantly lower than zero. The coefficient of the interaction term of the announcement is lower than the coefficient of the interaction term of the implementation for both groups. Second, the previous pattern is different for the placebo exercise. Units randomly allocated to the cartel group sometimes have an increase and sometimes a decrease in bidding prices after the announcement or the implementation period, which results in a zero average effect. Importantly, the standard deviation of the estimates from the bootstrap exercise suggests that our baseline estimates are unlikely to be the result of chance.

3.5.2 Robustness in the Cartel Definition: Alternative Criteria

So far, we have assumed that the cartel was formed by Thermal Atlantic units and have explored robustness using firms' ownership of units. In this subsection, we pursue a different approach in which we consider additional criteria to define our proxy for cartel membership. Specifically, we consider the role of (1) private (vs public) ownership, (2) forward contract positions, and (3) bidding behaviour in 2008, i.e., *before* the announcement date. We refine our baseline definition including these additional criteria progressively building on our baseline definition. In particular, we use factor analysis to define cartel membership based on different sets of variables. Given a set of explanatory variables, we define the cartel as being composed by those units to which the factor analysis assigns positive factors. Changing the variables used in the factor analysis leads to four alternative definitions of cartel:

1. **Cartel 2:** *Three dummies: Atlantic, Thermal, and Private.* The logic of this definition is to question the extent that private ownership matters for our results (in our baseline cartel, 36% of units are public). For instance, [Barros and Modesto \(1999\)](#) argue that private units maximize profits while public firms maximize welfare or other objective functions.
2. **Cartel 3:** *Two dummies: Atlantic and Thermal, and one continuous variable: Forward Contracts.* We include forward contracts to capture the incentive to modify short-term market aggregates. Since forward contracts are defined at the firm level, we include in the factor analysis the share of a firm's capacity that is not covered by forward contracts.

3. **Cartel 4:** *Three dummies: Atlantic, Thermal and Private, and one continuous variable: Trend in Bidding Behaviour in the Pre-Period.* We construct a proxy for the bidding behavior of each unit in all of the period of 2008 by regressing the logarithm of bids on unit fixed effects interacted with a linear time trend during 2008. We then include in the factor analysis the average estimated fixed effect for each unit. This exercise yields a parsimonious estimate of how a given unit changed its bidding behaviour during 2008.
4. **Cartel 5:** *Three dummies: Atlantic, Thermal, Private, and two continuous variable: Forward Contracts, and Bidding Behaviour in the Pre-Period.* Finally, we include in the factor analysis all the considered variables: A dummy for being located in the Atlantic coast, a dummy for Thermal production technology, a dummy for private ownership, our continuous measure for Forward Contract coverage, and our proxy for Bidding Behavior in 2008.

Table A4 shows the correlation matrix for the different definitions. Although the correlation is always positive and significant, it ranges from moderate (0.45) to high (0.95).

Table 3 shows the difference in difference estimates for these four alternative definitions. The coefficient of Cartel Announcement is always negative and significant and ranges from -0.27 to -0.73, suggesting that the effect of the policy change could be larger than that captured by our baseline definition. The coefficient of Cartel Implementation is not significant at conventional levels.²⁸

Figure A6 shows the event study for these four definitions. For all of them, the level of the coefficients after the announcement is lower than before the announcement. In particular, for all definitions, there is a sharp and discontinuous drop in the coefficients right after the announcement date.

Figure A7 shows that when we refine or extend the Cartel definitions as well as when we conduct a similar placebo exercise as proposed above, the coefficient estimated for the announcement interaction is always negative and larger in magnitude than the coefficient estimated for the implementation interaction.

²⁸Unreported result are robust to the contemporaneous inclusion of the interaction between date and technology fixed effects as well as date and region fixed effects. The additional criteria introduce variation within our baseline characterization that enables us to include this more exhaustive set of controls.

4 Incentives to Collude & Inner Functioning of the Cartel

The evidence in the previous Section is consistent with a subset of units in the market having entered a collusive agreement to increase bids. This Section provides further evidence on cartel units' incentives to enter the agreement and on the inner working of the cartel. In subsection 4.1 we show that cartel units had incentives to enter a cartel to increase payments in the positive reconciliation market. The argument unfolds in two steps. First, we show that cartel units have costs so high that they wouldn't be able to earn the right to supply electricity through the ideal dispatch if they were to bid competitively. Given this, they maximize profits through the positive reconciliation market. Second, we qualitatively confirm that incentive to collude exists in the positive reconciliation market. In particular, we show that revenues and profits are inverted-U shaped in bids: beyond a certain point, raising bids lowers the likelihood of being called upon for positive reconciliation as cheaper units might be available. Units thus benefit from a coordinated increase in bids.

Subsection 4.2 provides additional forensic evidence on the functioning of the cartel. We show that cartel units coordinated bids increase, particularly so when the probability of being called for positive reconciliation increases. Concretely, the cartel worked as follows: certain low cost units win in the ideal dispatch auction and, from time to time, declare unavailability and generate positive reconciliations for other units. Given network restrictions, these positive reconciliations are disproportionately awarded to other cartel units that coordinated increases in bids to maximize revenue from these positive reconciliations. We complement this forensic analysis using data from the minutes of the meetings of the Association of Generating Units (CNO in Spanish). This analysis shows that, before the reform, cartel units were relatively more likely to send staff involved in setting bids (as opposed to dealing with engineering problems) to the meeting -- suggesting that explicit coordination might have been going on. Finally, we confirm that, after the announcement of the regulatory change, profits from the reconciliation market (but not from the ideal dispatch) decreased relatively more for cartel units than for other units.

4.1 Incentives to Collude

Cartel Units are Unlikely to be in the Ideal Dispatch Figure 6 shows the comparison of the distribution of calculated marginal costs and average spot price for cartel units and other units separately. The average marginal cost of the units in the collusive agreement is larger than the average spot price. This contrasts with the units that are not in the collusive agreement. For them,

there is a significant mass of bids lower than the average spot price. This mass on the left of the figure is explained by hydro-power units that have low costs and, therefore, win the ideal dispatch most of the time. Given the large differences in marginal costs across cartel and non cartel units, cartel units try to make profits in the only remaining possible way: the positive reconciliations market. As a sanity check, Table A3 shows that under different scenarios the profits that cartel units obtain in the positive reconciliation market are larger than what they would obtain in the counterfactual case in which they bid their marginal costs and try to win in the ideal dispatch.

Revenues and Profits from Positive Reconciliations are Inverted-U Shaped in Bids Incentives to collude on prices arise when uncoordinated price increases lower profits. We thus need to check that the positive reconciliation market features the usual price setting trade-off: higher prices increase margins, but reduce quantity (in this case, the likelihood of being called for a positive reconciliation). Using the baseline specifications in Columns (2) and (5) of Table 2, Table 4 provides suggestive evidence that this is the case. The Table shows that the revenue and profits from positive reconciliations are inverted-U shaped in the submitted bid. The estimates should be interpreted cautiously, since bidding behaviour is endogenous and – as we shall see momentarily – responds to anticipation of positive reconciliations. With that caveat in mind, the pattern can be interpreted as follows: If the bid is very low, the unit is not called for positive reconciliations as it would be allocated the right to produce in the ideal dispatch. However, when the bid increases, the potential payment and likelihood of being called for positive reconciliation increases. This is however true only up to a certain point. When the bid is too high, the unit is unlikely to be called in for positive reconciliation.

4.2 Inner Working of the Cartel

Bids are Larger when Units Expect to Have Positive Reconciliations The first step to understand how the cartel worked is to check that, indeed, units bid strategically and increase bids when they anticipated a higher likelihood of being called for a positive reconciliation. If a unit expects to be called for a positive reconciliation, there are lower incentives to bid competitively to win the ideal dispatch. In the ideal dispatch, the price the unit receives is set by the bid of the marginal bidder. In the positive reconciliation market, instead, the price paid to the unit is equal to the submitted bid (at least up to a certain maximum allowed price). Note that this incentive applies to both cartel and non-cartel units.

We thus investigate the relationship between bidding behaviour and the likelihood of being

awarded a positive reconciliation. Obviously, we can not test the hypothesis using a simple OLS regression: the time-varying and unit-specific likelihood of being awarded a positive reconciliation is not directly observed and must be proxied with actual positive reconciliations. However, those are endogenous to bidding behaviour. We therefore need an instrument for (the probability of) a positive reconciliation for unit i at date t .

We use *security contingencies* as instrumental variable. These security contingencies provide us with an observable, unit-day level varying measure of exogenous shocks to the transmission network that result in positive reconciliations. Specifically, when contingent restrictions to the network occur, certain units might be asked to produce security contingencies – small amounts of electricity to help the transmission system recover stability from shocks and compensate for overcharges. Security contingencies are exclusively based on engineering criteria, i.e., units are called in depending on exogenous shocks to the transmission network and independently on whether they won in the ideal dispatch or not. The exclusion restriction is thus likely to be satisfied. Shocks to the transmission network take time to repair. We thus use the lag instead of the current level of the probability of positive reconciliations.

Table 5 presents the results of this exercise. The table shows that units increase their bids when they have a positive reconciliation in the previous period. Column 1 presents the OLS estimate which is negative but not significant. The OLS estimate could be either upward or downward biased as a higher bid can either increase (the unit is less likely to win the ideal dispatch) or decrease (the unit, if eligible, is less likely to be called in) the likelihood of being awarded a positive reconciliation. Column 2 reports a very strong first stage: conditional on unit and date fixed effects, shocks to the infrastructure significantly increase the probability that the unit is awarded a positive reconciliation. The Kleibergen-Paap F statistic is 25.37 – we thus have a strong instrument for positive reconciliations. Column 3 reports the second stage. We find a large, and statistically significant, increase in bids for units that are more likely to be awarded positive reconciliations due to shocks to the transmission network.

Coordination of bids and positive reconciliation across cartel units The previous exercise shows that there are incentives to increase bids in anticipation of positive reconciliations. We now show that cartel units likely coordinated to increase bids precisely when other cartel units generated positive reconciliations by winning the ideal dispatch and then declaring unavailability.

In order for units in the cartel to be able to profitably coordinate to win the auction and then

declare unavailability to generate positive reconciliations for other units that submitted high bids, two conditions are necessary. First, it must be the case that the cartel comprises specialized units that are able to win in the ideal dispatch, at least sometime. The top-left panel in Figure 7 shows that some of the units in the cartel actually do have low costs, submit relatively low bids, and are sometime awarded production in the ideal dispatch. On the top-right, we construct a measure for the second semester of 2008 on the intensity of unavailabilities. In particular, we report the fraction between the number of times that a unit has an unavailability and won over the total number of times that the unit has won. The top-right figure shows that this fraction is larger for cartel units than non-cartel units. Finally, the bottom of the figure shows that the probability that high price cartel units receive positive reconciliations when low price cartel units win is much larger than the probability for the same high price cartel units when low price no cartel units win.

The second ingredient is to show that units are indeed able to coordinate. To check whether this is the case, for each unit i we define “friends” as those units who are more likely to get a positive reconciliation when unit i has a negative reconciliation. For each unit i , we rank the “friends” by the probability of receiving positive reconciliations. Top 1 denotes the “friend” with the largest probability while Top 3 means the three “friends” with the largest probability. We focus on observations 6 months before and 6 months after the announcement date.

We then investigate whether the average bid of i ’s friends increase when the real availability of unit i is below its awarded ideal generation. While we are unable to separate in the data negative reconciliations that arise from strategic considerations of the unit from those that arise due to exogenous shocks (either to production or to transmission), an interesting pattern emerges. Figure 8 presents the baseline results when we focus on the “Top 1” friend of each unit and shows that only the friends of cartel units increase their bids when a positive reconciliation can be expected and that the effect is present (and significant) in the period before the announcement. The coordination of bids and declared availability between cartel units and their friends appeared only after the likely beginning of the cartel period and reverts to zero in 2009.²⁹

²⁹In the baseline analysis, we do not include in the explanatory dummy the cases where real availability is just slightly below ideal generation. These results are robust to different exercises, presented in Figure A8. In the top left panel, we still consider ‘top 1’ friends from the same period as in the baseline, but we also include cases when real availability is just slightly below ideal generation. In the top right panel, we consider the same period and same cases as in the baseline, but use the ‘top 3’ friends. In the bottom panel, we consider ‘top 1’ friends and the same cases as in the baseline, but we construct ‘friends’ using observations from a longer period (2005-2008) compared to the baseline. The estimates for 2009 needs to be interpreted cautiously. Data on real availability is missing for 63% of cartel observations and for 6% of non-cartel observations in 2009.

Summary In sum, we have gathered evidence that the cartel worked as follows: 1. There are two types of units in the cartel: low and high costs. 2. Low-cost units try to win the auction and declare unavailable from time to time. Given network restrictions, the right to allocate usually is assigned to other units in the cartel. As a consequence, the cartel was being profitable for the parties involved by having units with low costs that allow those with high costs to make super-competitive profits in the reconciliations market. Of course, units in the cartel didn't engage in this behaviour too frequently, presumably to avoid detection from the regulator (recall that to declare unavailability, units need to submit a report and, if they do it too often, they risk being investigated).

4.3 Further Evidence

Evidence from the Meetings of the Association of Generating Units We complement our forensic analysis using novel, hand-collected, data from the minutes of the meetings of the Association of Generating Units (CNO in Spanish).³⁰ For its engineering nature, this association held meetings to find problems and solutions related to technical difficulties and constraints of the system. The association explicit rule was that agents from the commercial area were not allowed to attend the meetings. However, rarely the organization checked the specific job being held by the attendees.

We downloaded the minutes of all the meetings in the second semester of 2008 and first semester of 2009. Within a DID framework, we are interested to check if there was any differential behavioural change between cartel and non-cartel units before and after the policy change. We focus on two main dependent variables: a dummy that takes the value of 1 if the unit sends someone to the meeting, and a dummy that takes the value of 1 if the unit sends someone from the commercial area to the meeting. For each of the attendees-minutes, we categorize the participants as belonging to the commercial area if at the time of the meeting their CV (accessed through websites such as LinkedIn) reports they belong to the commercial area. In total, there are 412 attendees in 18 different meetings (5 in the first semester of 2009). We were able to match 81% of these attendees to a specific job title during the moment that the minute occurred. We have two independent variables. The interaction term $\text{Cartel} \times 2009$ and a dummy for the presence of a regulator.

Table 6 reports the results. First, column (1) shows that, after the reform, units in the cartel were *not* more likely to send someone to the meetings of the association. However, column (3)

³⁰For more information, see <https://www.cno.org.co/content/quienes-somos> and the report from the regulators (Superintendencia Delegada para Energía y Gas, 2008)

shows that the composition of the attendees did change. Specifically, after the reform, units in the cartel are *less* likely to send someone from the commercial area – i.e., likely involved in setting bids. Columns (2) and (4) further control for whether someone from any of the Regulatory entities (SSPD, Ministry of Mines, UPME, XM among others) was attending the meetings and provides further evidence that attendance was likely a strategic choice. Column (2) shows that units are more likely to send someone to attend the meeting when any of the regulators were also present. The presence of the regulator could, of course, correlate with unobserved factors (e.g., the importance of the meeting, presumably known to participants from the agenda). Interestingly, however, when the regulator is present, units are less likely to send someone from the commercial area (column (4)). In sum, while this doesn't prove that cartel units explicitly communicated around the timing of the meetings to coordinate bidding behaviour, the evidence points at strategic behaviour in the attendance to the meeting. Similar evidence could presumably be used to evaluate the possibility of prosecution in other cases.³¹

Lower Profits from Positive Reconciliations After the End of the Cartel Finally, the hypothesis of an implicit agreement in the bidding scheme implies that after the break of the agreement the profits of the cartel units should decrease. As a sanity check, we therefore revisit our baseline specifications presented in Section 3.4 and consider the following dependent variables: A dummy for receiving positive reconciliations, profits from positive reconciliations and total profits.

Table 7 shows that, while the likelihood of receiving positive reconciliations was unaffected, the profits from positive reconciliations as well as the total profits sharply decreased for the collusive group after the announcement date.

We further explore whether profits were differently affected by the announcement depending on the costs, or the role, of units in the cartel. Table 8 presents the results. In columns 1-2, 'high' units are those with average marginal cost in the second half of 2008 above the median, and 'low' otherwise. In columns 3-4, 'high' units are those with average bids above the median, and 'low' otherwise. In columns 5-6, 'high' units are those with average amount of negative reconciliations *below* the median, and 'low' otherwise. The table shows that total profits fell for all units, and slightly more for high costs units who would unlikely be able to increase profits in the ideal generation market. Transfers might thus *not* have been needed to sustain the cartel in this case, as all units were better off colluding.

³¹In robustness tests, we drop the 19% of the observations for which we could not find a job title or assume that they did not belong to the commercial area. Results in Table 6 are similar with only slightly smaller estimated interactions.

5 Quantifying the Value of the Collusive Agreement

In this section, we quantify the incentive to collude of each unit and the cost of the cartel for consumers. In order to do so, we need to construct counterfactual bids and profits under three scenarios: competition, collusion, and optimal deviation from collusion. We conduct this exercise in three steps. First, we show empirically that cartel units could increase static profits submitting lower bids and deviating from the collusive agreement. Second, we construct counterfactual profits and show that such deviations are not incentive compatible under the old transparency rule due to the future value of the cartel, but they become profitable under the new 90 days rule. Third, we use such estimate to provide a back-of-the-envelope estimate of the cost of the cartel for consumers.

5.1 Bidding Strategy

Following the game theoretic framework of [Chassang and Ortner \(2022\)](#), the existence of a cartel involves departures from a static Nash equilibrium for its members, which implies a short run incentive to deviate from the cartel. The sustainability of a cartel depends on whether such deviations are incentive compatible or not, that is whether the gain from short run deviations compensate the loss of future gains from colluding. However, before verifying the incentive compatibility of such deviations, we empirically show the existence of deviations to increase static profits. Our hypotheses are that non-cartel units set bids to maximize their individual static profits while cartel units do not. In particular, cartel bids should be larger than static profits-maximizing bids. We test these hypotheses with the following three-step procedure: First, since the cartel operates on the market for positive reconciliations, we need to select a suitable comparison group of non-cartel units that are also more likely to make profits with positive reconciliations. Second, we estimate how the amount of positive reconciliations that a unit gets changes if the unit had submitted a different bid. Third, we use these estimates to compute the bid that maximizes static daily profits from positive reconciliations and compare it to the observed ones.

In the first step, we identify a suitable comparison group of non-cartel units using the following criteria. (i) Thermal units, because all cartel units are thermal. Furthermore, the assumption that units maximize static profits is realistic for thermal but not for hydro units. (ii) Private units, because publicly owned units might not be profit maximizers ([Barros and Modesto, 1999](#)). (iii) Units that are not owned by a cartel firm, because we want to limit the possibility of considering units that are actually in the cartel or pursuing different goals, as in the robustness exercise on the cartel definition presented in [Section 3.4](#). These criteria leave us with a comparison group

consisting of five non-cartel units.³² We focus on a one year period: six months before the policy change and the six months after the policy change. For these two periods, we compare observed bids with static profits maximizing bids for both cartel and non-cartel units.

We compute, for each day, the amount of positive reconciliations that a unit would have got had it submitted a counterfactual bid. In the spirit of [Porter and Zona \(1993\)](#), our analysis is based on the rank of bids rather than bids themselves, because a change in bid does not affect the winning probability unless it also changes the rank of the bid with respect to the other units. We follow a two steps estimation procedure to accommodate the non-linearity between bids and quantities: We first model the probability of having a positive reconciliation, and then we model the expected amount of positive reconciliation conditional on having some.³³ Since, due to transmission network constraints, the geographical position of a unit is crucial in determining who gets a positive reconciliation, and since cartel and non-cartel units are located in different regions, we estimate the two models separately for cartel and non-cartel units. In particular, for cartel units the rank of bids is computed with respect to all the others cartel units, while for non-cartel units the rank of bids is computed with respect to all the others non-cartel units. [Figure A9](#) presents in-sample predictions from this estimation procedure versus observed quantities. We further compare the distribution of our predictions and of observed quantities in [figure A10](#). Both diagnostic figures suggest that our model is able to replicate fairly well the amount of positive reconciliations awarded.

Given these estimates, we simulate, for each unit and day, alternative bids to the observed one and the corresponding quantities of positive reconciliation conditional on other units' bids. We then compute counterfactual profits and select the bid yielding the highest static daily profits. At the unit-day level, we compute the ratio between the observed bids and the static profits maximizing bids and plot the density of this ratio separately for the two groups of units and the two periods of time.

Under the assumption that units aim to maximize static profits from positive reconciliations, we expect the mass of the density to be centered around one. If units are colluding to raise prices in the positive reconciliation market, instead, we expect significant mass above one. [Figure 9](#) presents

³²The main results are robust to relaxing the second and/or the third restriction.

³³First, to model the probability of having a positive reconciliation we regress a dummy for having a positive reconciliation on the rank of the bid with respect to its competitors, its squared value, unit and time fixed effects. Since our goal is to make predictions, we estimate the model with maximum likelihood assuming the errors follow a logistic distribution. Second, to model quantities, we regress the natural logarithm of the awarded amount of positive reconciliation, conditional on being awarded some, on the same covariates as in the first step. We estimate the second model with OLS. Given these two sets of estimates, we compute for each unit, day and bid the expected amount of positive reconciliations as the product of the predicted probability of being awarded a positive reconciliations with the (conditional) expected amount.

the results of this exercise. Before the policy change, the distribution computed for cartel units is bimodal and displays a peak at a ratio around four (significantly larger than one), i.e., cartel bids are often much larger than their static profit maximizing bids. For non-cartel units, instead, the distribution is single-peaked with most of its mass closely around a ratio equal to one. After the policy change, instead, for both cartel and non-cartel units the density is centered around one, suggesting that both groups are now bidding competitively. To formally test for the equality of the distributions of the ratio for cartel and non-cartel units, we first aggregate data at the unit-month level to take into account correlated errors and then use a Kolmogorov–Smirnov test. The test rejects the null hypothesis of equality for the pre-reform period (p-value = 0.00), but not for the post-reform period (p-value = 0.62).

5.2 Dynamic Incentive Compatibility Constraints

The previous subsection provides evidence that cartel units could increase daily profits by deviating from the collusive bidding strategy. However, cartel sustainability relies on the fact that deviations are not profitable due to the future value of the collusive agreement. In this subsection, we check the mechanism through which the policy change undermined cartel sustainability. Similarly to [Igami and Sugaya \(2021\)](#), which however rely on a proven cartel, we check that the incentive to collude is positive for all cartel units under the old transparency rules, but negative for at least one unit under the new ones.

We assume that deviation of a unit from the collusive agreement triggers competition. Under the old transparency rule, this implies that a unit can unilaterally deviate for two days and undercut other cartel’s bids to increase static profits. But, from the third day onward, cartel units would bid competitively. However, under the new transparency rule, a unit can unilaterally deviate for 90 days before competition is triggered because only then the deviation becomes common knowledge. We thus define static profits for unit i at time t as π_{it}^j under three alternative scenarios: $j = C$ (collusion), N (competition), D (optimal deviation from the collusive agreement). We assume that units hold static expectations and denote with β the daily discount factor. We define the dynamic incentive compatibility (DIC) constraint under the old (2) and new (3) transparency rule as follows

$$\frac{1}{1-\beta}\pi_{it}^C - \frac{1-\beta^2}{1-\beta}\pi_{it}^D - \frac{\beta^2}{1-\beta}\pi_{it}^N > 0 \quad \text{For all units} \quad (2)$$

$$\frac{1}{1-\beta}\pi_{it}^C - \frac{1-\beta^{90}}{1-\beta}\pi_{it}^D - \frac{\beta^{90}}{1-\beta}\pi_{it}^N < 0 \quad \text{For at least one unit} \quad (3)$$

Our hypothesis is that the DIC in (2) is satisfied for *all* cartel units for all periods t before the

policy change, while the DIC in (3) is not satisfied for *at least* one cartel unit after the policy change. We empirically test this hypothesis as follows.

We focus on cartel units one year around the policy change and on the profits they can make with positive reconciliations.³⁴ Given the evidence presented above, we assume that cartel units were colluding before the announcement of the policy change and competing after the implementation. Thus, for each unit and day in these two periods we observe bids and quantities under one of the three possible scenarios. We then need to compute bids and quantities for the other two counterfactual scenarios. From August 2008 until the announcement of the new policy we observe bids and quantities under collusion and need to compute bids and quantities under competition and deviation from collusion, while from the policy implementation until June 2009 we observe bids and quantities under competition and need to compute bids and quantities under collusion and deviation from collusion. For the period between the announcement and the implementation we remain agnostic about the moment in which each unit moved from collusive to competitive bids, and we construct counterfactual variables for all the three scenarios.

To simulate counterfactual quantities we follow the approach presented in the previous subsection and a similar one for bids. Given these bids and quantities, we compute profits using the estimates for the production costs introduced above and compute the incentive to deviate for each unit at any point in time according to the definitions in (2) and (3). Below we provide details on the steps for this exercise.

First, we need counterfactual competitive bids b_{it}^N for the pre-reform period and counterfactual collusive bids b_{it}^C for the post-reform period. We model bids as a function of market fundamentals similarly to [Pesendorfer \(2000\)](#): We regress observed bids on unit fixed effects, production costs, the logarithm of the total amount of positive reconciliation in the previous day, and the logarithm of the total amount of ideal generation (that is the two exogenous quantities that are known at the time of submitting bids). We estimate this regression separately for the pre and post-reform periods and use these estimates to simulate counterfactual bids. [Table A5](#) presents the results. As argued by [Porter and Zona \(1993\)](#) and [Ishii \(2009\)](#), our estimates suggest that the levels of bids do not necessarily reflect the underlying market fundamentals when units are colluding, but they do when units are competing. In order to assess the goodness of our method, in [Figure A11](#) we plot in-sample predictions versus observed bids for the collusive and competitive period separately, and the respective distributions in [Figure A12](#). Our model seems to replicate well how cartel units set

³⁴We do not consider the unit Proelectrica 2 because it was never awarded positive reconciliations in the considered period of time. We thus focus on 13 of the 14 cartel units.

bids under both scenarios.

Second, we need counterfactual competitive quantities q_{it}^N for the pre-reform period and counterfactual collusive quantities q_{it}^C for the post-reform period. However, to correct for differences in units' availability and transmission problems, we also simulate q_{it}^C for the pre-reform period and q_{it}^N for the post-reform period instead of relying on observed ones. In practice, we thus simulate both counterfactual quantities - collusion and competition - for all days and units. We model how awarded quantities of positive reconciliation depends on the rank on the bids and rely on the same method used in the previous exercise. We then predict q_{it}^C using observed bids for the pre-reform period and using simulated bids for the post-reform period. We do the opposite for q_{it}^N . Figures [A13](#) and [A14](#) show the goodness of in-sample predictions.

Given simulated and observed bids, estimated costs, and simulated quantities, we predict profits π_{it}^C and π_{it}^N for all days and units. We finally need bids and quantities under the optimal deviation scenario to compute the corresponding profits. For each unit and day separately, we simulate quantities and profits for different possible values of a deviation bid b_{it}^D (above production cost and below the collusive bid) and select the one yielding the highest profits π_{it}^D . Figure [A15](#) presents the resulting average profits under the three different scenarios. By construction, for each units, deviation yield the largest average profits, competition the lowest with the collusion payoff in the middle. The Figure reveals significant variation in how much units stand to gain from collusion relative to competition. Given these counterfactual profits, we can compute the incentive to collude for each unit. We average profits at the monthly level and compute the incentive to collude in each month assuming static expectations (results are similar if we aggregate at the daily or weekly level). With the solid lines in Figure [10](#) we report the *smallest* incentive to collude across cartel units over time, assuming a daily discount factor $\beta = 0.9996$ ($\beta^{365} = 0.86$, the interest rate in 2008 and 2009 was around 10%). We use the definition in [\(2\)](#) for the period until the reform in January 2009 and [\(3\)](#) afterwards. The solid lines show that all cartel units were better off colluding until January 2009, but that afterwards the cartel became unsustainable as it was more profitable for at least one unit to deviate from the collusive agreement. As it happens, our estimates reveal that the dynamic incentive compatibility constraint [\(3\)](#) was violated for two units after the reform (Termocandelaria 1 and 2). To further investigate the cartel's sustainability, we assume that these two units adopt the optimal deviation as their bidding strategy and compute the incentive to collude for the remaining cartel units. Our model indicates that after the first two units deviate the incentive to collude becomes negative for four additional units (Cartagena 1 and 3, Flores 2

and 3), potentially starting a chain effect that would lead to the collapse of the cartel.

A potential concern is that the sudden drop in the incentive to collude as of January 2009 might have been driven by other changes in the market rather than the reform itself. To rule out this possibility, in Figure 10 we also report the smallest DIC according to (2) for the post-reform period and (3) for the pre-reform period with dashed lines. The figure shows that if deviations were possible only for two days, the smallest incentive to collude across cartel units would be positive both in the pre and post-reform period. However, if deviations were possible for 90 days, some units would have an incentive to deviate both before and after the reform. That is, the drop in the incentive to deviate observed in January 2009 and the cartel collapse are likely driven by the policy change and unlikely by other differences between the pre and the post-reform periods. As an additional robustness exercise, we repeat the calculations for slightly higher and lower values of the daily discount factor (0.9995 and 0.9997). The shaded area in Figure 10 presents the lower and upper bounds of the smallest incentive to deviate using the different discount factors.

5.3 Cost of the Cartel

The exercise we conducted above allows us to quantify the cost of the cartel for consumers. That is, the additional cost consumers paid for the electricity produced due to the high cost imposed by the cartel to the reconciliations market. For this exercise, we focus on the second semester of 2008, and compare the total cost paid for positive reconciliations with the total cost that would have been paid if the cartel firms had behaved competitively. The former quantity is observed, while the latter is deduced from the counterfactual variables in the previous section.

To advance in this direction, we make the simplifying assumption that the total amount of positive reconciliations produced by the cartel is independent of its members colluding or competing. That is, (i) units cannot strategically create positive reconciliations; (ii) the collusive behavior only changes the particular allocation of production of energy within cartel units. Our measure thus provides a lower bound estimate of the benefit of competition. The rationale of why this is the case is that if (i) does not hold, competition would imply that a share of positive reconciliation is awarded via the ideal dispatch and paid at the lower spot market price. Similarly, if (ii) does not hold, lower cartel members' bid could increase the market share of these units in the positive reconciliation market if their bids are lower than non-cartel units. If that is the case, we ignore the lower cost consumers would pay on the additional market share.

In practice, to conduct the estimation of the cost of the cartel, we multiply bids and amounts

at the unit-day level and then sum over units. As before, we aggregate costs at the monthly level and present the results in Figure 11. The two lines (scale on the left axis) refer to the total cost paid to cartel and non-cartel units for positive reconciliation under collusion and competition. The bars (scale on the right axis) show the percentage increase in cost due to the existence of the cartel. The figure shows that the cartel generated at least an additional cost of around 11 billion COP per month, which corresponds to an increase of around 12% with respect to the competitive scenario. Positive reconciliations account for approximately 10% of the electricity procured by the regulator, but since they are paid above the spot price this lead to an increase in overall costs of about 2.5%. Around 10 million households lived in Colombia in 2008. If all the energy allocated via positive reconciliations is bought by households, and assuming a full pass-through of the cost increase to consumers, the average household paid 1,100 COP in excess per month in the second semester of 2008 due to the collusive agreement (with many household living with less than a minimum wage of 461.500 COP).

Energy is an input in most other sectors of the economy, and therefore distortions and higher prices might have particularly large negative aggregate effects (Liu, 2019). Our ability to provide a reduced form quantification of the costs of the cartel to downstream sectors is, however, limited by contextual confounders and data limitations. Specifically, in the second semester of 2009 – i.e., after the demise of the cartel – meteorological events linked to El Niño adversely affected the production capacity of hydro-power units. These units clear the market most of the time and therefore El Niño increased the average price of electricity emerging from the ideal dispatch. Data on manufacturing electricity consumption and production are available only at the yearly level. This prevents us from linking the demise of the cartel to those outcomes.

More generally, we have focused our analysis until June 2009. El Niño induced the regulator to introduce several changes in the market, including to the regulation of thermal units bids and to market transparency. With regards to the latter, bidding behaviour for hydro-units is inherently dynamic and it is generally believed that better information on market conditions allow hydro-units to improve the inter-temporal allocation of scarce water capacity. To counter the negative effects of El Niño, the 90-days disclosure rule was eliminated on December 4, 2009 and the market reverted back to the older two-days disclosure policy (CREG, 2009b). Given the difficulty of building a collusive arrangement (Byrne and De Roos, 2019) and their fragility, we do not expect the change in policy to necessarily result in a new cartel.

6 Policy Implications and Conclusions

This paper has identified, and quantified the value of a collusive arrangement in the Colombia energy generation market. Our analysis has policy implications for market design – including energy markets – in developing countries. First, markets in developing countries tend to be thinner and more concentrated and regulatory authorities weaker. Non-competitive conduct and collusive behaviour might thus cause large distortions. When this happens in upstream sectors that provide inputs to many other sectors, such as energy, these distortions can be particularly detrimental to aggregate welfare (Liu, 2019).³⁵

Second, the Colombia case provides a particularly interesting example. The country’s energy sector was successfully reformed in the nineties and is generally considered one of the best designed and regulated markets among developing countries (World Bank, 2019). Still, despite the suspicion that the market might have been affected by non-competitive behaviour, the Colombian regulator did not advance further in cartel investigation and prosecution. Evidence of an express agreement is often needed to attempt prosecution (Chassang and Ortner, 2022) and lack of such evidence might have induced the regulator to change market design in the hope of hindering (potential) collusive practices. Besides contributing ideas that might help regulators to acquire sufficient evidence to attempt prosecution in other contexts, our analysis points at the possibility that collusive behaviour in energy markets might be even more pervasive in more concentrated and less well-designed markets. Research into market design of energy markets in developing countries is an important policy area for further research (Greenstone et al., 2019).

Finally, our analysis also contributes to our understanding of how market transparency affects firms’ conduct. Besides the electricity sector, this is relevant in several other contexts – including public procurement, e-commerce and agricultural markets. Digital technologies, for example, have the potential to increase sellers’ visibility among buyers, reduce search costs and increase competition in many contexts (Bai et al., 2020; Baldwin et al., 2021; Bergquist et al., 2021). The evidence in this paper introduces a word of caution: increased transparency could backfire by allowing competing firms to detect and punish deviations from collusive agreements. More research is thus also needed to evaluate the impact of market transparency in other contexts.

³⁵Furthermore, to the extent that energy prices are heavily distorted by non-competitive conduct, this should also be taken into account in the design of optimal policies to foster a green transition (Kellogg and Reguant, 2021).

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7 Figures

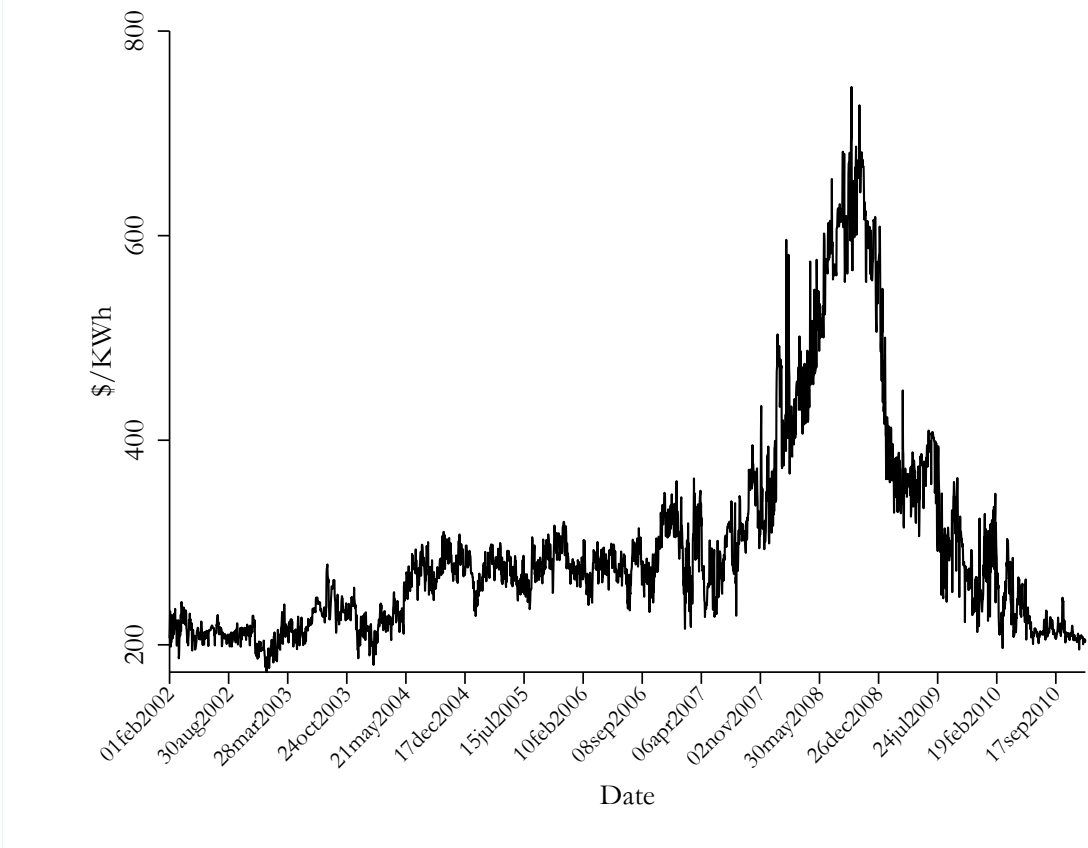


Figure 1: Average bid time series.

Note: Daily time series of the average bid and marginal bid (dotted line) from 2002 to 2010 in the Colombian wholesale electricity market.

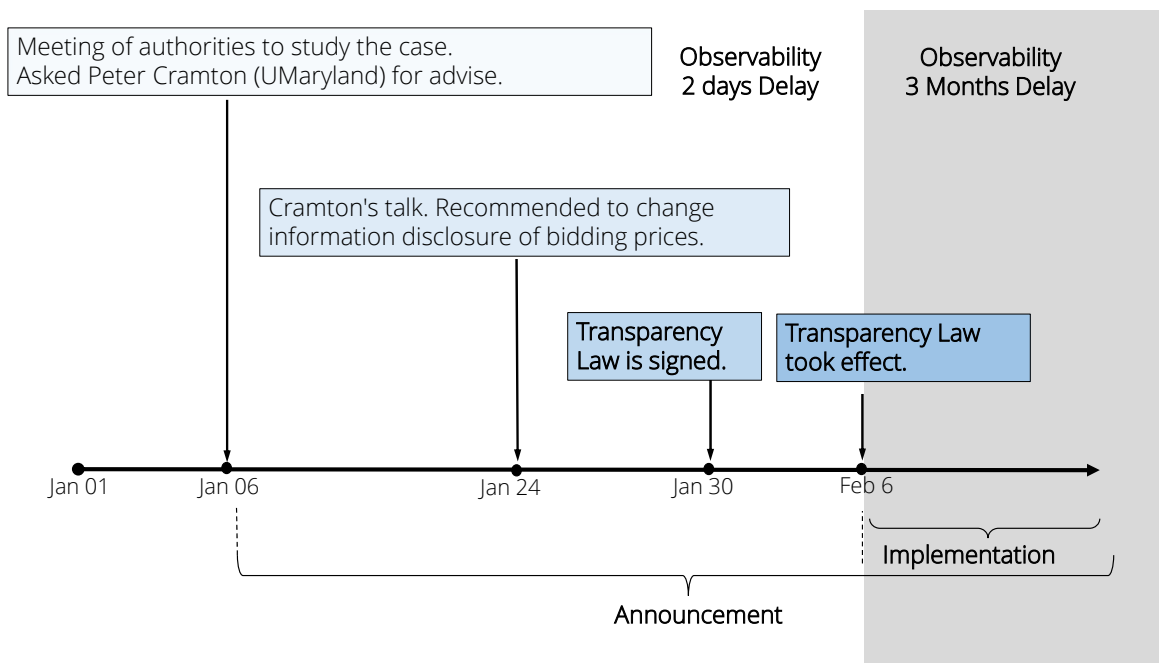


Figure 2: Timeline.

Note: Timeline of the announcement and implementation of the transparency policy.

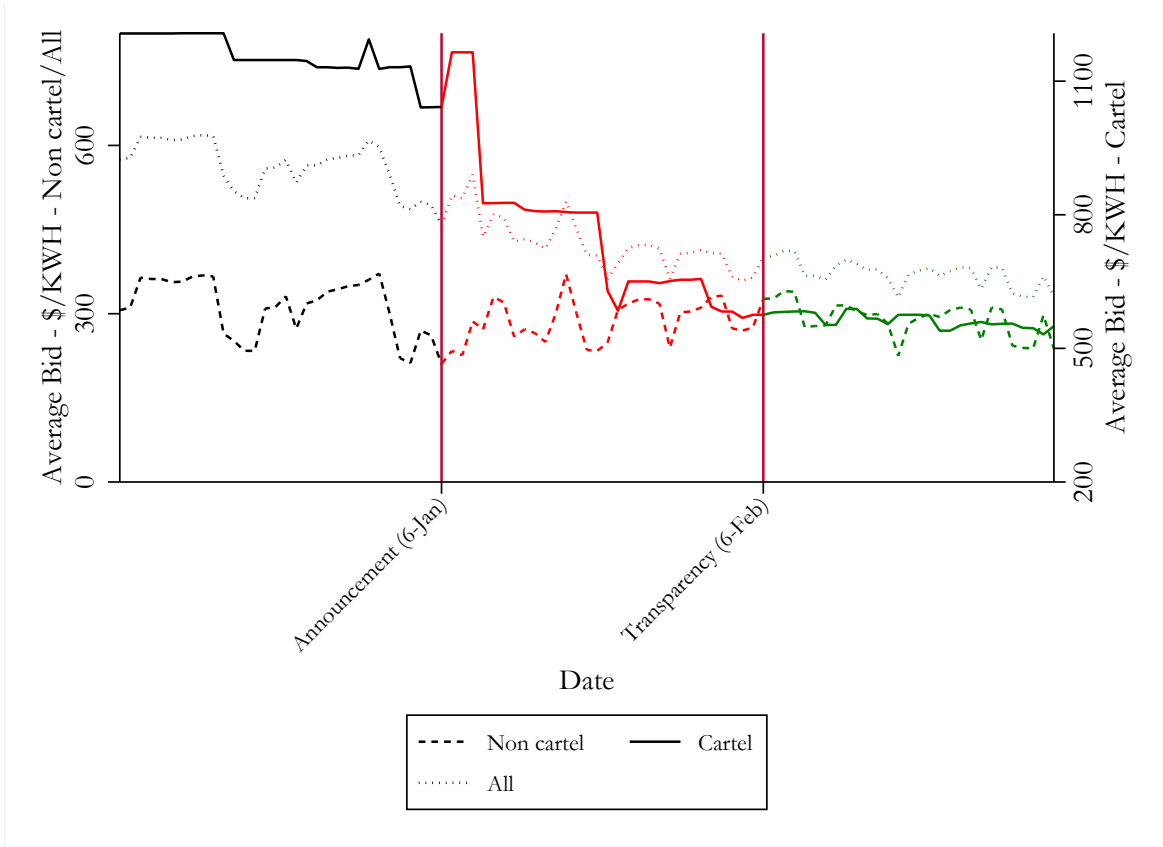


Figure 3: The Main Fact: Cartel and non cartel groups bids.

Note: Time series of the average bid of the cartel (solid line, right axis) and non-cartel groups (dashed line, left axis) around the dates of announcement and implementation of the transparency policy. We also report the overall average (dotted line, left axis). The vertical lines point the announcement and implementation dates.

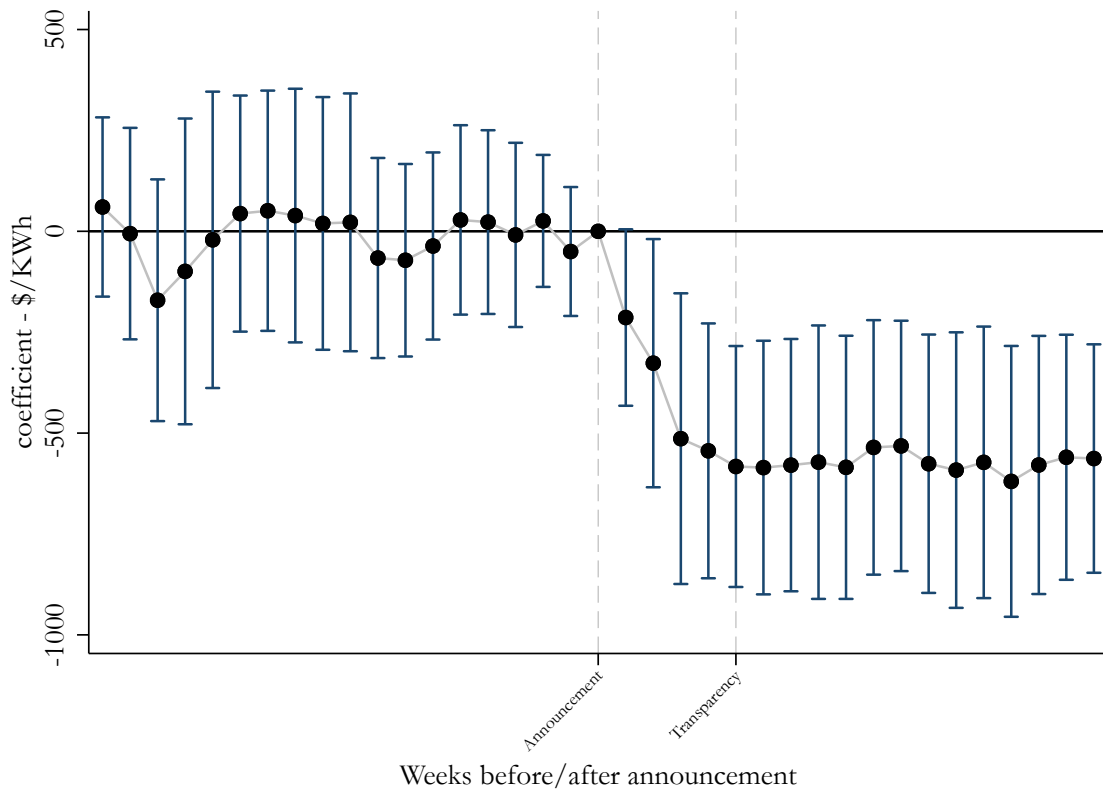


Figure 4: Event study representation of the differences-in-differences model.

Note: The figure presents the event study representation of the difference-in-difference model using the bid as the dependent variable. We performed a two-way fixed effects model including a specific treatment effect for each week of the period studied. Robust standard errors are clustered by unit. The x-axis represents weeks before and after the announcement of the transparency policy. The y-axis represents the difference in the coefficient of the bidding price with reference to the week of the announcement of the transparency policy. The black dots represent the estimated differences and the surrounding vertical lines represent the 95% confidence intervals. The dotted line labeled as “Announcement” represents the week of the announcement of the transparency policy. The dotted line labeled as “Transparency” represents the week of the implementation of the transparency policy.

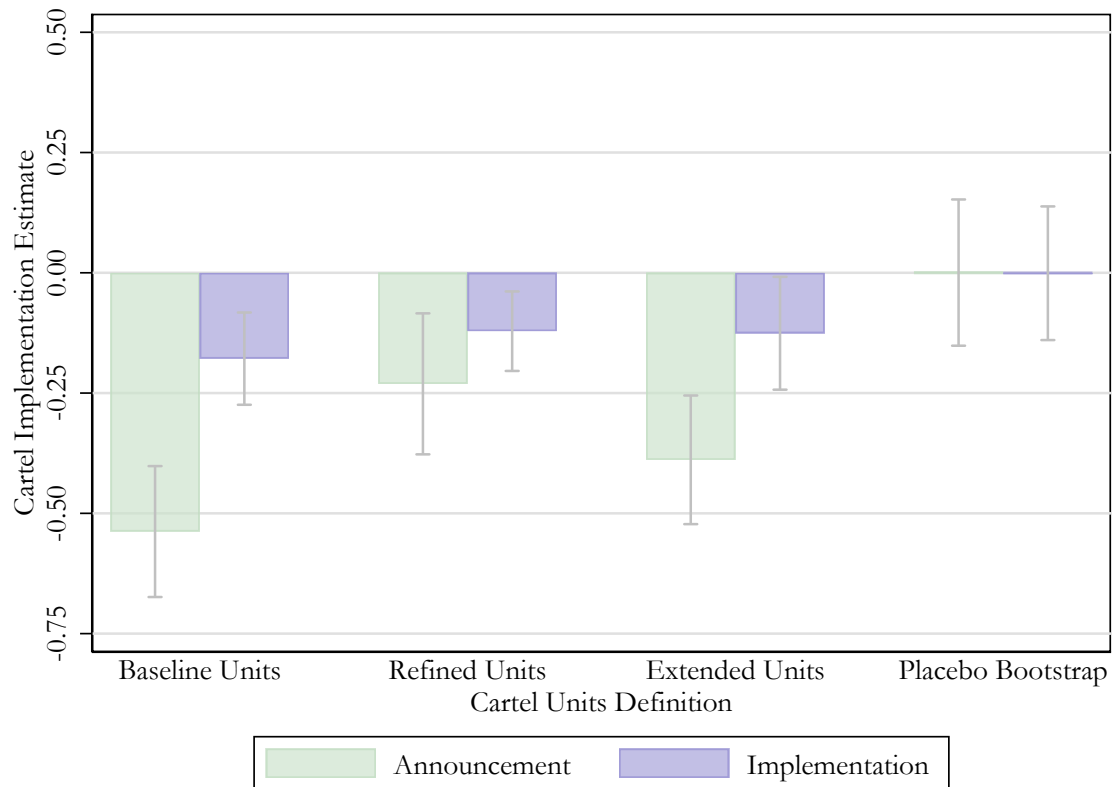


Figure 5: Robustness Exercises.

Note: The figure shows the coefficients and standard errors of the announcement and implementation parameters from 4 different estimations. Baseline units shows the 14 units we include in the main estimations. The refined units group only includes units (total treated=9) that belong to firms that has all their units in the cartel. The extended units group includes all of the units of firms for which at least one unit belong to the baseline cartel definition (total treated=22). Placebo test includes all of other units that are different from the extended units. For this exercise, the treated group consists of 14 units. All of the estimations control for Water Intake, Coal Price and Colombian Guajira Index as well as a battery of unit and date fixed effects.

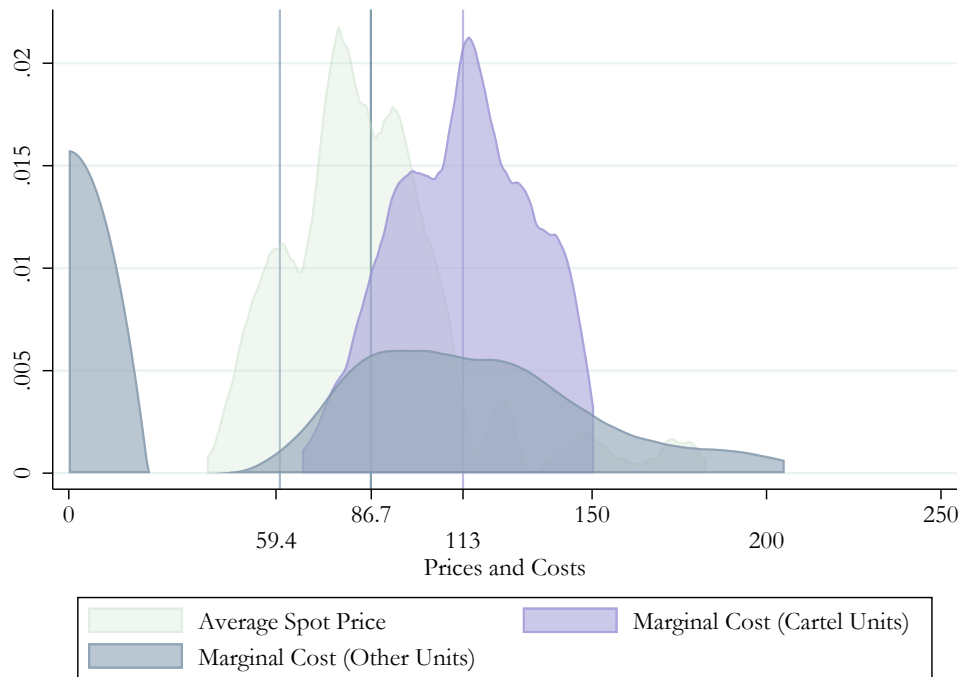


Figure 6: Competitiveness of the cartel and non-cartel units.

Note: The figure presents the kernel densities of the daily spot price (green shaded density), marginal cost of non-cartel units (grey shaded density) and cartel units (purple shaded density) for the second semester in the year 2008. The grey vertical line indicates the mean marginal cost for non-cartel units, the green vertical line denotes the average daily spot price and finally the purple vertical line denotes the average marginal cost for cartel units.

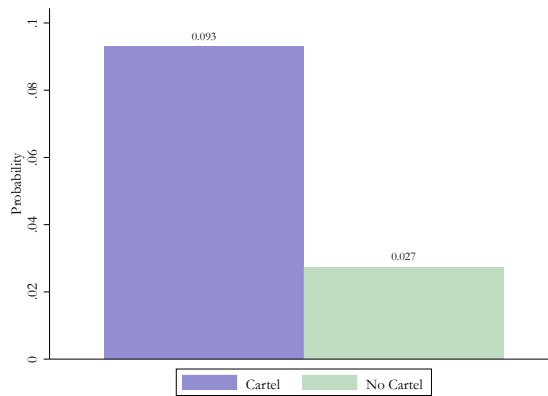
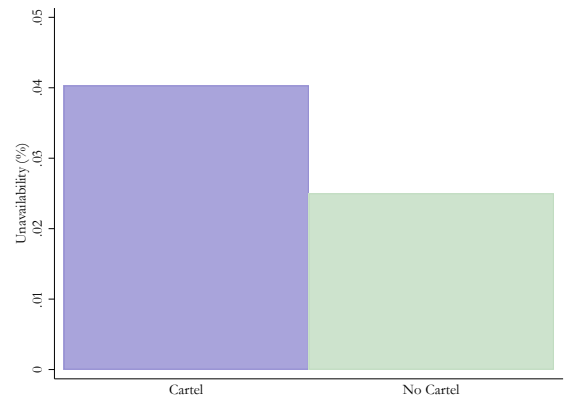
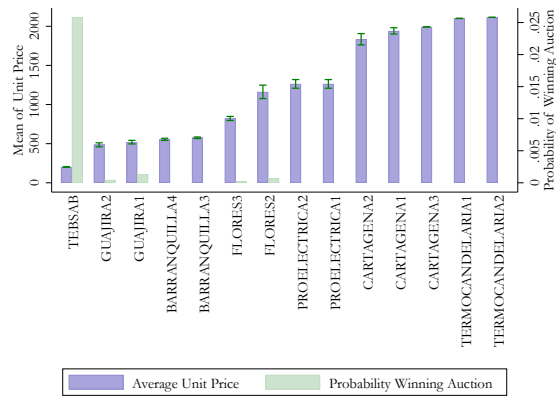


Figure 7: Inner Working of the Cartel

Note: The top left figure shows the average unit prices for the cartel units and their probability of winning the auction. The top right figure shows the fraction of unavailabilities over the total number of times that they have won in the auction for high and low bid cartel and non cartel firms. The bottom figure shows the probability that high price cartel units receive positive reconciliations when low price cartel units win, or low price no cartel units win. All of the graphs only use data for the second semester of 2008.

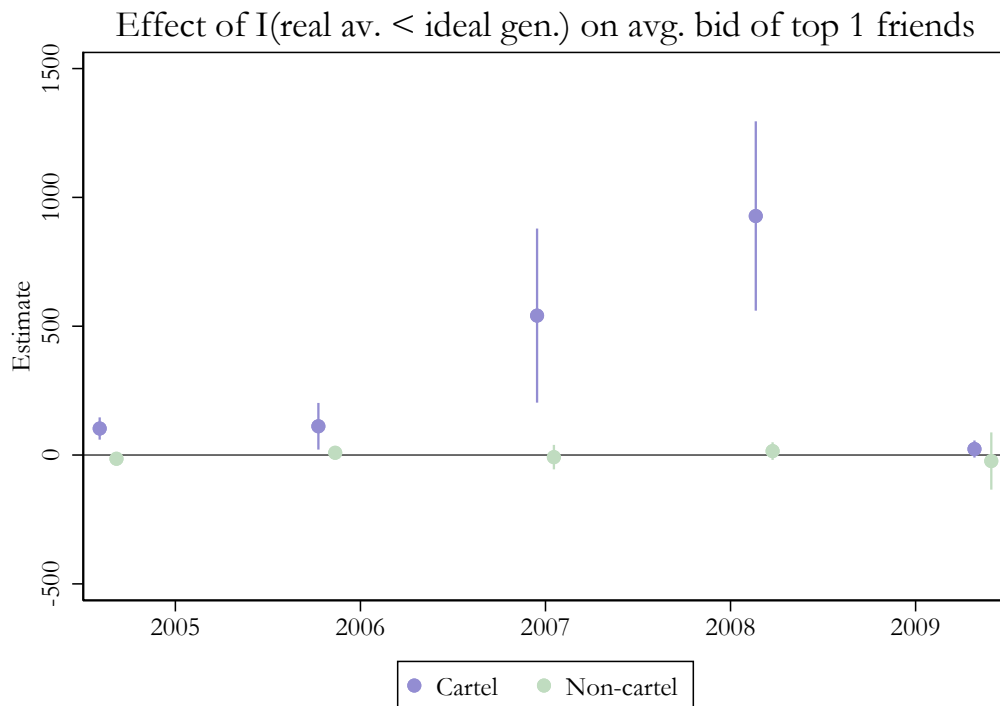


Figure 8: Baseline coordinated bids analysis.

Note: Estimates from a regression where the outcome variable is the average bid of the friends of unit i and the explanatory variables is an indicator for unit i declaring a level of real availability below the ideal generation quantity it was awarded. We run two separate regression for the two groups (cartel, non-cartel). The estimates for 2009 needs to be interpreted cautiously. Data on real availability is missing for 63% of cartel observations and for 6% of non-cartel observations in 2009.

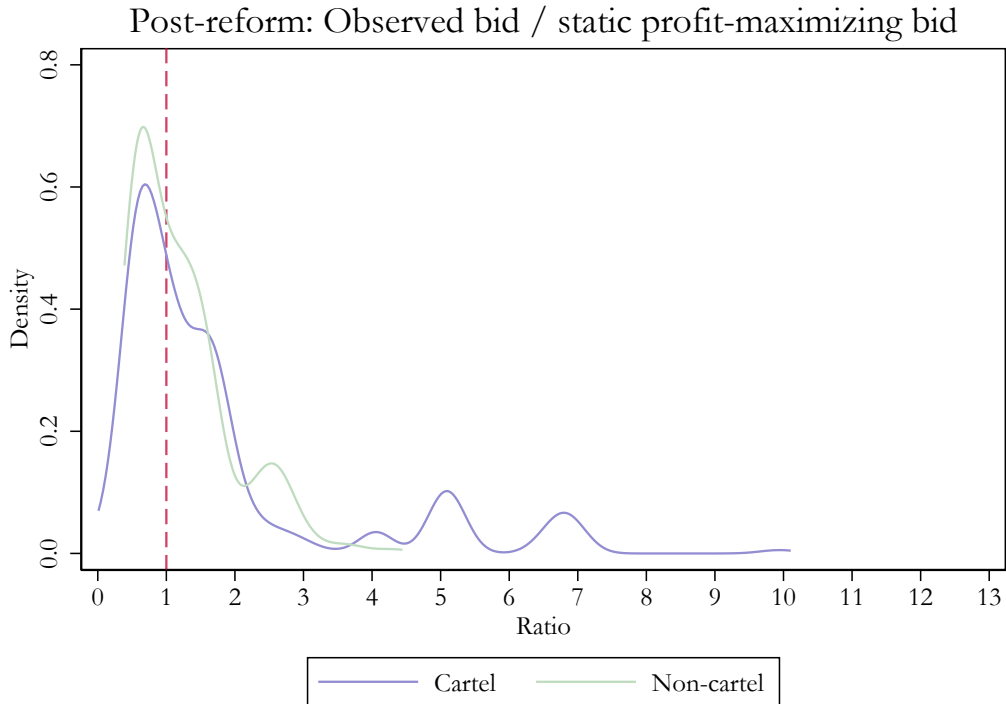
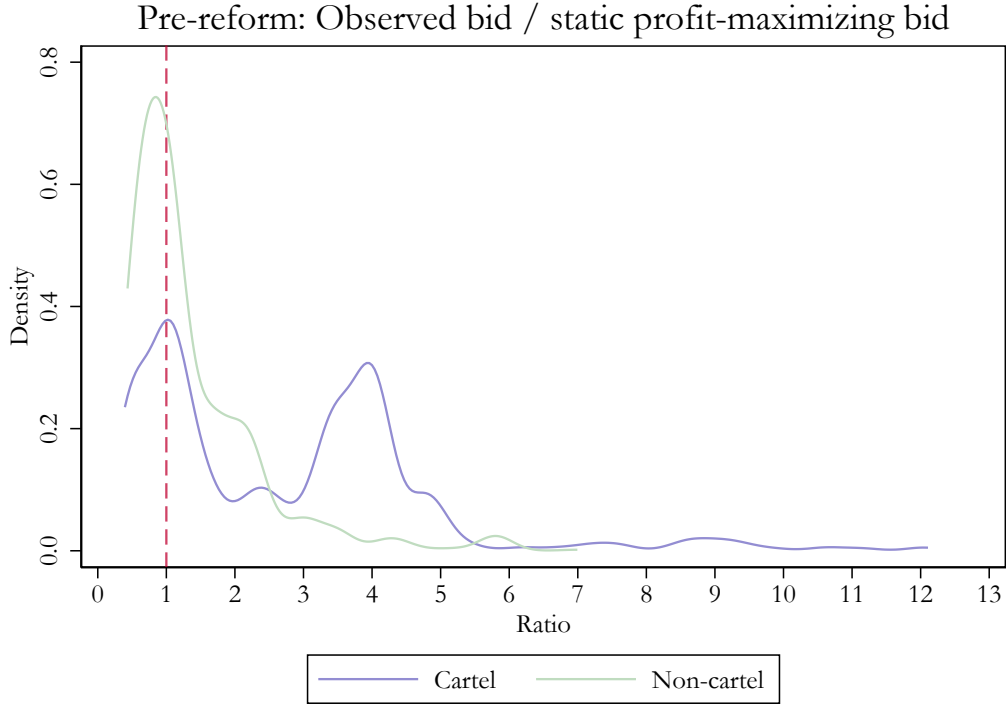


Figure 9: Density of the ratio between unit-daily observed and static profits maximizing bids for cartel and non-cartel units over two different six month periods.

Note: For cartel and non-cartel units, we simulate counterfactual bids and the corresponding amount of positive reconciliations and select the static profit maximizing bids. We then compare it with the observed bid: At the unit-day level, we compute the ratio between the observed bid and the profit maximizing bid. We plot the density of this ratio. The top figure presents the density using data from the six months before the policy change; the bottom figure refers to the six months after the policy change.

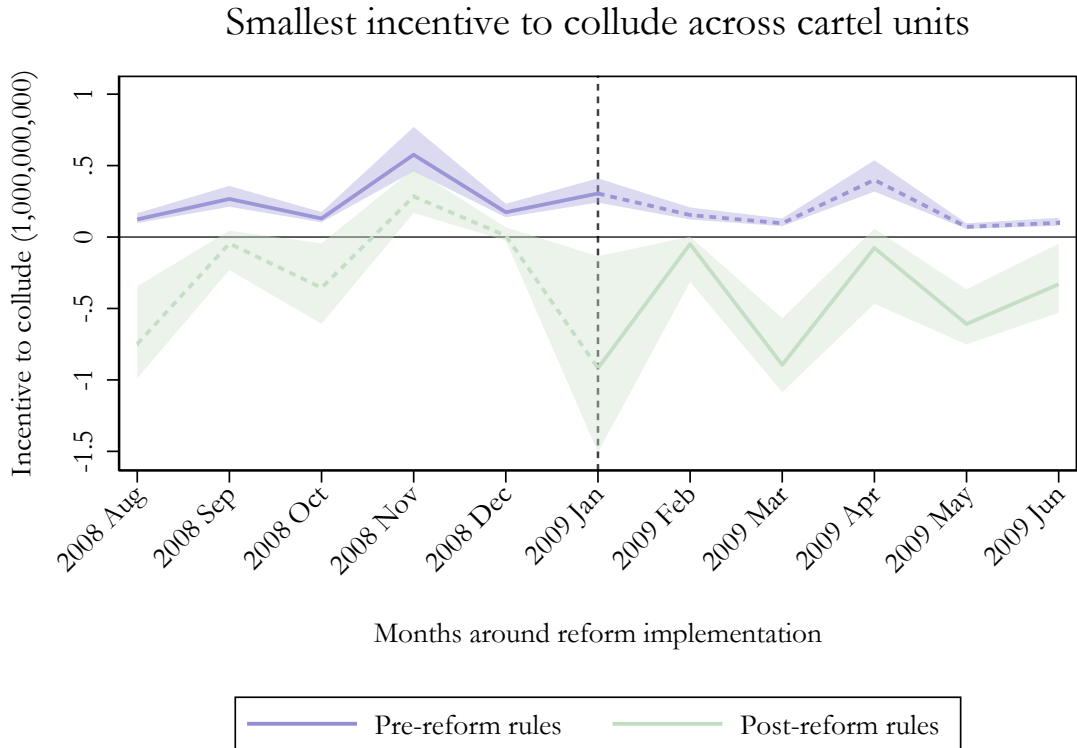


Figure 10: Smallest incentive to collude across cartel firms.

Note: For each cartel unit we compute the incentive to collude in each month from August 2008 to June 2009. The purple line shows the smallest incentive to collude across cartel units assuming that a unit can unilaterally deviate for two days before triggering competition; for the the green line we assume that a unit can deviate for 90 days. Under the pre-reform rules we use a solid line in the pre-reform period and a dashed line in the post-reform; the opposite is true for post-reform rules. The incentive to collude is computed assuming a daily discount factor $\beta = 0.9996$ ($0.9996^{365} = 0.86$). The shaded area presents the boundaries of the result when the calculation is based on a discount factor of 0.9995 or 0.9997.

Cost of positive reconciliations

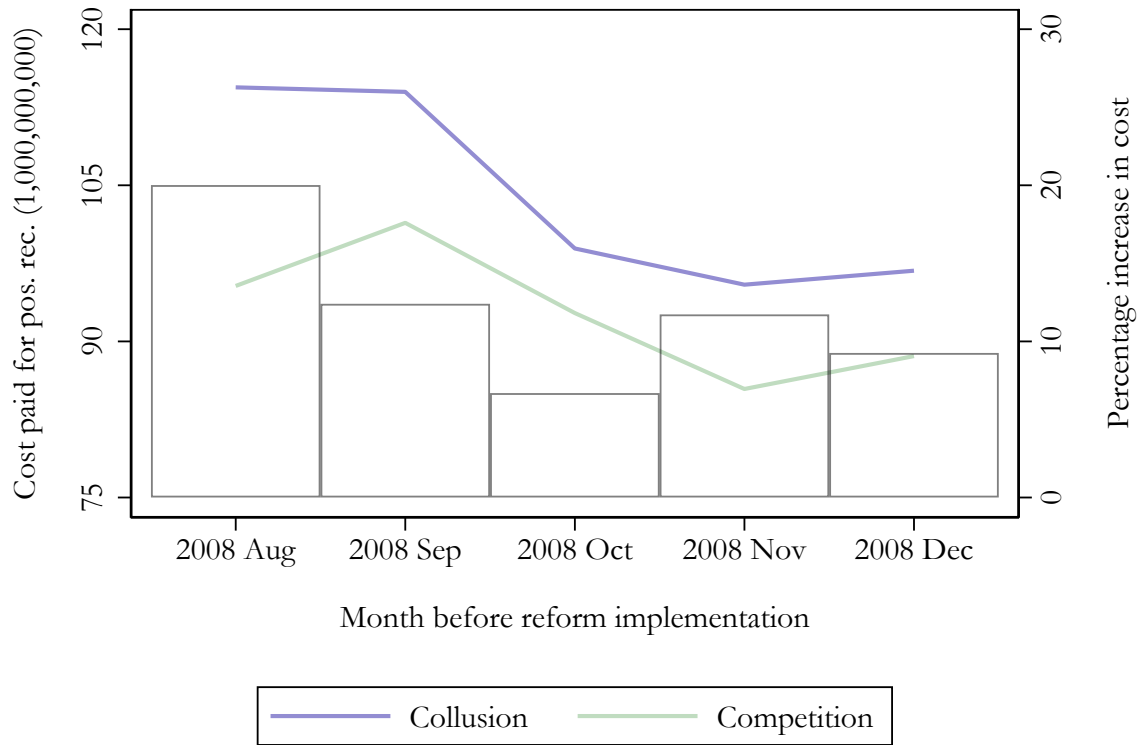


Figure 11: Total cost of positive reconciliations paid to cartel and non-cartel units under collusion and competition.

Note: The purple line (scale on the left axis) represents the total cost paid to cartel and non-cartel units for positive reconciliations in every month between August and December 2008. The green line (scale on the left axis) represents the counterfactual cost assuming cartel units were competing rather than colluding. The bars (scale on the right axis) present the percentage increase in the cost paid for positive reconciliations with respect to the competitive scenario.

8 Tables

Variable(Unit)	Before 06/01/2009						
	Cartel			No Cartel			
	Obs	Mean	SD	Obs	Mean	SD	T-Test
Bid(COP/KWh)	2212	1213.57	714.17	5214	362.06	557.36	49.99***
Ratio forward contracts/availability(Percentage)	2212	0.27	0.25	5046	0.66	1.17	-22.76***
Probability positive reconciliation(probability)	2212	0.13	0.31	5214	0.24	0.34	-13.50***
Average Positive reconciliation(KWh)	2212	22702.29	76145.57	5214	10127.97	29856.41	7.53***
Revenue from Positive reconciliation(Millions COP)	2212	107.76	347.30	5214	17.87	53.33	12.11***
Average Availability(KW)	2212	126946.42	164209.28	5214	282285.07	299716.71	-28.64***
Estimated Marginal Cost(COP/KWh)	2212	113.22	19.07	5214	60.55	63.09	54.69***
Variable(Unit)	After 06/01/2009						
	Cartel			No Cartel			
	Obs	Difference	T-Test	Obs	Difference	T-Test	T-Test
Bid(COP/KWh)	2898	-631.84	35.70***	6831	-73.00	7.65***	27.38***
Ratio forward contracts/availability(Percentage)	2898	0.01	-1.35	6799	0.26	-9.51***	-28.86***
Probability positive reconciliation(probability)	2898	0.01	-1.39	6831	0.04	-5.47***	-18.23***
Average Positive reconciliation(KWh)	2898	-3157.89	1.51	6831	2263.29	-3.64***	5.12***
Revenue from Positive reconciliation(Millions COP)	2898	-36.15	4.10***	6831	5.94	-5.17***	9.75***
Average Availability(KW)	2898	8199.63	-1.71*	6831	731.54	-0.13	-30.20***
Estimated Marginal Cost(COP/KWh)	2898	-27.14	50.93***	6831	-7.95	7.22***	44.44***

Table 1: Descriptive Statistics

Note: The table presents the descriptive statistics of the cartel and non-cartel groups for two different period before and after the announcement of the policy. Columns 2 to 4 present information of the cartel group while columns 5 to 7 present information of the non-cartel group. The top panel presents information for the period 1st August of 2008 until 6th January of 2009. The bottom panel starts on the 6th January of 2009 and ends 31st July 2009.

VARIABLES	(1) LnBid	(2) LnBid	(3) LnBid	(4) LnBid	(5) LnBid	(6) LnBid
Cartel Announcement	-0.54*** (0.13)	-0.54*** (0.14)	-0.54*** (0.13)	-0.54*** (0.14)	-0.36** (0.13)	-0.63*** (0.12)
Cartel Implementation	-0.18** (0.08)	-0.18* (0.10)	-0.18** (0.08)	-0.18* (0.10)	-0.03 (0.12)	-0.08 (0.05)
Announcement	-0.01 (0.06)		-0.02 (0.06)	-0.02 (0.07)		
Implementation	-0.12 (0.08)		-0.07 (0.06)	-0.07 (0.08)		
Observations	17,155	17,155	17,155	17,155	16,955	16,955
R-squared	0.29	0.82	0.29	0.81	0.83	0.84
Unit FE	NO	YES	NO	YES	YES	YES
Date FE	NO	YES	NO	NO	NO	NO
Inputs Control	NO	NO	YES	YES	NO	NO
Demand Control	NO	NO	YES	YES	NO	NO
Date x Technology FE	NO	NO	NO	NO	YES	NO
Date x Region FE	NO	NO	NO	NO	NO	YES
Forward Control	NO	NO	NO	NO	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Table 2: Difference-in-difference estimates

Note: The table presents the estimation results of the difference in difference model proposed in expression 1 in sub-section 3.4 using the logarithm of the bid as the dependent variable. Columns 3 and 4 control for Coal Price, Water Intake, Guajira Index, and Demand. Last Column further controls for forward contracts over total capacity. Robust standard errors clustered by unit and date in parenthesis.

VARIABLES	(1) LnBid	(2) LnBid	(3) LnBid	(4) LnBid	(5) LnBid	(6) LnBid	(7) LnBid	(8) LnBid	(9) LnBid	(10) LnBid
Cartel Announcement	-0.54*** (0.14)	-0.36** (0.13)	-0.48*** (0.12)	-0.27* (0.14)	-0.49*** (0.14)	-0.33** (0.13)	-0.63*** (0.13)	-0.49*** (0.14)	-0.67*** (0.14)	-0.54*** (0.14)
Cartel Implementation	-0.18* (0.10)	-0.03 (0.12)	-0.15 (0.11)	0.09 (0.21)	-0.18* (0.10)	-0.06 (0.12)	0.03 (0.13)	0.16 (0.13)	0.02 (0.15)	0.12 (0.14)
Observations	17,155	16,955	17,155	16,955	17,155	16,955	17,155	16,955	17,155	16,955
R-squared	0.82	0.83	0.82	0.83	0.82	0.83	0.81	0.83	0.81	0.84
Unit FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Date FE	YES	YES	YES	YES	YES	YES	YES	YES	YES	YES
Date x Technology FE	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES
Forward Control	NO	YES	NO	YES	NO	YES	NO	YES	NO	YES
Cartel Definition	1	1	2	2	3	3	4	4	5	5

*** p<0.01, ** p<0.05, * p<0.1

Table 3: Difference in Difference Estimations for Alternative Cartel Definitions

The table presents the estimation results of the difference in difference model proposed, using the logarithm of the bid as the dependent variable. Column 1 controls for unit and Date Fixed effects. Column 2 controls for Date x Technology Fixed Effects and forward contracts. The next columns have similar patterns. Cartel 1 is baseline. Cartel 2 comes from using PCA to Atlantic, Thermal, and Private. Cartel 3 comes from using PCA to Atlantic, Thermal, and Forward Contracts. Cartel 4 comes from using PCA to Atlantic, Thermal, and Bid slope. And Cartel 5 comes from using PCA to Atlantic, Thermal, Forward Contracts, and Bid slope. Robust standard errors clustered by unit and date in parenthesis.

VARIABLES	(1) LnRevenues	(2) LnRevenues	(3) LnProfits	(4) LnProfits
Ln(Bid)	13.41*** (2.96)	13.16*** (2.95)	16.68*** (3.73)	16.52*** (3.67)
Ln(Bid) 2	-1.06*** (0.25)	-1.05*** (0.25)	-1.29*** (0.31)	-1.28*** (0.30)
Observations	991	991	907	907
R-squared	0.67	0.68	0.68	0.69
Unit FE	YES	YES	YES	YES
Date FE	YES	NO	YES	NO
Inputs Control	NO	NO	NO	NO
Demand Control	NO	NO	NO	NO
Date x Technology FE	NO	YES	NO	YES
Date x Region FE	NO	NO	NO	NO
Forward Control	NO	YES	NO	YES

*** p<0.01, ** p<0.05, * p<0.1

Table 4: Revenues and Profits from Positive Reconciliations

The table presents the estimation results of the linear regression models proposed in 4.1 using the logarithm of the daily revenues (and profits) from positive reconciliation as the dependent variable. The sample is restricted to the observations with positive values of positive reconciliations. All the columns control for unit fixed effects. Columns (1) and (3) includes additional controls for Date Fixed Effects. Columns (2) and (4) control for Technology x Date and levels of forward contracts. Robust standard errors clustered by unit and date in parenthesis.

	(1)	(2)	(3)
	Ln(Bid)	Probability Positive R (t-1)	Ln(Bid)
Probability Rec.Pos ($t - 1$)	-0.199 (0.130)		0.620*** (0.168)
Security Contingencies ($t - 1$)		0.113*** (0.0225)	
Observations	17,087	17,087	17,087
R-squared	0.838	0.539	-0.135
Unit F.E.	YES	YES	YES
Date F.E.	YES	YES	YES
Sample	2008	2008	2008
Estimation	OLS	First Stage	Second Stage
Kleibergen-Paap F	-	25.369	-

*** p<0.01, ** p<0.05, * p<0.1

Table 5: Positive Reconciliations and Electric Network Contingencies

Note: The table presents the two-stage instrumental variables regression of the logarithm of the bid price on the first lag of the probability of positive reconciliation for the year 2008. The first column presents the results of the regression by OLS. The second column presents the first stage of the estimation. We use the security contingencies in the transmission system as instruments of the lag of the probability of positive reconciliation. The coefficient estimate of this column is multiplied by 10.000 to facilitate interpretation. The last column presents the second stage of the estimation. All the columns control by Unit and Date fixed effects. The Probability of positive reconciliation in day t : is the *mean* across the hourly dummies $DummyPR_{iht}$. Robust standard errors clustered by unit in parenthesis.

VARIABLES	(1) Someone	(2) Someone	(3) Someone Commercial	(4) Someone Commercial
Cartel x 2009	-0.188 (0.165)	-0.146 (0.162)	-0.316* (0.180)	-0.331* (0.184)
Regulator Presence		0.483*** (0.110)		-0.167** (0.0706)
Observations	399	399	399	399
R-squared	0.629	0.659	0.518	0.525
Unit FE	YES	YES	YES	YES
Meeting FE	YES	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Table 6: Meetings Minutes Evidence

Note: The table presents the relationship between having someone or someone from commercial area on two variables: an interaction term cartel*post and the regulator presence. Cartel takes the value of 1 for the units classified in the baseline collusive agreement and 0 otherwise. Post is 1 for minutes in 2009 and 0 otherwise. The dummy regulator presence takes the value of 1 when the minute reports having at least one regulator. Robust standard errors clustered by unit in parenthesis.

VARIABLES	(1) Dummy for PR	(2) Profits from PR	(3) Total profits
Cartel Post	0.02 (0.05)	-135.88** (62.01)	-74.29*** (21.80)
Observations	17,155	6,721	17,155
R-squared	0.43	0.68	0.79
Unit FE	YES	YES	YES
Date FE	YES	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Table 7: Effects of announcement on profits

Note: The table presents difference in differences estimates controlling for unit and time fixed effects, where the Post period refers to the period after the policy announcement. Column 1 presents the estimates for the probability of receiving positive reconciliations. Column 2 presents the estimates for the profits from positive reconciliations, conditional on receiving some positive reconciliations. Column 3 presents the estimates for the total profits (unconditional). Robust standard errors clustered by unit and date in parenthesis.

VARIABLES	(1) Profits from PR	(2) Total profits	(3) Profits from PR	(4) Total profits	(5) Profits from PR	(6) Total profits
Cartel High Post	-66.25** (27.57)	-89.11*** (21.05)	-67.85 (43.90)	-83.41*** (21.21)	-91.02** (37.14)	-85.83*** (21.20)
Cartel Low Post	-153.99** (70.56)	-59.47** (22.92)	-146.13** (67.52)	-65.17*** (23.66)	-141.78** (68.01)	-62.75*** (23.35)
Observations	6,721	17,155	6,721	17,155	6,721	17,155
R-squared	0.69	0.79	0.68	0.79	0.68	0.79
Unit FE	YES	YES	YES	YES	YES	YES
Date FE	YES	YES	YES	YES	YES	YES
Split high/low	Mg. Cost	Mg. Cost	Bid	Bid	Neg. Rec.	Neg. Rec.

*** p<0.01, ** p<0.05, * p<0.1

Table 8: Effects of announcement on profits

Note: The table presents difference in differences estimates controlling for unit and time fixed effects, where the Post period refers to the period after the policy announcement, for two outcome variables: The profits from positive reconciliations, conditional on receiving some positive reconciliations, and the total profits (unconditional). We split the cartel group in two using different measures. In columns 1-2, 'high' units are those with average marginal cost in the second half of 2008 above the median, and 'low' otherwise. In columns 3-4, 'high' units are those with average bids in the second half of 2008 above the median, and 'low' otherwise. In columns 5-6, 'high' units are those with average amount of negative reconciliations *below* the median in the second half of 2008, and 'low' otherwise. Robust standard errors clustered by unit and date in parenthesis.

A Appendix: Additional Figures and Tables

A.1 Figures

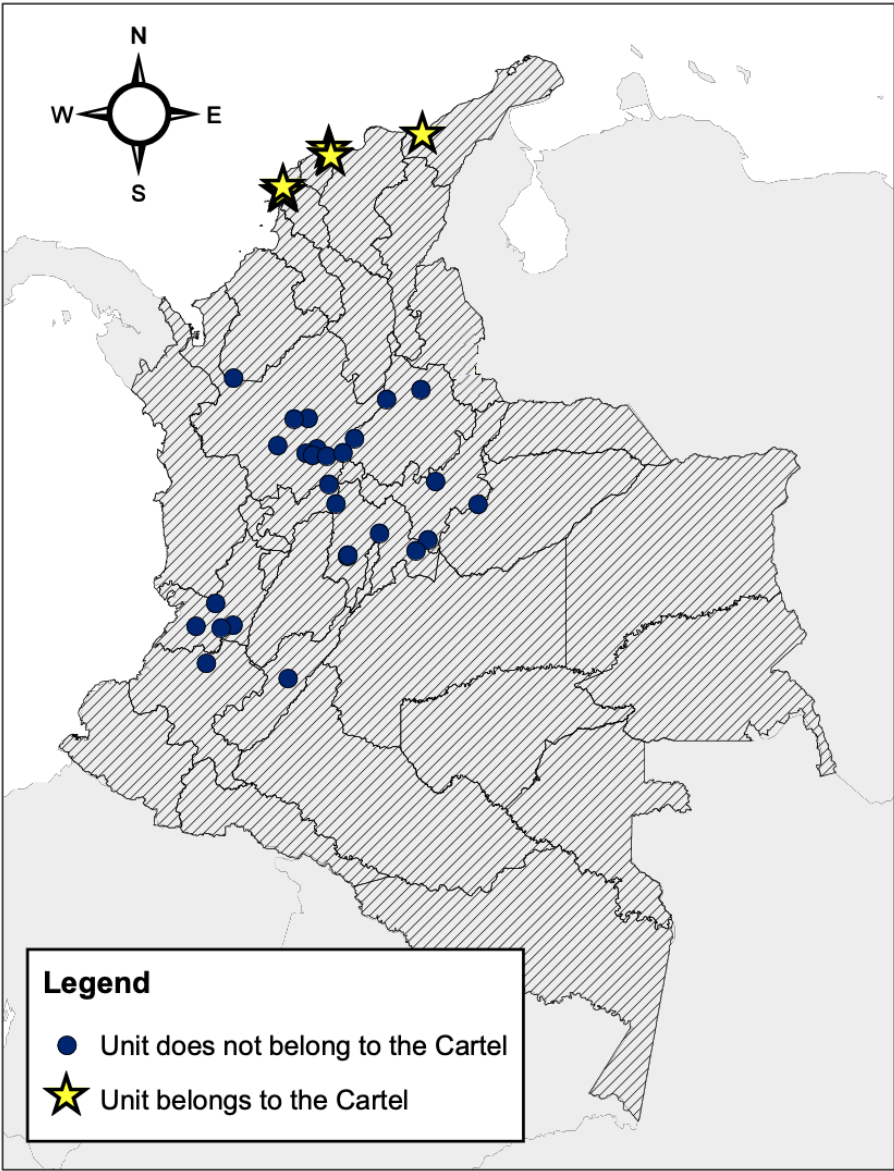


Figure A1: Geographical location of cartel units.

Note: The figure presents Colombia's map and the location of the electricity generation units participating in the wholesale electricity market. The dark shaded area represents Colombian territory. The black thick line represents the division of the country in political units called "departamentos". The star shaped yellow marks locate the cartel generation units and the circle shaped blue marks locate the non-cartel units.

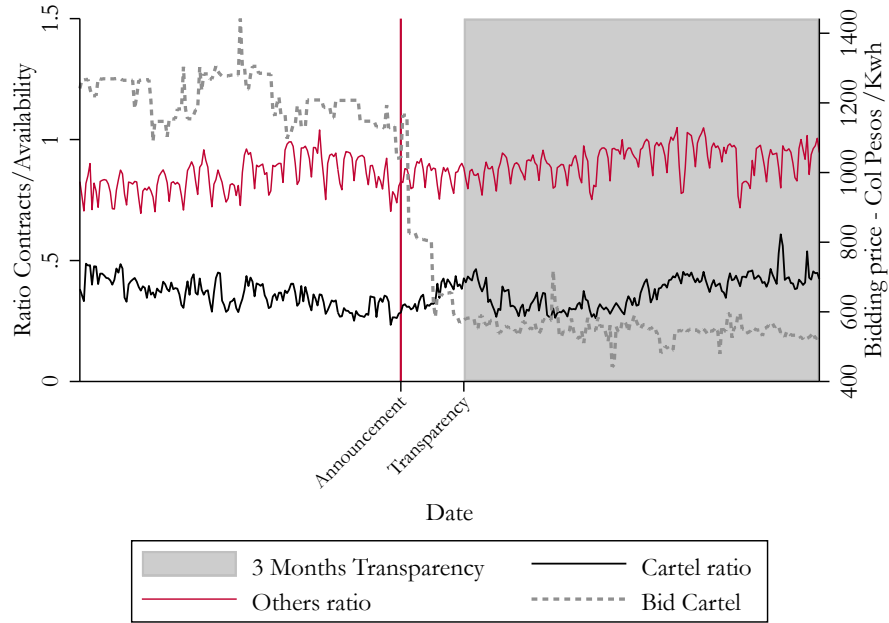


Figure A2: Time Series of Forward Contracts for Cartel and Non-Cartel Members

Note: The figure presents the time series of the portion of capacity sold through forward contracts of the cartel and non-cartel groups around the dates of announcement and implementation of the transparency policy. The shaded area represents the period with the transparency policy in place. The black line represents the cartel group time series, the red line represents the non-cartel group time series and the dotted line represents the average bidding price for the cartel group.

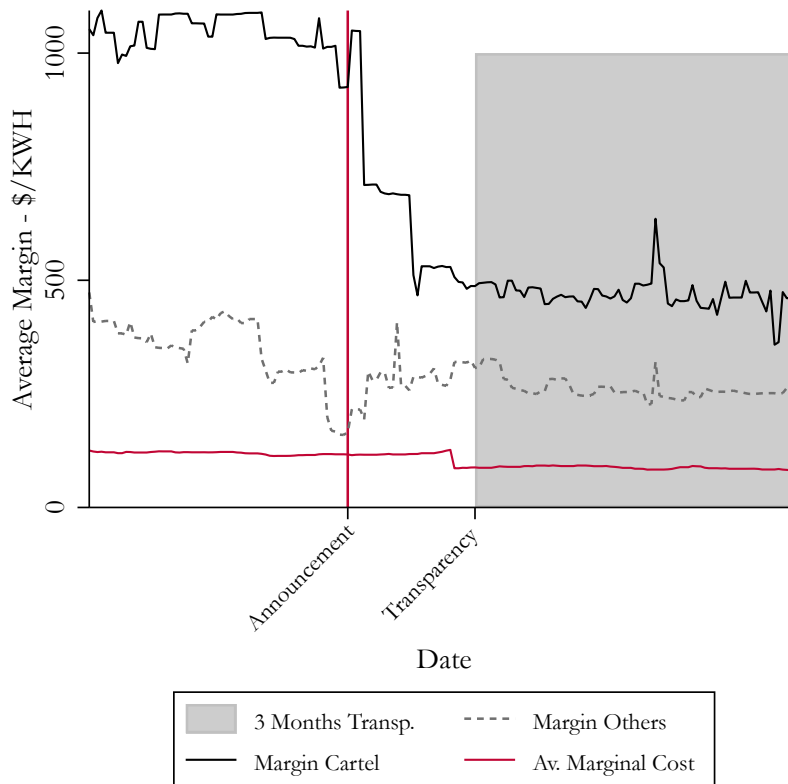


Figure A3: Average margin time series.

Note: The figure presents the time series of the average margin of the cartel (solid black line) and non-cartel (dotted grey line) groups around the dates of announcement and implementation of the transparency policy (From November 2008 to April 2009). The margin is computed as the difference of the bid minus the marginal cost. It also presents the time series of the average marginal cost of the cartel units (solid red line). The shaded area represents the period with the transparency policy in place.

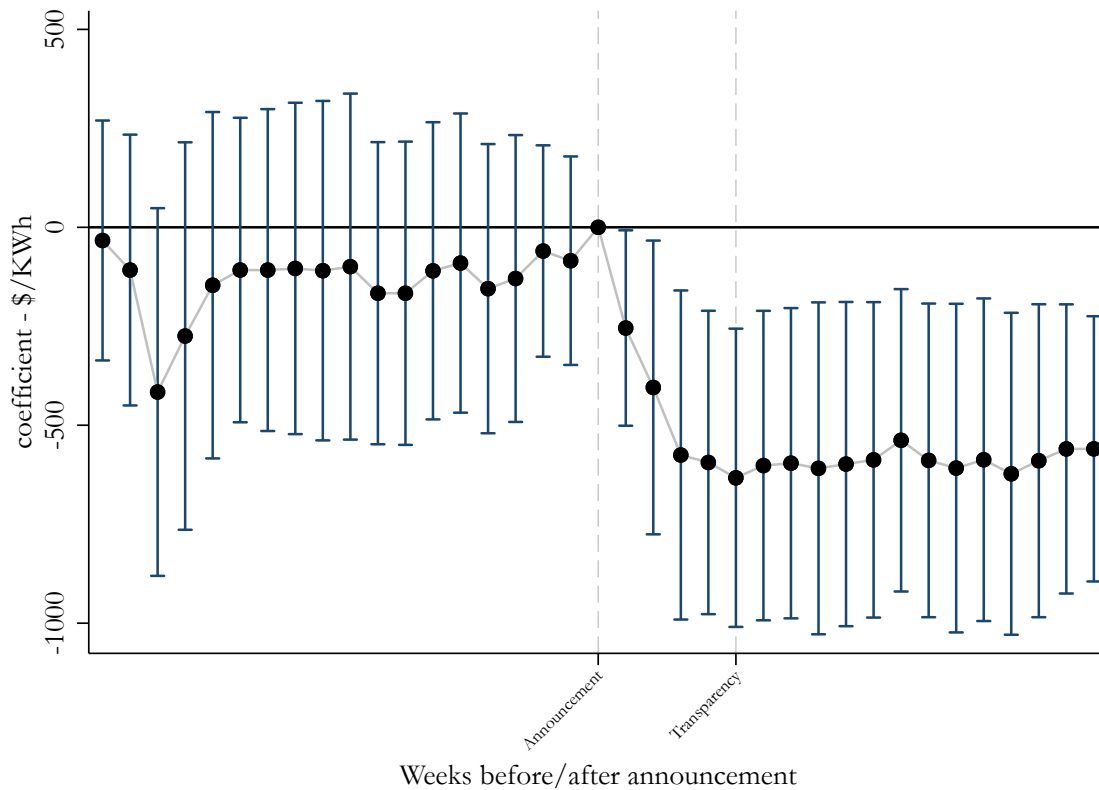


Figure A4: Event study representation using margin as the dependent variable

Note: The figure presents the event study representation of the difference-in-difference model using the margin as the dependent variable. The margin is computed as the difference of the bid minus the marginal cost. Only thermal units are included in the sample. We performed a two-way fixed effects model including a specific treatment effect for each week of the period studied. Robust standard errors are clustered by unit. The x-axis represents weeks before and after the announcement of the transparency policy. The y-axis represents the difference in the bidding price with reference to the week of the announcement of the transparency policy. The black dots represent the estimated differences and the surrounding vertical lines represent the 95% confidence intervals. The zero (omitted) coefficient corresponding to the week of the announcement of the transparency policy is not presented in the figure. The dotted line labeled as "Announcement" represents the week of the announcement of the transparency policy. The dotted line labeled as "Transparency" represents the week of the implementation of the transparency policy.

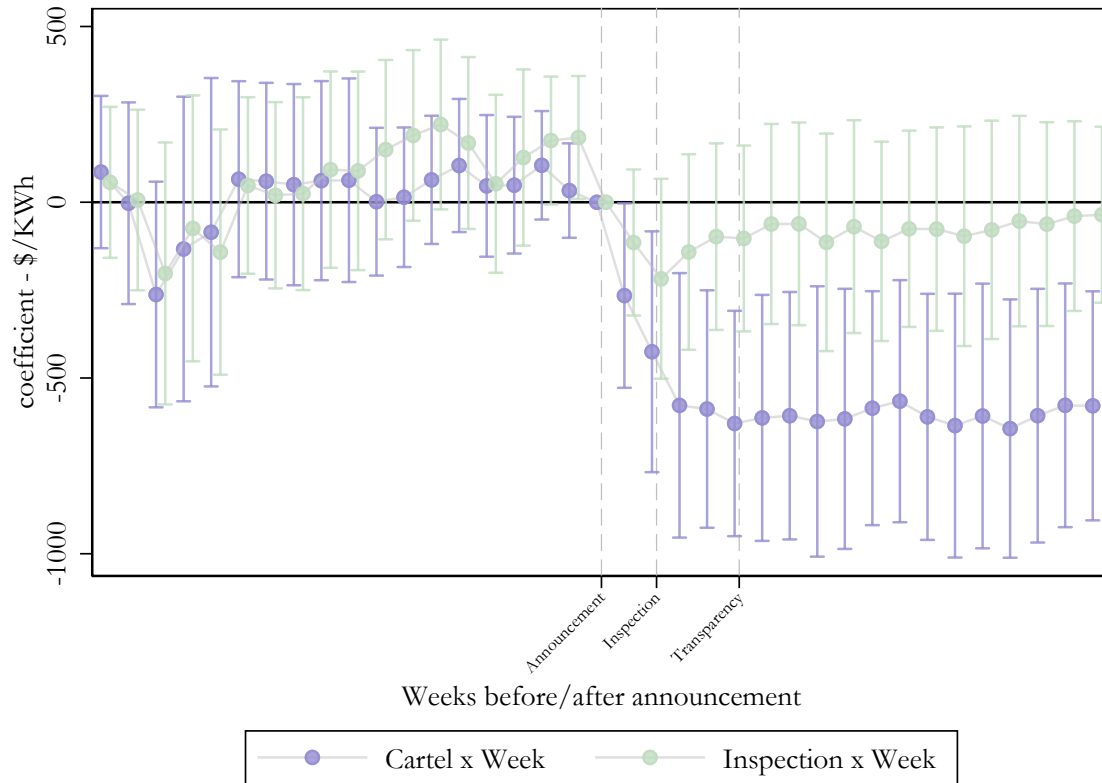


Figure A5: Event study representation of the differences-in-differences model.

Note: The figure presents the event study representation of the difference-in-difference model using the bid as the dependent variable and the event study of the inspection sites. We performed a two-way fixed effects model including a specific treatment effect for each week of the period studied. Robust standard errors are clustered by unit. The x-axis represents weeks before and after the announcement of the transparency policy and weeks before and after the inspection. The y-axis represents the difference in the coefficient of the bidding price with reference to the week of the announcement of the transparency policy. The dots represent the estimated differences and the surrounding vertical lines represent the 95% confidence intervals. The dotted line labeled as “Announcement” represents the week of the announcement of the transparency policy. The dotted line labeled as “Transparency” represents the week of the implementation of the transparency policy. Finally, the dotted line labeled as “Inspection” represents the week of the inspection (20th January 2009).

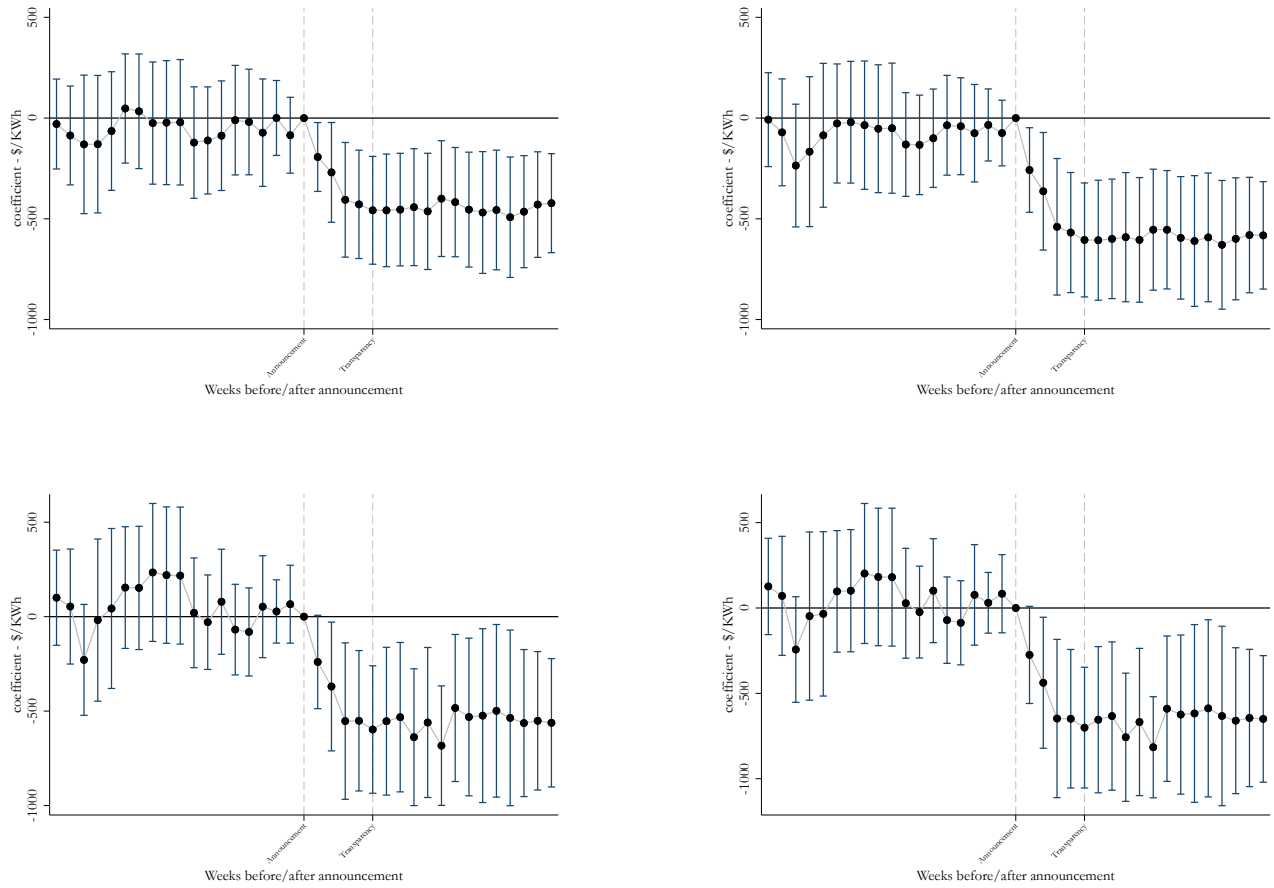


Figure A6: Event study representation for alternative cartel definitions

Note: Note: The figure presents the event study representation of the difference-in-difference model using the bid as the dependent variable. We performed a two-way fixed effects model including a specific treatment effect for each week of the period studied. Robust standard errors are clustered by unit. The x-axis represents weeks before and after the announcement of the transparency policy. The y-axis represents the difference in the bidding price with reference to the week of the announcement of the transparency policy. The black dots represent the estimated differences and the surrounding vertical lines represent the 95% confidence intervals. The zero (omitted) coefficient corresponding to the week of the announcement of the transparency policy is not presented in the figure. The dotted line labeled as “Announcement” represents the week of the announcement of the transparency policy. The dotted line labeled as “Transparency” represents the week of the implementation of the transparency policy. The sub-figure (a) shows the event study for cartel 2 (PCA on Atlantic, Thermal, and Private) definition. The sub-figure (b) shows the event study for cartel 3 (PCA on Atlantic, Thermal, and Forward Contracts) definition. The sub-figure (c) shows the event study for cartel 4 (PCA on Atlantic, Thermal, Private and Bid slope) definition. The sub-figure (d) shows the event study for cartel 5 (PCA on Atlantic, Thermal, Forward Contracts, Private and Bid slope) definition.

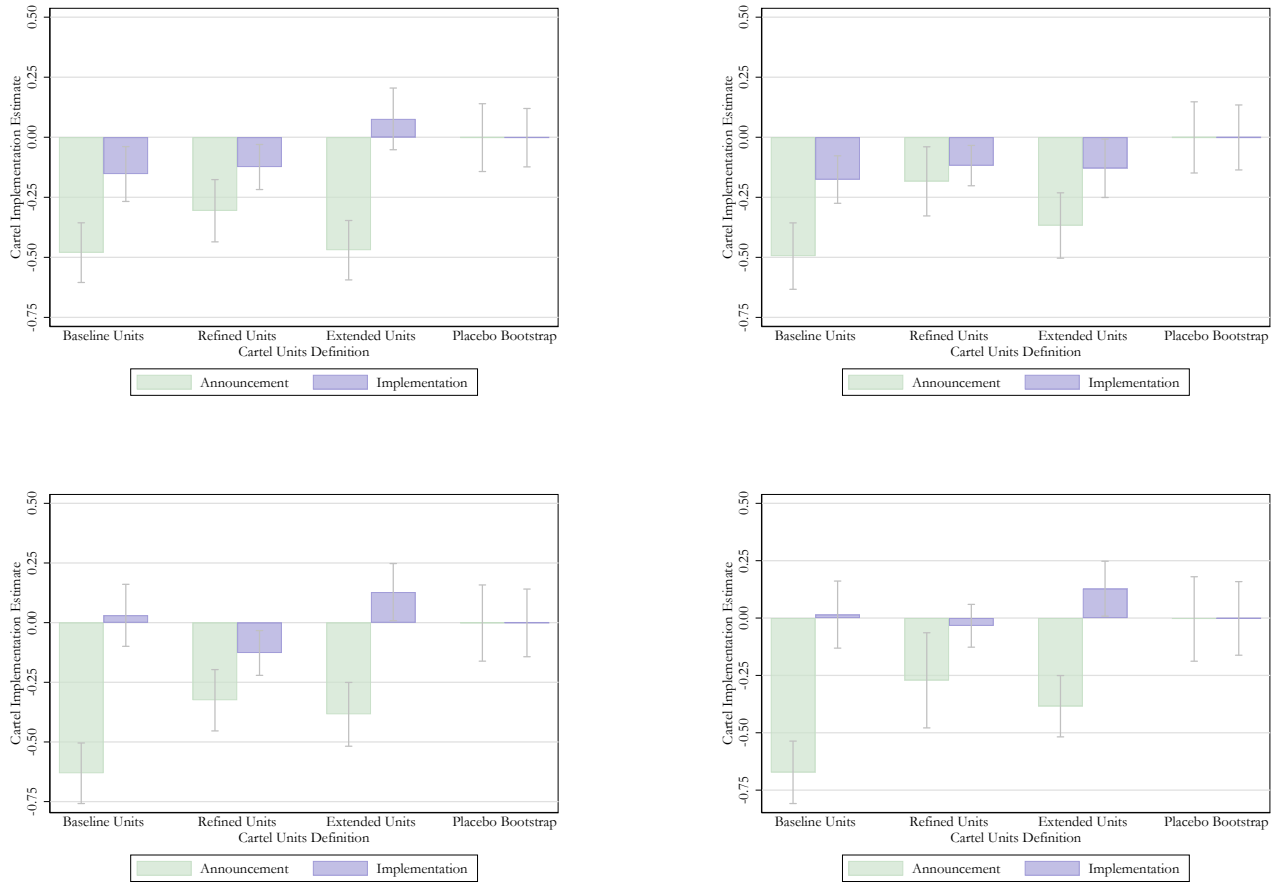


Figure A7: Refined and extended units from four cartel definitions

Note: The figure shows the coefficients and standard errors of the announcement and implementation parameters from 4 different estimations. Baseline units shows the units we include in the main estimations. The refined units group only includes units that belong to firms that has all their units in the cartel. The extended units group includes all of the units of firms for which at least one unit belong to the baseline cartel definition. Placebo test includes all of other units that are different from the extended units. All of the estimations control for Water Intake, Coal Price and Colombian Guajira Index as well as a battery of unit and date fixed effects. The sub-figure (a) shows the event study for cartel 2 (PCA on Atlantic, Thermal, and Private) definition. The sub-figure (b) shows the event study for cartel 3 (PCA on Atlantic, Thermal, and Forward Contracts) definition. The sub-figure (c) shows the event study for cartel 4 (PCA on Atlantic, Thermal, Private and Bid slope) definition. The sub-figure (d) shows the event study for cartel 5 (PCA on Atlantic, Thermal, Forward Contracts, Private and Bid slope) definition.

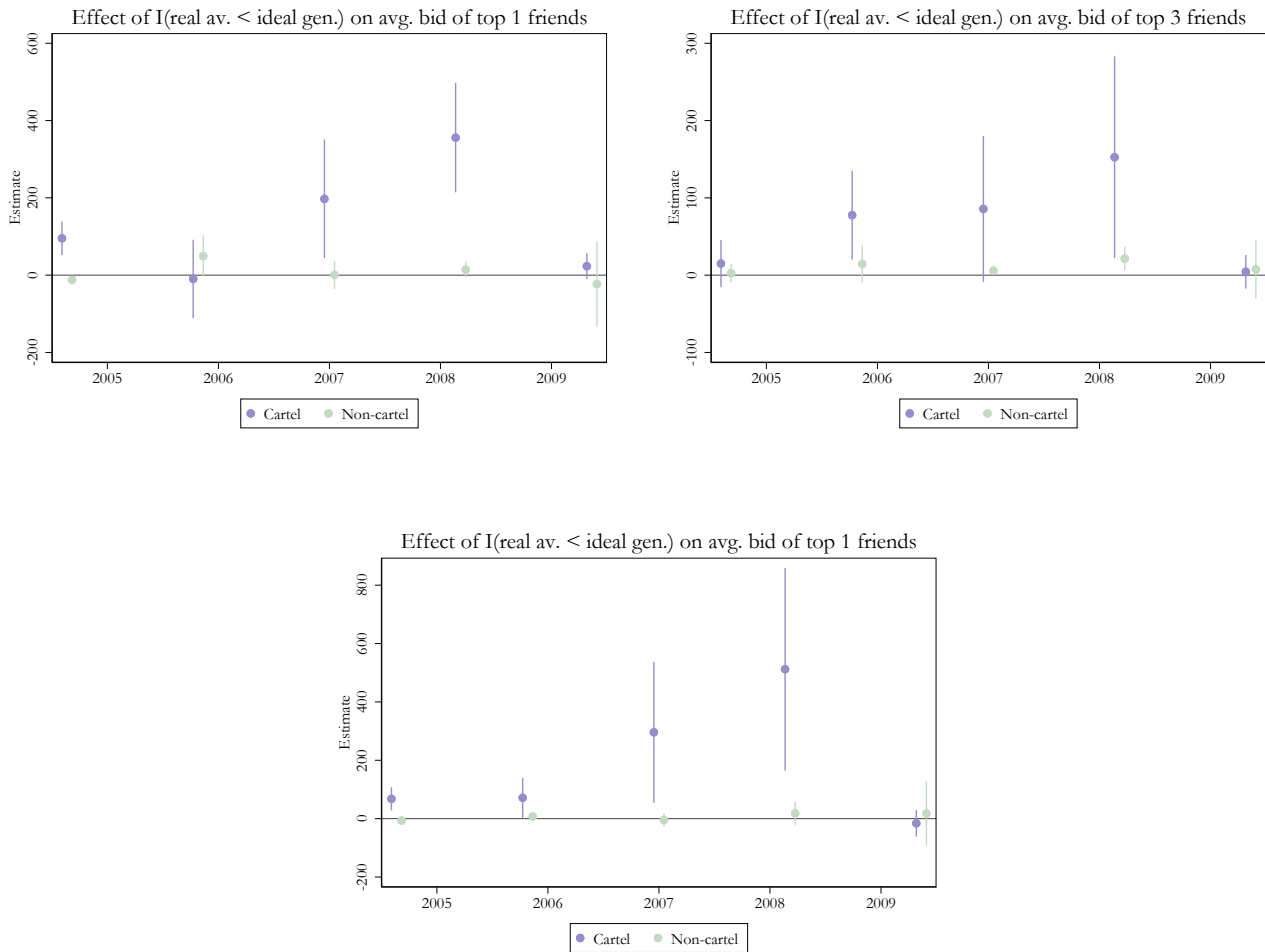


Figure A8: Robustness for coordinated bids analysis.

Note: Estimates from a regression where the outcome variable is the average bid of the friends of unit i and the explanatory variable is an indicator for unit i declaring a level of real availability below the ideal generation quantity it was awarded. We run two separate regressions for the two groups (cartel, non-cartel). Compared to the baseline analysis, we perform three robustness exercises. (i) In the top left panel, we still consider 'top 1' friends from the same period as in the baseline, but we also include cases when real availability is just slightly below ideal generation. (ii) In the top right panel, we consider the same period and same cases as in the baseline, but use the 'top 3' friends. (iii) In the bottom panel, we consider 'top 1' friends and the same cases as in the baseline, but we construct 'friends' using observations from a longer period (2005-2008) compared to the baseline. The estimates for 2009 need to be interpreted cautiously. Data on real availability is missing for 63% of cartel observations and for 6% of non-cartel observations in 2009.

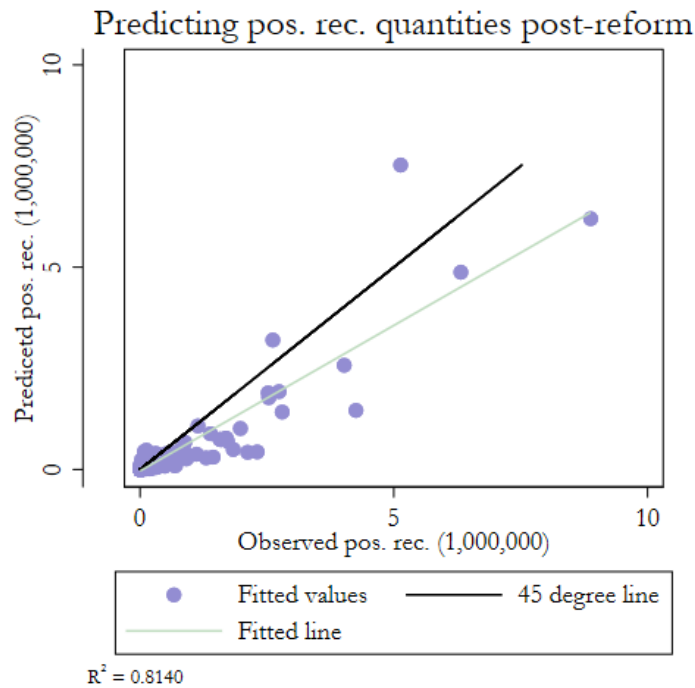
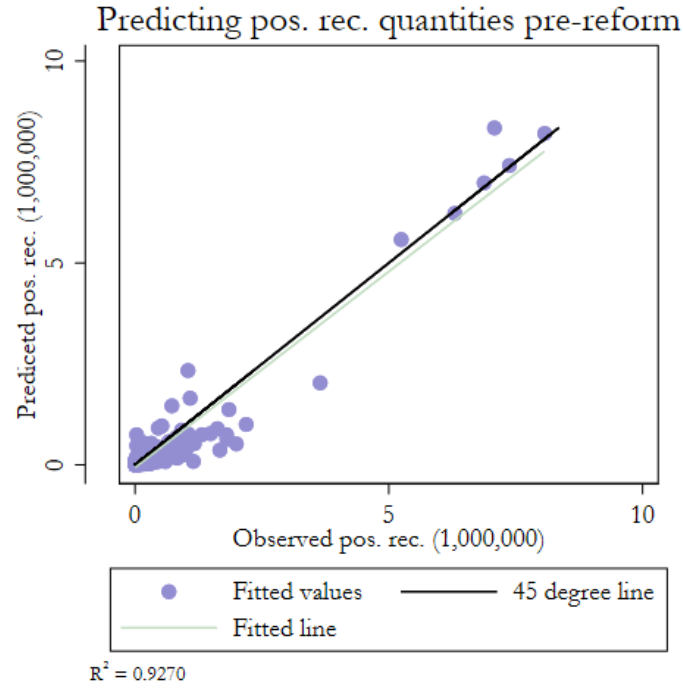


Figure A9: Comparing observed quantities of positive reconciliations with in-sample predictions for cartel and non-cartel units in the pre and post-reform periods.

Note: We use the method described in Section 5.1 to estimate how the quantity of positive reconciliation awarded to a unit depends on the rank of its bid. We use both cartel and non-cartel units in this exercise. We use these estimates to make in-sample prediction and average at the monthly level for each unit. We compare the average predicted quantity (y-axis) with the average observed one (x-axis). The left figure refers to observations from the six months before the reform; the right figure refers to the six months after the reform.

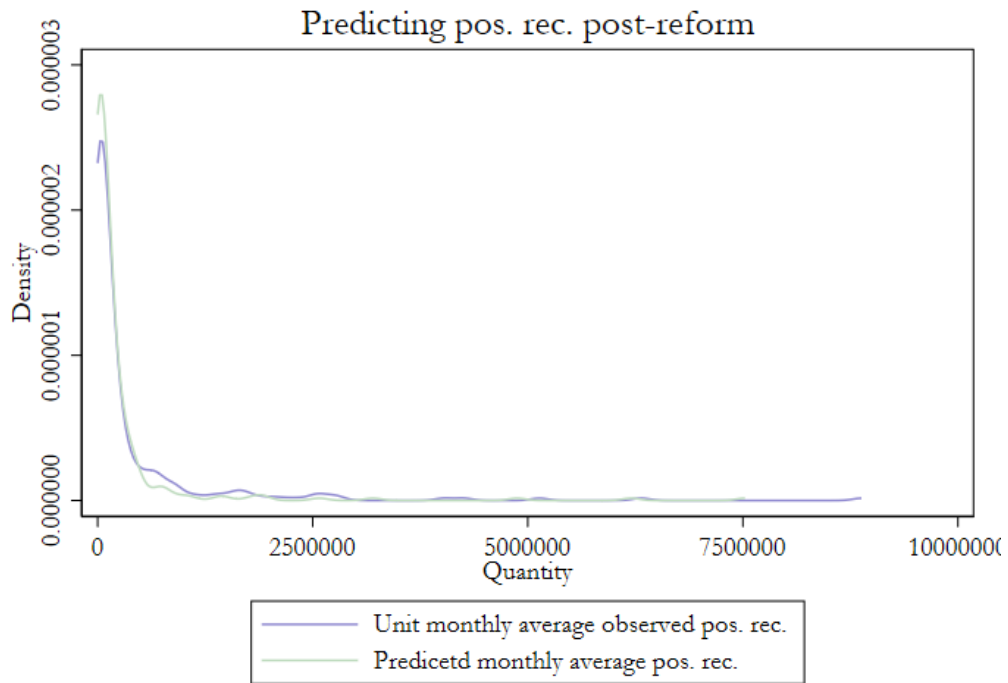
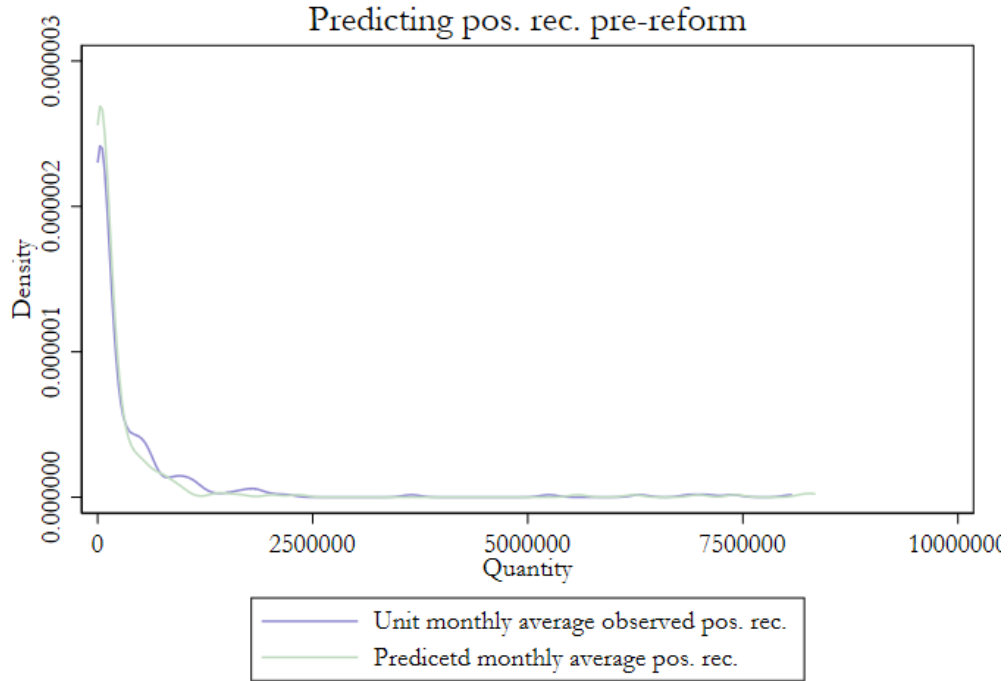


Figure A10: Comparing the distribution of observed quantities of positive reconciliations with in-sample predictions for cartel and non-cartel units in the pre and post-reform periods.

Note: We use the method described in Section 5.1 to estimate how the quantity of positive reconciliation awarded to a unit depends on the rank of its bid. We use both cartel and non-cartel units in this exercise. We use these estimates to make in-sample prediction and average at the monthly level for each unit. We compare the density of the average predicted quantity (orange line) with the density of the average observed one (green line). The left figure refers to observations from the six months before the reform; the right figure refers to the six months after the reform.

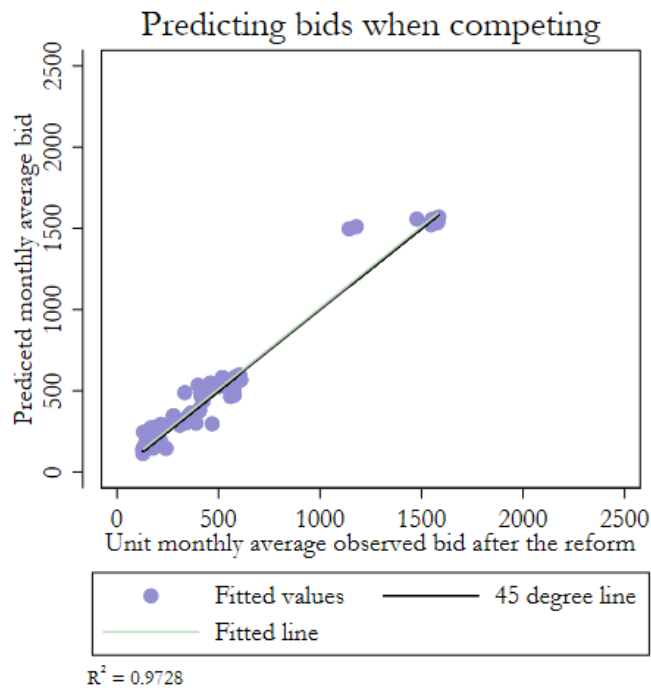
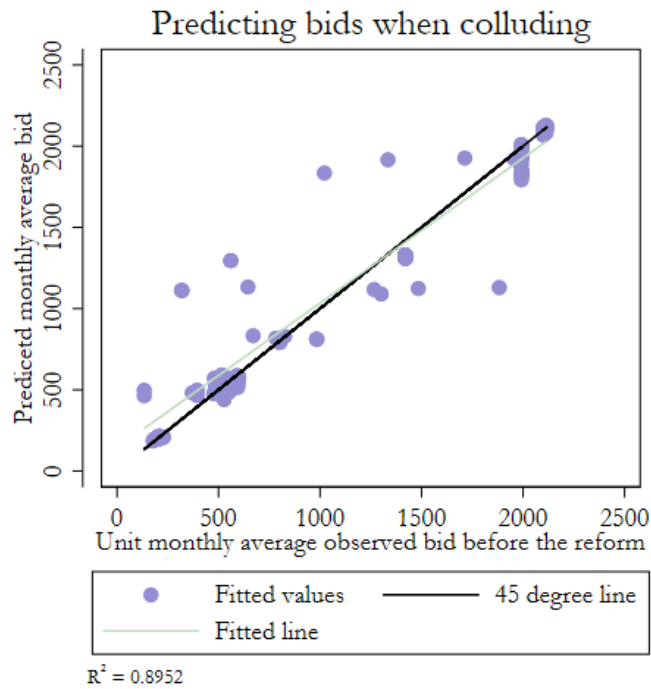


Figure A11: Comparing observed bids with in-sample predictions.

Note: We use the method described in Section 5.2 to estimate how cartel units set bids by regressing bids on costs, the lagged logarithm of the total amount of positive reconciliations, and the logarithm of the ideal generation quantity. We use these estimates to make in-sample prediction and average at the monthly level for each unit. We compare the average predicted bid (y-axis) with the average observed one (x-axis). The left figure refers to observations from the six months before the reform; the right figure refers to the six months after the reform.

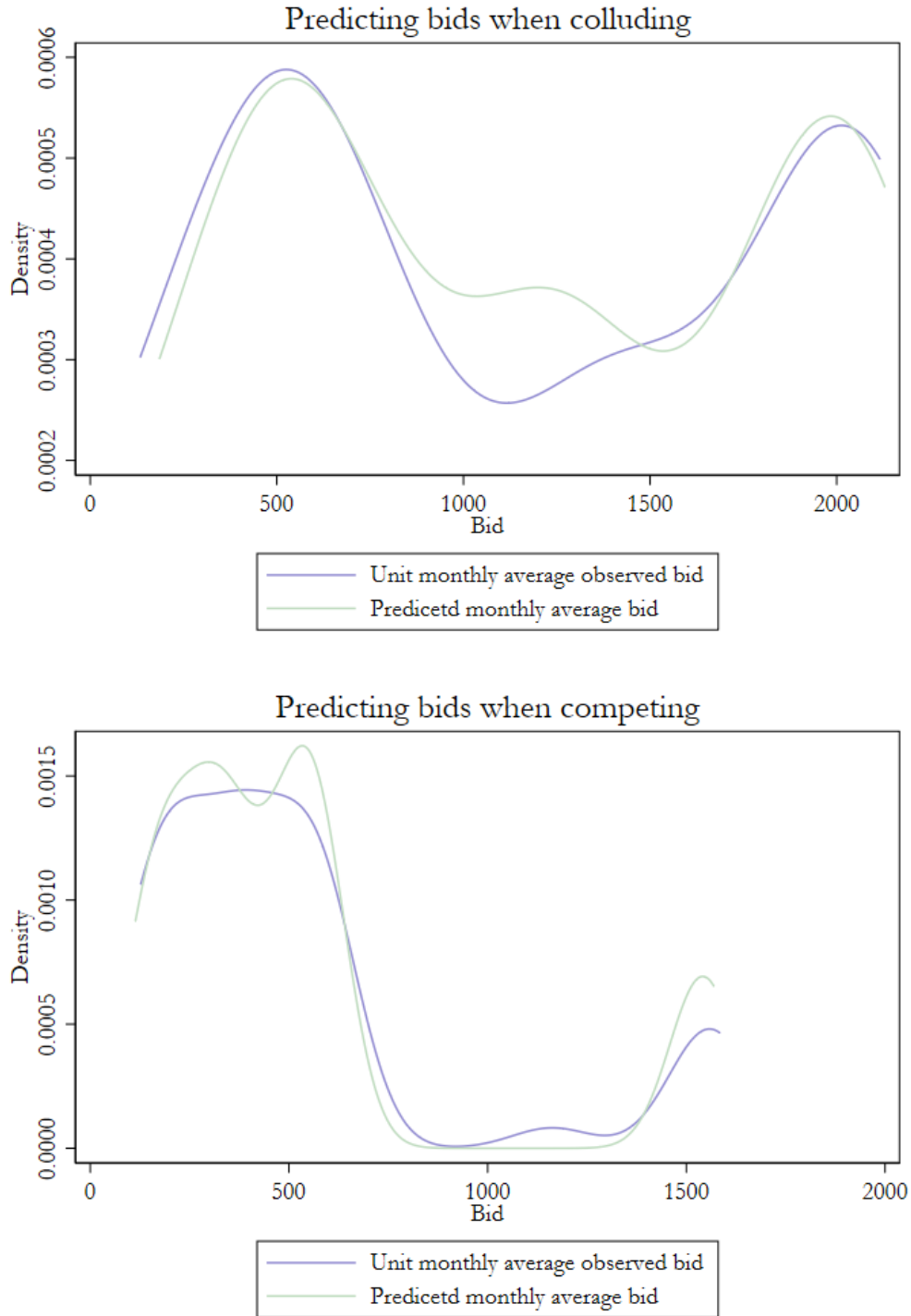


Figure A12: Comparing the distribution of observed bids with in-sample predictions.

Note: We use the method described in Section 5.2 to estimate how cartel units set bids by regressing bids on costs, the lagged logarithm of the total amount of positive reconciliations, and the logarithm of the ideal generation quantity. We use these estimates to make in-sample prediction and average at the monthly level for each unit. We compare the density of the average predicted bid (orange line) with the density of the average observed one (green line). The left figure refers to observations from the six months before the reform; the right figure refers to the six months after the reform.

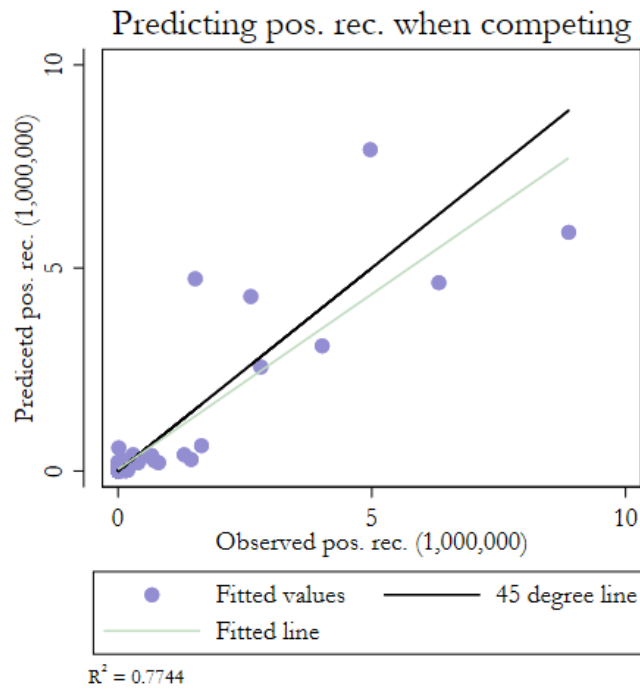
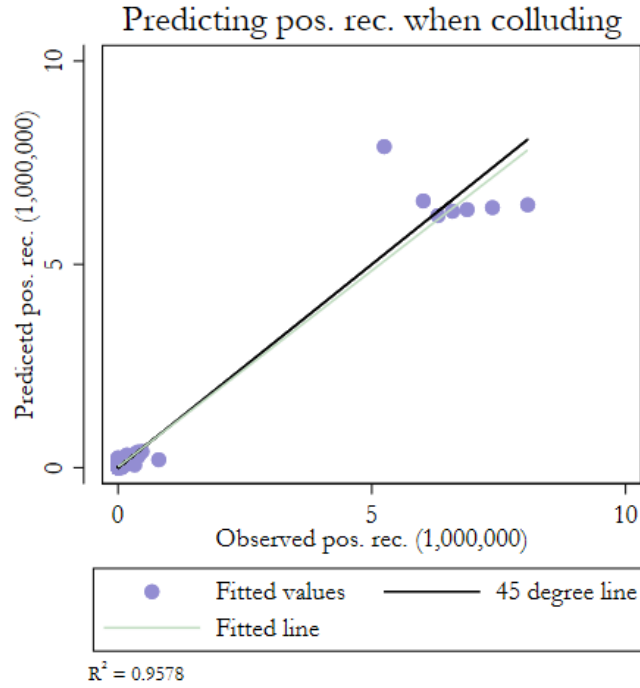


Figure A13: Comparing observed quantities of positive reconciliations with in-sample predictions for cartel units in the pre and post-reform periods.

Note: We use the method described in Section 5.2 to estimate how the quantity of positive reconciliation awarded to a unit depends on the rank of its bid. We focus on cartel units in this exercise. We use these estimates to make in-sample prediction and average at the monthly level for each unit. We compare the average predicted quantity (y-axis) with the average observed one (x-axis). The left figure refers to observations from the six months before the reform; the right figure refers to the six months after the reform.

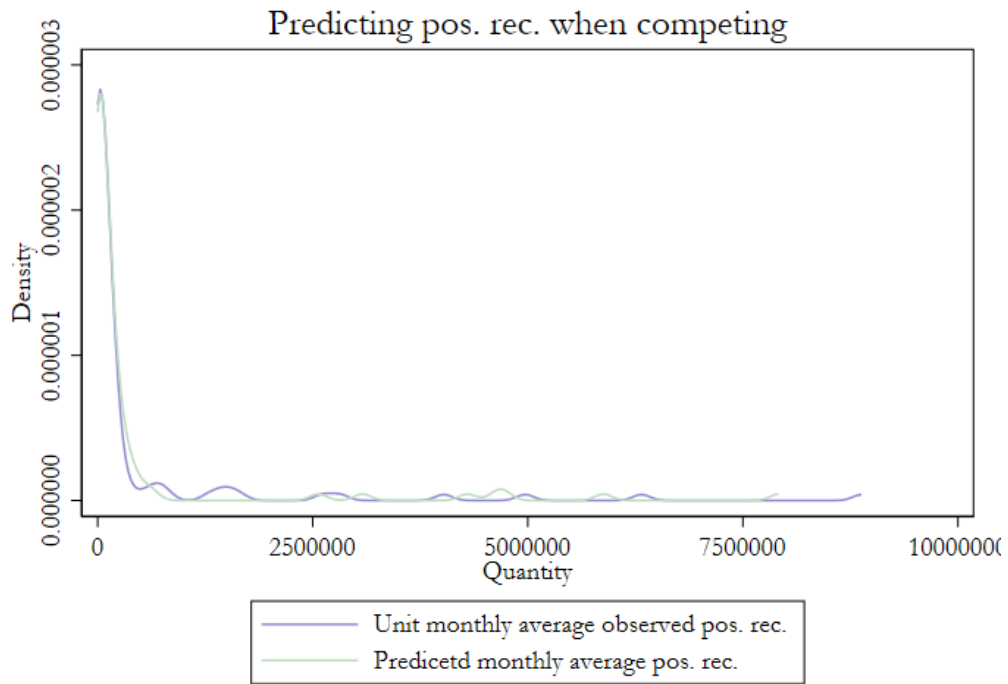
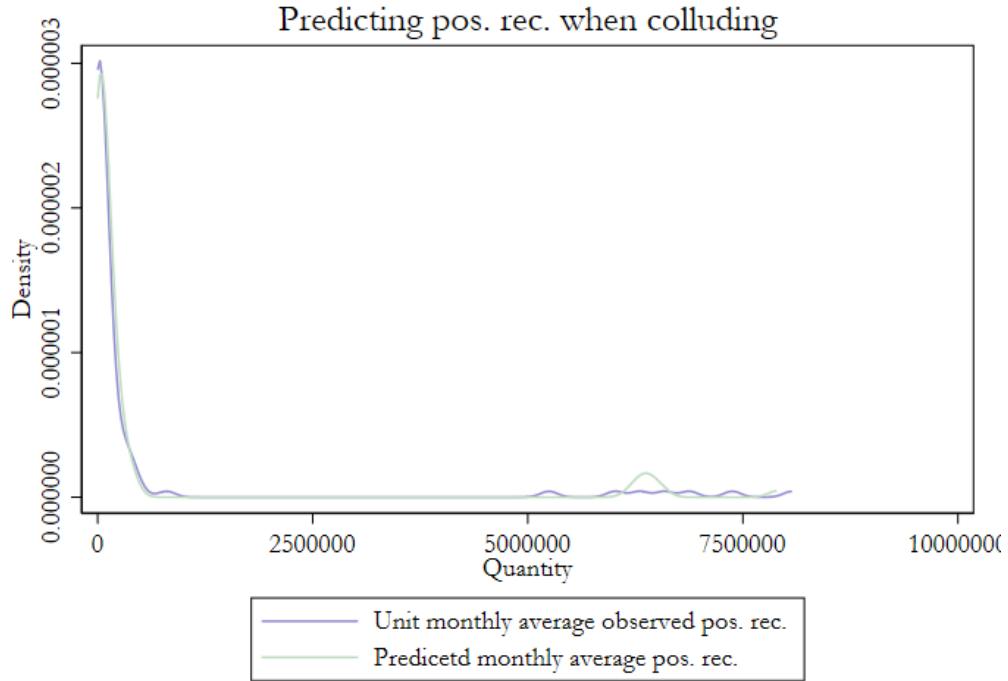


Figure A14: Comparing the distribution of observed quantities of positive reconciliations with in-sample predictions for cartel units in the pre and post-reform periods.

Note: We use the method described in Section 5.2 to estimate how the quantity of positive reconciliation awarded to a unit depends on the rank of its bid. We focus on cartel units in this exercise. We use these estimates to make in-sample prediction and average at the monthly level for each unit. We compare the density of the average predicted quantity (orange line) with the density of the average observed one (green line). The left figure refers to observations from the six months before the reform; the right figure refers to the six months after the reform.

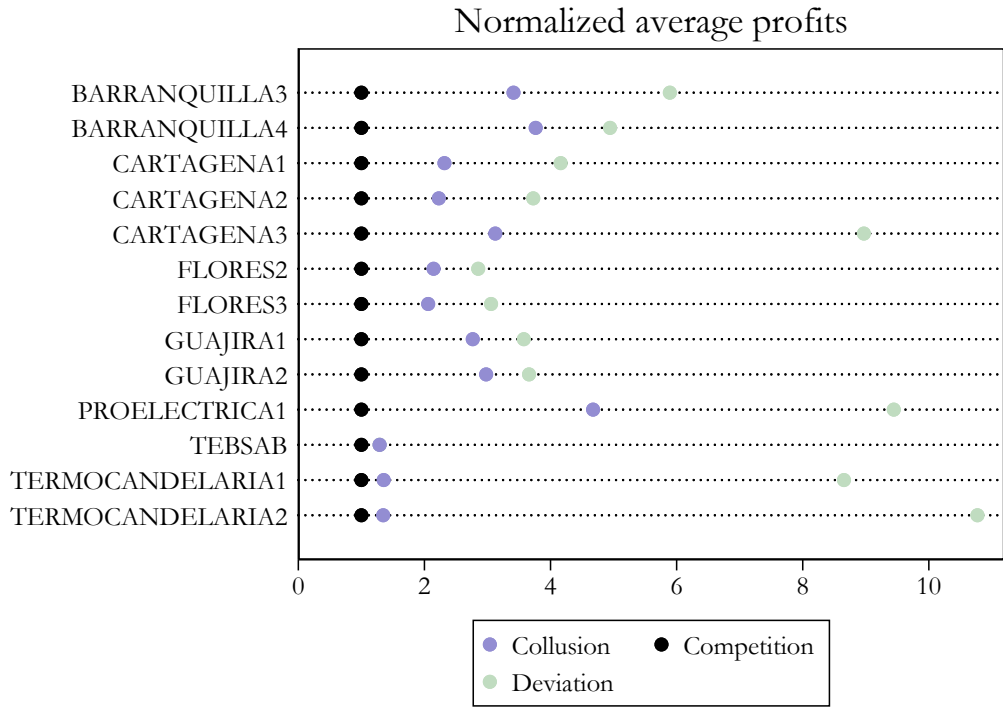
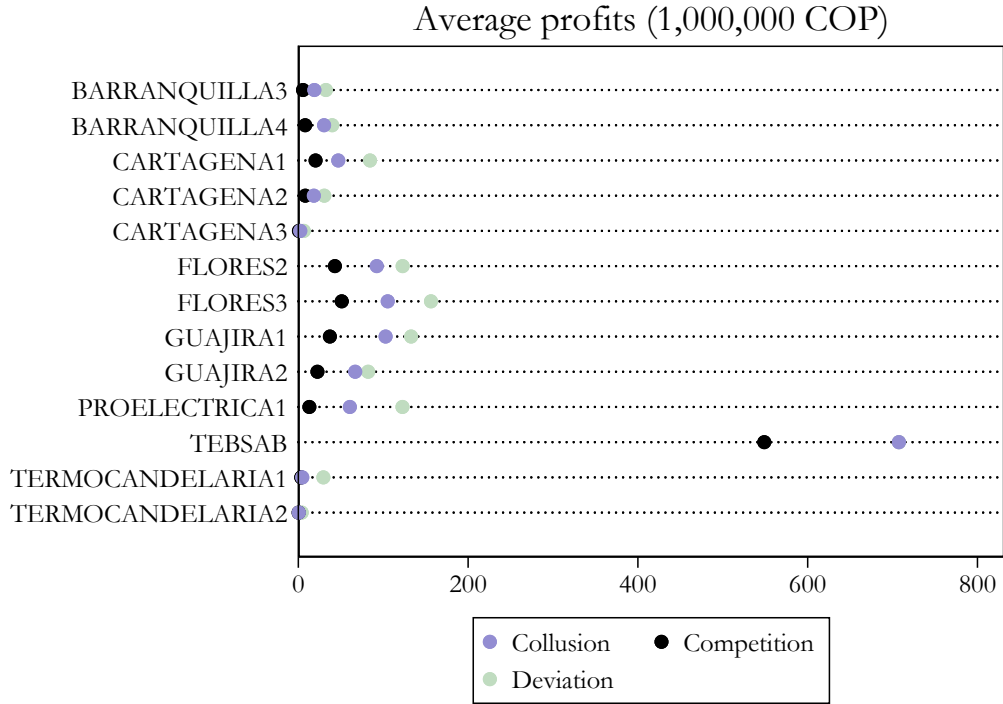


Figure A15: Average profits of cartel units under competition, collusion, and optimal deviation.

Note: We use the methods described in Sections 5.1 and 5.2 to construct counterfactual bids and quantities under three alternative scenarios: Collusion, competition, and optimal deviation from collusion. Based on these variables we construct profits for each unit under the three scenarios and average over a one year period around the reform. The top figure reports the level of the average profits (for some units, profits under different scenarios overlap in the figure), while the bottom one reports the ratio with respect to competitive profits.

A.2 Tables

Variable(Unit)	Obs	Before 06/01/2009			
		Mean	SD	Min	Max
Water Intake (GWh)	158	171.35	57.18	80.43	369.79
Guajira Index (COP/KWh)	158	36.66	3.17	30.07	40.61
Demand (GWh)	158	148.50	10.63	113.16	161.20
Variable(Unit)	Obs	After 06/01/2009			
		Mean	SD	Min	Max
Water Intake (GWh)	207	129.30	44.12	66	283.61
Guajira Index (COP/KWh)	207	27.41	4.61	22	41.09
Demand (GWh)	207	147.90	10.74	113	159.40

Table A1: Descriptive Statistics for Control Variables

Note: The table presents the descriptive statistics of the main controls used for two different period before and after the announcement of the policy. The top panel presents information for the period 1st August of 2008 until 6th January of 2009. The bottom panel starts on the 6th January of 2009 and ends 31st July 2009.

VARIABLES	(1) Margin	(2) Margin	(3) Margin	(4) Margin	(5) Margin	(6) Margin
Cartel Announcement	-320.52** (125.83)	-320.52** (130.50)	-320.52** (127.91)	-320.52** (130.42)	-308.65** (130.40)	-453.95*** (116.93)
Cartel Implementation	-146.57*** (47.66)	-146.57** (57.54)	-146.57** (53.80)	-146.57** (57.31)	-146.34** (56.79)	-145.20*** (35.40)
Announcement	-130.83*** (41.96)		-123.89*** (39.74)	-123.89*** (44.03)		
Implementation	-33.78 (24.93)		39.11 (31.41)	39.11 (46.52)		
Observations	11,315	11,315	11,315	11,315	16,955	16,955
R-squared	0.23	0.82	0.23	0.82	0.81	0.82
Unit FE	NO	YES	NO	YES	YES	YES
Date FE	NO	YES	NO	NO	NO	NO
Inputs Control	NO	NO	YES	YES	NO	NO
Demand Control	NO	NO	YES	YES	NO	NO
Date x Technology FE	NO	NO	NO	NO	YES	NO
Date x Region FE	NO	NO	NO	NO	NO	YES
Forward Control	NO	NO	NO	NO	YES	YES

*** p<0.01, ** p<0.05, * p<0.1

Table A2: Difference-in-difference estimates - Margin

The table presents the estimation results of the difference in difference model proposed in expression 1 in sub-section 3.4 using the margin as the dependent variable. The margin is computed as the difference of the bid minus the marginal cost. Only thermal units are included in the sample. Columns 3 and 4 control for Coal Price, Water Intake, Guajira Index, and Demand. Robust standard errors clustered by unit and date in parenthesis.

Scenario	Variable	Obs	Mean	Std. Dev.	Min	Max	Frec. Negative	T-Test
Scenario 1	Actual profit	2295	60.03768	194.8847	-29.83928	1275.529	.0013072	14.40
	Counterf spot market profit	2295	2.881308	15.72966	0	269.273		
Scenario 2	Actual profit	1140	61.08083	202.0675	0	1139.433	0	7.66
	Counterf spot market profit	1140	21.74932	46.23523	0	357.1698		
Scenario 3	Actual profit	1140	61.08083	202.0675	0	1139.433	0	10.21
	Counterf spot market profit	1140	0.0073915	.1629634	0	4.913246		
Scenario 4	Actual profit	1155	59.00808	187.6077	-29.83928	1275.529	.0025974	5.31
	Counterf spot market profit	1155	35.77655	68.62892	0	691.9288		
Scenario 5	Actual profit	1155	59.00808	187.6077	-29.83928	1275.529	.0025974	10.34
	Counterf spot market profit	1155	2.51874	16.88746	0	246.2969		

Table A3: Comparison of profits form positive reconciliation and counterfactual competition

We performed a comparison between the profits that the units of the cartel group obtained from the positive reconciliation collusive agreement and the profits that those units would obtain in the counterfactual case in which they bid their marginal costs and try to win in the ideal dispatch. First, we computed the profits from the positive reconciliation collusive agreement as the value of income from positive reconciliations minus the cost of generating the energy. Second, for computing the counterfactual of the profits if the units bid as a competitive firm, we assumed that if cartel firms would bid competitively it had the same probability of being in merit than the competitive units. Hence, we computed the probability of being on merit of the no cartel units. We computed the counterfactual profits for cartel units as the product of the probability of being on merit (if the unit is competitive) multiplied by the profit obtained by the unit if it would sell its energy at the spot price and would generate its declared availability. We allow the possibility of inaction of the unit. Hence if the profit above is negative we replace it by zero. For this computation we only consider thermal units. We use the data of second semester 2008. We compute five counterfactual scenarios. **Scenario 1:** Average spot price and average hydro resources condition. The spot price used for computation is the average spot price. All the days in the sample are considered. **Scenario 2:** High spot price and high hydro resources condition. The spot price used for computation is the spot price in the higher demand hour (7 p.m.). Only the days with hydro resources higher than the median are considered. **Scenario 3:** Low spot price and high hydro resources condition. The spot price used for computation is the spot price in the lower demand hour (3 a.m.). Only the days with hydro resources higher than the median are considered. **Scenario 4:** High spot price and low hydro resources condition. The spot price used for computation is the spot price in the higher demand hour (7 p.m.). Only the days with hydro resources lower than the median are considered. **Scenario 5:** Low spot price and low hydro resources condition. The spot price used for computation is the spot price in the lower demand hour (3 a.m.). Only the days with hydro resources lower than the median are considered.

	Cartel 1	Cartel 2	Cartel 3	Cartel 4	Cartel 5
Cartel 1	1.000	0.694	0.951	0.579	0.684
Cartel 2	0.694	1.000	0.638	0.526	0.450
Cartel 3	0.951	0.638	1.000	0.541	0.648
Cartel 4	0.579	0.526	0.541	1.000	0.888
Cartel 5	0.684	0.450	0.648	0.888	1.000

Table A4: Correlation Table of Alternative Cartel Definitions

The table shows the correlation between the different cartel definitions presented in section 3.5.2. All the correlations are significant at 99%.

VARIABLES	(1) Pre-reform	(2) Post-reform
Marginal cost	1.065 (1.245)	1.763 (1.464)
Lagged logarithm of total amount of pos. rec.	51.43 (77.33)	-22.72* (10.72)
Logarithm of total ideal generation	20.99 (93.33)	-95.14*** (27.74)
Observations	2,506	2,534
R-squared	0.859	0.940
Unit FE	YES	YES

Robust standard errors in parentheses

*** p<0.01, ** p<0.05, * p<0.1

Table A5: Estimation of bids on market fundamentals

Note: The table presents the estimates of the model proposed in section 5.2 in order to predict the bids of cartel units. We regress bids on costs, the lagged value of the logarithm of the total amount of positive reconciliations, and the logarithm of the total amount of ideal generation. We use observations from cartel units from a one year period around the reform (six months pre and six months post-reform in columns 1 and 2 respectively). Robust standard errors in parenthesis.

VARIABLES	(1) Logit	(2) OLS
Rank	-1.089*** (0.267)	0.189 (0.233)
Rank ²	0.0468* (0.0266)	-0.0156 (0.0150)
Observations	4,211	1,033
R-squared		0.648
Unit FE	YES	YES
Date FE	YES	YES
Robust standard errors in parentheses		
*** p<0.01, ** p<0.05, * p<0.1		

Table A6: Estimation of the positive reconciliation quantities model

Note: The table presents the estimates of the models proposed in section 5.2 in order to predict the expected quantity of positive reconciliations for cartel units. In the first column, we present the logit estimates of a binary model where we regress a dummy for receiving positive reconciliations in a day on the rank of the bid, its squared value, unit and date fixed effects. The second column presents the OLS estimates of a linear model where we regress the logarithm of the amount of positive reconciliations in a day on the same covariates as above, using only observations with some amount of positive reconciliations. We use observations from a one year period around the reform. Robust standard errors in parenthesis.

B Calculation Marginal Costs

As previous studies in the literature on market power in electricity markets ([Green and Newbery, 1992](#); [Wolfram, 1998, 1999](#); [Wolak, 2000](#); [Fabra and Reguant, 2014](#)), we use information about the fuel burned, the thermal efficiency, and the price and transportation cost of the corresponding fuel to compute an estimate of the unit cost per kilowatt hour of each generation plant.

We calculated marginal costs of thermal plants using the heat rate, fuel costs and fuel transportation costs with the following formula:

$$\underbrace{Exchange R.._t}_{\frac{COP\$}{US\$}} \times \left[\underbrace{Heat R.._i}_{\frac{MBTU}{KWh}} \times \underbrace{(Transp. fuel cost_i + Fuel cost_t)}_{\frac{US\$}{MBTU}} \right] = \underbrace{Marginal Cost_{it}}_{\frac{COP\$}{kWh}}$$

Where *COP* are Colombian pesos, *MBTU* are one thousand of the British thermal unit, *US* are United States dollars and *KWh* is one kilowatt per hour. The heat rate is a measure of the thermal efficiency of the generation unit. It represents the quantity of fuel measured in *MBTU* necessary to generate one kilowatt per hour. As previous studies, we obtained heat rates from statistical reports issued by public entities ([Green and Newbery, 1992](#); [Wolfram, 1998, 1999](#)). The parameters of the heat rate of thermal electricity generation Colombian units were extracted from reports of the Mines and Energy Planning Unit (UPME) ([Unidad de Planeación Minero Energética \(UPME\), 2003](#)).

Regarding fuel prices, for non-internationally tradable inputs, we used a reference price of the contracts as in [Wolfram \(1999\)](#) and for tradable inputs, we used public information on prices in international energy markets as in [Fabra and Reguant \(2014\)](#).

In 2008 and 2009 natural gas was a non-tradable input in Colombia, given that it did not have import regasification facilities nor it was connected to an international gas hub. We use as a reference of the price of the natural gas contracts the price of the basin Guajira which is the most important gas supply source for Colombian thermal generation. From September 1995 Until August 2013, the Colombian Government regulated the prices of the sales contracts of this gas source. The regulation consist in imposing a maximum sale price of gas. This maximum price at period t , p_t , is given by the formula $p_{t-1}[\text{index}_{t-1}/\text{index}_{t-2}]$ where index_{t-1} is the average of the last semester of the New York Harbor Residual Fuel Oil 1.0 % Sulfur LP Spot Price according to the series that was published by the Energy Information Administration of the United States. A period t is defined as semester and it changes 1st February and 1st August of each year ³⁶. This

³⁶The formula was established in Resolution 119/2005 of CREG ([CREG, 2005](#))

price is given in *US dollars/MBTU*.

We calculated the Guajira regulated price applying the formula presented above and converting the resulting price (*US dollars/MBTU*) to *Colombian pesos/KWh*. The exchange rate data was obtained from the Colombian central bank (Banco de la República)³⁷.

As the previous studies of [Green and Newbery \(1992\)](#) and [Wolfram \(1999\)](#) we included the transportation cost in the marginal cost computation.

Consequently with the fuel cost reference, for gas fired units, we take as transportation costs the sum of the fees for the use of each segment of the gas transmission network necessary to take the gas from Guajira well to the respective generation units. These fees are regulated by the CREG and are published in regulatory acts ([CREG, 2003a,b](#)).

Regarding the coal fired units, we use as price reference the coal price in international energy markets as suggested by [Fabra and Reguant \(2014\)](#). Given that Colombia is a net exporter of coal we use the weighted average FOB export price as fuel cost. We computed it as the ratio between the total value of coal exportation (in *US dollars*) and the quantities exported (Tons) according to the data from the non-traditional exports report of the National Department of Statistics (DANE). The price in dollars per ton was transformed to dollars per *MBTU* units, multiplying for a calorific value of the Colombian thermal coal of 1,370 btu per pound (Source: regulation 2009 180507 Colombian Ministry of Energy and Mines ([Ministerio de Minas y Energía \(MME\), 2009](#))). For computing the coal transportation costs, an importation parity approach is adopted. According to this criteria, we estimate it as the road freight transportation fee from the closest importation port to the respective location of the generation unit. These fees were extracted from the system of information of efficient costs for road freight transportation provided by the Transportation Ministry of Colombia ³⁸.

³⁷See:<https://www.banrep.gov.co/es/estadisticas/trm>

³⁸See: https://www.mintransporte.gov.co/publicaciones/359/sistema_de_informacion_de_costos_eficientes_para_el_transporte_automotor_de_carga_sicetac/