HEC MONTRÉAL
École affiliée à l'Université de Montréal

Essays on Competition in Public Procurement

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Essays on Competition in Public Procurement

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Résumé

Les marchés publics représentent une part substantielle de la dépense gouvernementale. Ainsi, le Canada, en 2015, leur consacrait 33% de son budget, i.e. 13% de son PIB. Face à la taille de ces marchés se pose inévitablement la question de leur efficacité. Pour atteindre de meilleures performances en termes de prix et de qualité, l'un des outils dont disposent les décideurs politiques est de stimuler la compétition. Cette thèse de doctorat s'organise en trois chapitres. Y sont explorées, de manière empirique, les dynamiques de compétition au sein des marchés publics.

Le premier chapitre, *Collusion through Market Sharing Agreements: Evidence from Quebec's Road Paving Market*, s'intéresse aux accords de partage de marché. Il dévoile les pratiques collusives des deux plus grandes entreprises de pavage routier au Québec. Cette analyse s'appuie sur une base de données contenant tous les contrats de pavage routier attribués par le Ministère des Transports du Québec entre 2007 et 2015. Lors des appels d'offres pour l'obtention de ces contrats, les deux firmes ont collaboré via i) leurs soumissions, et ii) leur taux de participation dans la même enchère. Cette deuxième dimension, certes différente d'une entente sur les prix, influence les coûts d'approvisionnement.

Le deuxième chapitre, *Complementary Bidding: Evidence from Quebec's Construction Industry*, montre la convergence des soumissions les plus basses en cas de collusion. Cet essai exploite les contrats municipaux d'approvisionnement d'asphalte octroyés par la Ville de Montréal entre 2007 et 2013. Les résultats obtenus contestent d'autres cas de cartels, où la différence entre les soumissions les plus basses était généralement plus élevée.

Le troisième chapitre, *Hospital Purchasing with Reference Pricing: Evidence from an Anti-Corruption Program in Italy*, évalue l'impact de l'introduction de prix plafond sur les coûts d'approvisionnement des dispositifs médicaux en milieu hospitalier. Se fondant sur les données nouvellement collectées de chaque ordre d'achat des organismes publics de santé dans une région italienne entre 2014 et 2018, l'analyse expose la diminution des prix unitaires moyens pour les dispositifs médicaux sujets à la réglementation. Toutefois, cette politique n'a pas affecté la dépense globale de santé dans la région; révélant un ajustement à la hausse des prix ex ante en-dessous du prix de référence.

Mots-clés

Enchères; Cartel des soumissions; Collusion; Compétition head-to-head; Marchés publics; Soumissions fantômes; Prix plafond; Dispositifs médicaux

Méthodes de recherche

Microéconomie appliquée; Différence dans les différence; Effets fixes; Économétrie structurelle

Abstract

Public procurement represents a large share of government expenditure. In Canada, 33% of total expenditure, i.e. 13% of the GDP, was spent on public procurement in 2015. The size of this market makes the question of its efficiency unavoidable. To achieve lower prices and possibly better quality in this market, one of the available tools for policy-makers is to stimulate competition. This doctoral thesis consists of three empirical essays related to competition in public procurement.

The first essay, *Collusion through Market Sharing Agreements: Evidence from Quebec's Road Paving Market*, studies a case of market sharing agreements. It sheds light on the collusive practices implemented by the two largest firms in the road paving industry in the Canadian province of Quebec. It exploits a dataset containing all road paving contracts awarded by the Quebec Ministry of Transportation between 2007 and 2015. In the auctions for the award of these contracts, the two firms colluded on i) their bidding behavior, and ii) the number of times they bid against each other in a given auction. This second dimension of collusion, albeit different from colluding on prices, has an impact on procurement costs.

The second essay, *Complementary Bidding: Evidence from Quebec's Construction Industry*, shows that the two lowest bids tend to be clustered under collusion. This essay uses municipal contracts for asphalt procurement awarded by the City of Montreal between 2007 and 2013. The findings contradict other cartel cases where the difference between the lowest bids was typically higher.

The third essay, *Hospital Purchasing with Reference Pricing: Evidence from an Anti-*

Corruption Program in Italy, investigates the impact of the introduction of statutory reference prices on the hospital procurement of medical devices. Using a newly collected dataset on purchase orders in one Italian region between 2014 and 2018, the results show a decrease in unitary prices paid for the medical devices subject to the policy. On the other hand, total expenditure did not change, pointing to adjustment of prices for devices that were paid on average below the reference price.

Keywords

Auction; Bidding ring; Collusion; Head-to-head competition; Public procurement; Complementary bidding; Statutory reference price; Healthcare; Medical devices

Research methods

Empirical microeconomics; Difference-in-difference; Fixed effects; Structural econometrics

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To Giulio Regeni,

for his passion for research.

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General Introduction

This doctoral thesis consists of three independent essays related to competition in public procurement. These essays are self-contained and each written with the purpose of being published as a separate article in academic journals.

The first essay, *Collusion through Market Sharing Agreements: Evidence from Quebec's Road Paving Market*, studies a case of market sharing agreements. It sheds light on the collusive practices implemented by the two largest firms in the road paving industry in the Canadian province of Quebec. The empirical analysis is based on a dataset containing all road paving contracts awarded by the Quebec Ministry of Transportation between 2007 and 2015. These contracts are awarded through first-price, sealed-bid auctions where the lowest bidder wins the contract. In the auctions for the award of these contracts, the two firms colluded on i) their bidding behavior, and ii) the number of times they bid against each other in a given auction (henceforth referred to as head-to-head competition). This second dimension of collusion, albeit different from colluding on prices, has an impact on procurement costs.

I use the start of the police investigations into collusion and corruption in the Quebec construction industry launched in October 2009 to capture the end of this cartel. This event makes it possible to identify a before (suspected collusive) and after (competitive) period in the data. A descriptive analysis shows that head-to-head competition increased by about 8% after the start of the police investigations and bids of the two suspected firms decreased by about 15% of the value of the contract.

To claim that the start of the police investigations implied a shift from collusive to competitive behavior in terms of i) head-to-head competition, and ii) bids, the empirical analysis is based on a difference-in-difference design. The treatment is assigned at the auction level and it is represented by the auctions in which the two largest firms could have been potential competitors, i.e. they could have competed head-to-head and they could have submitted competitive bids.

The results show that in the "treated" auctions, the two largest firms compete head-to-head to a larger extent and submit lower bids after the start of the police investigation. Since the difference-in-difference design cannot quantify the impact of coordinating head-to-head competition on procurement costs, a structural model containing two stages, i.e. participation in auctions and bidding, is estimated. The findings suggest additional procurement costs associated with firms coordinating on a dimension different from bids.

This study is one of the first to document price and non-price collusion with an application to public procurement. It demonstrates that firms with multiple plants that potentially compete in multiple markets can share the market by i) avoiding competing against each other and ii) coordinating prices. Finally, the analysis of the delays and cost overruns in these contracts suggests that a sudden switch from collusion to competition does not worsen the *ex post* procurement performance.

The second essay, *Complementary Bidding: Evidence from Quebec's Construction Industry*, documents clustering of the two lowest bids as a sign of collusion. While recent papers suggest that a relatively high distance between the winning and all losing bids is associated with collusion, this essay provides evidence that clustering of the two lowest bids is also consistent with collusive behavior.

This essay documents bid clustering using a dataset on municipal contracts for the procurement of asphalt awarded by the City of Montreal. In this city, a cartel including all firms in the asphalt market was discovered and some investigative documents reported that in the auctions for the award of these municipal contracts clustering of bids represented one way for firms to simulate competition. As in the previous essay, this essay uses the start of the police investigation in the Quebec construction industry to check whether this event affected the bidding behavior of colluding firms in this market.

The results show that the difference between the two lowest bids in Montreal significantly increased after the start of the police investigation compared to the two lowest bids submitted in auctions for the municipal procurement of asphalt in Quebec City. Quebec City is used in the essay as a control market since there have been no allegations of collusion.

In this essay, bid clustering can be unequivocally identified as a sign of collusion because i) bid clustering disappears after the start of the police investigations, and ii) bid clustering is absent in markets with similar characteristics. This pattern can thus be used as a screen and is probably indicative of collusive behavior.

The third essay, *Hospital Purchasing with Reference Pricing: Evidence from an Anti-Corruption Program in Italy*, studies the impact of the introduction of statutory reference prices on public procurement of medical supplies. It uses a newly collected dataset on purchase orders for medical devices made by Italian hospitals between 2014 and 2018. To evaluate the impact of the policy, this essay exploits the scattered implementation of reference prices as an exogenous source of variation.

The results show that unitary prices for devices subject to reference prices decreased on average by 10% compared to those devices not targeted by the policy. This evidence suggests that, on average, the policy had price effects.

To fully evaluate the impact of the policy, this essay investigates two margins of adjustment. First, it looks at possible heterogeneous effects depending on the price of the treated devices before the implementation of the policy, finding that prices increased for devices that had a price below the reference price before the reform. Second, it looks at quantities purchased and total spending, providing evidence that the policy was not successful in reducing total spending for medical devices.

This essay shows that the reform has been successful in reducing the prices for devices subject to reference prices but has not been successful in reducing spending. This essay documents the margins of adjustment.

Chapter 1

Collusion Through Market Sharing Agreements: Evidence from Quebec's Road Paving Market

Abstract

I study a case of market sharing agreements to provide evidence of coordination between colluding firms on the degree to which they compete against each other (henceforth referred to as head-to-head competition) and their bidding behavior, and to quantify the impact that coordinating head-to-head competition has on procurement costs. My focus is on the two largest firms bidding in provincial road paving procurement auctions in Quebec between 2007 and 2015. I use the police investigation into collusion and corruption in the Quebec construction industry launched in October 2009 to capture the end of this cartel. I find that after this date, the two suspected firms i) were more likely to bid in the same auction (about 8% higher probability) and ii) submitted lower bids when they competed in the same auction (about 15% lower). A structural model of participation and bidding shows that if the firms had kept competing head-to-head at the same rate as in the collusive period but had stopped colluding on bids, bids would have increased by about

3% with respect to the competitive scenario observed after the police investigation began. This finding suggests that there were additional procurement costs associated with firms coordinating on the degree of head-to-head competition.
JEL codes: L22, L74, D44, H57.
Keywords: Auction; Bidding ring; Collusion; Head-to-head competition; Public procurement.

1.1 Introduction

Researchers have devoted considerable attention to the study of price collusion (see for instance Porter and Zona, 1993, 1999; Bajari and Ye, 2003; Kawai and Nakabayashi, 2014; Clark et al., 2018). Yet less attention has been paid to studying the impact that other types of coordination can have on prices. One of these other types of coordination between firms consists in adjusting the degree to which they compete against one another (henceforth referred to as head-to-head competition). In a market for differentiated products, for example, there can be collusion between firms not only in price-fixing but also in choosing the sets of products that they offer in an effort to lessen competition and share the market amongst themselves (Sullivan, 2017). In the same way, in procurement auctions firms can collude by agreeing on the degree to which each of them will participate in the same auction.

In this paper, I study a case of market sharing agreements i) to find evidence of coordination between firms on the degree of head-to-head competition and evidence of coordination on bids and ii) to quantify the impact that coordinating head-to-head competition has on procurement costs. I focus on two firms alleged to have reached market sharing agreements in the road paving procurement market in the Canadian province of Quebec.

In the market for provincial road paving contracts awarded by the Quebec Ministry of Transportation between 2007 and 2015, these two firms are the largest in terms of both the number of asphalt plants that they own and the number of contracts that they won. The Commission of Inquiry on the Awarding and Management of Public Contracts in the Construction Industry (henceforth referred to as the Commission), which investigated collusive practices in the construction industry, has provided evidence that these two firms colluded i) in agreeing on the degree of head-to-head competition and ii) in submitting the bids conditional on competing head-to-head.[1,2]

In the road paving procurement market, firms have considerable transportation costs because they must bring asphalt from their plants to paving project locations. This means that there are two margins on which firms can coordinate head-to-head competition. First, colluding firms can coordinate relative to the location of their asphalt plants. To avoid head-to-head competition, they can place these asphalt plants at a certain distance from one another. Second, they can decide to avoid head-to-head competition when they are close to the paving project location by alternating their participation in the auctions. Both margins allow colluding firms to coordinate the degree of head-to-head competition and thus share the market amongst themselves.

My empirical analysis is based on an original dataset for paving contracts awarded between 2007 and 2015. I constructed the dataset using publicly available contracts listed on the official tendering website of the Quebec government (*Système Électronique d'Appel d'Offres, SEAO*). These contracts contain information on the auction outcomes (indicating both winning and losing bids) and on the number and the identities of the participants in every auction. The auctions are first-price (lowest price) sealed bid auctions. I expand the auction data by providing information on the geographic location of the asphalt plants that I obtained by making an official request to the Quebec Ministry of Transportation.

To begin the analysis, I use the start of the police investigations into collusion and corruption in the Quebec construction industry launched in October 2009 to capture the end of this cartel. The beginning of these investigations predated by two years the Commission and this makes it possible to identify a pre-October 2009 (suspected collusive)

[1] See Charbonneau and Lachance (2015), p.531

[2] **Legal disclaimer:** This paper analyzes market sharing agreements from a strictly economic point of view. It is based on the analysis of publicly available contracts, testimony transcripts, and the final report from the Commission. Begun in 2015, the investigations of these allegations by the Canadian Competition Bureau are still ongoing. Newspapers have reported that to investigate these firms, the Canadian Competition Bureau obtained search warrants. See Lévesque (2015).

period and post-October 2009 (competitive) period in the dataset. In this way, it is possible to test whether there were significant changes between the two periods in i) the degree of head-to-head competition (the probability that the two suspected firms bid on the same contract) and in ii) the level of bids.

A descriptive analysis shows that head-to-head competition increases by about 8% between the pre-investigation and post-investigation periods, and that the bids of the two cartel firms conditional on bidding decrease by about 15.43% of the value of the contract. I do not find a significant change in terms of the location of the firms' asphalt plants. This is probably because given the short sample period, there was insufficient time for the colluding firms to react along the plant location dimension.

To find causal evidence that the observed differences in head-to-head competition and bidding were driven by the start of the police investigation, I use a difference-in-difference design that compares the outcomes of *treated* auctions with the outcomes of a control group of auctions. A *treated* auction is one in which the two cartel firms could have potentially competed. I describe an auction as *potentially competitive* if the asphalt plants of the two cartel firms were close enough to the paving project location for both of them to have participated in the auction and to have bid competitively.

The results show that the increase in the probability of head-to-head competition was significantly greater in the potentially competitive auctions than in the control group of auctions. Coordination on the degree of head-to-head competition in the *potentially competitive* auctions appeared to be driven by two factors: i) firms allocated territories amongst themselves before the investigation; and ii) in territories that were not allocated during the collusive period, firms competed head-to-head less often. There is evidence of the first factor in the significant increase in the number of cartel bids after the start of the investigation in territories where only one of the cartel firms had been actively bidding before the investigation began. Finally, the average winning bid decreased by 15% after the start of the investigation. Given that the average value of contracts was about C$2 million before the start of the investigation, this means that the average winning bid was C$260,000 higher during this period. Back-of-the-envelope calculations indicate the savings for the Quebec Ministry of Transportation to be C$12 million per year after the end of the cartel.

The descriptive analysis fails to distinguish between the impact that avoiding head-to-head competition has on procurement costs and the impact that coordinating bids has on these costs. It is important to determine which part of the decrease in procurement costs should be attributed to coordination on bids and which part should be attributed to coordination on head-to-head competition. In a cartel that does not include all the firms in the market, the two types of coordination have a different impact on procurement costs.

To quantify the extent to which restricting head-to-head competition increased procurement costs, I use a structural model of participation and bidding that allows for the existence of asymmetric bidders in the assumed competitive period, that is, the period after the start of the investigation into collusion. I consider a counterfactual scenario in which firms continue to compete head-to-head at the same rate as in the collusive period, but submit competitive bids. In this counterfactual scenario, the average bid would have been 3% higher than the average bid observed in the competitive period. Thus there are extra procurement costs associated with this type of coordination. One fifth of the average price increase observed before the police investigation began is due to firms coordinating the degree of head-to-head competition. The other four fifths of this increase are due to firms coordinating bids.

Colluding firms avoid head-to-head competition for various reasons. First, there is the magnitude of the entry cost, for example the costs of submitting a bid. Second, in avoiding head-to-head competition, colluding firms face a less aggressive bidding strategy from bidders that are not part of the cartel. The bidding strategy in first-price auctions depends in fact on the number of bidders. Finally, when colluding firms avoid head-to-head competition, the bidder in the cartel with the lowest cost does not have to worry about preventing another cartel member from cheating. Thus the cartel firm with the lowest cost can bid less aggressively (Marshall and Marx, 2007).

This study is among the first to show that multi-plant firms acting in multiple markets can share the market by colluding not only to set prices but also to determine the degree of head-to-head competition. Sullivan (2017) was the first to empirically analyze coordination on the degree of head-to-head competition in the US ice cream industry. For Sullivan (2017), the degree of head-to-head competition is represented by the extent to which firms produce the same varieties of ice cream. In my study, it is the degree to which firms compete against one another in auctions. However, my study differs from Sullivan (2017) in several ways. First, I use an exogenous event to capture the end of the coordination on the degree of head-to-head competition between firms. This event was the starting point for a series of investigations into collusion and corruption in the Quebec construction industry. Similarly, Clark et al. (2018) show that this event affected the bidding behavior of colluding firms in the city of Montreal. Second, my study analyzes a market with different characteristics. In the road paving market colluding firms have two ways to avoid head-to-head competition: they can collude to determine the locations of their asphalt plants or to decide on whether or not to participate in the same auction when their asphalt plants are fairly close to the location of the paving project. Sullivan (2017) does not investigate whether firms sell ice cream in different supermarkets, which would be equivalent to colluding on the location of the asphalt plants. Finally, I identify several possible drivers of collusion on the degree of head-to-head competition.

This study contributes to the empirical literature on multimarket contact and collusion. Following Bernheim and Whinston (1990), empirical studies have shown that the higher the frequency of interactions, the greater the likelihood of collusion; but to the best of my knowledge no empirical study has taken into account the degree of competition between multimarket firms as a strategic choice of these firms. Belleflamme and Bloch (2004) is the first theoretical study that endogenizes multimarket contact. Belleflamme and Bloch (2004) establish that firms can implement market sharing agreements by colluding to determine the degree of head-to-head competition (i.e. the number of contacts between firms).[3]

[3]The theoretical predictions in Bernheim and Whinston (1990) have been tested in various industries: Pilloff (1999) tests them for the banking industry, Jans and Rosenbaum (1997) for the cement industry, and Evans and Kessides (1994) and Ciliberto and Williams (2014) for the airline industry. The most relevant study of procurement auctions is Gupta (2001).

This study also extends the empirical literature on collusion in public procurement auctions (Porter and Zona, 1993, 1999; Pesendorfer, 2000; Bajari and Ye, 2003; Conley and Decarolis, 2016; Kawai and Nakabayashi, 2014; Clark et al., 2018). The studies most closely related to mine are Porter and Zona (1999), Pesendorfer (2000) and Clark et al. (2018). Porter and Zona (1999) provide a statistical test to determine the presence of collusion acting through territorial allocation or through complementary bidding, and they find evidence of the latter form of collusion in the Ohio school milk market. Pesendorfer (2000) compares a cartel based on market sharing agreements and a cartel based on sidepayments, but he does not investigate the participation behavior of firms in the cartel. Clark et al. (2018) focus on municipal asphalt contracts for asphalt awarded by the two biggest cities in the Canadian province of Quebec, examining an all-inclusive cartel and the impact that the entry deterrence of firms outside the cartel had on bids. In this study, I empirically test for the causal impact of the police investigation on the participation behavior of cartel firms, quantifying the impact that coordinating the participation behavior had on bids. In addition, I examine the *ex post* procurement performance. In particular, I analyze the final amount paid by the Quebec Ministry of Transportation once a paving project had been completed in order to verify whether greater competition had unintended consequences on the *ex post* procurement performance. After colluding firms stop coordinating, they may accept a larger degree of head-to-head competition and submit more aggressive bids at the time of the awarding of a contract. Yet when executing the project, they may incur cost overruns that increase the final procurement costs forecast at the time of the signing of the contract. This pattern is not, however, observed in the data. This indicates that competition effectively lowers the overall procurement costs.

The remainder of the study is structured as follows. Section 1.2 describes the publicity requirements and the adjudication process for the auctions together with a description of the cartel allegations faced by paving companies. Section 1.3 presents the data and summary statistics for all the firms in the market and for the two cartel firms analyzed. Section 1.4 examines the question whether the head-to-head competition and the bids of the cartel firms changed between the collusive and the competitive periods because the police investigation had begun. Section 1.5 introduces the structural model of participation and bidding used in order to quantify the extent to which avoiding head-to-head competition increased bids. Section 1.6 draws some general conclusions.

1.2 Institutional background and the investigation into collusion

1.2.1 Publicity requirements and adjudication process

According to the *Act Respecting Contracting by Public Bodies* (in French *Loi sur Les Contrats des Organismes Publics*), if awarded by ministerial bodies, construction contracts with an estimated value above C$100,000 must be publicly advertised on the Quebec government's electronic tendering website (*SEAO*) and they must be awarded through an open auction. The only firms allowed to bid are ones from the province of Quebec or from a province that has a commercial agreement with the province of Quebec.[4]

Contracts are awarded through open tenders using the mechanism of first-price sealed bid auctions where the firm with the lowest bid wins. For the type of activities involved, such as transportation and production of asphalt, a contract has multiple tasks and each firm participating in an auction has to bid a unitary price for the quantities indicated by the Ministry for each task.[5] The final bid is the sum of the products of the price and the quantities for each of the tasks described in the contract. Each bid has to meet conformability and admissibility requirements. Except when firms bid C$0, these requirements are generally met, and in the dataset there are only five cases when the lowest bid was not the winning bid.[6] Another conformability requirement is the submission of a warranty that

[4]The electronic tendering website has published calls for tender for the award of ministerial contracts since February 2005. For municipalities, it has been mandatory to publish only since April 2011.

[5]The Ministry of Transportation has different regional departments (one for each Quebec administrative region) that each year check the status of the roads under their administration and submit their request to the central administration. The central administration then looks at the priorities and fills in the final plan (contracts to award, whether to use an open or restricted auction according to the value of the contract). Thus the location of the paving project is subject to the priorities of the Ministry and its budget constraints.

[6]Auctions where the lowest bid is not the winning bid have been excluded from the dataset.

should be equal to either 5% or 10% of the submitted bid.

The winning bid is usually equal to the amount for which the contract is signed. The only cases in which the contract amount is different from the final amount are those contracts where, at the time of the awarding, the Ministry asks for the renegotiation of the contract and the bidder agrees with the renegotiation. Finally, there is no reserve price in these auctions.

1.2.2 The investigations into collusion

On October 15, 2009, a TV program called *Enquête* reported that collusion was widespread in the construction industry in Quebec, especially in the City of Montreal. According to the report, collusive practices inflated the amounts paid for public works projects by the municipal government by about 30% in Montreal.[7] Following this report, a police operation called *Opération Marteau* was launched by the Quebec government to investigate allegations of collusion, corruption and possible relationships between firms and organized crime.

Two years later, the *Commission of Inquiry on the Awarding and Management of Public Contracts in the Construction Industry* was created on October 19, 2011 to analyze the allegations of collusion and corruption in the various sectors of the construction industry. The Commission's mandate was to find evidence of collusion and corruption in the construction industry and to make recommendations on the awarding and management of public contracts. After completing its investigation, the Commission issued a final report in November 2015.[8]

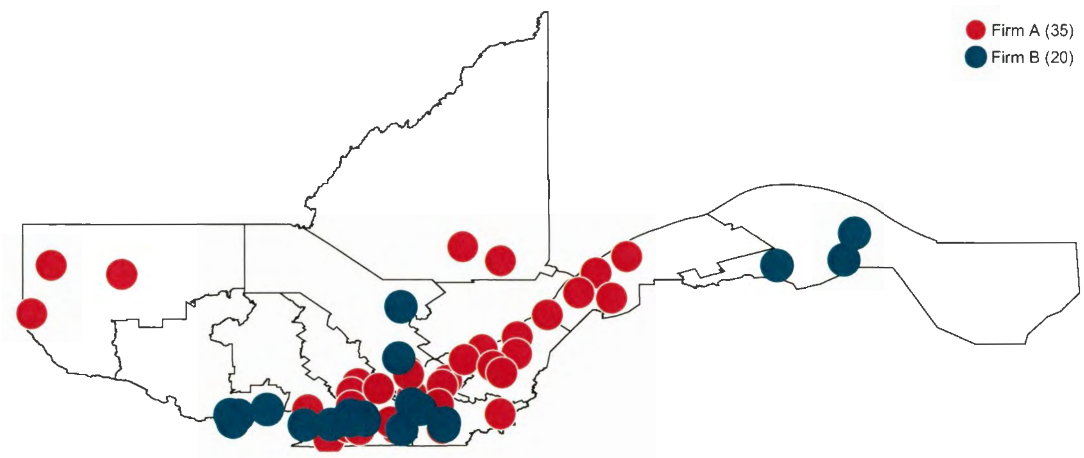
In the final report, a whole chapter was dedicated to contracts awarded by the Ministry of Transportation of Quebec. The report provided evidence of a market segmentation scheme based on the locations of the asphalt plants of two firms (firm A and firm B in my analysis). These two firms had market sharing agreements about not having asphalt

[7] See *Enquête*, Radio Canada (2009).
[8] See Charbonneau and Lachance (2015).

plants in an administrative region where the other firm was already present.[9]

Figure 1.1 shows the distribution of the asphalt plants of firms A and B as they appeared in 2006 (one year before the start of the sample) in each administrative region of Quebec. Only four of these regions have plants belonging to firm A as well as ones belonging to firm B; and in most of the remaining regions, the distribution of the plants belonging to the two firms is such that they are too far away from each other for competition between the firms to be possible. The distance of a firm's closest asphalt plant to the paving project location is a major cost factor affecting competition in this industry. If we observe significant changes in the number of asphalt plants owned by the two firms and in the distances between these plants, it is impossible to determine whether they coordinated their plant location choices or whether it was simply a question of geographical differentiation.[10]

Figure 1.1 – Geographic map of asphalt plants of firms A and B for all Quebec administrative regions in 2006



Since 2015, the Bureau has focused its attention on 18 firms (among those, firms A and B) suspected of having shared the market, having allocated territories and having rigged

[9]An executive of firm A admitted the existence of a market sharing agreement with firm B. The two firms coordinated their participation and their bidding behavior in open auctions administered by the Ministry of Transportation of Quebec. See Bédard (2014), pp. 20-24.

[10]The map in Figure 1.1 does not show the entire province of Quebec. I have excluded in my analysis the two most northern regions of the province where there are few inhabitants and few viable roads. These regions have a low population density of less than 1 inhabitant per km^2.

the bids between 1982 and 2011 in the road paving market. Some firms' plants were searched in March 2015. The name of the firms involved were not publicly released, but newspapers reported that firms A and B were among them.[11] According to newspapers, the Canadian Competition Bureau affirmed that the cartel was active in five administrative regions. Four of these five administrative regions are regions where firms A and B had at least one plant and where their plants were close to each other.[12]

1.3 Data and summary statistics

The dataset includes contracts above C$100,000 awarded by the Ministry of Transportation of Quebec through open auctions between 2007 and 2015. The Quebec Ministry of Transportation awarded road paving contracts for a total value of C$1.46 billion between 2007 and 2015 through the process of calls for tenders with an yearly average of C$162 million. The database is obtained by merging two different datasets. The first is obtained by scraping the contracts from the Official Tendering website of the Quebec government. The second is obtained by downloading data on all contracts awarded by the Quebec public administration in the open data website of the Quebec government. This second dataset enables me to verify whether the contracts included paving as a principal component of the construction work.[13]

A total of 751 contracts were kept.[14] These contracts include the description of the job, the name of firms participating and their bids, the code identifying the type of job, the location of the job, the date when the contract was published and the date of the award of the contract. A nice feature of these data is that both winning bid and losing bids are

[11] See Lévesque (2015).

[12] Table A.1 in Appendix A shows that for the other 16 firms involved in the searches the number of times they bid with either firm A or firm B (or both) did not increase. In Table A.2 I run a difference-in-difference where I put all suspected firms in the treatment group and observe that if firms A and B are removed from the sample, I obtain a non-significant drop in the winning bids.

[13] https://www.donneesquebec.ca/recherche/fr/dataset/systeme-electronique-dappel-doffres-seao. Since the open data begin in 2009, I cannot verify the scraped data for 2008 and 2007.

[14] I dropped contracts in the most northern regions of Quebec (administrative region of *Cote-Nord*) given the size of the region and its density.

reported together with the identity of the firms participating in the auction. On the other hand, the dataset includes only an interval of the *ex ante* estimated value of the contract because the precise value is confidential information. In the descriptive and structural analysis, I use the mean value of the contract. It is the mean of the upper and lower bounds of the interval indicating the value of the contract.

I augmented the auction data with asphalt plant data. The Ministry of Transportation issued (in 2005, 2006, 2008, 2010 and 2014) a detailed map showing not only the location of the asphalt plants of each firm but also the main shareholders of the firm together with the total number of plants owned by each firm. With this additional information, I compute the distance between the location of the paving project and the closest asphalt plant of each firm.[15]

Table 1.1 reports summary statistics for the pre-investigation (2007-2009) and post-investigation (2010-2015) periods. There are 86 different firms bidding at least once in the dataset and 51 firms that won at least one auction. Competition in the paving market is localized. The distance of a firm's asphalt plant from the project location is the main cost factor, given that asphalt is relatively expensive to transport. Given the magnitude of transportation costs, this market is similar to others analyzed in the literature of collusion in public procurement (Porter and Zona, 1999). There is a substantial number of auctions with one bidder, equal to 13.3% of the number of contracts in the dataset. The maximum number of bidders is equal to 9, and 72.4% of auctions in the dataset have between 2 and 4 bidders. The number of bidders does not change substantially in the two time periods considered. From the table we can observe a decline in the average and winning bids between the two periods considered, while the mean value of the contracts is approximately constant around $2 million.

[15]More details on the data cleaning process are in Appendix A.

Table 1.1 – Summary statistics for pre-investigation and post-investigation period.

Variables	Pre 2007-2009	Post 2010-2015
Number of firms	58	73
Number of firms winning at least one contract	36	45
Number of contracts awarded	194	557
Total value of contracts awarded (C$ million)	392.10	1064.14
Total value of contracts awarded by year (C$ million)	130.70	177.36
Average value of the contract	2.02	1.91
Number of bidders	3.04	2.95
Average bid (C$ million)	1.60	1.27
Average bid (% value)	84.51	76.88
Average winning bid (C$ million)	1.46	1.16
Average winning bid (% value)	81.34	72.08

Notes: *2007-2009* is the period before the start of the police investigation (October 2009). *2010-2015* is the period after the start of the police investigation (October 2009). *Number of firms* indicates the number of firms bidding in at least one auction. *Number of firms winning at least one contract* indicates the number of firms winning at least one auction. *Total value of contracts awarded (C$ million)* indicates the total value of contracts (C$ millions) awarded in the period considered expressed as the sum of all mean values of the contracts. *Total value of contracts awarded by year (C$ million)* indicates the average total value of contracts (C$ millions) awarded by year. *Average value of contract* indicates the average value (C$ millions) of a contract. *Number of bidders* indicates the average number of bidders in an auction. *Average bid (C$ million)* is the average bid expressed in C$ millions. *Average bid (% value)* indicates the average bid expressed in % of the value of the contract. *Average winning bid (C$ million)* indicates the average winning bid expressed in C$ millions. *Average winning bid (% value)* indicates the average winning bid expressed in % of the value of the contract.

1.3.1 Firms

In the road paving market, a firm's location is a key strategic decision given that transportation is a relevant component of costs in this industry; firms have to produce asphalt and transfer it to the place where the job is undertaken.[16]This characteristic makes competition in this market localized. Multi-plant firms are thus more likely to win ministerial contracts than firms with a small number of plants. Each firm also faces capacity constraints since they cannot afford more than a certain amount of work within a certain period of time.

[16]Bajari and Ye (2003) underline the importance of transportation costs in these types of industries in the analysis of seal-coating contracts.

Table 1.2 shows summary statistics for the 10 firms with the highest participation rates in the market. The market is characterized by firms that bid occasionally and firms that have multiple plants and bid in many auctions. Since paving projects can be located across the whole province of Quebec, having more plants allows a firm to have higher participation rates. In the dataset, in 751 contracts, there are a total of 86 firms bidding in at least one auction. I group these firms by the main shareholder since subsidiaries have different names but they all belong to the main firm. There are only 9 firms bidding in more than 50 auctions, and only 4 bidding in more than 100 (including firms A and B). Firm A is the leading firm in the market and had twice the number of plants of firm B in 2006. Firms A and B have the highest participation rates in the market. For the 76 firms with the lowest participation rates, the average participation rate is only 1%. These firms win, on average, 25% of the auctions in which they participate in.

Table 1.2 – Descriptive statistics of firms bidding in the road paving contracts (2007-2015).

ID Firm	Participation rate (%)	Win/Participation (%)	Distance (km)	Plants
A	70.57	48.68	38.69	41.00
B	45.01	31.07	45.02	21.00
C	17.98	38.52	51.14	9.00
D	21.57	40.12	42.85	6.00
E	12.52	32.98	44.94	6.00
F	12.92	28.87	30.19	6.00
G	11.45	13.95	44.23	3.00
H	8.26	25.81	38.53	10.00
I	7.19	14.81	49.70	3.00
J	6.52	10.20	45.17	1.00
others (76 firms)	1.09	24.29	53.20	.

Notes: *ID Firm* indicates an anonymous identifier replacing the actual name of a firm in the dataset. *others* indicates all firms other than the top 10 participating firms. For this category of firms, we report their averages. *Participation rate (%)* indicates the number of contracts in which a given firm participates over total contracts. *Win/Participation (%)* indicates the total number of contracts won over the total participation rate of a firm. *Distance (km)* represents the average distance of the firm from the project location of the auction. *Plants* indicates the number of asphalt plants for each firm in 2006 for the whole province of Quebec.

1.3.2 Cartel firms' statistics

Table 1.3 shows summary statistics for firms A and B for the periods pre-October 2009 and post-October 2009. Firm A has a higher participation rate than firm B over the whole sample period. The internal division of the aggregate market shares seems to correspond until 2009 to what the executive of firm A testified in front of the Commission, that is, a division of 2/3 and 1/3 for the collusive years. I observe that the % of head-to-head competition out of total contracts increases by about 8% while the reduction in bids of firms A and B when they compete head-to-head is 15.43% of the mean value of the contract in the period post-October 2009. Another interesting statistic is the % of territories where both firms have ever bid. A territory is defined as the smallest geographical unit that identifies the location of the paving project, called *municipalité régionale de comté* (from now on MRC). A MRC is a regional county municipality. It is a supra-local type of regional municipality and it groups different municipalities. Out of a total number of MRCs equal to 68, there are 23 MRCs in which cartel firms competed against each other only after the start of the police investigations. This fact signals that colluding firms were no longer allocating territories amongst themselves after the presumed end of the cartel.

Table 1.3 – Summary statistics for firms A and B for pre-investigation and post-investigation periods

Variables	Pre 2007-2009	Post 2010-2015
Participation firm A (%)	65.46	72.35
Participation firm B (%)	42.27	45.96
Market shares firm A (% value)	24.7	38.72
Market shares firm B (% value)	16.73	11.93
Asphalt plants firm A	35	36
Asphalt plants firm B	20	25
Head-to-head competition (%) (all contracts)	23.2	31.24
Head-to-head competition (%) (contracts with at least firm A or firm B bidding)	27.44	35.88
MRCs where both firms ever bid (%) (out of total MRCs)	31	54
Average bid when head-to-head (% mean value)	88.87	73.44

Notes: *2007-2009* refers to the period before the start of the police investigations (*Operation Marteau*). *2010-2015* refers to the period after the start of the police investigations. *Participation firm* refers to % of contracts out of total contracts where cartel firms participate. *Market share firm* refers to the market share of the cartel firm as % of total value in the period. The total value in the period is calculated summing all the winning bids. *Head-to-head competition (%) (all contracts)* is the percentage of contracts where firms A and B both participate out of total contracts. *Head-to-head competition (%) (contracts with at least firm A or firm B bidding)* is the percentage of contracts where firms A and B participate out of contracts that receive at least one bid from either firm A or firm B. *MRCs where both firms ever bid (%) (out of total MRCs)* indicates the % of smallest territorial units (*municipalité régionale de comté*, MRC) out of all MRCs where both firms ever bid. The total number of different MRCs in the dataset is 68. *Average bid when head-to-head (% mean value)* is the average bid expressed in % of the mean value of the contract for those contracts where firms A and B are both bidding.

Table 1.4 shows cartel firm statistics for every Quebec administrative region for the years before and after the start of the investigation while Figure 1.2 and 1.3 show the changes in % of head-to-head competition on the map of the administrative regions of Quebec. From Table 1.4 we can observe that the presence of a firm's asphalt plant in a region is highly correlated with the participation rate of the firm in the region: the correlation between the probability of having a plant in a region at the beginning of the sample period and the participation rate in the whole sample period is equal to 0.8536 for cartel firms, significant at 1%. In regions 4, 5, 14 and 15, where plants of cartel firms are located closer to each other than in the other regions, the degree of head-to-head competition is the highest in the collusive period (from 40% in region 14 to 57% in region 5). The degree of head-to-head competition increased in these four regions after the investigations began, reaching 87% of the contracts in region 5. In these four regions, plants remain the same across the whole sample period. The increase in head-to-head competition is more pronounced in those regions where both firms had plants at the beginning of the sample period.

From Table 1.4 we can also observe that there is weak evidence of collusion on asphalt plant location. Firms A and B are not putting any more plants after the start of the investigation in regions where only one of the two firms has at least one plant compared to those regions where both firms have either at least one or no plants at all. Since the decision on where to locate an asphalt plant is a long-term strategic variable, only the availability of additional years of data can allow me to conclude that the observed geographic separation of the asphalt plants is due to collusion rather than to geographic differentiation. The average difference in each contract between the distances of the two firms from the paving project is almost the same for the whole sample period (70 km in the period pre-investigation and post-investigation). The change in % head-to-head competition is not driven by the increase in asphalt plants in the post-investigation period in comparison to the pre-investigation period. If we exclude administrative regions where the number of asphalt plants did not change, the increase in % of head-to-head competition out of total contracts is about 11%. Thus the increase in head-to-head competition has not been driven by the fact that one cartel firm has put new plants closer to the other cartel firm.

Table 1.4 – Contracts and cartel firm statistics by Quebec administrative region.

Region	Period	Contracts	% both	Dist.plant (km)	Avg.bid (%)	Firm A statistics			Firm B statistics		
						Plants	% part	Mkt sh	Plants	% part	Mkt sh
1	pre	3	0%	294	107.39	5	100%	66.66%	0	0%	0%
	post	115	9.57%	45	77.5	6	80.87%	66.09%	2	19.13%	11.3%
2	pre	20	0%	186	86.4	2	90%	35%	0	5%	5%
	post	46	0%	186	71.14	2	54.35%	28.26%	0	2.17%	2.17%
3	pre	16	6.25%	151	71.92	0	37.5%	0%	0	6.25%	0%
	post	47	36.17%	37.4	72.67	0	36.17%	2.13%	2	80.85%	27.66%
4	pre	15	46.67%	36.6	79.99	1	53.33%	6.67%	2	93.34%	33.34%
	post	24	70.83%	36.6	78.68	1	70.84%	12.5%	2	100%	25%
5	pre	41	56.1%	2.9	93.67	3	65.85%	31.71%	2	90.24%	29.27%
	post	75	86.67%	2.9	68.52	3	94.67%	42.67%	2	92%	25.34%
6	pre	1	0%	16	115.56	0	0%	0%	2	100%	100%
	post	5	40%	16	75.37	0	40	20	2	100	40%
7	pre	6	16.67%	65	106.37	0	16.67%	0%	4	83.34%	33.34%
	post	6	0%	65	85.49	0	0%	0%	4	100%	33.34%
8	pre	4	0%	486	86.77	3	100%	50%	0	0%	0%
	post	4	0%	486	112.28	3	100%	25%	0	0%	0%
9	pre	0	0%	294	.	0	0%	0%	3	0%	0%
	post	23	0%	294	81.94	0	0%	0%	3	60.87%	47.83%
10	pre	25	0%	151	69.36	5	64%	48%	0	4%	0%
	post	59	8.47%	37.4	74.98	5	91.53%	49.15%	0	8.47%	0%
11	pre	12	8.34%	33	81.73	0	33.34%	16.67%	0	25%	0%
	post	14	35.71%	14	69.99	0	64.29%	14.29%	1	50%	0%
12	pre	8	0%	97	68.62	4	87.5%	37.5%	0	12.5%	12.5%
	post	13	7.69%	97	67.22	4	92.31%	30.77%	0	7.69%	0%
13	pre	9	0%	74	80.59	1	66.67%	0%	0	0%	0%
	post	31	3.23%	74	91.02	1	54.84%	3.22%	0	9.68%	0%
14	pre	25	40%	15	84.51	6	72%	28%	5	64%	12%
	post	48	54.17%	15	76.60	6	72.92%	18.75%	5	77.08%	18.75%
15	pre	9	22.22%	19	81.23	4	100%	88.89%	2	22.22%	11.11%
	post	47	51.06%	19	77.35	4	100%	61.7%	2	51.06%	6.38%

Notes: *pre* refers to years 2007-2009. *post* refer to years 2010-2015. *% both* refers to number of times firms A and B compete head-to-head over total contracts (in %). *Dist.plant (km)* represents the distance (in km) between closest plant of firm A and firm B in the region. *Avg.bid* is the average bid submitted by firms A and B in each region as % of the mean estimated value of contract. *Plants* refer to the number of plants the firm has in the administrative region. *% part* is the percentage participation of the firm in the road paving auctions in the administrative region. *Mkt sh* represents the percentage of contracts won over total contracts. *Plants* refers to the number of asphalt plants in a given administrative region. For the pre-investigation period, I consider the location of the asphalt plants in 2006. For the post-investigation period, I consider the location of asphalt plants in 2015.

From Figures 1.2 and 1.3 we can observe on the map that the increase in the % head-to-head competition for firms A and B is higher in regions where plants of both firms are close to each other.[17]

[17] The location of asphalt plants in Figure 1.2 is the one observed in 2006, while the location of asphalt plants in Figure 1.3 is the one observed in 2015.

Figure 1.2 – % head-to-head competition out of total contracts and plant location of firms A and B by Quebec administrative regions (pre-investigation period, 2007-2009).

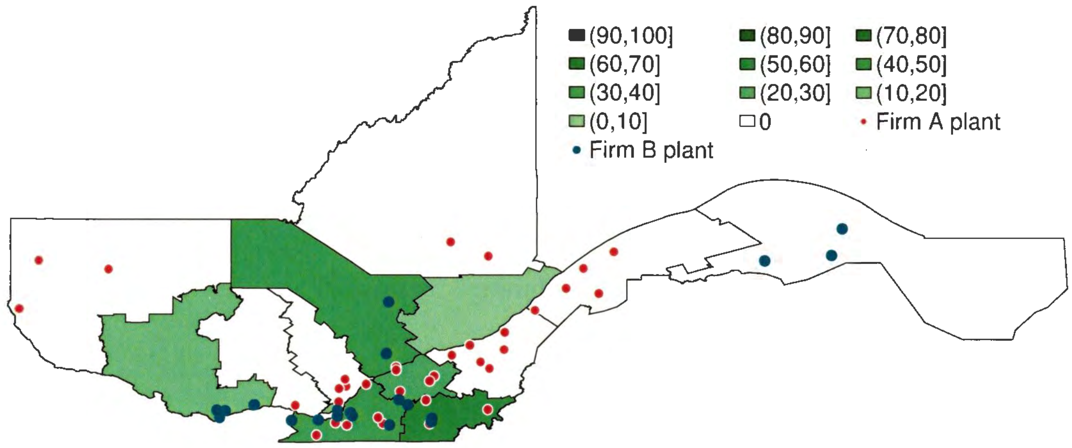
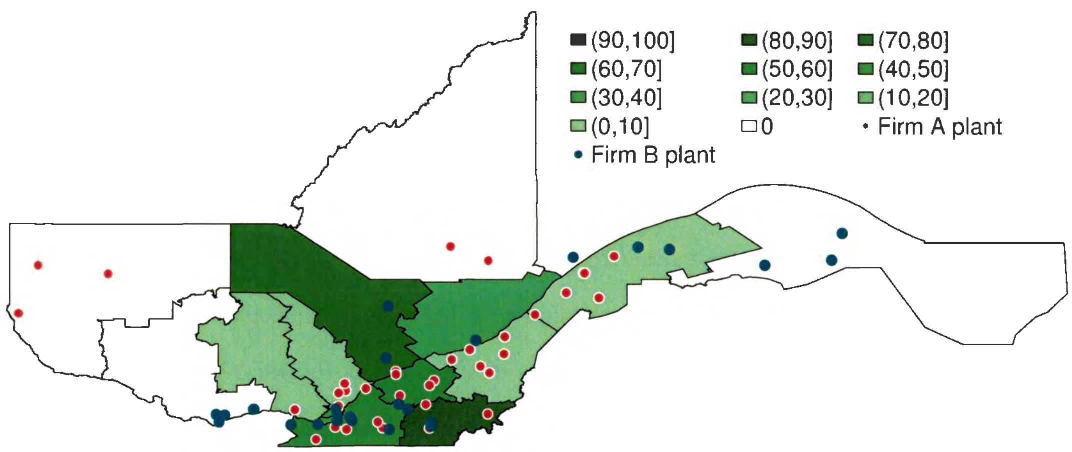


Figure 1.3 – % head-to-head competition out of total contracts and plant location of firms A and B by Quebec administrative regions (post-investigation, 2010-2015).



From the descriptive statistics, the following facts can be observed:

- An increase in the % of head-to-head competition after the start of the investigation,
- An increase in the % of head-to-head competition in those administrative regions of Quebec where both firms had at least one asphalt plant at the beginning of the sample period considered,

- A decrease in bids of cartel firms when they compete head-to-head (15.43% of the mean value of the contracts).

The increase in head-to-head competition and the decrease in bids could have also been driven by other factors different from the police investigation. To account for this, in the next section I propose a difference-in-difference design to identify whether the start of the police investigation had a causal effect on the increase in the degree of head-to-head competition and the drop in bids submitted by firms A and B.

1.4 Descriptive analysis

1.4.1 Identification strategy

I identify the causal effect of the end of the cartel on the two main outcomes analyzed, that is, the probability of head-to-head competition and the bids submitted by firms A and B when they compete head-to-head. I want to establish whether the increase in head-to-head competition and the decrease in bids were caused by the police investigation.

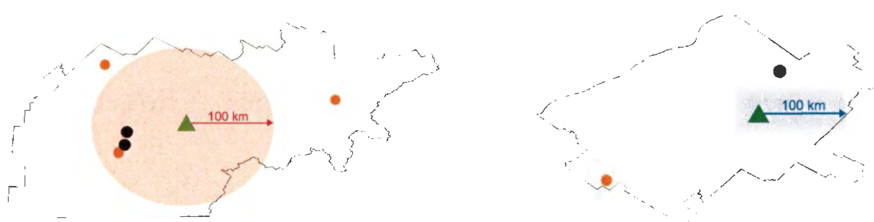
To capture the effect, I employ a difference-in-difference strategy. I compare two different groups of auctions, a "treated" and "control" group to analyze significant changes in the probability of head-to-head competition between the two cartel firms and their bids. I define the treated group of auctions in terms of potential competition i) at the bidding stage, and ii) at the participation stage. Thus, I define an auction as "potentially competitive" if the two cartel firms are located within a 100 km radius around the paving project awarded with the auction. I chose a radius of 100 km because it reflects the average distance that firms participating in these auctions have to cover to reach the paving project location. The average distance of participating firms in the dataset is 45 km and the average distance of participating firms in the treated group of auctions is 41 km. Interestingly, the median distance of participating firms is 35 km and is identical to the median distance of participating firms in the treated group of auctions.[18]

[18]In Appendix A I show that the results are robust i) to the choice of a radius of 90 km (Tables A.12 and

Figure 1.4 shows examples of auctions in the treated group (left) and the control group (right). Paving projects can be awarded in different regions of Quebec, but this does not mean that the division between treated auctions and control auctions is region-specific. The division is instead auction-specific. Figure 1.4 reports the location of firm A (orange circle), firm B (black circle) and the location of the paving project (green triangle). The black lines represent the borders of an administrative region in Quebec. Since the plant location could be itself a strategic choice of firms, I cannot exploit the location of a firm in a given administrative region. Using the radius allows me to overcome this endogeneity problem.

Figure 1.4a shows one case of treated auctions. Both cartel firms have at least one plant located within a 100 km radius around the paving project awarded with the auction. Figure 1.4b shows a case of an auction in the control group in which one of the cartel firms is located outside a 100 km radius around the project.

Figure 1.4 – Location of paving project (green triangle), of firms A (orange circle) and B (black circles) in an administrative region of Quebec



(a) Treated auction (b) Control auction

1.4.2 Head-to-head competition

Table 1.5 reports the average number of cartel bids in an auction (bids of firms A and B) for the two groups of auctions (treated and control). There is a lower probability of head-to-head competition for projects considered in the control group of auctions. Since I built my empirical strategy on the identification of treated auctions as the ones with higher potential competition between cartel firms, in the control group the probability of

A.13 in Appendix A), ii) to the choice of a radius of 110 km (Tables A.14 and A.15 in Appendix A).

head-to-head competition for the cartel firms is close to 0. The two groups are thus not comparable on this dimension. On the other hand, observing a higher gap in the difference between the two groups in the probability of head-to-head competition after the start of the police investigation could represent a sign that the investigation affected the participation behavior of cartel firms in those auctions in which they could be potential competitors. The difference between the two groups increases from 0.35 to 0.45.

Table 1.5 – Average number of cartel bids in the pre-investigation and post-investigation periods.

Variable	Sample	Group	Pre (2007-2009)	Post (2010-2015)	Difference
Number of cartel bids	All auctions	Treated	1.26	1.40	0.14
		Control	0.73	0.78	0.05
Probability head-to-head	All auctions	Treated	0.35	0.47	0.12
		Control	0.00	0.02	0.02

Next, I investigate whether these results are robust with the inclusion of other contract characteristics. The econometric specification is the following:

$$Y_a = \beta_0 + \beta_1 TreatedAuction_a X Post_a + \beta_2 TreatedAuction_a + \beta_3 Post_a + \beta_4 Z_a + \varepsilon_a \quad (1.1)$$

where Y_a is the measure of head-to-head competition (the number of cartel bids in an auction). The variable *TreatedAuction* is equal to 1 if the two cartel firms are located within a 100 km radius around the project, 0 otherwise. The variable *Post* indicates whether the auction was published after October 2009, and Z_a represents a set of auction characteristics: i) the number of potential cartel bidders (firms A and B); ii) the number of potential bidders outside the cartel (firms other than A and B); iii) a proxy for the demand, that is the percentage in value of contracts awarded up to auction a in a given administrative region of Quebec and year; iv) dummies identifying the administrative region of project location of the auction, the year of publication of the auction and the value of the auction's project. I also include a variable that represents the highest level of free capacity of cartel firms in a given region and year in order to control for capacity constraints.

Since one of the contract characteristics is the number of potential bidders (cartel and non-cartel bidders), I need to identify a set of potential participants for which I do not have data. Thus, I rely on a proxy for potential competition at the participation stage. The dataset does not provide any information on the number of firms that downloaded the call for tender on the electronic tendering website. I define a firm as a potential participant if it has ever bid in an auction nearby. I associate nearby auctions with the smallest geographic unit I can identify for the paving project. This geographic unit is the MRC.[19] If a firm has bid at any time in any auction in a given MRC, the firm is considered a potential participant.[20]

Table 1.6 reports the results of the estimation of equation 1.1. After the start of the police investigation, the number of cartel bids increases by about 0.23 with respect to the control group of auctions, once I control for contract characteristics. The increase is about 18% of the average outcome observed in the pre-investigation period in the treated group. If I consider head-to-head competition as a binary variable, the probability of both firms competing head-to-head in the same auction is 22% higher in the treated than in the control group of auctions after the beginning of the police investigation, once I include all contract characteristics and additional controls, such as whether the two cartel firms are close to full capacity. The inclusion of the number of potential cartel bidders and the number of potential bidders outside the cartel does not affect the result. The increase in head-to-head competition represents 63% of the average outcome in the treatment group in the pre-investigation period.[21]

[19]The definition of a MRC has been provided in subsection 1.3.2.

[20]This procedure is similar to that of Athey et al. (2011) and Conley and Decarolis (2016).

[21]Tables A.3 and A.4 in Appendix A report the results for the test of the common trend assumption for the two groups of auctions considered. If I interact the dummy variable indicating the treated group of auctions with a linear trend (*Year*), I reject the parallel trend assumption. On the other hand, if I interact the dummy variable indicating the treated group of auctions with year dummies, I cannot reject the hypothesis that the coefficient of *Treated*2008* is equal to the coefficient of *Treated*2009*.

Table 1.6 – Diff-in-diff for the number of cartel bids in an auction and probability of head-to-head competition

Sample	All auctions					
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	nbr. cartel bids	nbr. cartel bids	nbr. cartel bids	prob. head-to-head	prob. head-to-head	prob. head-to-head
TreatedAuctionXPost	0.0847	0.168	0.231**	0.0999	0.136**	0.222***
	(0.138)	(0.108)	(0.116)	(0.0817)	(0.0674)	(0.0510)
TreatedAuction	0.528***	0.299***	-0.0169	0.354***	0.221***	-0.0377
	(0.114)	(0.0890)	(0.115)	(0.0628)	(0.0503)	(0.0491)
Post	0.0510	-0.0423	-0.0585	0.0155	-0.0203	-0.0222
	(0.0949)	(0.0802)	(0.161)	(0.0112)	(0.0219)	(0.110)
N potential cartel bidders		0.425***	0.262***		0.238***	0.0970***
		(0.0414)	(0.0548)		(0.0382)	(0.0287)
N potential non-cartel bidders		-0.0412***	-0.0302*		-0.00966	-0.00556
		(0.0137)	(0.0173)		(0.00766)	(0.00971)
Free capacity of cartel firms (%)		-0.00185*	-0.000573		-0.000795	-0.000164
		(0.000946)	(0.000822)		(0.000579)	(0.000424)
Demand (%)		-0.00271**	-0.00114		-0.00123*	-0.000403
		(0.00107)	(0.00104)		(0.000650)	(0.000524)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Size project effects	No	No	Yes	No	No	Yes
Observations	751	751	751	751	751	751
R-squared	0.202	0.336	0.494	0.209	0.280	0.479
Average Outcome Treated Pre	1.260	1.260	1.260	0.354	0.354	0.354

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *nbr. carte bids* indicates the number of cartel bids in an auction. *prob head-to-head* is a binary variable indicating whether both cartel firms (firms A and B) bid in the auction. *Post* is a dummy equal to 1 if the contract is published after October 2009. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Free capacity of cartel firms (%)* is the highest level of free capacity (%) of cartel firms in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10% (*), at 5% (**), and at 1% (***).

The increase in head-to-head competition in the treated group of auctions, includes two types of effects: i) colluding firms do not divide territories amongst themselves after the start of the investigation, and ii) colluding firms do not alternate their participation in territories where they are both "active" bidders. To find evidence of i), I examine the participation behavior in an MRC. In particular, I look at those MRCs where in the pre-investigation period only one of the two firms bid. The outcome I consider is the number of cartel bids in an auction.

Table 1.7 reports the statistics for the treated and control groups. By construction, in the treated and control groups, the average number of cartel bids is less than 1 in the pre-investigation period. In the treated group of auctions, there has been a 36% increase in the average number of cartel bids in the post-investigation period.

Table 1.7 – Number of cartel bids for pre-investigation and post-investigation periods.

Outcome	Sample	Group	Pre (2007-2009)	Post (2010-2015)	Difference
Number of cartel bids	All auctions in MRCs with one cartel firm bidding pre investigation	Treated	0.91	1.24	0.33
		Control	0.85	0.84	-0.01

As in the previous subsection, I investigate whether these results are robust with the inclusion of other contract characteristics. The econometric specification is the following:

$$Y_a = \beta_0 + \beta_1 TreatedAuction_a X Post_a + \beta_2 TreatedAuction_a + \beta_3 Post_a + \beta_4 Z_a + \varepsilon_a \quad (1.2)$$

where Y_a is now the number of cartel bids in auction a. The variable *TreatedAuction* is equal to 1 if the cartel firms are located within a 100 km radius around the project, 0 otherwise. The variable *Post* indicates if the auction was published after October 2009 and Z_a represents auction characteristics as above. The interest relies on the coefficient β_1.

Table 1.8 reports the results. The increase in the number of cartel bids in the treated with respect to the control group of auctions is about 0.35 in a model that does not account for contract characteristics (column 1). The inclusion of all contract characteristics does not change the results. The observed increase in the number of cartel bids in the treated group represents an increase by about 35% of the average number of cartel bids in the pre-investigation period in the treated group.[22]

[22]Table A.5 reports the results of the test of the common trend. The non-significance of the interaction between the treated group and a linear trend (*Year*) means that we cannot reject the null hypothesis of a linear common trend between the two groups of auctions.

Table 1.8 – Diff-in-diff for the number of cartel bids in an auction. Only MRCs in which only one cartel firm ever bid in the pre-investigation period are considered.

Dependent variable	Number of cartel bids in an auction		
	(1)	(2)	(3)
	diff-diff	diff-diff	diff-diff
TreatedAuctionXPost	0.349***	0.336***	0.315**
	(0.105)	(0.105)	(0.137)
TreatedAuction	0.0579	0.00132	-0.228*
	(0.0637)	(0.0782)	(0.119)
Post	-0.0157	-0.0366	-0.155
	(0.0945)	(0.0923)	(0.194)
N potential cartel bidders		0.223***	0.156**
		(0.0577)	(0.0714)
N potential non-cartel bidders		-0.0208	-0.0107
		(0.0173)	(0.0251)
Free capacity of cartel firms (%)		-0.000172	0.000259
		(0.00126)	(0.00117)
Demand (%)		-0.000772	-0.000515
		(0.00148)	(0.00149)
Admin Region effects	No	No	Yes
Year effects	No	No	Yes
Size project effects	No	No	Yes
Observations	345	345	345
R-squared	0.127	0.166	0.374
Average Outcome Treated Pre	0.907	0.907	0.907

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *TreatedAuction*Year* represents the interaction between *TreatedAuction* and a linear trend (*Year*). *Post* is a dummy equal to 1 if the contract was published after October 2009. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Free capacity of cartel firms (%)* is the highest level of free capacity of cartel firms in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10%(*), 5% (**), 1%(***) $p < .01$.

1.4.3 Bids

In the last part of the descriptive analysis, I show the impact of the police investigations on bids. The bids are expressed in % of the mean value of the contract. Table 1.9 reports the results. On average, bids decrease in the treated group of auctions by about 11.29%. The most relevant decrease in bids is observed for the bids submitted by cartel firms when they compete head-to-head in the same auction (-15.64%). In the control group of auctions, the bids on average remain at the same level.

Table 1.9 – Average bid as % of mean value of contract for pre-investigation and post-investigation periods

Outcome	Sample	Group	Pre (2007-2009)	Post (2010-2015)	Difference
Bid (% value)	All bids	Treated	86.68	75.39	-11.29
	Bids in auctions firms A and B head-to-head	Treated	87.37	73.05	-14.32
	Cartel bids in auctions firms A and B head-to-head	Treated	88.87	73.23	-15.64
	All bids	Control	79.76	81.59	+1.83

I investigate whether these results are robust with the inclusion of other contract and bidder characteristics. The econometric specification is the following:

$$Bid_{ia} = \beta_0 + \beta_1 TreatedAuction_a X Post_a + \beta_2 TreatedAuction_a + \beta_3 Post_a + \beta_4 X_{ia} + \beta_5 Z_a + \varepsilon_{ia} \quad (1.3)$$

where Bid_a is the bid submitted by firm i in auction a (as% of the mean value of the contract). The variable *TreatedAuction* is equal to 1 if both cartel firms are within a radius of 100 km around the paving project awarded with auction a, 0 otherwise. The variable *Post* indicates whether the auction was published after October 2009, while the variables X_{ia} and Z_a represent respectively bidder and contract characteristics. Bidder characteristics are i) capacity, ii) distance of the closest asphalt plant from the project location, iii) the value of contracts won up to auction a in a given administrative region and year. Contract characteristics are the number of potential cartel and non-cartel bidders, demand and the dummies related to the year of publication of the auction and related to the location of the auction (administrative region).

Table 1.10 reports the results. Columns 1-3 report the estimates for bids (winning and losing bids), and columns 4-6 report the estimates only for winning bids. In all the different specifications there is a negative and significant coefficient for the treated group of auctions compared to the control group, in line with what we found in the descriptive table above. The bids in the treated group of auctions decrease by about 13% of the mean estimated value of the contract compared to auctions in the control group. The decrease in bids represents 15% of the average bid observed in the pre-investigation period in the treated group of auctions. The observed decrease in the bids is robust to the inclusion of relevant cost factors of firms, such as their distance (in km) from the project and their capacity. The decline in bids is also robust to other contract characteristics, such as the number of contracts awarded in a given administrative region and year and the number of potential competitors. For the average bids, there seems to be a significant impact of the number of contracts previously won by a given firm. This variable represents firm's economies of scale (the more contracts a firm wins in a region, the lower they will bid in the following contracts). The winning bids decrease by about 13% of the value of the contract. This means that if we consider the average value of a contract (C$2 million), firms in the treated group of auctions are winning by submitting bids that are about C$260,000 lower than those observed in the pre-investigation period. This implies an average saving for the public administration of about C$12 million per year after the investigation started.[23]

Appendix A shows several robustness checks. Table A.7 replicate Table 1.10 using the upper bound of the interval identifying the estimated value of the contract as a measure to normalize bids. In all the main estimations, I have used the mean of this interval. Table A.8 replicates Table 1.10 excluding auctions with only one bidder. Table A.9 replicates Table 1.10 controlling for the number of actual bidders, instead of the number of potential bidders.

[23]Table A.6 reports the tests for the presence of a linear common trend for the two groups of auctions. The null hypothesis of a linear common trend in the pre-investigation period for the treated and control groups of auctions is only weakly rejected considering all bids. The null hypothesis of a linear common trend is not rejected for the winning bids.

Table 1.10 – Diff-in-diff for bids over mean value of contract (%)

Treated Sample	All auctions					
Dependent variable	Bid over mean value of the contract (%)					
	(1) all bids	(2) all bids	(3) all bids	(4) winning bids	(5) winning bids	(6) winning bids
TreatedAuctionXPost	-13.12**	-13.06**	-14.77**	-11.12**	-10.11**	-12.93**
	(5.550)	(5.415)	(5.929)	(5.076)	(4.973)	(5.623)
TreatedAuction	6.923	9.435**	12.81**	5.205	7.051*	12.41**
	(4.334)	(4.156)	(4.999)	(4.227)	(4.077)	(5.027)
Post	1.831	2.166	11.07	-1.993	-3.517	9.116
	(4.623)	(4.517)	(7.961)	(3.799)	(3.788)	(6.389)
Distance (km)		0.0335**	0.0364**		0.0339	0.0356
		(0.0169)	(0.0175)		(0.0224)	(0.0245)
Capacity (%)		0.0262	0.0237		0.0321	0.0196
		(0.0374)	(0.0381)		(0.0690)	(0.0769)
Value firm region		-0.101*	-0.110*		0.0154	0.00534
		(0.0537)	(0.0563)		(0.0986)	(0.113)
N potential cartel bidders		-5.388**	-6.713**		-2.953	-3.924
		(2.487)	(2.963)		(2.097)	(2.642)
N potential non-cartel bidders		0.0259	0.543		-0.678	-0.306
		(0.597)	(0.970)		(0.492)	(0.843)
Demand (%)		0.0797*	0.0818*		0.00708	0.0151
		(0.0452)	(0.0468)		(0.0446)	(0.0463)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	2,230	2,230	2,230	751	751	751
R-squared	0.0186	0.0341	0.0522	0.0267	0.0375	0.0554
Average Outcome Treated Pre	86.68	86.68	86.68	83.14	83.14	83.14

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether auction *a* was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage of total value of contracts won up to auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over the total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Table 1.11 reports the results for the same econometric specification as in equation 1.3, including in the treated sample only the bids coming from auctions in which cartel firms compete head-to-head. The magnitude of the coefficient of *TreatedAuctionXPost* is higher than the one estimated in Table 1.10.

Table 1.11 – Diff-in-diff for bids over mean value of contract (%)

Treated sample	All auctions where cartel firms compete head-to-head					
Dependent variable	Bid over mean value of the contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-16.15**	-16.33**	-20.22**	-14.89**	-13.61**	-15.70**
	(7.375)	(7.554)	(8.822)	(6.623)	(6.737)	(7.773)
TreatedAuction	7.612	11.67*	14.79	6.626	9.247	10.25
	(6.135)	(6.427)	(9.686)	(5.722)	(6.104)	(8.460)
Post	1.831	2.123	13.74	-1.993	-3.208	10.90
	(4.628)	(4.652)	(9.397)	(3.806)	(3.952)	(7.933)
Distance (km)		0.0177	0.0207		-0.00921	-0.0153
		(0.0188)	(0.0199)		(0.0326)	(0.0373)
Capacity (%)		0.0238	0.0422		-0.1000	-0.0624
		(0.0521)	(0.0563)		(0.0945)	(0.114)
Value firm region		-0.109	-0.153*		0.143	0.0423
		(0.0704)	(0.0841)		(0.119)	(0.157)
N potential cartel bidders		-5.912	-5.513		-3.274	-3.163
		(3.657)	(4.134)		(3.396)	(4.261)
N potential non-cartel bidders		-0.280	0.102		-0.885	-1.007
		(0.828)	(1.270)		(0.743)	(1.154)
Demand (%)		0.111*	0.115*		0.0937	0.102
		(0.0639)	(0.0659)		(0.0611)	(0.0668)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	1,388	1,388	1,388	476	476	476
R-squared	0.0230	0.0387	0.0680	0.0303	0.0446	0.0707
Average Outcome Treated Pre	87.37	87.37	87.37	84.56	84.56	84.56

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether auction a was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project.*Capacity (%)* is the percentage of total value of contracts won up to auction a over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction a over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Finally, Table 1.12 reports the results for the same econometric specification as in equation 1.3, including in the treated sample only the bids coming from cartel firms in auctions where they compete head-to-head. The magnitude of the coefficient of *TreatedAuctionXPost* is the highest between the three different treatment samples if we consider the winning bids. The decrease in bids between the pre- and post-investigation period is about

21% of the average bid observed in the pre-investigation period for the treated group of auctions considered.

Table 1.12 – Diff-in-diff for bids over mean value of contract (%)

Treated sample	Cartel bids in auctions where cartel firms compete head-to-head					
Dependent variable	Bid over mean value of the contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-17.47**	-17.74**	-20.26**	-18.82***	-18.94***	-19.53**
	(7.015)	(7.201)	(8.456)	(7.013)	(7.198)	(8.617)
TreatedAuction	9.111	13.27**	14.56	13.20**	16.56**	19.16*
	(5.724)	(6.081)	(9.011)	(5.949)	(6.407)	(10.19)
Post	1.831	2.079	18.93**	-1.993	-2.767	9.679
	(4.630)	(4.690)	(9.382)	(3.810)	(4.076)	(11.92)
Distance (km)		0.0173	0.0172		-0.0222	-0.0240
		(0.0207)	(0.0220)		(0.0346)	(0.0396)
Capacity (%)		0.0152	0.0505		-0.113	-0.0697
		(0.0603)	(0.0628)		(0.113)	(0.139)
Value firm region		-0.0547	-0.129		0.165	0.0832
		(0.0770)	(0.0837)		(0.133)	(0.172)
N potential cartel bidders		-6.013	-4.670		-3.503	-1.226
		(3.744)	(4.139)		(3.500)	(4.570)
N potential non-cartel bidders		-0.247	-0.251		-0.700	-1.894
		(0.795)	(1.232)		(0.902)	(1.333)
Demand (%)		0.0790	0.0815		0.0908	0.0815
		(0.0577)	(0.0588)		(0.0721)	(0.0806)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	1,011	1,011	1,011	386	386	386
R-squared	0.0209	0.0334	0.0729	0.0275	0.0421	0.0909
Average Outcome Treated Pre	88.87	88.87	88.87	91.13	91.13	91.13

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether auction *a* was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage of total value of contracts won up to auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

1.5 The effect of the increase in head-to-head competition on bids

The results presented in the previous section show that head-to-head competition increased and bids decreased after the start of the police investigation in the Quebec construction industry. The econometric model was not capable of capturing whether the decrease in the bids was due to firms A and B avoiding head-to-head competition or coordinating bids. Determining which part of the decrease in procurement costs should be attributed to coordination on bids and which part should be attributed to coordination on head-to-head competition is important. In a cartel that does not include all the firms in the market, the two types of coordination can have a different impact on procurement costs.

To quantify the extent to which restricting head-to-head competition increased procurement costs, I propose two approaches: a reduced form and a structural one. To determine the impact that coordination on the degree of head-to-head competition has on bids, I mimic a situation in which, even in the period without collusion, the two firms suspected of collusion compete head-to-head at the same rate as under the collusive regime observed before October 2009.

1.5.1 Reduced-form approach

In Table 1.13 I estimate a model in which I exclude all auctions awarded in MRCs where one of the two cartel firms participated for the first time after the start of the investigation. For example, suppose that firm A was the only bidder in the MRC of Montreal until October 2009. If firm B started bidding in Montreal after October 2009, I drop the auctions in Montreal in which firm B bids. The results obtained are almost identical to those observed in Table 1.10. This implies that the effect of coordination on the degree of head-to-head competition is smaller relative to the effect of coordination on bids.

The reduced-form approach presents different issues. First, it considers the decision of firms to participate in an auction as exogenous. Second, in some of the MRCs both cartel firms were already active bidders in the period pre-investigation but they simply competed head-to-head to a lower extent. This second aspect cannot be captured with a reduced-form approach. Finally, an additional reason is related to the entry effect established by Li and Zheng (2009). They show that the probability of entry decreases with the number of potential bidders. Thus bids do not always decrease with an increase in competition because bidders are more willing to participate when facing a lower number of potential opponents.

Table 1.13 – Diff-in-diff for bids over mean value of contract (%)

Sample	Auctions in MRCs where firms have bid before and after the police investigation					
Dependent variable	Bid over mean value of the contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-12.41**	-13.03**	-13.50**	-10.36**	-9.976*	-12.08**
	(5.669)	(5.599)	(6.044)	(5.162)	(5.044)	(5.687)
TreatedAuction	7.174*	10.20**	10.71**	5.334	7.632*	11.37**
	(4.300)	(4.264)	(5.092)	(4.222)	(4.081)	(5.075)
Post	1.831	1.875	8.074	-1.993	-3.720	6.533
	(4.624)	(4.556)	(7.525)	(3.800)	(3.800)	(6.464)
Distance (km)		0.0397**	0.0423**		0.0284	0.0271
		(0.0183)	(0.0187)		(0.0234)	(0.0253)
Capacity (%)		0.00993	0.00854		0.0326	0.0232
		(0.0393)	(0.0409)		(0.0750)	(0.0834)
Value firm region (%)		-0.0650	-0.0721		0.0368	0.0226
		(0.0577)	(0.0619)		(0.110)	(0.127)
N potential cartel bidders		-6.030**	-8.453***		-3.393	-4.949*
		(2.709)	(3.055)		(2.143)	(2.669)
N potential non-cartel bidders		-0.138	0.455		-0.903	-0.505
		(0.648)	(1.007)		(0.562)	(0.920)
Demand (%)		0.0615	0.0625		-0.0114	-0.00426
		(0.0446)	(0.0460)		(0.0456)	(0.0470)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	1,895	1,895	1,895	674	674	674
R-squared	0.0164	0.0334	0.0510	0.0228	0.0345	0.0524
Average Outcome Treated Pre	86.93	86.93	86.93	83.27	83.27	83.27

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether auction *a* was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage of total value of contracts won up to auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

1.5.2 Structural model of participation and bidding

To make the participation decision of firms endogenous, I employ a structural model of participation in auction and bidding that models the participation decision and bidding behavior as endogenous. I can simulate a counterfactual scenario in which firms A and

B coordinate the degree of head-to-head competition and do not coordinate their bids. While in the data there is a scenario in which firms coordinate the degree of head-to-head competition and bids (the period before the start of the police investigation) and a scenario in which firms A and B do not coordinate the degree of head-to-head competition and bids (the period after the start of the police investigation), the scenario in which firms A and B coordinate only the degree of head-to-head competition is not observed.

To identify the effect of coordination on the degree of head-to-head competition on bids, I use a model of participation in an auction and bidding that strictly follows Athey et al. (2011) and Gugler et al. (2015). The model is based on the following assumptions. First, the model has two steps: the individual decision of each firm to participate in an auction (step 1) and the decision on the bid level once the firm decides to participate (step 2). In line with the firm statistics presented in Table 1.2, the model allows for the existence of asymmetric bidders, since there are differences between the two cartel firms and, more generally, between almost every firm in terms of participation behavior and the number of asphalt plants they own in the province of Quebec. I adopt a parametric assumption on the bid distribution. I assume, again strictly following Athey et al. (2011) and Gugler et al. (2015), that bids are distributed according to a Weibull distribution. With asymmetric bidders and given the nature of the counterfactual experiment, putting parametric assumptions on the bid distribution makes the estimation of counterfactual bids easier. Finally, the model is estimated using auctions from the competitive period, i.e. the period after October 2009, and I assume independent private costs.[24]

The model

The model can be characterized as a two-stage game. In the first stage, firms choose whether or not to participate in the auction. In the second stage, only firms that decided to participate in the first stage bid in the auction. The preparation of the bid is a costly activity. Each bidder willing to participate in an auction has to pay a submission warranty; and, before submitting the final bid, each firm has to estimate the price offered for each

[24] Appendix A contains a more detailed discussion of the modeling assumptions.

task in the contract (the price per ton of asphalt or the transportation costs of asphalt, for example).

Participation and bidding are independent activities because the participation stage only determines at the bidding stage the number of firms effectively participating. Since the model is characterized by a two stage game, it is solved by backward induction. For the bidding process, a standard first-price sealed-bid auction setting is adopted. Bidders are risk neutral and each bidder i draws his own private cost c_i for completing the project from his own distribution $F_i(.)$. At the bidding stage, participating firms already know how many bidders n they face out of a set of potential bidders N, and each bidder maximizes its own profits:

$$\pi_i(c_i,b_i,n) = (b_i - c_i) \prod_{j \in n \setminus i} [1 - F_j(b_j^{-1}(b_i);n)] \tag{1.4}$$

where $1 - F_j(b_j^{-1}(b);n) = 1 - G_j(b;n)$ is the probability that j will bid higher than b and the inverse bidding strategy $b_j^{-1}(b)$ is equal to the cost of player j, called c_j. Maximizing with respect to b_i, we can find the first-order condition of the problem, which is the following:

$$\frac{1}{b_i - c_i} = \sum_{j \in n \setminus i} \frac{g_j(b_i;n)}{(1 - G_j(b_i;n)} \tag{1.5}$$

The asymmetric equilibrium bidding is characterized by the following equation

$$b_i(c_i,n) = c_i + \frac{1}{\sum_{j \in n \setminus i} \frac{g_j(b_i;n)}{(1 - G_j(b_i;n)}} \tag{1.6}$$

which depends on the firm's own cost and the opponents' bid distribution and density of bids.

At the participation stage, a potential bidder i decides whether or not to enter in the auction. Each bidder enters the auction if its expected profits from entering are higher than its entry costs. In other words,

$$\Pi_i(p) = \sum_{n \subset N} \pi_i(n) Pr[n|i \in n] \geq K_i \tag{1.7}$$

where K_i is the entry cost, $\pi_i(n)$ is the ex-ante markup from the auction, and $Pr[n|i \in n]$ is the probability that n bidders out of N potential bidders enter the auction if bidder i

enters. Although the model is more flexible since it allows for asymmetric bidders and for bidder-specific participation costs, the asymmetric participation equilibrium exists, but it need not be unique. The result has been established by Li and Zhang (2015) who give a more detailed discussion of it.

Identification

As in Guerre et al. (2000), it is possible to directly identify the cost c_i of each bidder from the observed bids and their distribution. Here, I apply a parametric version of GPV. In an auction with a set of contract characteristics Z, number of potential cartel bidders N_c, number of potential bidders outside the cartel N_{nc}, number of actual bidders in the cartel n_c and those outside the cartel n_{nc}, the estimated cost of bidder i with characteristics X is given by

$$\hat{c}_i = b_i - \frac{1}{\sum_{j \in N \setminus i} \frac{\hat{g}_j(b_i|X,Z,N_c,N_{nc},n_c,n_{nc})}{(1-\hat{G}_j(b_i|X,Z,N_c,N_{nc},n_c,n_{nc})}} \tag{1.8}$$

The participation probability p_i is directly identifiable from the data. Owing to the variation in the number of potential bidders (both in the cartel and outside the cartel), entry costs are also identifiable. I estimate these costs to check whether the relevance of these entry costs explains the reluctance of head-to-head competition in the collusive period. To do so, I find an expression for the expected profits through the estimation of the participation probabilities of each firm and the repeated simulations of auction outcomes in which each firm participates as in Athey et al. (2011).

Estimation

In the first stage, firms decide whether or not to participate in the auction. The participation decision is a binary choice variable that takes value 1 if equation 1.7 is satisfied. The distribution of bidders' participation is binomial. This binomial distribution has a parametric (logit) specification that allows estimating the predicted participation of each firm:

$$p_i(X,Z,N_c,N_{nc}) = \frac{exp(\alpha_1 X + \alpha_2 Z + \alpha_3 N_c + \alpha_4 N_{nc})}{1 + exp(\alpha_1 X + \alpha_2 Z + \alpha_3 N_c + \alpha_4 N_{nc})} \tag{1.9}$$

With the logit estimation, I can obtain the predicted probabilities of participation for each firm in each auction. With these probabilities, I simulate 1000 times the participation behavior in a given contract. The participation of potential bidders in an auction is simulated 1000 times using individual predicted participation probabilities for each potential bidder. Thus, 1000 new samples of auctions are obtained.

At the subsequent bidding stage, participants choose their bid b_i which is dependent on their cost c_i given the number of bidders entering the auction $n \subseteq N$. Costs are estimated through the method proposed by Guerre et al. (2000) with parametric assumptions on the distribution of bids. As in Athey et al. (2011), a Weibull distribution has been chosen for bids:

$$G_i(b_i|X,Z,N_c,N_{nc},n_c,n_{nc}) = 1 - \exp\left(-\frac{b_i}{\lambda_i(X,Z,N_c,N_{nc},n_c,n_{nc})}\right)^{\rho_i(X,Z,N_c,N_{nc},n_c,n_{nc})} \tag{1.10}$$

where the parameters of the distribution λ_i and ρ_i depend on a set of bidder characteristics, auction characteristics and the number of potential and actual bidders in the cartel and outside the cartel. These two parameters are linearized and estimated through maximum likelihood.

Given the 1000 different samples of auctions obtained and the estimated bid distribution parameters, for each participation draw we can find the empirical distribution and density of bids for each bidder in order to recover the estimated cost $\hat{c}_i$ given by

$$\hat{c}_i = b_i - \frac{1}{\sum_{j \in n \setminus i} \frac{\hat{g}_j(b_i|X,Z,N_c,N_{nc},n_c,n_{nc})}{(1-\hat{G}_j(b_i|X,Z,N_c,N_{nc},n_c,n_{nc}))}} \tag{1.11}$$

with empirical distribution $\hat{F}_i(\hat{c}_i|X,Z,N_c,N_{nc},n_c,n_{nc})$. The variables representing the bidder characteristics are the capacity, the value of contracts won by the firm in a given administrative region up to the auction, and the firm's own distance from the paving project. The set of contract characteristics include dummies for year of publication of the auction, dummies identifying the administrative region of location of the paving project of auction a, and the value of contracts awarded up to auction a in a given region and year. The number of potential bidders in the cartel is defined as the number of bidders (firms A and

B) bidding at least once in the post-investigation period in a given MRC where the paving project is located. The number of potential non cartel bidders is the number of bidders other than firms A and B bidding at least once in the whole post-investigation period in a given MRC where the paving project is located.

Results

Table 1.14 reports the estimates of the parameters in equation 1.9 using the observed bidder participation. The capacity, contracts won and the firm's own distance enter the participation decision in the expected way. The higher the occupied capacity, the lower is the probability of participating in an auction. The higher the distance from the project, the lower is the probability of participation. The higher the value of contracts won (a proxy capturing economies of scale), the higher is the participation probability. In addition, the probability of participation is negatively influenced by the number of potential non-cartel bidders. This effect is similar to the one found in Li and Zheng (2009), who estimate a negative relationship between the number of potential and actual bidders in the auction. The number of potential cartel bidders is not significantly correlated with the probability of participation.

Table 1.14 reports also the estimates of bid parameters λ_i (the scale of distribution) and ρ_i (shape of the distribution). The only significant parameters for the scale of the distribution are the demand and number of potential and actual bidders. If the value of contracts awarded in a given administrative region and year is higher, firms bid higher. This might be due to the fact that the higher the number of awarded contracts, the more firms are likely to reach their capacity constraints. The negative coefficient of the number of potential cartel bidders shows that if firms A and B are potential competitors, the competitive pressure is higher, causing bids to be lower. The number of actual cartel bids is another factor influencing the bid distribution. If both cartel firms bid in the auction, there is a downward pressure on bids (as expected).

Table 1.14 – Determinants of participation and parameters of the bid distribution

	Participation	λ	ρ
Distance (km)	-0.0150***	0.0315	0.00142
	(0.00101)	(0.0202)	(0.00149)
Capacity (%)	-0.000861	-0.00351	-0.00234
	(0.00180)	(0.0404)	(0.00284)
Value firm region (%)	0.0590***		0.00446
	(0.00572)		(0.00537)
Demand (%)	-0.0100***	0.120***	0.000969
	(0.00145)	(0.0337)	(0.00279)
N potential cartel bidders	-0.0512	-9.416***	-0.224
	(0.109)	(2.285)	(0.202)
N potential non-cartel bidders	-0.241***	1.580**	0.0597
	(0.0307)	(0.676)	(0.0514)
n cartel bidders		-4.141**	-0.192
		(1.828)	(0.147)
n non-cartel bidders		0.714	0.170**
		(0.988)	(0.0859)
Admin region dummies	Yes	Yes	Yes
Year dummies	Yes	Yes	Yes
Size project dummies	Yes	No	No
N	3351	1641	1641
Pseudo R^2	0.2110		
Log-pseudolikelihood	-1831.5758	-7864.4686	

Notes: Standard errors in parentheses. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage capacity of the bidder expressed as % of value of contracts won up to auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over total value of contracts awarded in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*).*N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *n cartel bidders* is the number of cartel bidders (firms A and B) bidding in the auction. *n non cartel bidders* is the number of bidders (other than firms A and B) bidding in the auction. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Finally, I estimate entry costs. I take an average of firms' profits across simulations of each contract and multiply these profits by the probability of participation found by estimating equation 1.7. The median entry cost is 17% of the average bid. The relevance of these entry costs is one of the factors motivating coordination on the degree of head-to-head competition between cartel firms.

Counterfactual: The relative importance of coordinating head-to-head competition with respect to coordination on bids

For the counterfactual experiment, I simulate an unobserved scenario where firms collude on the degree at which they compete head-to-head. In this way, I establish what would have been the price effect if firms were allowed only to collude on the degree of head-to-head competition. In order to implement this counterfactual scenario, I use the participation probabilities of the cartel firms observed in the pre-investigation period, assuming that firms outside the cartel keep the same participation probabilities they had in the competitive period. Then, I simulate competitive bidding under this alternative scenario.

When I use the participation probabilities of cartel firms in the pre-investigation period, I have to consider one issue. The baseline estimation of the previous section computes the participation probabilities that are firm-auction specific. For the counterfactual, in order to find the participation probability in the pre-investigation period, I use the empirical frequencies of participation of these two firms at the MRC level.

The steps for the estimation of the counterfactual experiment are as follows:

- For cartel firms, I compute the empirical frequencies in the pre-investigation period (2007-2009) in a given MRC.
- I leave the participation probabilities of firms not in the cartel as those estimated in the competitive period.
- I simulate participation in 1000 replications of a contract.

- I keep the parameters of the bid distribution equal to those estimated in the competitive period.
- I adjust the number of potential cartel bidders and actual cartel bidders to that observed in the collusive period.
- I attach all draws and find the counterfactual average bid as the mean of all average bids in the different 1000 draws.

The 1000 samples produce a counterfactual average bid of 79.78% of the mean value of the contract, 3% higher with respect to the average bid that was estimated from the actual data. The effect of the coordination on the degree of head-to-head competition is low if compared to the effect on prices of coordination in bids. It accounts for one-fifth of the overall effect of collusion on bids. The small magnitude of this effect could be due to two factors going in opposite directions. With fewer potential bidders, the competition effect suggests that prices should increase, since bidding is less aggressive. However, there is a participation effect going in the opposite direction. Because of this second effect, bidders would be more willing to participate when they face fewer potential rivals (Li and Zheng, 2009).

1.5.3 Discussion

In the structural exercise, I found that the effect of coordinating head-to-head competition accounts for a small part of the average increase in bids observed in the collusive period. This pattern could be at odds with the fact that, in principle, the two effects should not be different. I explain why colluding firms prefer to coordinate the degree of head-to-head competition rather than coordinating on bids.

Entry costs

The entry costs are the costs of the preparation of a bid. Through the structural model, the median entry cost is 17% of the average bid. Part of these entry costs comes from the fact that the Quebec Ministry of Transportation requires all bidders willing to participate in an auction to submit 5 or 10% of the submission as warranty. The submission warranty is a real cost for firms, as it is money frozen for a certain period of time.

Bidding behavior of bidders not in the cartel.

Bidders not in the cartel respond to realized competition. In a cartel that does not include all firms in the market, colluding firms could potentially prefer to avoid head-to-head competition because the "designated" winner within the cartel faces a less aggressive bidding behavior by the firms outside the cartel. Suppose that we observe an auction in which there are three potential bidders: two bidders are in the ring and one bidder is outside the ring. If the two colluding firms avoid head-to-head competition, the one firm in the ring designated to participate in the auction faces less aggressive bidding by the bidder outside the ring compared to the case in which both firms in the ring participate in the auction.

To support this idea, Table 1.15 shows the relationship between bids and the number of bidders in an auction. The relationship is negative and significant if I consider all bids and also if I consider only the bids of firms different from firms A and B. All bidders, and in particular bidders other than firms A and B, respond to realized competition.

Table 1.15 – OLS estimation for bids as % of the mean value of the contract over the number of bidders

Sample	All auctions					
Dependent variable	Bid over mean value of the contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	non cartel bids	non cartel bids	non cartel bids
n cartel bids	-4.924**	-4.497**	-4.110*	-5.698***	-5.261**	-5.339**
	(2.165)	(2.197)	(2.267)	(2.168)	(2.239)	(2.271)
n non-cartel bidders	-0.538	-0.382	-0.588	-0.353	0.0505	-0.0503
	(1.087)	(1.138)	(1.558)	(1.162)	(1.184)	(1.766)
Distance (km)		0.0322*	0.0373**		0.0261	0.0305
		(0.0165)	(0.0177)		(0.0185)	(0.0199)
Capacity (%)		0.0321	0.0243		0.0546	0.0342
		(0.0362)	(0.0385)		(0.0426)	(0.0446)
Value firm region (%)		-0.130**	-0.121**		-0.167*	-0.159*
		(0.0561)	(0.0574)		(0.0900)	(0.0909)
Demand (%)		0.0783*	0.0832*		0.0809*	0.0877*
		(0.0464)	(0.0484)		(0.0478)	(0.0497)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
N	2230	2230	2230	1362	1362	1362
R^2	0.0033	0.0145	0.0456	0.0038	0.0192	0.0524

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *n cartel bidders* is the number of cartel bidders (firms A and B) bidding in the auction. *n non-cartel bidders* is the number of bidders (other than firms A and B) bidding in the auction. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage capacity of the bidder expressed as % of value of contracts won up to auction a over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction a over total value of contracts awarded in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Bid coordination is weaker than the bid selection mechanism. Marshall and Marx (2007) have shown that, in first-price auctions, a bidding ring can suppress competition from other firms in the ring if the ring is able to control ring members' bids (what they call a "bid selection mechanism"). By avoiding head-to-head competition, firms in the cartel implement the strongest case of bid selection mechanism. On the other hand, a ring that relies on a bid coordination mechanism does not have the ability to perfectly control all ring members' bids. That is why in this mechanism the bidder in the ring with the lowest cost should bid aggressively not to let a ring member with the lowest cost cheat on the agreement.

Given all the possible reasons that make colluding firms choose to avoid head-to-head competition with respect to coordinating bids, it is not rational for them to avoid head-to-head competition in every auction. If colluding firms avoided competing against each other in every auction, this would clearly be a red flag for collusion. In this particular case, for antitrust authorities, it is easy to understand that firms coordinate their participation behavior, ruling out the possibility that they do not compete in an auction for other reasons, such as capacity constraints. In some parts of Quebec, for example, the two firms are so close to each other that it is suspicious if they decide to avoid competing against each other. In region 5, for example, as shown in Table 1.4, the two firms are located only 3 km away from each other. In that region, it is difficult to avoid head-to-head competition in every auction.

1.6 Conclusion

Through the study of a case of market sharing agreements, I found evidence of coordination on the degree of head-to-head competition, and I quantified the extent to which avoiding head-to-head competition represents a cost for public procurement. I have analyzed the participation and bidding behavior in auctions of the two largest firms bidding in the provincial road paving procurement market in Quebec. Using the start of a police investigation into collusive behavior to capture the end of this cartel, I documented that the two suspect firms were more likely to compete head-to-head and submit lower bids after the police investigation was launched.

A structural model of participation and bidding with asymmetric bidders quantified the extent to which colluding on the degree of head-to-head competition increased bids. If the firms had kept competing head-to-head at the same rate as in the collusive period but had stopped colluding on bids, bids would have increased by about 3% with respect to the competitive scenario observed after the beginning of the police investigation.

This study is one of the first to document price and non-price collusion in a public procurement setting. I show that multi-plant firms that potentially compete in multiple markets can share the market by i) avoiding competing against each other, and ii) coordinating on prices. The results also demonstrate that collusion on a dimension other than prices, such as the degree of head-to-head competition, is associated with higher procurement costs, although these costs are lower on average than when firms collude on prices. Finally, I provide different explanations for why colluding firms may prefer to avoid head-to-head competition in a context of a cartel that does not include all the firms in a market.

In terms of policy implications, reducing entry costs could provide a solution to stimulate competition. The Ministry of Transportation, for example, requires all bidders to submit 5 or 10% of the submission as a warranty. This requirement makes entry costs high and gives an incentive to large firms to coordinate their respective decisions to participate in an auction. In addition, I demonstrate that antitrust authorities should investigate the participation behavior of firms: if firms that are not in the cartel respond to competition, coordinating the participation behavior in auctions may be more likely to occur than coordinating bids.

A sudden switch from collusion to competition could potentially worsen the *ex post* procurement performance. After colluding firms stop coordinating, they may compete head-to-head to a larger extent and submit more aggressive bids at the time of the awarding of the contract. Yet when executing the project, they may incur cost overruns. These cost overruns increase the final procurement costs compared to the procurement costs forecast at the time of the signing of the contract. This pattern is not, however, observed in the data, reinforcing the assertion that stimulating competition through encouraging bidder participation provides a tool to achieve not only a better *ex ante*, but also a better *ex post* procurement performance. Table A.11 in Appendix A shows that there was a significant decrease in delays and a small and non-significant increase in cost overruns in the treated auctions after the start of the police investigation.

This study comes with some caveats. First, the unavailability of precise estimated values of the contracts could partially bias the estimates of the difference-in-difference design for bids, although my results are robust to a different specification for the bids, as shown in Table A.7 in Appendix A. Second, the relatively short sample period of a few years makes it challenging to disentangle whether the geographic separation of asphalt plants observed in some administrative regions of Quebec for the two suspected firms could be associated with collusion rather than simple geographic differentiation. Although not directly identifiable as collusion because of the unavailability of additional years of data, such geographic differentiation does help multi-market firms mitigate losses from the collapse of a cartel, as shown in other studies (Chilet, 2018).

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Chapter 2

Complementary Bidding: Evidence from Quebec's Construction Industry

Coauthored with Robert Clark[1] and Decio Coviello[2]

Abstract

A number of recent papers have proposed that a pattern of *missing bids* may be associated with collusion (see for instance Tóth et al., 2014, Imhof et al., 2018, and Chassang et al., 2019). These articles suggest that a significant gap between the winning and losing bids can be linked with collusion, since cartel members may wish to avoid scrutiny from authorities based on bid proximity, or help to facilitate coordination on a designated winner. In this paper, we provide evidence from a discovered cartel of the opposite bidding pattern. That is, we document greater clustering of the two lowest bids than of other pairs of bids. Moreover, our setting and dataset allow us to demonstrate convincingly that this pattern is directly linked with the collusive arrangement. We study bidding in municipal procurement auctions for asphalt provision in the City of Montreal where a police investigation arose following allegations of bid rigging. We use a difference-in-difference strategy comparing the change in clustering patterns in Montreal before and

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after the investigation to similar changes in Quebec City, where there were no allegations of collusion. We show that clustering of the two lowest bids falls relative to other bid pairs and relative to clustering in Quebec City following the investigation.

JEL codes: L22, L74, D44, H57

Keywords: Auction; Bidding ring; Collusion; Complementary bidding; Public procurement

2.1 Introduction

Bid rigging involves groups of firms that explicitly agree on raising prices, thus earning higher profits at the expense of consumers. This led former EU commissioner Mario Monti to describe cartels as "cancers on the open economy."[3] Since public procurement represents on average 13% of the GDP in OECD countries and 30% of total general government expenditures, cartels impose a significant cost on taxpayers. Detecting collusion is therefore a primary objective of antitrust authorities, and many have started to look for suspicious bidding patterns in an effort to uncover signs of collusive behavior. For example, instances of high correlation in the residuals of the bidding function (Bajari and Ye, 2003) and low bid variance across auctions (Harrington, 2005; Abrantes-Metz et al., 2006) are thought to imply coordinated efforts of industry participants and are being used to provide guidance about which markets antitrust authorities should target for investigation with their limited resources.

A number of recent papers have proposed that a pattern of *missing bids* may also be consistent with collusion (see for instance Tóth et al., 2014, Imhof et al., 2018, and Chassang et al., 2019). These articles suggest that a significant gap between the winning bid and losing bids can be associated with collusion, since cartel members may wish to avoid scrutiny from authorities on the basis of bid proximity, or help to facilitate coordination on a designated winner. In this paper, we provide evidence of the opposite bidding pattern from a discovered cartel. That is, we document greater clustering of the two lowest bids in

[3]See press release on the website of the European Commission: Speech/00/295.

contrast to other pairs of bids. Moreover, our setting and dataset allow us to demonstrate convincingly that this pattern is directly linked with a collusive arrangement.

Our focus is on the construction industry in Montreal, where the existence of cartels in some sectors was discovered in October 2009, following an investigation by a news show, *Enquête*, that shed light on collusive practices in this industry, namely bid-rigging, complementary bidding, and market-sharing agreements. Immediately after the show, the Quebec government launched a police investigation called *Opération Marteau* in order to verify the reported allegations. This naturally lends itself to a difference-in-difference approach in which we compare the clustering of bids in Montreal's asphalt industry before and after the investigation to clustering patterns over the same time span in Quebec City, whose asphalt industry has not been the subject of collusion allegations.[4]

Our dataset covers contracts for the municipal procurement of asphalt in the years between 2007 and 2013. Contracts were awarded through first-price, sealed-bid auctions in which the lowest bidder wins the contract. Information on all open auctions, including winning and losing bids and bidder identities is provided. We first document that the two lowest bids were, on average, more clustered than other pairs of bids in Montreal during the cartel period. We then study the evolution of this difference between the two lowest bids after the start of the investigation and compare it to the evolution of the difference between lower-ranked bids and pairwise bid differences in auctions in Quebec City. We find that in the market for the municipal procurement of asphalt in Montreal, the difference between the two lowest bids is significantly closer before October 2009 than are i) the difference between bid pairs other than the lowest during this same time period, ii) the differences between the lowest bid pair in Montreal after the investigation, and iii) the differences between the lowest bid pair in Quebec City before and after the investigation.

There are several reasons why bids might be clustered in first-price auctions. The

[4]**Legal disclaimer:** This paper analyses the alleged cartel case strictly from an economic point of view. We base our understanding of the facts mostly on data obtained from the municipal clerk's office through access to information requests, through transcripts of testimony from the Charbonneau Commission, and the testimony presented in the *Enquête* broadcast. The investigation into, and prosecution of, firms involved in the alleged conspiracy is ongoing. The allegations have not been proven in a court of justice. However, for the purpose of this analysis, we take these facts as established.

first is that firms may try to simulate competition in order to avoid detection. While authorities may use identical (tied) bids as an indicator of collusion (DOJ, 2005), close bids may be confounded with competition under complete information (Marshall and Marx, 2007). A second reason for clustering of bids is that, once costs become common knowledge within the cartel, the lowest-cost firm may worry that the second-lowest-cost firm will undercut it (Marshall and Marx, 2007). Standard models of collusion (see for instance Rotemberg and Saloner, 1986; Athey and Bagwell, 2001, 2008) would therefore predict bid clustering. In this paper, we can conclude that the observed clustering of the two lowest bids is inconsistent with the presence of complete information. If auctions were characterized by the presence of complete information, we should have observed the same pattern across the whole time period of the data in Montreal and in Quebec City. Furthermore, we only observe clustering of the two lowest bids in Montreal before the start of the police investigation.

This paper relates to the literature on the detection of cartels in procurement auctions. (Porter and Zona, 1993; Porter and Zona, 1999; Pesendorfer, 2000; Bajari and Ye, 2003; Conley and Decarolis, 2016; Kawai and Nakabayashi, 2014; Schurter, 2017). Like us, Kawai and Nakabayashi (2014) document clustering of the lowest bids and associate this with collusion. However, the setting is different. In their context, auctions involve multiple bidding rounds (re-bidding), and they find that the order of the lowest bids in the first round is maintained even in the second, although the second lowest bidder in the first round lost only marginally.

This study also relates to the literature on the functioning of cartels (see for instance Asker, 2010, Genesove and Mullin, 2001, and Clark and Houde, 2013). The Quebec construction cartels were studied by Clark et al. (2018).

The paper is structured as follows. In the next section we discuss the adjudication process of the contracts, the police investigation and the special Commission appointed by the Quebec government. Section 2.3 presents the data. Section 2.4 provides a descriptive pattern of the difference in bids observed in the data. Section 2.5 describes the empirical strategy and the results. Section 2.6 discusses the potential explanations for clustering of the lowest bids. Finally, section 2.7 concludes.

2.2 The markets and the investigation

In this section we describe the markets, the adjudication process, the police investigation and the Commission established to learn more about corruption and collusion in the construction industry in Quebec. Further details can be found in Clark et al. (2018).

2.2.1 The markets

The focus of the analysis is on municipal contracts for the procurement of asphalt in Montreal and Quebec City. Montreal is composed of 19 boroughs, while Quebec is composed of six borough.[5] For the procurement of asphalt, each borough makes predictions about the asphalt required for the maintenance of their roads for the coming year. Due to the weather conditions, most contracts are awarded for the spring and summer seasons. In each of the 19 boroughs of Montreal there can be one auction per asphalt type. So every year there can be up to 209 contracts awarded in Montreal. Quebec City operates differently, using a single auction per borough, combining all asphalt types. As a result, there are more calls for tender in Montreal than in Quebec City.

Firms propose bids with two components. First, firms submit a unit price per metric ton for each type of asphalt required. Second, firms submit a bid that matches the total unit cost multiplied by the quantity required for each type of asphalt and to this they add their shipping costs and taxes. Auctions are first-price, sealed-bid and single-attribute (cost). This means that the firm offering the lowest bid wins the contract. In our empirical analysis below we focus on raw bids without the transportation cost, because there were changes to the way transport charges were calculated in Montreal during our sample period.

[5]Prior to 2010 Quebec City was was composed of eight boroughs. In 2010, the boroughs of Quebec City were amalgamated.

2.2.2 The investigation

In October 2011, two years after the start of the police investigation, the *Commission of Inquiry on the Awarding and Management of Public Contracts in the Construction Industry* (commonly referred to as the Charbonneau Commission) was formed to dig into the allegations of collusion and corruption in various sectors of the Quebec construction industry. Among the targeted sectors was the asphalt industry in Montreal.

According to the *Enquête* allegations, complementary bidding was part of the cartel scheme. Firms acquired confidential information about the contracts from officials of the municipality or officials working at the Quebec Ministry of Transportation. Firms' representatives then met to define the winner of the contract. The designated winner was responsible for managing the bids each firms had to submit in the auction, giving instructions to the other cartel members about the level of their complementary bid. To simulate a competitive environment and to avoid detection, the winner would just bid below a threshold specified by a coded vocabulary. The specified winner would claim to be organizing a round of golf. He would call other firms saying, for example, "we will start from the 4th hole and we will be 9 players". This meant that the complementary bids must be over \$4 900 000 (4th = \$4 000 000 and 9 players = \$900 000). The specified winner would bid just below this threshold (Théberge, 2013; *Enquête*, Radio Canada, 2009).

2.3 Data

The dataset, described in Clark et al. (2018), consists of borough-level asphalt contracts for Montreal and Quebec City, obtained through access to information requests at the Municipal Clerk's office. The dataset covers procurement auctions from 2007 to 2013 for both cities.[6] The data contain information on all submitted bids (raw bids and transportation charges) and the identity of the winner. Addresses for all asphalt plants in Montreal

[6]Additional information was collected in the Cahiers d'appels d'offres (Call for tender books).

and Quebec City were also collected from the Quebec Ministry of Transportation, and we gathered addresses of the central point of reception for each neighborhood in the two cities. Together these allow us to determine delivery distances for each tender. Capacity information is also available for Montreal.

The dataset consists of 662 contracts. The median number of participants is 3 and the mean number of participants is 3.42. The mean winning bid is $68.72 per ton with a standard deviation of 10.32. Table 2.1 presents summary statistics for Montreal and Quebec City.[7] The winning bid in Montreal decreases after the start of the police investigation by $7 per ton, while in Quebec City it increases by $6 per ton. There is a remarkable difference in the winning bid between the two municipalities equal to $18 per ton. This difference is equal to $4 per ton between 2010 and 2013. As documented in Clark et al. (2018), part of the cartel scheme in Montreal involved the deterrence of some firms from bidding in auctions. In Montreal, after the police investigation was launched, the number of firms bidding in these contracts increased from 6 to 9. This increase in the number of firms bidding drove the increase in the average number of bidders from 2.6 before the start of the police investigation to 3.6 after. In Quebec City, we observe that the average number of bidders is between 3 and 4 bidders in both periods. The number of firms bidding in at least one auction in Quebec decreased from 7 to 6.

[7]Table 2.1 replicates entirely Table 1 in Clark et al. (2018).

Table 2.1 – Descriptive statistics for Montreal and Quebec City

Year	$ awarded (millions)	Nbr contracts	Nbr bidding boroughs	Avg tons of ashphalt	Nbr bidding firms	Nbr bids per contract	Avg winning bid ($/ton)
				Montreal			
2007	3.1	73	12	637	6	3	65
2008	2	61	11	443	4	2.5	71
2009	3	81	14	392	6	2.4	89
2010	3	174	19	244	8	3.6	68
2011	2	149	15	189	8	4.4	66
2012	2.6	43	16	879	8	3.7	65
2013	3.1	35	16	1287	7	2.9	69
	Total				Average		
2007-2009	8.1	215	12	491	5.3	2.6	75
2010-2013	11	401	17	650	7.8	3.6	67
				Quebec City			
2007	1.6	7	7	3539	6	3.6	55
2008	1.4	7	7	3552	6	3.6	48
2009	2.9	8	8	4361	7	3.9	69
2010	2	6	6	5243	6	3.5	52
2011	2.9	6	6	5562	4	3.2	72
2012	2.6	6	6	5435	4	2.8	64
2013	2.6	6	6	5358	5	3.7	63
	Total				Average		
2007-2009	5.9	22	7.3	3818	6.3	3.7	57
2010-2013	10	24	6	5399	4.8	3.3	63

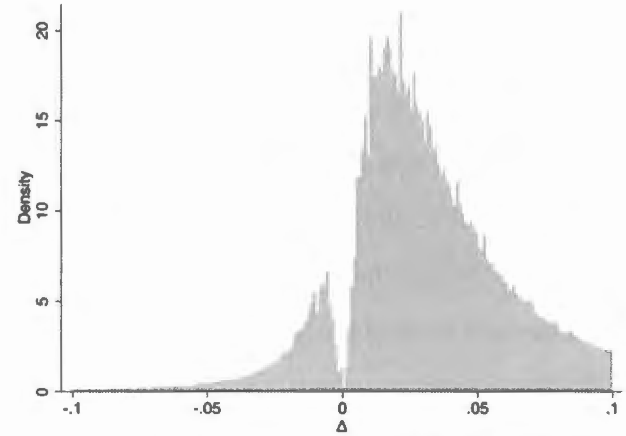
2.4 Motivating facts

As mentioned in the introduction, Chassang et al. (2019) document *missing bids* around 0 in the distribution of bid differences for public works procurement auctions in Japan. They define bid differences as the difference between a given bidder's own bid and the most competitive bid in the auction. In particular, the bid for any firm i bidding in auction a is $b_{i,a}$, while the most competitive bid by a firm other than i in this auction is denoted by $b_{-i,a}$. For example, suppose an auction with three bidders (1, 2 and 3). Suppose further that bidders 1, 2 and 3's bids are respectively $60, $75, and $78 per ton. Then the difference between bidder 1's bid and the most competitive bid is -15 (since bidder 1 wins the auction, the most competitive bid is the second lowest bid), the difference between bidder 2 and the most competitive bid is +15, and the difference between bidder 3 and the most competitive bid is 18. Given the design of this function, the difference between the winning bid and the most competitive bid (the second lowest bid) in the distribution appears to the left of 0, while the difference between a losing bid and the most competitive bid (the lowest bid) appears to the right of 0. Figure 2.1a displays the findings from Chassang et al. (2019) (Figure 1 from their paper).

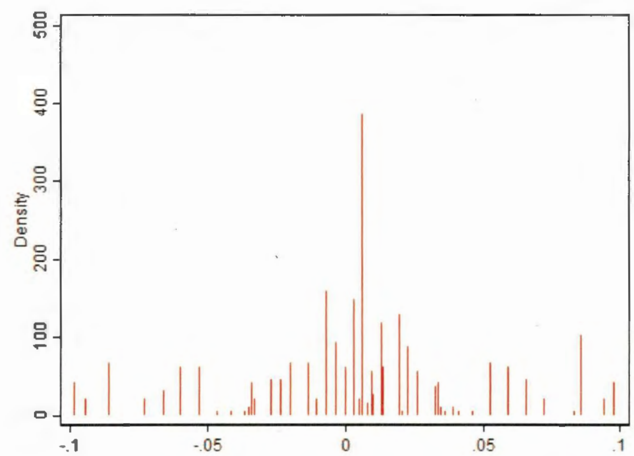
We construct the same measure of bid differences for our sample of auctions from the known cartel period in Montreal. Given that there is no reserve price in auctions in Montreal, we normalize the bid difference by the average winning bid observed in Montreal in the period before the start of the investigation. In contrast with Chassang et al. (2019), we find no such *missing bids* in the neighborhood around 0. Results are displayed in Figure 2.1b. These findings suggest that isolation of the winning bid is not part of the collusive arrangement in this context, but do not establish a causal link between clustering of the two lowest bids and collusion. For that we turn to difference-in-difference analysis whereby we compare changes in clustering in Montreal before and after the investigation to similar changes in Quebec City.

Figure 2.1 – Differences between own bid and most competitive bid.

(a) Public works procurement auctions in Japan. Difference in bids as % of the reserve price



(b) Asphalt procurement auctions in Montreal before the police investigation. Difference in bids as % of the average winning bid in the period before the start of the police investigation



Panel a is taken from Chassang et al. (2019) (Figure 1 from their paper). Panel b plots the differences between own bid and most competitive bid in auctions for asphalt procurement contracts in Montreal during the cartel period.

2.5 Identification strategy and results

We employ a difference-in-difference strategy in which we compare changes in clustering in Montreal (the treated city) before and after the investigation to similar changes in Quebec City (the control city). Contracts in both Montreal and Quebec City are negotiated only once a year in the spring, and we assume that the investigation implied a shift from a collusive to a competitive regime. This allows us to set our structural break in 2010.

As mentioned in Clark et al. (2018), Quebec City is a suitable control for the following reasons. First, the asphalt market in Quebec City was never cited during Operation Marteau or in documents from the Charbonneau Commission. Based on the *Enquête* broadcast, the allegations were focused mostly on the asphalt market in Montreal. Second, Quebec City is located further away from Montreal, at a distance of about 250 km. This is an important aspect since many municipalities surrounding Montreal were cited in investigative reports. In addition, the firms operating in Quebec City are different from the ones operating in Montreal. Finally, the auctions in the two cities are similar in terms of i) the period in which they are run, ii) the design of the auctions, i.e. per borough, and iii) the budget allocated to the procurement of asphalt.

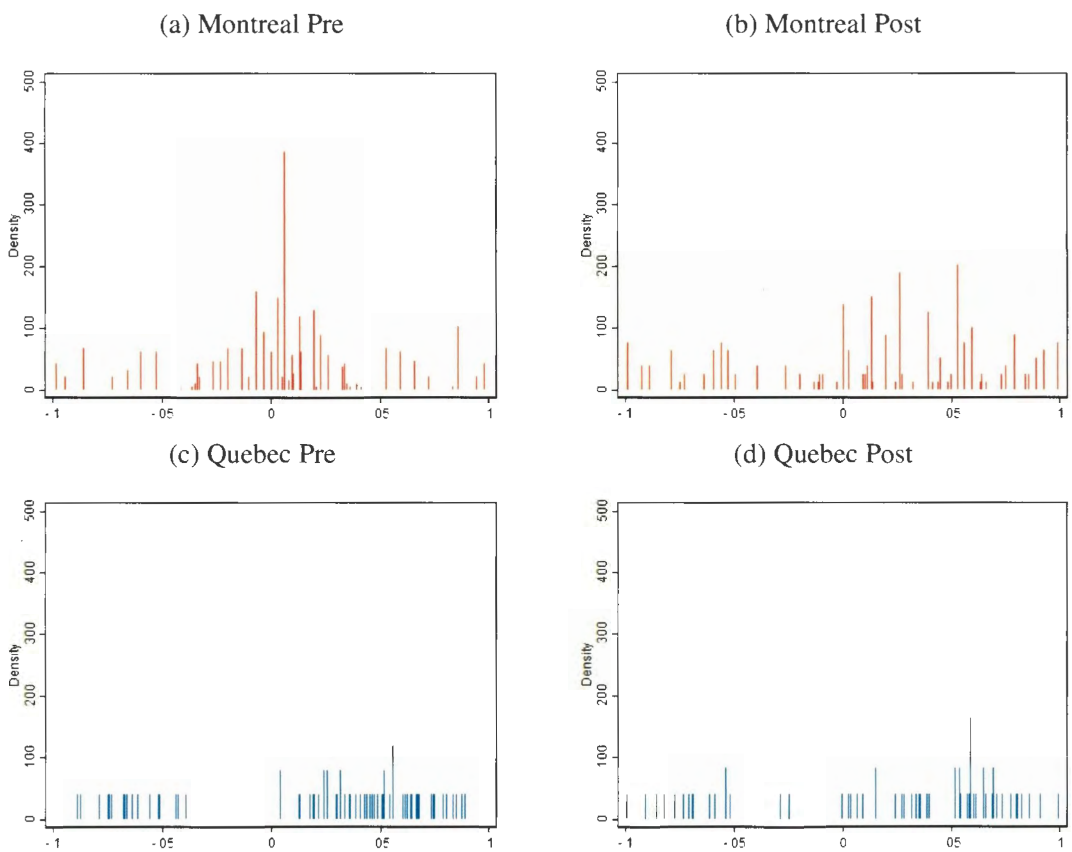
For the City of Montreal, part of the cartel scheme involved the deterrence of other players from entering the market (Clark et al., 2018). To make the analysis consistent, we dropped the auctions in which the entrants participated. Thus, we analyze the difference in bids from the six firms suspected of having joined the cartel.

We consider the following outcomes: (i) bid differences as defined above, (ii) pairwise bid differences, and (iii) standard deviation of bids within auctions. For the pairwise bid differences we analyze the difference between bids, that is the difference between the lowest and second lowest bid, the difference between the third and second lowest bid, and the difference between consecutive ranks higher than the second lowest, i.e. fourth and third lowest bid, fifth and fourth lowest bid, and sixth and fifth lowest bid.

2.5.1 Differences in bids

In Figure 2.1 we have already seen that there is a high degree of clustering in Montreal prior to the investigation. This is presented again in the top left panel of Figure 2.2 for comparison purposes. The other three panels show the extent of clustering in Montreal after the investigation (top right) and in Quebec City before and after the investigation (bottom left and right respetively). For Quebec City, as for Montreal, the difference in bids are normalized by the average winning bid observed in the collusive period. The clustering of bid differences around 0 disappears in Montreal in the period after the start of the investigation. For Quebec City, we do not observe clustering of bid differences around 0 either before or after the start of the investigation.

Figure 2.2 – Difference between own bid and most competitive bid as % of the average winning bid in the period before the start of the police investigation. Asphalt procurement auctions in Montreal (red) and Quebec City (blue) before and after the start of the police investigation.



2.5.2 Pairwise bid differences

We study the effect of the investigation on the difference in bids for consecutive ranks. Figures 2.3 and 2.4 plot the difference between the two lowest bids and difference between the third and second lowest bids in Montreal (red) and Quebec City (blue) before and after the start of the investigation. We observe substantial clustering of the two lowest bids before the start of the police investigation. About 70% of the auctions awarded before October 2009 face a difference of the two lowest bids of less than \$1 per ton. This is striking since the average winning bid in that period is \$73.91 per ton. The clustering of the two lowest bids disappears after October 2009. We do not observe the same pattern in Quebec City and for bids different from the two lowest in Montreal.

Figure 2.3 – Difference between the two lowest bids in Montreal (red) and Quebec City (blue) before and after the start of the investigation

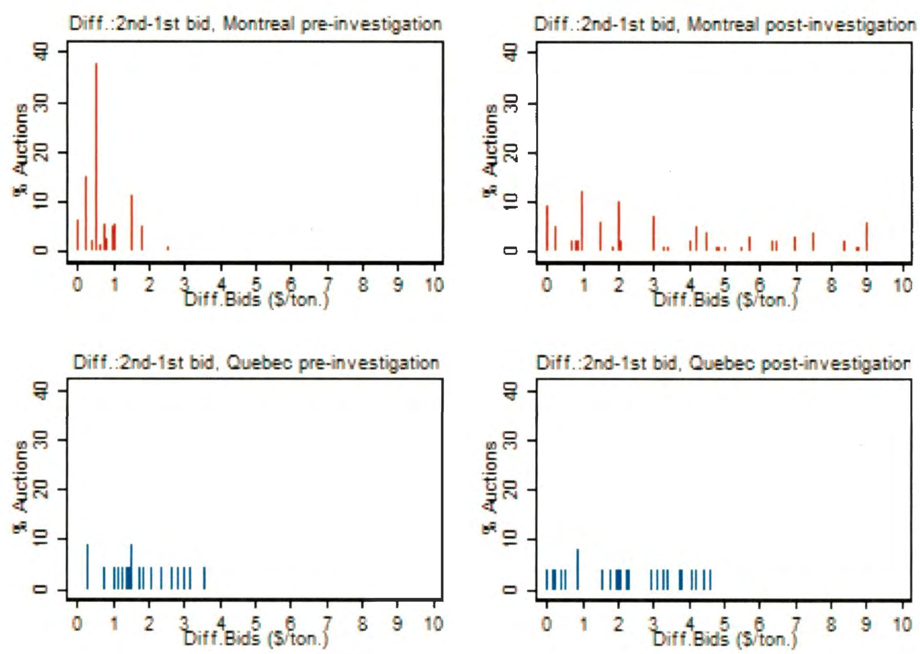


Figure 2.4 – Difference between the third and second lowest bid in Montreal (red) and Quebec City (blue) before and after the start of the investigation

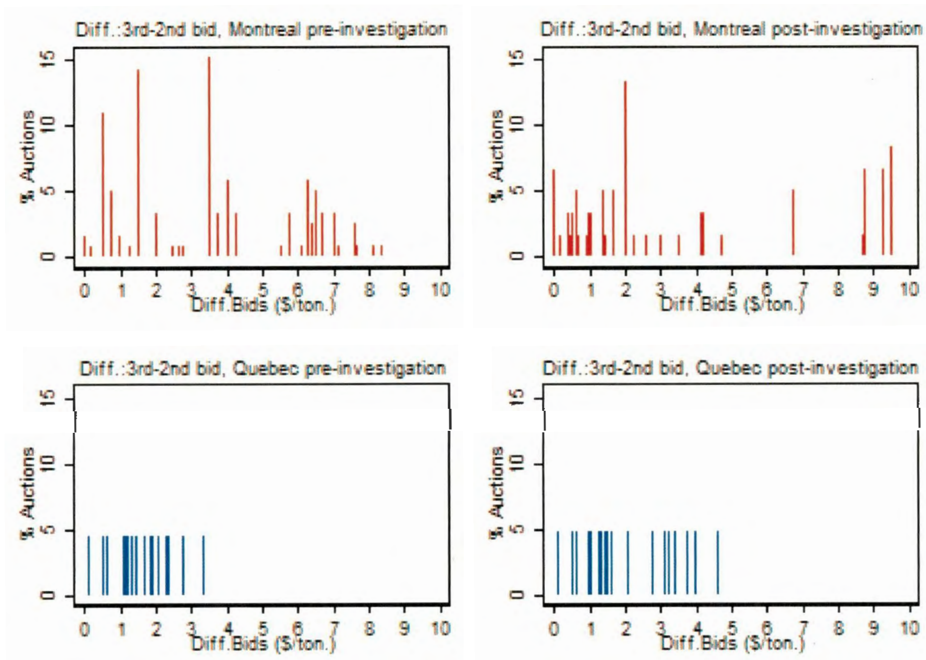


Figure 2.5 plots the evolution of the difference between the second lowest and the lowest bid in Montreal and Quebec City. The difference in the two lowest bids is higher in Quebec City before the investigation, but the trends are common. The difference in the two lowest bids in Montreal jumped after the start of the police investigation while this difference did not change substantially in Quebec City. Table 2.2 confirms the evolution of differences in bids by looking at the average between the two periods for the two cities. The increase in the difference of the two lowest bids in Montreal is about 417% compared to an increase of 30% in Quebec City.

Figure 2.5 – Yearly average difference between second lowest and lowest bid

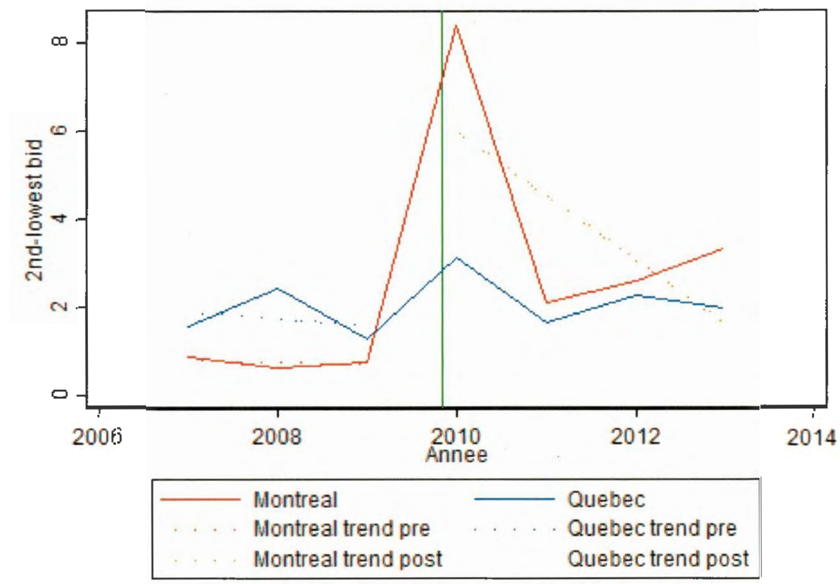


Table 2.2 – Average difference between second lowest and lowest bid

	Pre	Post	Post-Pre
Montreal	0.77	3.97	3.21
Quebec	1.75	2.27	0.52
Post-Pre	-0.98	1.70	2.68

Figure 2.6 plots the evolution of the difference between the third and second lowest bids and Table 2.3 shows average difference for the two time periods. We do not observe substantial changes for difference in bids for ranks lower than the two lowest. In Montreal the average difference between the third and second lowest bid in the period before the investigation is 465% bigger than the difference between the two lowest bids.

Figure 2.7 plots the evolution of the difference between other consecutive ranks (4th-3rd, 5th-4th) and Table 2.4 shows the average difference for the two time periods. Even in this case, the difference in bids does not substantially change in the city of Montreal after the start of the police investigation.

Figure 2.6 – Yearly average difference between third and second lowest bid

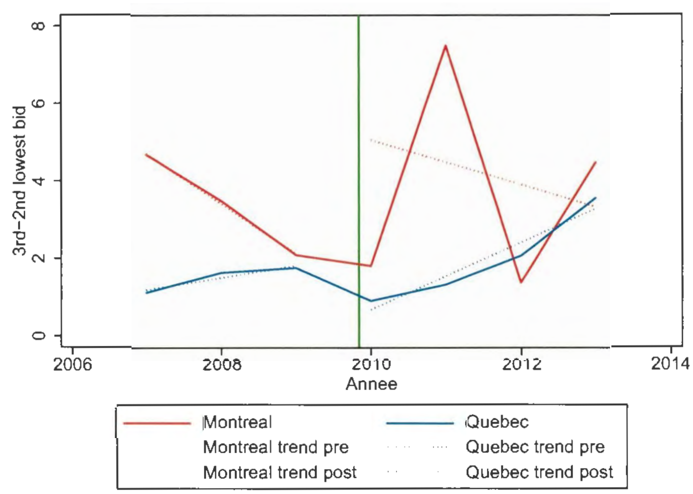


Table 2.3 – Average difference between third and second lowest bid

	Pre	Post	Post-Pre
Montreal	3.58	4.25	0.66
Quebec	1.54	1.90	0.36
Post-Pre	2.05	2.35	0.30

Figure 2.7 – Yearly average difference between consecutive ranks higher than the two lowest ranks

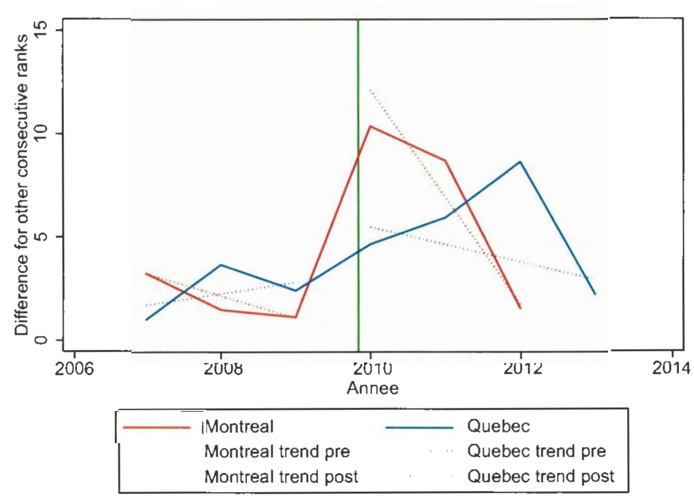


Table 2.4 – Average difference between consecutive ranks higher than the two lowest ranks

	Pre	Post	Post-Pre
Montreal	2.67	3.34	0.67
Quebec	2.39	3.99	1.60
Post-Pre	0.28	-0.65	-0.93

We next investigate whether the change in the difference of the two lowest bids found in the descriptive statistics is robust and not driven by factors other from the police investigation. The econometric model is the following:

$$\Delta Bid_{r,a} = \beta_0 + \beta_1 Montreal_{r,a} X Marteau_{r,a} + \beta_2 Montreal_{r,a} + \beta_3 Marteau_{r,a} + \beta Z_a + \varepsilon_{r,a} \tag{2.1}$$

where $\Delta Bid_{r,a}$ is the difference in bids between consecutive rank r in auction a, $Montreal_{r,a}$ is a dummy equal to 1 if the auction is run for the procurement of asphalt in Montreal, $Marteau_{r,a}$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009, and Z_a represents auction characteristics such as the lagged average price of crude oil, the quantity of asphalt in the call for tender, and the Herfindahl index (city-specific). Auction characteristics are the same as those in Clark et al. (2018). We run the specification for i) the difference between second lowest and lowest bid, ii) the difference between third lowest and second lowest bid, and iii) the difference between other consecutive ranks higher than the two lowest. We are interested in the coefficient β_1.

The results are presented in Table 2.5. We present the results for the difference between the two lowest bids (columns 1 and 2), for the difference between the third and second lowest bids (columns 3 and 4), and for the difference between bids of other consecutive ranks (columns 5 and 6). Results from the estimation of equation (2.1) match the descriptive statistics presented. In particular, in a model including auction characteristics and borough and year effects, the difference in the bids of the two most competitive bidders increased by about \$ 2.16 per ton in Montreal after the start of the investigation in comparison to Quebec City. This increase represents 281% of the difference between the two lowest bids observed in Montreal before the start of the investigation. There is no significant change in the bid difference for other pairs of bids relative to similar changes in Quebec City.

Table 2.5 – Difference-in-difference for difference in bids between consecutive ranks

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	2nd-1st	2nd-1st	3rd-2nd	3rd-2nd	other ranks	other ranks
MontrealXMarteau	2.6824***	2.1592***	0.3002	0.3956	-0.9292	0.3333
	(0.660)	(0.633)	(1.073)	(1.152)	(1.718)	(2.621)
Montreal	-0.9814***	-1.3325	2.0461***	0.7037	0.2837	-3.2545
	(0.200)	(1.380)	(0.357)	(1.809)	(0.815)	(2.868)
Marteau	0.5239	3.1812	0.3636	33.1546**	1.5974	-0.1768
	(0.352)	(5.463)	(0.333)	(13.509)	(1.098)	(42.357)
Crude oil lag		-0.0198		-0.2009**		-0.0039
		(0.032)		(0.078)		(0.246)
Quantity		-0.0002***		0.0002		-0.0005**
		(0.000)		(0.000)		(0.000)
HHI		2.4551***		0.3601		4.2222
		(0.851)		(1.784)		(4.721)
Borough FE	No	Yes	No	Yes	No	Yes
Year FE	No	Yes	No	Yes	No	Yes
Observations	351	351	228	228	79	79
R-squared	0.339	0.688	0.0914	0.441	0.0339	0.560
Mean Y Montreal Pre	.77	.77	3.58	3.58	2.67	2.67

Notes: Coefficient (standard error in parentheses) of the effect of the start of the police investigations (*Operation Marteau*) on difference in bids: difference in the two lowest bids (columns 1 and 2), difference in the third and second lowest bid (columns 3 and 4), difference in other ranks (columns 5 and 6). *Montreal* is a dummy equal to 1 if the auction is run for the procurement of asphalt in Montreal. $Marteau_{r,a}$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Crude oil lag* is the price of crude oil lagged. *Quantity* is the number of tons in the call. *HHI* is the yearly Herfindahl index. SEs are clustered at borough-year level. Significance at 10% (*), 5% (**), and 1% (***).

The main identifying assumption for the difference-in-difference design that we apply is the presence of common trends in the outcomes for difference in bids for Montreal and Quebec City before the start of the police investigation. Table 2.6 presents the results of formal tests for the presence of common trends. In the odd columns we report the test under the null hypothesis of a linear common trend, while in the even columns we do the same test assuming a non-linear common trend. The assumption of a linear common trend is not rejected for the two lowest bids but is rejected for the other ranks. The hypothesis of non-linear common trend is not rejected for the difference between the third and second lowest bid. The p-value for the test of the equality of the coefficients *MontrealXYear2008* and *MontrealXYear2009* is 0.333.

Table 2.6 – Test of common trend

	(1)	(2)	(3)	(4)	(5)	(6)
Dep.Variable	2nd-1st	2nd-1st	3rd-2nd	3rd-2nd	other ranks	other ranks
MontrealXYear	0.1929		-1.4629***		-1.3183**	
	(0.183)		(0.253)		(0.507)	
MontrealXYear2008		-1.0565***		-1.9668***		-5.9251***
		(0.373)		(0.677)		(1.458)
MontrealXYear2009		0.3179		-2.9152***		-2.3357**
		(0.312)		(0.501)		(0.923)
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	218	218	142	142	43	43
R-squared	0.230	0.270	0.340	0.341	0.254	0.312
Mean Y Montreal Pre	.77	.77	3.58	3.58	2.67	2.67
P-value		.6579		.3330		.0330

Notes: Coefficient (standard error in parentheses) of the interaction term between *Montreal* and a linear trend (*Year*) on difference in bids: difference in the two lowest bids (columns 1 and 2), difference in the third and second lowest bid (columns 3 and 4), difference in other ranks (columns 5 and 6). In columns 2,4 and 6, the trend is specified with two dummy variables for the years 2008 and 2009. P-value is the p-value for the F-test $MontrealXYear2008 = MontrealXYear2009$. SEs are clustered at borough-year level. Significance at 10% (*), 5% (**), and 1% (***).

2.5.3 Standard deviation of bids

We next examine whether the clustering of the lowest bids translates into lower standard deviation within an auction. Figure 2.8 plots the standard deviation of bids within an auction in the City of Montreal (red) and Quebec City (blue) before and after the start of the investigation. We observe a substantial increase in the standard deviation of bids after October 2009 in Montreal. In Quebec City, instead, the standard deviation of bids within an auction remains constant throughout the whole sample period.

Figure 2.8 – Standard deviation of bids within an auction in Montreal (red) and Quebec City (blue) before and after the start of the investigation

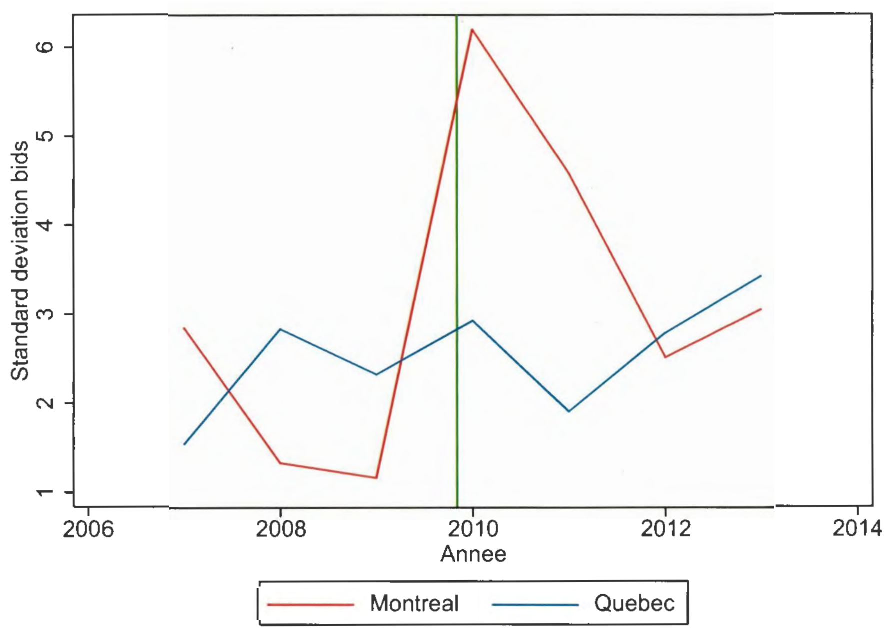


Table 2.7 confirms the evolution of the standard deviation of bids within an auction looking at the average between the two periods for the two cities. The increase in the standard deviation of bids in Montreal is about 130% compared to an increase of 23% in Quebec City.

Table 2.7 – Average standard deviation within auctions

	Pre	Post	Post-Pre
Montreal	1.82	4.19	2.37
Quebec	2.25	2.77	0.52
Post-Pre	-0.43	1.42	1.85

We investigate whether the change in the standard deviation of the bids found in the descriptive statistics is robust and not driven by factors different from the police investigation. The econometric model is the following:

$$Std.Dev._a = \beta_0 + \beta_1 Montreal_a X Marteau_a + \beta_2 Montreal_a + \beta_3 Marteau_a + \beta Z_a + \varepsilon_a \quad (2.2)$$

where $Std.Dev._a$ is the standard deviation of bids in auction a, $Montreal_a$ is a dummy equal to 1 if the auction is run for the procurement of asphalt in Montreal, $Marteau_a$ is a dummy equal to 1 if the contract is awarded after the start of the investigation in October 2009, and Z_a represents auction characteristics such as the lagged average price of crude oil, the quantity of asphalt in the call for tender, and the Herfindahl index (city-specific). Auction characteristics are thus the same as those in Clark et al. (2018). We are interested in the coefficient β_1.

Table 2.8 reports the results of the estimation of equation 2.2. Columns 1 and 2 report the estimation of the difference-in-difference model presented in equation 2.2. Columns 3 and 4 report the result of the test for the common trend assumption between the standard deviation of bids in an auction observed in Montreal and Quebec City before the start of the police investigation. The standard deviation of bids within auctions in Montreal after the start of the investigation increases significantly. In the model including auction characteristics, the increase represents 81% of the standard deviation of bids within an auction observed before the start of the police investigation. Given the results presented in Tables 2.5 and 2.8, we conclude that the increase in the standard deviation of bids is driven by the large increase in the differences between the two lowest bids.

Table 2.8 – Difference-in-difference for standard deviation of bids within auctions

Dep.Variable	(1) Diff-diff std.dev. auction	(2) Diff-diff std.dev. auction	(3) linear trend before std.dev. auction	(4) non linear trend before std.dev. auction
MontrealXMarteau	1.8522***	1.4867**		
	(0.544)	(0.617)		
Montreal	-0.4308	-0.0376		
	(0.316)	(1.241)		
Marteau	0.5224	6.3237		
	(0.332)	(6.370)		
MontrealXYear			-1.1112***	
			(0.300)	
MontrealXYear2008				-2.8042***
				(0.504)
MontrealXYear2009				-2.3143***
				(0.533)
Crude oil lag		-0.0442		
		(0.037)		
Quantity		-0.0001		
		(0.000)		
HHI		2.3858*		
		(1.335)		
Observations	351	351	218	218
R-squared	0.285	0.569	0.477	0.501
Borough FE	No	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes
Mean Y Montreal Pre	1.82	1.82	1.82	1.82
P-value				.093

Notes: Columns 1 and 2 report the coefficient (standard error in parentheses) of the effect of the start of the police investigations (*Operation Marteau*) on standard deviation of bids within an auction. Column 3 reports the coefficient (standard error in parenthesis) of the interaction term between *Montreal* and a linear trend *Year* on the standard deviation of bids within an auction. In column 4 the trend is specified with two dummy variables for the years 2008 and 2009. $p - value$ is the p-value for the F-test $MontrealXYear2008 = MontrealXYear2009$. *Montreal* is a dummy equal to 1 if the auction is run for the procurement of asphalt in Montreal. $Marteau_{r,a}$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Crude oil lag* is the price of crude oil lagged. *Quantity* is the number of tons in the call. *HHI* is the yearly Herfindahl index. SEs are clustered at borough-year levels. Significance at 10% (*), 5% (**), and 1% (***).

2.5.4 Robustness of difference-in-difference results

The difference-in-difference models estimated in the previous subsections did not control for the number of bidders in the auction. The clustering of bids could potentially depend on how many bidders are in the auction. Table 2.9 reports the results from the estimation of equation 2.1 controlling for the number of bidders. The results are even stronger than those reported above.

Table 2.9 – Difference-in-difference for standard deviation of bids and difference in bids between consecutive ranks controlling for the number of bidders in the auction

Dep.Variable	(1) std.dev. auction	(2) 2nd-1st	(3) 3rd-2nd	(4) other ranks
MontrealXMarteau	1.4725***	2.5594***	0.5145	0.5143
	(0.524)	(0.548)	(1.147)	(2.674)
Montreal	0.1408	-1.1190	0.8887	-3.3900
	(0.380)	(1.272)	(1.833)	(2.980)
Marteau	1.0651**	-2.3548	31.7841**	-1.4237
	(0.441)	(4.186)	(13.760)	(42.981)
N bidders	0.6621***	-0.7555***	-0.3108	-0.3896
	(0.181)	(0.172)	(0.357)	(1.370)
Crude oil lag	-0.0079***	0.0104	-0.1931**	0.0031
	(0.001)	(0.024)	(0.080)	(0.249)
Quantity	-0.0001	-0.0002***	0.0002	-0.0005**
	(0.000)	(0.000)	(0.000)	(0.000)
HHI	0.2032	2.1258***	0.2140	3.8960
	(1.051)	(0.771)	(1.822)	(4.978)
Observations	351	351	228	79
R-squared	0.453	0.723	0.444	0.561
Borough FE	No	Yes	Yes	Yes
Year FE	No	Yes	Yes	Yes
Mean Y Pre Montreal	1.82	.77	3.58	2.67

Notes: Coefficient (standard error in parentheses) of the effect of the start of the police investigations (*Operation Marteau*) on difference in bids: standard deviation of bids in an auction (column 1), difference in the two lowest bids (column 2), difference in the third and second lowest bid (column 3), difference in other ranks (column 4). *Montreal* is a dummy equal to 1 if the auction is run for the procurement of asphalt in Montreal. $Marteau_{r,a}$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Number bidders* represents the number of bidders in the auction. *Crude oil lag* is the price of crude oil lagged. *Quantity* is the number of tons in the call. *HHI* is the yearly Herfindahl index. SEs are clustered at borough-year level. Significance at 10% (*), 5% (**), and 1% (***).

2.6 Potential explanations for clustering of lowest bids

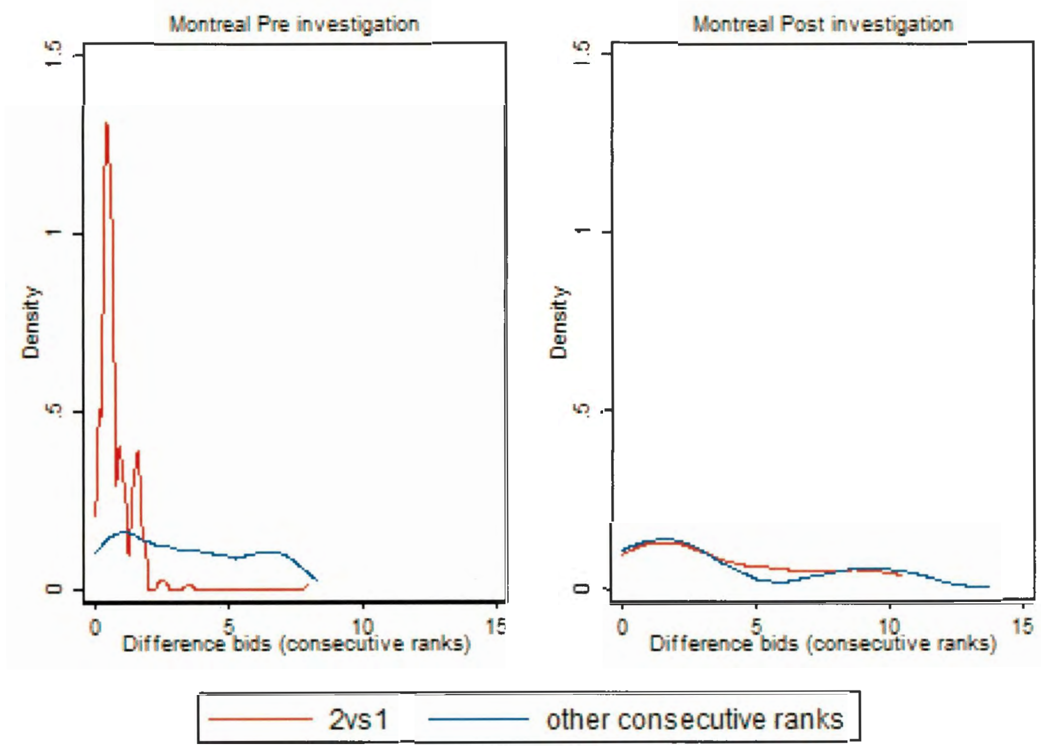
We have documented that the difference between the two lowest bids was small in Montreal before the start of the investigation and this difference increased afterwards. In this section, we provide two possible explanations for the observed clustering of the two lowest bids in Montreal before October 2009. Both of these explanations derive from theoretical results established in Marshall and Marx (2007).

In a cartel where the two lowest bidders are part of a ring based on bid coordination, clustering of the two lowest bids could be observed because the designated winner, i.e. the lowest-cost firm, wants to prevent cheating from the second-lowest-cost firm. Thus, the lowest-cost firm would bid ε above the second-lowest-cost firm. If the lowest-cost firm bid above the second-lowest-cost firm, the lowest-cost firm would end up losing the auction since the second lowest-cost firm in the ring would have found it profitable to bid more aggressively than the lowest-cost firm.

Clustering of the two lowest bids in an auction could also be the result of non-cooperative bidding strategies in auctions with complete information. In this case, the two lowest bids are close to one another for reasons different from collusion. With the availability of a competitive period in the data, we are able to rule out this second explanation and we can unequivocally associate clustering of bids with collusive behavior.

Figure 2.9 plots the kernel density for the difference between the two lowest bids (red) and between all other consecutive ranks (blue) in the City of Montreal for auctions in which only the six firms in the cartel participated. We observe a substantial spike around a difference in bids close to \$0 per ton. This spike in the density is absent for the other differences in bids considered in the collusive period. On the other hand, after the start of the police investigation, the spike in the difference between the two lowest bids disappears. The Kolmogorov-Smirnov (K-S) test shows that the difference in the two densities in the pre-investigation period is significant with a p-value of 0.0000, while in the post-investigation period we obtain a p-value of 0.415. The Mann-Whitney test confirms the findings of the K-S test. The null hypothesis of no difference between the difference in the two lowest bids and the difference in bids for lower ranked bids is rejected in the period before the start of the investigation, but it is not rejected in the period after the start of the investigation. Thus, the availability of the post-investigation period helps in disentangling collusion with respect to non-cooperative bidding in a complete information setting. We might think that cartel firms were smart enough to complicate the work of antitrust authorities by faking competition.

Figure 2.9 – Kernel densities for difference in bids for consecutive ranks in the City of Montreal before (left) and after (right) the start of the police investigation



Another possible way to detect collusive behavior in this setting would be to estimate the second lowest-cost in every auction in the period before the investigation. With the availability of this information, we could easily find the distance between the winning bid and the second lowest-cost. If the winning bid is abnormally higher than the second lowest-cost, this indicates a potentially collusive behavior.

2.7 Conclusion

We have documented that in a cartel including all firms in a market, the two lowest bids are clustered. This finding is different from other cartel cases analyzed in the literature where a gap between winning and losing bids is observed (Chassang et al., 2019; Imhof et al., 2018).

In the construction industry in Montreal, firms faked competition to prevent antitrust authorities from detecting collusion. This paper helps antitrust authorities supervising public contracts to find possible ways to disentangle that the observed clustering of bids is unequivocally related to collusion. The ideal setting would be to obtain data from auctions run in a similar market not suspected of collusion. Another possibility would be to obtain information on firms' costs.

As Harrington (2005) points out, it is costless in some cases for firms to beat collusive tests. We studied a case in which the availability of a competitive period in the data could help in detecting clustering of bids as a sign of collusive behavior of bidders.

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Chapter 3

Hospital Purchasing with Reference Pricing: Evidence from an Anti-Corruption Program in Italy

Coauthored with Robert Clark[1] and Decio Coviello[2]

Abstract

We study the impact that the introduction of statutory reference prices has on public procurement of medical supplies. We use a newly collected dataset on purchase orders for medical devices made by Italian hospitals between 2014 and 2018. We exploit the scattered implementation of reference prices to a sub-set of devices regularly purchased by hospitals as an exogenous source of variation and we document that unitary prices for devices subject to a reference price decreased on average by 10% compared to medical devices not subject to a reference price. This evidence indicates that, in this context, reference prices acted as price ceilings and could represent a policy to reduce spending by hospitals. We further evaluate the impact of the policy looking at two margins of adjustment. First, we look at possible heterogeneous effects depending on the price of the

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treated devices before the implementation of the policy. We find that prices increased for devices that had a price below the reference price before the reform. Second, we look at quantities purchased and total spending and find that they did not change. Overall, our evidence suggests that reference prices did not reduce spending by hospitals.

JEL classification: D44; H51; H57; I18

Keywords: Public procurement; Reference Price; Medical devices; Demand analysis; Supply analysis

3.1 Introduction

In Italy, public expenditure in the health procurement sector accounted for 7% of the total GDP in 2016 (Eurostat, 2018). The expenditure for medical devices reached €4.17 billion in Italy in 2016 with a high degree of price dispersion between different public buyers operating in the health sector (Ministero della Salute, 2017).[3] Price dispersion and waste of funds can be due to various factors: buyers' incompetence, buyers' corruption, price discrimination (Bandiera et al., 2009). To limit public expenditure and reduce price dispersion, the Italian Anti-Corruption Authority (since 2014 known as *A.N.AC.*) imposed binding reference prices on all Italian public hospitals in March 2016.

This paper studies the impact of the introduction of reference prices on public procurement of medical devices. The analysis focuses on medical devices that are purchased frequently and in large quantities by hospitals and that have a low degree of complexity such as syringes, needles, bandages and cotton. We investigate the effect of this policy on prices, quantities, total expenditure and delays in deliveries.

We use a newly collected dataset containing the entirety of purchase orders made by Italian public hospitals in a given Italian region (Lazio region) between 2014 and 2018.[4]

[3]In 2010, the Italian government in the person of its Minister of Economy and Finance, Giulio Tremonti, pointed out the need to standardize costs for supplies in the heath sector, from pharmaceuticals to medical devices because *"a syringe ml 5 cannot cost €0.05 in Sicily and €0.03 in Tuscany"* (Turati, 2016). In 2018, reference prices for medical products were the most commonly applied pricing policy in European countries (Habl et al., 2018).

[4]This region spent about €300 million for the procurement of medical devices between 2014 and 2017

The orders issued by these hospitals contain information on the characteristics of each medical device, the quantities ordered, the unitary price of the device, the identity of the supplier and information on the deliveries, including the exact number of days it took from the order to the delivery of the devices.

To evaluate the impact of reference prices, we exploit their introduction in March 2016 by the Italian Anti-Corruption Authority to a sub-set of devices regularly purchased by hospitals. Using a difference-in-difference design, we test whether there have been significant changes between the period before and after the policy change in the unitary prices.

We find that prices for treated devices decreased by 10% of the average unitary price observed for this group of devices before the policy was implemented. We conclude that the legislation has been effective in reducing the unitary prices of the treated medical devices, suggesting that reference prices can be an effective means for reducing hospital spending.

We further evaluate the impact of the policy by looking at two margins of adjustment. First, we look at possible heterogeneous effects depending on the unitary price of medical devices paid before the implementation of the policy. The price effects of the policy are mostly driven by devices that cost, on average, above the reference price before March 2016. However, we also provide some evidence that prices increased for devices that cost on average below the reference price before March 2016. Second, we look at quantities purchased and total spending and find that they did not significantly change after March 2016. This evidence suggests that hospitals (suppliers) adjusted other dimensions, such as quantities purchased (sold), and the policy was not effective in reduce spending.

To inspect the mechanism, we investigate whether the policy had heterogeneous effects for public hospitals and suppliers. First, we rank public hospitals according to their exposure to the policy. A hospital's exposure is defined as the share of expenses out of all expenses coming from the purchase of treated medical devices. We find that one stan-

(Ministero della Salute, 2017). Out of 21 regions, Lazio is the one with the sixth highest level of public health expenditure on medical devices.

dard deviation of exposure to the reference price policy decreases unitary prices paid by 15.37%, corresponding to a drop of about €0.15. Second, we rank suppliers according to their exposure to the policy. A supplier's exposure is defined as the share of revenues out of total revenues coming from the provision of treated medical devices. We find that one standard deviation of exposure to the reference price policy decreases the number of days suppliers deliver the medical devices by 12%, corresponding to almost two days.

Looking at the total revenues of the suppliers, the market leader lost a significant amount of money after the implementation of the policy. Therefore, reference prices allows us to document some evidence of redistribution of revenues from the market leader to smaller suppliers, with the market leader losing about 20% of its total revenues from the procurement of medical devices.

The paper is structured as follows. Section 3.2 describes the related literature and our contribution. Section 3.3 explains the legislative background. Section 3.4 presents the data. In section 3.5 we present the identification strategy and the main difference-in-difference results. Section 3.6 analyzes the heterogeneous effects of the policy across public hospitals. Section 3.7 studies the effect of the exposure to the policy on public hospitals (the demand side) and the suppliers (the supply side). Section 3.8 concludes.

3.2 Related literature

A large body of the literature provides several explanations for the observed price dispersion between hospitals. Different hospitals' bargaining ability is one possible explanation. Grennan (2013) documents that measures aimed at decreasing hospital costs, such as an increase in transparency, are not always effective. The effectiveness of these policies depends on i) the extent to which they soften competition and ii) the bargaining ability of hospitals. Grennan and Swanson (2019) attribute the reason for price dispersion to a lack of information. While these articles consider a setting in which prices are negotiated between buyers and suppliers, and hospitals are private entities, we apply the analysis to a set of public hospitals. The first application to a context of public hospitals is Bucciol et al. (2017). Bucciol et al. (2017) infer that the ability of these hospitals explains a significant part of the variation in prices. In addition, reference prices only slightly decrease public expenditure: efficient hospitals pay higher prices when the reference prices are in place, and inefficient hospitals are instead able to pay lower prices. Thus, the policy is not effective and could have unintended consequences driven by the demand side of the market (the hospitals). In this project, we exploit a different policy change since the reference prices exploited in Bucciol et al. (2017) were invalidated by a court in 2013. We employ a strategy that identifies the causal effect of the introduction of reference prices using a population of purchase orders made by public buyers. We also investigate the consequences of the policy on the market structure by observing the impact of the policy on suppliers. Another recent paper investigating the effect of uniform pricing policy is Dubois et al. (2018), which analyzes the effect of an hypothetical reference pricing policy in the US. A relevant difference from these papers in analyzing the effect of uniform pricing policies is that we analyze data on the deliveries of the medical devices that can be matched through the order identifier. Thus we can analyze the *ex-post* procurement outcomes as in Decarolis and Palumbo (2015), Coviello et al. (2017) and Giuffrida and Rovigatti (2018), and the reliability of suppliers.

Another related strand of literature studies public buyers' inefficiencies as determinants of worse procurement outcomes. One source of these inefficiencies could be corruption (Di Tella and Schargrodsky, 2003). Public buyers' inefficiencies are also analyzed in a recent paper by Decarolis et al. (2018) which attributes inefficient procurement outcomes to bureaucratic incompetence. Bandiera et al. (2009) disentangle the effect of passive waste (inefficiencies that do not benefit the public buyer) and active waste (inefficiencies such as corruption, that benefit directly the public decision maker). Coviello et al. (2017) document the effect of discretion on procurement outcomes. In this paper we analyze efficiency also by considering the *ex-post* procurement outcomes, i.e. the delivery times. We identify the efficiency of a public health unit on the basis of the distance from the reference price before the policy. We observe that more efficient units pay higher prices for medical devices than they were paying less before the implementation of the policy. On the other hand, worse procurement performance is accompanied by reduced delivery times by the suppliers.

This paper is also related to the literature on price transparency. Albæk et al. (1997) study the evolution of prices after the Danish competition authority decided to publish firm-specific transaction prices for concrete in some regions of Denmark. Similarly, Luco (2019) shows that once information on prices is disclosed to firms and consumers, this policy causes an increase in firms' margins. Brown (2018) uses the introduction of a state-run website providing information about out-of-pocket prices for some medical procedures in the state of New Hampshire to check whether this event affected spending for those visits whose information is available on the website. Brown (2018) also disentangles the supply from the demand side effects of price transparency. Finally, Grennan and Swanson (2019) document that if a hospital knows the purchase prices of medical devices paid by peer hospitals, it would pay lower prices since this knowledge reduces the asymmetric information between buyer and supplier. With respect to our setting, the information in Grennan and Swanson (2019) is not common knowledge to buyers and suppliers.

3.3 Institutional background and reference prices

Following legislative Decree 98/2011 and legislative decree 95/2012 (the so-called *Spending Review*), Italy's National Anti-Corruption Authority (*A.N.AC.*) published reference prices for a sub-set of medical devices in March 2016. These prices were applied to medical devices with a low degree of complexity: syringes, needles, bandages and cotton.

These prices have been set by the authority in the following way:

1) The National Agency for Regional Health Services (*Agenas*) provided a list of standardized medical devices in September 2015.

2) The authority (*A.N.AC.*) sent a survey to a sample of 283 public bodies providing health services between March and May 2014. These units informed the authority

about prices paid for some of these "standardized" medical devices.

3) *A.N.AC.* elaborated the data obtained from the survey in order to set the reference prices for each device.

4) These reference prices were set at the national level in March 2016 for 39 medical devices. These reference prices are set equal to the bottom quartile of the unitary price distribution.

Figure 3.1 provides a concrete example of the reference prices adopted by *A.N.AC.* In particular, this example concerns a plastic spool of sticking plaster with length longer than 9 meters and a height of 2.5 centimeters. There are three different reference prices depending on the material of the plastic spool. The reference price for the plastic spool with silk is 2.5 times more than the reference price for the plastic spool with non-woven fabric. Reference prices are net of VAT.

Figure 3.1 – Example of medical devices subject to reference prices. Plastic spool of sticking plaster with length longer than 9 meters and a height of 2.5 centimeters.

ALLEGATO A					
TIPOLOGIA	CND_DISPOSITIVO	DESCRIZIONE_DISPOSITIVO	SPECIFICHE_TECNICHE_DISPOSITIVO	DESTINAZIONE_USO_DISPOSITIVO	Prezzo di riferimento al netto dell'iva
Cerotti	M050101	Cerotti su rocchetto (a nastro)	in TNT, altezza 2,5 cm, lunghezza ≥ 9 m	per il fissaggio di medicazioni, sonde e cateteri	0,18000
Cerotti	M050101	Cerotti su rocchetto (a nastro)	in tela, altezza 2,5 cm, lunghezza ≥ 9 m	per il fissaggio di medicazioni, sonde e cateteri	0,26000
Cerotti	M050101	Cerotti su rocchetto (a nastro)	in seta, altezza 2,5 cm, lunghezza ≥ 9 m	per il fissaggio di medicazioni, sonde e cateteri	0,45000

Source: Italian Anti-Corruption Authority (*A.N.AC.*). www.anticorruzione.it

According to the policy, a public buyer after March 2016 cannot pay for any given item subject to the legislation a unitary price above the reference price, meaning that the reference price acts as a reserve price. For contracts between the public health units and suppliers already in place before March 2016 and with a unitary price above 120% of the reference price, public health buyers can propose a renegotiation of these contracts to the suppliers. If the suppliers do not accept the renegotiation, buyers can invalidate these contracts at no cost.[5] For example, a public health unit signed a contract with a supplier for the provision of 1 kg of cotton wool at a unitary price of €4.2. This unitary price is above 120% of the reference price equal to €3.24, so the health unit can propose a renegotiation of the contract. If the supplier does not agree with the renegotiation, the health unit can invalidate the contract and award another contract for the provision of 1 kg of cotton below €3.24.

Public health units follow the procurement law on how to procure a medical supply. Depending on the size of the purchases a public health unit can buy supplies by running auctions with limited competition, an open auction or by directly bargaining with the supplier. The direct negotiation with the supplier implies that the value of the contract is less than €40,000. Contracts are awarded on the basis of the best offer, i.e. first price or average-bid auctions, or on the basis of the best "economically advantageous offer". After the award of the contract between the public health unit and the supplier, the public buyer issues purchase orders in which the prices and quantities are specified. On average, there are 2 purchase orders per month for a given medical device by a given public health unit in our dataset.

3.4 Data

The dataset consists of data on purchase orders issued by Italian public hospitals and all other public health units in the Italian region *Lazio*. It contains information on the orders between 2014 and 2018. In particular, we restrict attention to orders that were issued two years before and two years after the start of the reference price policy (March 2016). Thus, the data cover the period from 1st March 2014 to 28th February 2018. For every order, we obtained information on the description of the medical device, the total value of the order together with the quantities ordered for the medical device, and its unitary price. Concerning the medical device, we also know the product identifier that consists

[5]The buyer can act notwithstanding the provisions of article 1671 of the Italian Civil Code (*Codice Civile*)

of an alphanumeric code. In addition, the orders contain information on the supplier of the medical device. The data also contain an alphanumeric code identifying whether the order is based on an auction or a negotiation. This alphanumeric code has been matched to the auction and negotiations data obtained from the Anti-Corruption Authority. We matched around 40% of the orders with data on the different awarding mechanisms.

The key variables in the data are the unitary price of the medical device and the quantities ordered of that medical device. After aggregating quantities in orders with the same description and the same unitary prices issued on the same day by the same public health unit, we obtained a dataset of 10,647 orders across 26 different public health units. These health units are divided in three categories: *Aziende Sanitarie Locali* are the units that simply provide health services, while the *Aziende Ospedaliere* are healthcare facilities where patients can be hospitalized. Finally, *Istituti per il ricovero e cura a carattere scientifico (IRCCS)* are hospitals where healthcare services are provided and where clinical research is carried on.[6]

The data on purchase orders have been augmented with detailed data on the classification of the medical devices made in September 2015 by the *National Agency for Regional Health Services* (henceforth referred to as *Agenas*). This agency classified a set of simple medical devices (syringes, needles, cotton and bandages) and sent this list to the Anti-Corruption Authority so that it could fix the reference price for each item. The list contains 155 medical devices classified by product identifier and technical characteristics. This classification helps us in turn to classify medical devices combining the product identifier with the description of the medical device made by the public health units in every purchase order.

Finally, the data were completed with the list of reference prices by medical device adopted by the Anti-Corruption Authority on 2nd March 2016. The authority decided to set reference prices only for a subset of the devices classified by *Agenas*. The number of

[6]Some public health units merged starting in January 2016. In our regression analysis, we treat them as separate entities. Before January 2016, in this Italian region the number of public health units was 20, and after January 2016 the number of public health units was 17. We have 26 different public health units because we consider the units derived from the merger of other units as separate entities.

medical devices subject to the policy is 39. Thus, the authority has established reference prices on only 25% of the total set of medical devices classified by *Agenas*.

Summary statistics of the key variables are reported in Table 3.1. The average unitary price of the orders for medical devices is €0.92 and the average quantities ordered by hospitals and public health units for each order are 5,100. The probability that an order is issued as a result of bargaining between the buyer and the supplier is about 42%. The average monthly coefficient of variation is about 0.37 in the sample. In order to give an example of the variation in prices, before the policy was implemented, the unitary price of syringes with a capacity of ml 20 with luer cone in 3 pieces without needles is €0.07, with a standard deviation of 0.007. In particular, the hospital Tor Vergata paid €0.04 before March 2016 and another hospital called S.Andrea paid €0.08 for the same syringe. The two hospitals are just 28 km away from each other (they are both located in Rome). The average delivery time is around 2 weeks. We are able to match only 65% of the deliveries with the corresponding order.

Table 3.1 – Summary statistics at the order level

VARIABLES	(1) mean	(2) sd	(3) p10	(4) p50	(5) p90	(6) N
Unitary price	0.920	1.841	0.0105	0.190	3.450	10,647
Total quantity	5,100	11,904	100	1,000	12,000	10,647
Total expenses per order	590.5	1,033	41.60	238.1	1,470	10,647
Negotiation (0/1)	0.420	0.494	0	0	1	4,205
Open auction (0/1)	0.440	0.496	0	0	1	4,205
Delivery time (days)	13.21	12.89	5	10	23	6,881

3.5 Identification strategy and results

Figure 3.2 highlights *prima facie* evidence of the introduction of reference prices by plotting the difference between the unitary prices of the orders and the reference price adopted by the *A.N.AC.*. The difference between the unitary price of the order and the reference price dropped after March 2016. To establish whether this drop is due to the introduction of reference prices, we have to design an identification strategy that allows us to establish the causal relationship between the drop in unitary prices and the introduction of the policy.

Figure 3.2 – Difference between unitary prices of the order and the reference price adopted by the A.N.AC.

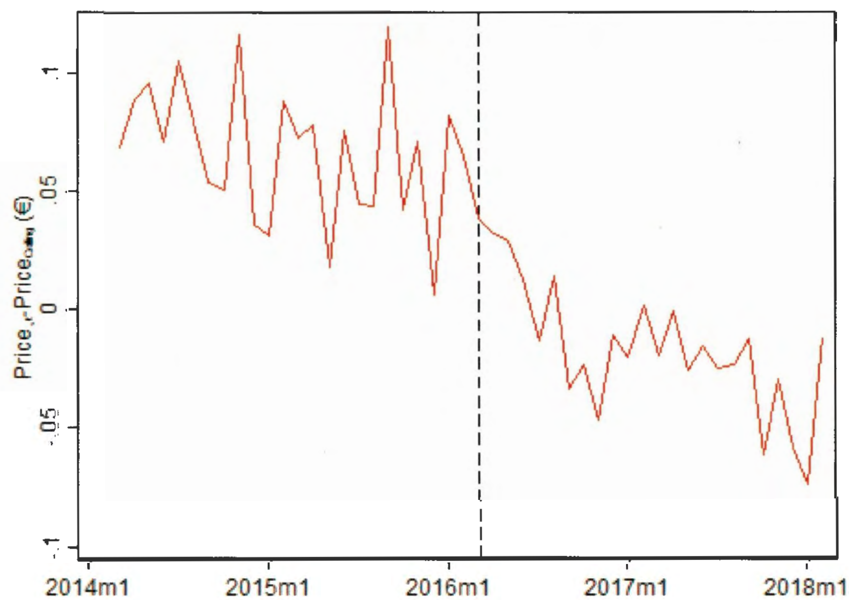
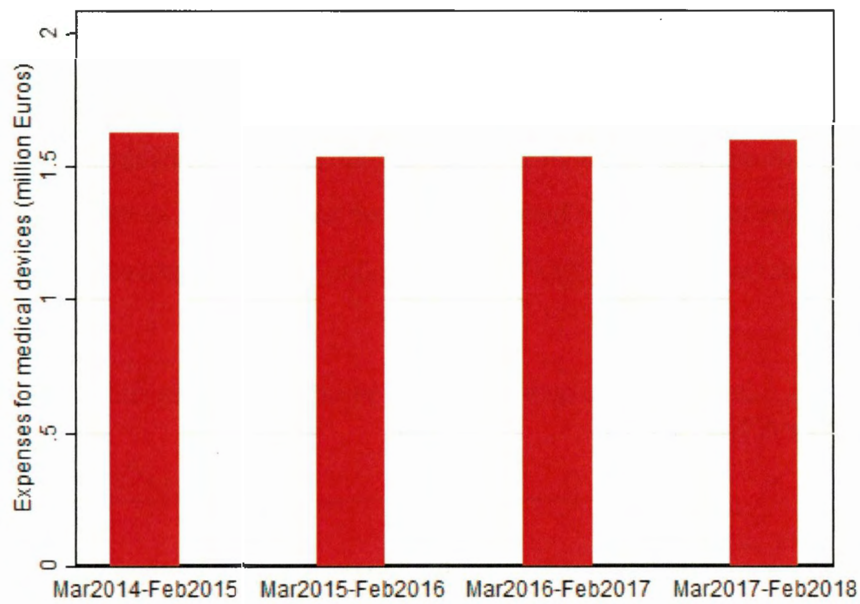


Figure 3.3 plots the total expenditure for the medical devices in our dataset in millions of euros. Medical devices subject to reference prices represent less than one-third of the total expenditure. Interestingly, the overall health expenditure in the region did not decrease after the policy was implemented. Thus, there could have been some adjustments since, all things being equal, a decrease in unitary prices for the treated medical devices should bring lower public health expenditure.

Figure 3.3 – Expenditure for medical devices for Lazio region (€million) two years before and after the reference price policy



3.5.1 Impact of the policy on unitary prices

To identify the causal effect of the policy on public expenditure, we exploit a difference-in-difference design based on whether medical devices are subject to the reference prices implemented in 2016. The *A.N.AC.* resolution is an exogenous event that provides a period before and after the policy change. The resolution is at the national level. Thus, considering only the local public buyers of a single region could support the assumption of the exogeneity of this resolution. Only 10% of the observations that have been used by the *A.N.AC.* to elaborate the binding reference prices come from local public buyers in the region. The possibilities that local public buyers in the Lazio region "lobbied" for the decision is then low.

In the analysis, we include medical devices that have been classified by *Agenas.* We use syringes, needles, bandages and cotton. These items have a low degree of complexity. Figures 3.4 and 3.5 provide examples of medical devices subject to the policy (treated on the left) and those not subject to the policy (control on the right).

Figure 3.4 – Treated

Figure 3.5 – Control

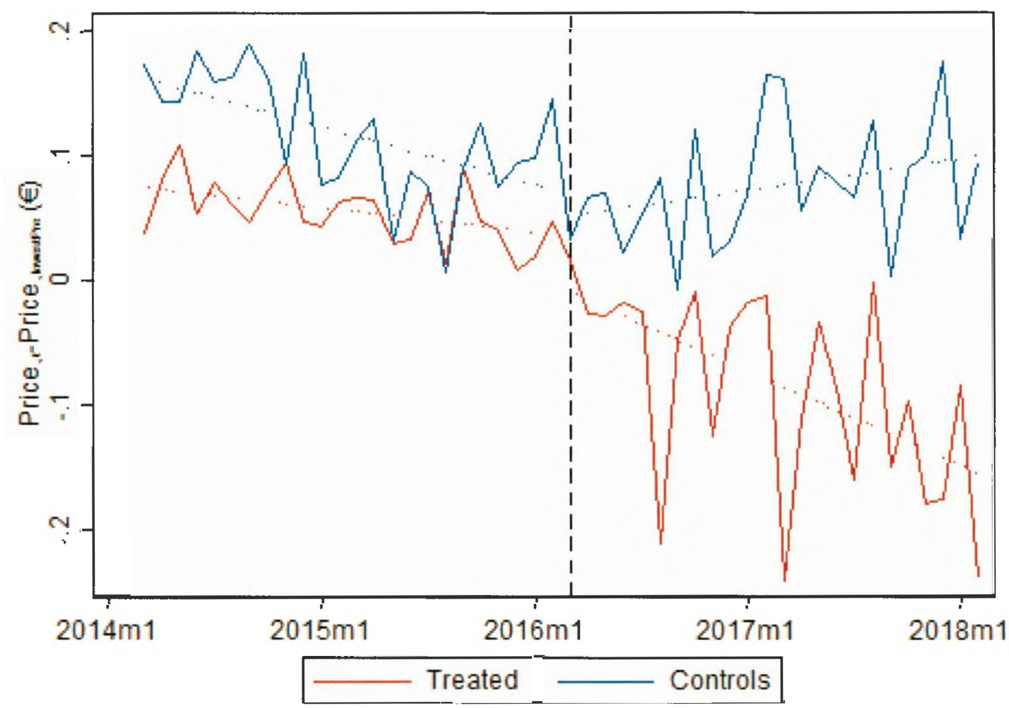
The econometric specification is the following:

$$p_{hdt} = \beta_0 + \beta_1 Treated_d X Post_t + \beta_2 Treated_d + \beta_3 Post_t + \varepsilon_{hdt} \tag{3.1}$$

where p_{hdt} is the unitary price paid by hospital *h* for medical device *d* in order *t*. *Treatment* is equal to 1 if the medical device *d* is subject to the policy, 0 otherwise. *Post* is equal to 1 if the order *t* is made after 2nd March 2016. The model also allows for public buyer-by-medical device effects along with month effects.

To rely on the difference-in-difference design, we test whether or not the outcomes of the two groups of devices do not have different trends before the implementation of the policy. Figure 3.6 plots the average difference between the unitary price of the order and the lowest price paid by the same public buyer for the same medical device. We cannot use the reference price because we do not have this information for the control group of medical devices. Graphically, we observe a parallel trend between the group of items subject to reference prices in 2016 and those not subject to the policy before the implementation of the policy.

Figure 3.6 – Difference between unitary prices of the order and the lowest price paid by the public health unit for the medical device before March 2016



We test the parallel trend assumption by regressing the unitary prices on a linear trend (*TreatedXYear*). Once we include in the estimation public buyer-by-medical device effects, along with month effects, the coefficients of *TreatedXYear* in Table 3.2 is not statistically different from 0. Thus, it is not possible to reject the assumption of common trend before the policy change.

Table 3.2 – Test of the common trend assumption in the period before the implementation of reference prices

	(1)	(2)	(3)	(4)
Dep.Variable	unitary price	unitary price	unitary price	unitary price
TreatedXYear	0.0189	0.0950		
	(0.150)	(0.073)		
Treated	-38.0312	-191.1994	0.0151	0.2091**
	(302.745)	(146.348)	(0.271)	(0.091)
Year	-0.0058	-0.1404**		
	(0.121)	(0.070)		
TreatedXMonth			-0.0073	-0.0010
			(0.019)	(0.003)
Month			0.0028	0.0026
			(0.016)	(0.003)
Med.Dev.IDXPublicUnitID FE	No	Yes	No	Yes
Time FE	No	No	No	No
Observations	5,537	5,512	5,537	5,512
R-squared	6.19e-05	0.833	9.28e-05	0.832
Mean Y Treated Pre	0.889	0.889	0.889	0.889

Notes: Coefficient (standard error in parentheses) of the interaction term between *Treated* medical devices and a linear trend (*Year* in column 1 and 2, *Month* in column 3 and 4) on unitary price of orders for medical devices. *Treated* is a dummy variable equal to 1 if the medical device is subject to a reference price. SEs are clustered at the medical device and public health unit level. Significance at 10% (*), 5% (**), and 1% (***).

The results from the estimation of equation 3.1 are presented in Table 3.3. We present the results for the unitary prices of the orders. In column (1) we estimate the model without any control while in columns (2) and (3) we estimate the model including public buyer-by-medical device effects and time (month) effects. The parameter of interest is β_1, which can be interpreted as the difference between the change in the unitary prices of orders in the group of medical devices subject to the price regulation and those medical devices not subject to reference prices after March 2016. The treated medical devices cost less after the implementation of the policy compared to the group of medical devices not subject to the policy. The decrease represents about 10% of the average unitary price of the orders before the policy. The decrease is significant when public buyer-by-medical device effects and time effects are included in the model. Standard errors are clustered at the medical device and public health unit levels.

Table 3.3 – Difference-in-difference for unitary prices of the orders

Dep.Variable	(1) unitary price	(2) unitary price	(3) unitary price
TreatedXPost	-0.0757	-0.0885**	-0.0872**
	(0.351)	(0.0376)	(0.0388)
Treated	-0.0288	0.176***	0.164***
	(0.295)	(0.0580)	(0.0571)
Post	0.0486	-0.0144	
	(0.285)	(0.0195)	
Med.Dev.IDXPublicUnitID FE	No	Yes	Yes
Time FE	No	No	Yes
Observations	10,647	10,634	10,634
R-squared	0.000409	0.827	0.827
Mean Y Treated Pre	0.889	0.889	0.889

Notes: Coefficient (standard error in parentheses) of the effect of reference prices on unitary price of orders: *Post* is a dummy variable equal to 1 if the orders are issued after the start of the reference pricing policy. *Treated* is a dummy variable equal to 1 if the medical device is subject to reference price. SEs are clustered at device-hospital level. Significance at 10% (*), 5% (**), and 1% (***).

3.5.2 Effect on prices

When reference prices represent a binding price ceiling and public health units pay on average higher prices than the reference price before the policy was implemented, we should observe a price decrease in these categories of devices. On the other hand, when reference prices are still binding but the price paid by public health units before the policy was lower than the reference price, we should not observe any effect of the policy unless there is an adjustment, In this latter case, prices could increase following the implementation of the policy. Reference prices could in fact represent a focal point that might induce collusion (Knittel and Stango, 2003).

Figure 3.7 plots the monthly difference between unitary prices and reference prices for devices whose average price before the policy was above the reference price (red line) and for those devices whose average price was below the reference price before the policy (orange line). The two time series converge around a difference of 0 after March 2016, although with a certain delay due probably to the fact that some contracts are sticky.

Figure 3.7 – Monthly difference between unitary price and reference price for medical devices with an average pre-policy price above the reference price (red) and below the reference price (orange).

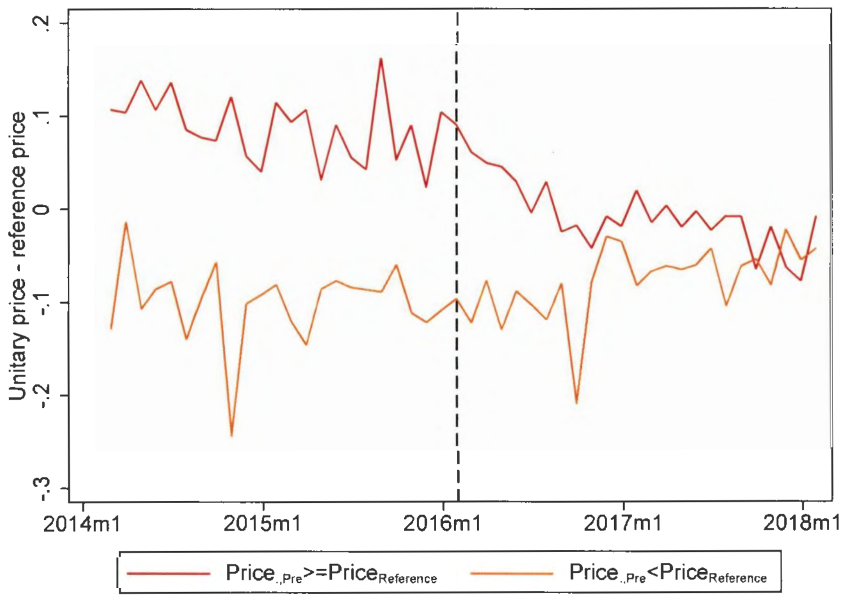


Table 3.4 estimates the difference-in-difference including in the treated group of devices only those medical devices (*semitreated*) whose average price before the policy was below the reference price fixed by the authority (column 1) and those treated medical devices (*treated*) whose average price before the policy was above the reference price (column 2). The overall decrease in unitary prices of the orders is driven by the latter group, and it is slightly mitigated by an increase in unitary prices for the former group.

Table 3.4 – Heterogeneous effects by average price before policy.

Dep.Variable	(1) Semitreated	(2) Treated
TreatedXPost	0.0104	-0.0914**
	(0.0263)	(0.0426)
Treated		0.166***
		(0.0576)
Med.Dev.IDXPublicUnitID FE	Yes	Yes
Time FE	Yes	Yes
Observations	7,661	10,187
R-squared	0.797	0.827
Mean Y Treated Pre	0.252	0.978

Notes: Coefficient (standard error in parentheses) of the effect of reference prices on unitary price of orders. In column 1 we consider in the treated group only those medical devices with an average price before the policy lower than the reference price fixed by the authority. In column 2 we consider in the treated group only those medical devices with an average price before the policy higher than the reference price fixed by the authority. *Post* is a dummy variable equal to 1 if the orders are issued after the start of the reference pricing policy. *Treated* is a dummy variable equal to 1 if the medical device is subject to reference price. SEs are clustered at the medical device and public health unit level. Significance at 10% (*), 5% (**), and 1% (***).

3.5.3 Other outcomes

We have shown that, following the introduction of reference prices, the unitary price of orders decreased significantly. We have also assessed that the effect was only been partially mitigated by an increase in prices for those treated medical devices that hospitals were paying on average less than the reference price. In this subsection, we investigate whether other dimensions faced significant changes, namely the quantities per order, the expenses and the days between the order of the device and its delivery to the public health unit. Unfortunately, we were not able to match all the orders with the deliveries.

Table 3.5 reports the effect of the policy on several other outcomes. Interestingly, the quantities purchased by every hospital do not vary significantly at the order level, and there is the same pattern for the total expenses per order. On the other hand, there is a significant reduction in the number of days in which treated devices were delivered.

Table 3.5 – Difference-in-difference estimation for quantities per order, expenses per order and days of delivery of the device

	(1)	(2)	(3)
Dep.Variable	Q.Ord	Tot.Exp.Ord.	DaysDeliv.Ord.
TreatedXPost	-1,513	-119.7	-1.975**
	(1,877)	(94.62)	(0.883)
Treated	-12,314	-284.9	4.032
	(9,904)	(185.8)	(3.966)
Med.Dev.IDXPublicUnitID FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	10,634	10,634	6,862
R-squared	0.543	0.537	0.209
Mean Y Treated Pre	6566	568.1	15.09

Notes: Coefficient (standard error in parentheses) of the effect of reference prices on different outcomes at the order level. Column 1 shows the effect of the policy on the quantities ordered. Column 2 shows the effect of the policy on the total expenses by order. Column 3 shows the days of delivery expressed as the difference between the day on which the order for the device was issued and the day of delivery of the device. *Post* is a dummy variable equal to 1 if the orders were issued after the start of the reference pricing policy. *Treated* is a dummy variable equal to 1 if the medical device is subject to reference price. SEs are clustered at the medical device and public health unit levels. Significance at 10% (*), 5% (**), and 1% (***).

Table 3.6 reports outcomes for quantities and expenses by month for each public health unit and medical device. In addition, we also report the number of orders issued per month. We do not observe significant changes for these outcomes, although the total expenses per month and the total quantities decrease on average.

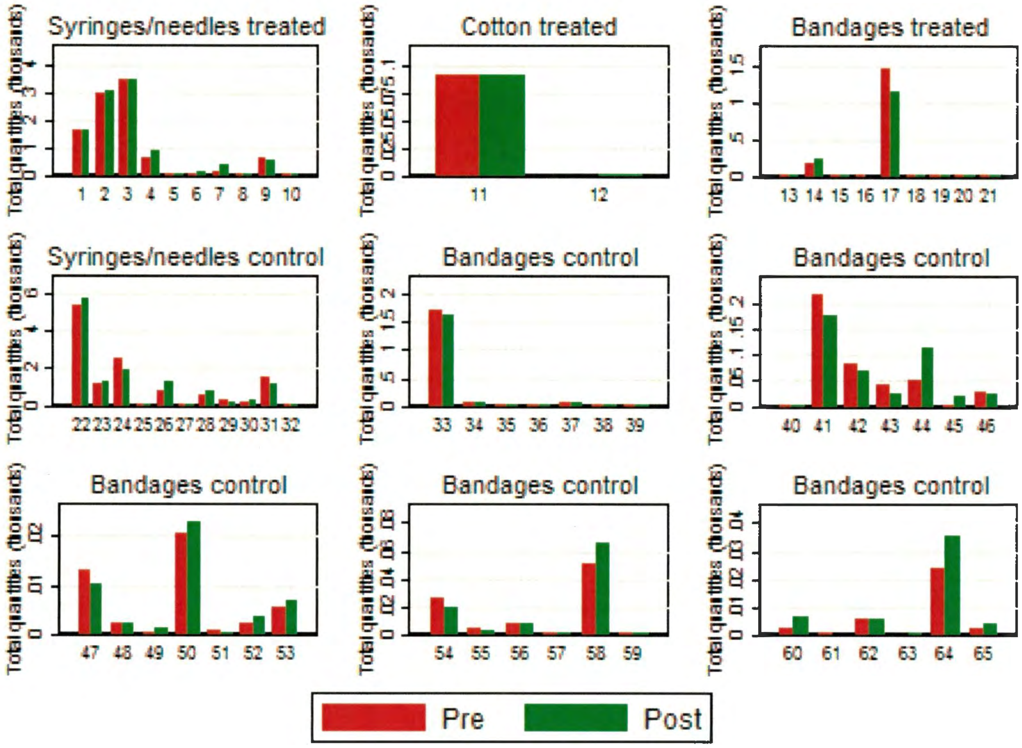
Table 3.6 – Difference-in-difference estimation for quantities per month, expenses per month and number of orders per month

Dep.Variable	(1) Tot.Q.Month	(2) Tot.Expenses.Month	(3) N.Ord.Month
TreatedXPost	-1,527	-143.0	0.115
	(2,542)	(121.9)	(0.0933)
Treated	-29,127	-830.0	-0.158
	(23,189)	(670.3)	(0.580)
Med.Dev.IDXPublicUnitID FE	Yes	Yes	Yes
Time FE	Yes	Yes	Yes
Observations	5,128	5,128	5,128
R-squared	0.718	0.660	0.581
Mean Y Treated Pre	12799	1093	1.916

Notes: Coefficient (standard error in parentheses) of the effect of the reference pricing policy on different outcomes at the device-public unit-month level. Column 1 shows the effect of the policy on the total quantities ordered per month. Column 2 shows the effect of the policy on the total expenses per month. Column 3 shows the number of orders per month. *Post* is a dummy variable equal to 1 if the orders were issued after the start of the reference pricing policy. *Treated* is a dummy variable equal to 1 if the medical device is subject to reference price. SEs are clustered at public buyer-by-medical device levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure 3.8 shows the total demand for each class of medical devices, distinguishing between the treated and control groups. By using the same amount of time before and after the implementation of the policy, we provide a fair representation of the demand. The composition of the demand does not seem to have changed over time.

Figure 3.8 – Quantities (thousands) ordered by product



3.6 Public health units ranking: heterogeneity at unitary price level

To check the heterogeneous effects of the policy at the public health unit level, we classify the public health units by looking at their average distance from the reference price for each medical device subject to reference prices. We investigate whether the policy implied any change in the ability of the public health units to purchase at lower prices. We rank public health units according to the average difference across all treated medical devices between the unitary price paid before the implementation of the policy and the reference price. The econometric model is the following:

$$P_{hdt} = \beta_0 + \beta_1 Dist.Ref.Price_{hd} X Post_t + \beta_2 Dist.Ref.Price_{hd} + \beta_3 Post_t + \varepsilon_{hdt} \quad (3.2)$$

P_{hdt} is the unitary price paid by public health unit h for medical device d in order t. *Dist.Ref.Price* is a continuos variable identifying how far public health unit h is from the reference price of device d. This variable is computed by taking the average distance for each public health unit and medical device in the period before the implementation of the policy. *Post* is equal to 1 if the order t is made after 2nd March 2016. The model allows for public buyer-by-medical device effects along with month effects. In the regression analysis, we look at treated medical devices only, and we investigate separately those combinations of buyer-device with an average distance above reference price compared to those combinations buyer-device with an average price below the reference price.

Table 3.7 reports the estimates for the main outcomes in our analysis for the combination of public health units and medical devices that are on average above the reference price. We can observe a strong negative effect of the coefficient of *Dist.Ref.PriceXPost*. According to Table 3.7 column 1, one standard deviation of average distance from the reference price decreases prices by 28.8%. This is computed by multiplying $0.246 * (1.088) = -0.268$, corresponding to a drop of €0.268, or 28.8% of the unitary prices for the treated devices.

Table 3.7 – Difference-in-difference estimation for main outcomes. Public health units with average distance from reference price for a given device above zero

Dep.Variable	(1) Unit.Price	(2) Q.Ord.	(3) Expenses.Ord.	(4) DaysDeliv.
Dist.Ref.PriceXPost	-1.088***	3,595	45.24	3.743
	(0.0513)	(3,119)	(163.9)	(3.449)
Dist.Ref.Price	1.978***	-3,981	191.7	-3.530
	(0.111)	(3,805)	(190.7)	(3.245)
Med.Dev.IDXPublicUnitID FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	2,514	2,514	2,514	1,511
R-squared	0.988	0.622	0.535	0.245
Mean Y Pre	0.931	8061	629.4	15.49
Std.Dev.Distance	0.246	0.246	0.246	0.246

Notes: The table reports estimates of the effects of distance from reference prices on main public buyer outcomes: *Unit.Price* is the unitary price of the order (column 1); *Q.Ord.* is the quantity ordered (column 2); *Expenses.Ord.* are the expenses per order (column 3); *DaysDeliv.* is the difference between the day of the order and the day of the delivery (column 4).*Post* is a dummy variable equal to 1 if the orders are issued after the start of the reference pricing policy. *Dist.Ref.Price* is a continuous variable identifying how far on average the public buyer is from the reference price for a given device. SEs are clustered at medical device and public health unit level. Significance at 10% (*), 5% (**), and 1% (***).

Table 3.8 reports the estimates for the main outcomes in our analysis for the combination of public health units and medical devices that are on average below the reference price. We can observe a positive effect of the coefficient of *Dist.Ref.PriceXPost*. According to Table 3.8 column 1, one standard deviation of average distance from the reference price increases prices by 10%. This is computed by multiplying $0.0794 * (0.734) = +0.058$, corresponding to an increase of €0.058, or 8.8% of the unitary prices for the treated devices. In addition, we observe that for combinations of public health units and medical devices with an average distance from reference price below the reference price before the policy, not only have the unitary prices increased, but also delays in the delivery of the items have decreased. This aspect is particularly interesting since it raises suspicions about the buyer-supplier relationship. It documents that the supplier is more "reliable" if he is paid more. Thus, efficient public health units could face a trade-off between paying lower prices and being subject to more delays in the deliveries of the devices.

Table 3.8 – Difference-in-difference estimation for main outcomes. Public health units with average distance from reference price for a given device below zero

Dep.Variable	(1) Unit.Price	(2) Q.Ord.	(3) Rev.Ord.	(4) DaysDeliv.
Dist.Ref.PriceXPost	0.734**	3,734	69.33	-15.70*
	(0.337)	(4,476)	(453.6)	(8.607)
Dist.Ref.Price	3.157***	-3,351	-767.9***	-22.23**
	(0.607)	(3,428)	(253.9)	(10.44)
Med.Dev.IDXPublicUnitID FE	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes
Observations	702	702	702	432
R-squared	0.974	0.461	0.818	0.192
Mean Y Pre	0.661	2322	426.6	11.87
Std.Dev.Distance	0.0794	0.0794	0.0794	0.0794

Notes: The table reports estimates of the effects of exposure to reference prices on main public buyer outcomes: *Unit.Price* is the unitary price of the order (column 1); *Q.Ord.* is the quantity ordered (column 2); *Expenses.Ord.* are the expenses per order (column 3); *DaysDeliv.* is the difference between the day of the order and the day of the delivery (column 4). *Post* is a dummy variable equal to 1 if the orders are issued after the start of the reference pricing policy. *Dist.Ref.Price* is a continuous variable identifying how far on average the public buyer is from the reference price for a given device on average. SEs are clustered at medical device and public health unit levels. Significance at 10% (*), 5% (**), and 1% (***).

3.7 Measuring public health unit and firm exposure to the policy

In this section, we estimate the effects of reference prices by using an exogenous measure of exposure of the buyers (demand) and the suppliers (supply) to the policy.

3.7.1 Public health units analysis

Table 3.9 reports summary statistics for public health units.[7] In the region considered, three public health units in Rome represent about 30% of the total health expenditure for the medical devices included in our analysis. There exists a certain degree of variation in terms of share of expenses coming from medical devices subject to the policy and these expenses seem to be stable or to increase slightly after the regulation on reference prices. On the other hand, two public health units, accounting for about 15% of the total expenses, relied less on the treated medical devices after the reference prices were introduced (public health unit number 2 and number 9). They both increased the quantities purchased from the control set of medical devices as well as their overall expenditure.

[7]Note that public health units which merged or were renamed after 1st January 2016 are treated as a single entity in this table.

Table 3.9 – Public health units' summary statistics

Public health unit	ID	Exp.(ShareTot)		Expenses (1,000,000€)		Exp.Sh.Negot.		Exp.Sh.Treated		Tot.Q (1,000,000)		Tot.Q.Tr.		Tot.Q.Semitr.		Tot.Q.Ctrl		DaysDeliv.	
		Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
ASL ROMA 2	1	0.120	0.109	0.380	0.340	0.226	0	0.297	0.418	2.144	2.233	0.885	0.953	0.0217	0.0597	1.237	1.220	12.88	12.76
AO S. ANDREA	2	0.0993	0.134	0.314	0.418	0.0582	0.0911	0.251	0.173	3.058	3.169	1.174	1.166	0.00972	0.0103	1.874	1.993	12.15	10.11
ASL ROMA 5	3	0.0972	0.0719	0.308	0.224	0.314	0.997	0.291	0.440	2.006	2.319	1.069	1.525	0.0297	0.131	0.908	0.663	0	0
ASL FROSINONE	4	0.0925	0.101	0.293	0.316	0	0	0.127	0.131	1.406	1.660	0.185	0.268	0.00306	0.00468	1.218	1.387	15.14	15.74
ASL VITERBO	5	0.0915	0.101	0.290	0.314	0	0	0.419	0.394	2.519	2.435	1.494	1.374	0.0632	0.0608	0.961	1.000	18.22	17.38
AO S. CAMILLO	6	0.0838	0.0844	0.265	0.263	0.700	0.667	0.744	0.777	4.108	3.817	3.220	3.364	0.0241	0.0299	0.863	0.424	11.76	13.06
ASL ROMA 6	7	0.0835	0.0739	0.264	0.231	0.309	0.965	0.355	0.324	2.222	2.006	1.334	0.900	0.0305	0.144	0.858	0.962	14.04	12.23
AO S. GIOVANNI	8	0.0657	0.0727	0.208	0.227	0	0	0.0732	0.158	0.748	1.027	0.0624	0.364	0.00360	0	0.682	0.663	12.52	11.39
TOR VERGATA	9	0.0575	0.0694	0.182	0.217	0	0	0.159	0.0152	3.482	4.195	0.0859	0.0104	0.168	0.0182	3.228	4.166	8.386	13.57
ASL ROMA 3	10	0.0567	0.0519	0.179	0.162	0	0	0.226	0.221	1.197	1.097	0.629	0.428	0.00422	0.0978	0.564	0.571	11.21	12.27
UMBERTO I	11	0.0287	0.0291	0.0909	0.0909	0.451	0.285	0.653	0.840	1.487	1.195	0.157	0.294	0.00660	0.0654	1.324	0.836	15	11.87
ASL ROMA 1	12	0.0267	0.0176	0.0844	0.0549	0.492	0.260	0.548	0.453	0.636	0.789	0.345	0.197	0.0373	0.135	0.254	0.457	7.870	24.02
ASL ROMA 4	13	0.0257	0.0403	0.0813	0.126	0	0	0.213	0.159	0.419	0.549	0.0431	0.0652	0.0110	0.00702	0.365	0.477	14.35	14.41
ASL RIETI	14	0.0248	0.00751	0.0786	0.0234	1	1	0.0980	0.153	0.592	0.228	0.345	0.163	0	0	0.247	0.0652	12.85	12.50
ASL LATINA	15	0.0220	0.0235	0.0697	0.0733	0.945	0.902	0.682	0.646	0.178	0.216	0.0891	0.128	0	0	0.0889	0.0880	9.333	10.20
IRCCS L. SPALLANZANI	16	0.0122	0.0125	0.0386	0.0389	1	1	0.120	0.153	0.338	0.358	0.0173	0.00684	0.00144	0.00398	0.319	0.348	8.180	11.72
IRCCS IFO	17	0.0122	0.000955	0.0385	0.00298	0.890	1	0.0183	0.0983	0.408	0.0602	0.000207	0.000100	0	0	0.408	0.0601	9.353	9.400
Total	.	1	1	3.165	3.121	.	.	.	.	26.95	27.35	11.14	11.21	0.414	0.768	15.40	15.38	.	.

Notes: The table reports summary statistics for all public health units in the dataset, decreasingly ranked in terms of share of total expenditure. *Exp.(ShareTot)* is the share of total expenditure. *Expenses* represent the expenses (in €million). *Exp.Sh.Negot.* represent the share (out of all total expenditure) that is purchased with direct negotiation. *Tot.Q* represents (in millions) the total quantities purchased. *Exp.Sh.Treated* represents the share of expenditure from medical devices subject to reference price. *Tot.Q.Tr* represents the total quantities purchased for those treated medical devices with an average price before March 2016 above the reference price. *Tot.Q.Semitr* represents the total quantities purchased for those treated medical devices with an average price before March 2016 below the reference price. *Tot.Q.Ctrl* represents the total quantities purchased for those devices not subject to reference prices. *DaysDeliv.* represents the number of days between the issuing of the order and the delivery of the device. Note that the public health units merged or renamed on the 1st January 2016 are treated as unique entities.

We study the impact of the policy by analyzing the exposure of each public health unit to it in terms of share of expenses in the period before the policy from the purchase of the treated medical devices. The econometric specification is the following:

$$Y_{hdt} = \beta_0 + \beta_1 Exp.Hosp._{hd} X Post_t + \beta_2 Exp.Hosp._{hd} + \beta_3 Post_t + \varepsilon_{hdt} \quad (3.3)$$

where Y_{hdt} is the price paid (quantity, expenses, delays) by hospital h for device d for order t. *Exp.Hosp.* is a continuous variable identifying the exposure of the hospital to the policy, represented by the expenses out of all expenses coming from treated medical devices before the policy was implemented, *Post* is equal to 1 if the order is made after 2nd March 2016. Regressions include public unit-by-medical device effects as well as month fixed effects.

Figure 3.9 plots the frequency of public health units by exposure to the treated medical devices. The median exposure is 30% and the mean exposure is 35%. To compute, the magnitude of the effect that the exposure to the reference price policy has on public health units' expenses, we did a back-of-envelope computation. We found in the difference-in-difference estimation of table 3.3 that unitary prices decreased by about 10%. Given that the average public health unit has a 35% exposure to the policy, this implies that on average the expenses of the public health unit should drop by 3.5%. A similar public health unit with one more standard deviation has an exposure to the reference price policy of 57%, which implies that after the reference price policy was implemented, the unitary expenses for medical devices for this public health unit would drop by 5.7%. Thus, we expect one additional standard deviation of exposure to the reference price policy to decrease unitary prices paid by the public health unit by 2.2%.

Figure 3.9 – Heterogeneity in public health units' exposure to the reference price policy

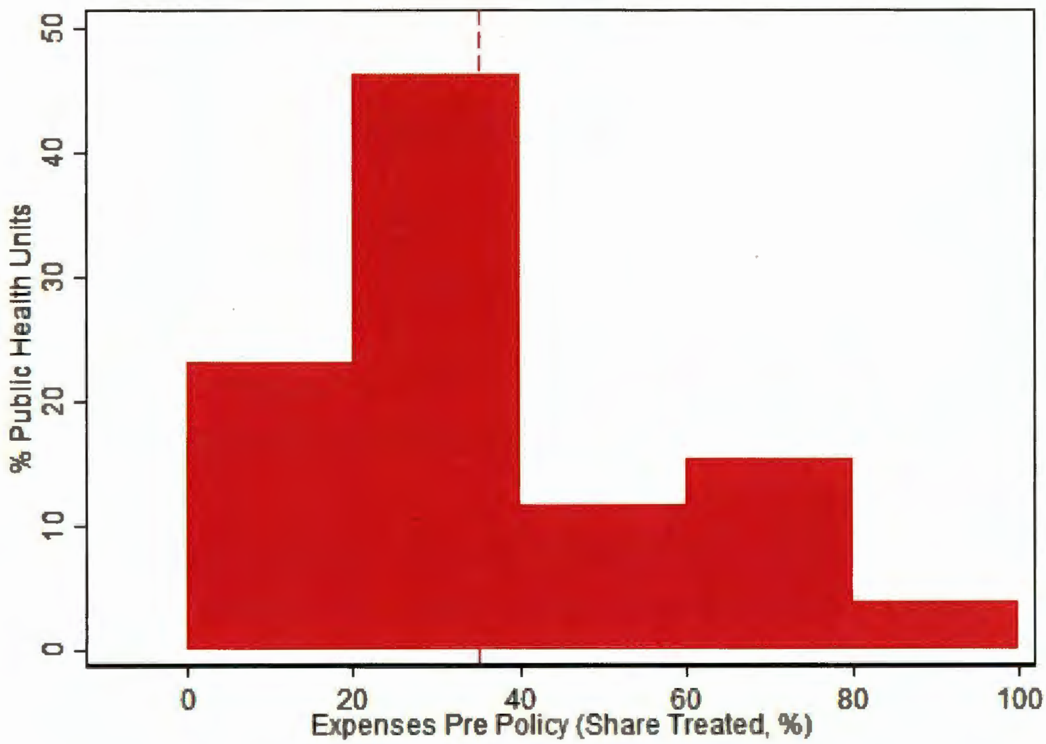


Table 3.10 presents the results of the estimation of equation 3.3. In the first 4 columns, we present the outcomes for all medical devices. In columns 5-8 we present the outcomes for the treated medical devices with an average price before the policy above the reference price. In columns 9 to 12 we present the outcomes for the semi-treated medical devices (the treated medical devices with an average price before the policy below the reference price). In columns 13 to 16, we present the outcomes for the control set of devices. On the basis of column 5, one standard deviation of exposure to the reference price policy decreases unitary prices paid by public health units by 15.37% for the treated medical devices. This is computed by multiplying $21.92 * (-0.00680) = 0.1491$, corresponding to a €0.1491 drop, or 15.37% of average unitary prices. Thus, the unitary price of orders drop much more than the 2.2% that was computed as the average effect.

Table 3.10 – Effect of public health units' exposure to the reference price policy on main outcomes

Devices	All				Treated				Semitreated				Control			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dep.Variable	Unit.P.	Q	Cost	Delays	Unit.P.	Q.	Cost	Delays	Unit.P.	Q.	Cost	Delays	Unit.P.	Q.	Cost	Delays
Exp.Hosp.XPost	-0.00248*	-16.15	0.738	-0.00522	-0.00680**	-84.82	-4.659	0.0379	0.00111	9.587	2.331	-0.0685	0.00189	-1.559	1.282	-0.0165
	(0.00144)	(15.83)	(1.402)	(0.0202)	(0.00301)	(60.18)	(3.894)	(0.0322)	(0.00102)	(32.17)	(3.477)	(0.0823)	(0.00196)	(18.86)	(1.257)	(0.0347)
Observations	10,647	10,647	10,647	6,880	2,974	2,974	2,974	1,806	445	445	445	281	7,226	7,226	7,226	4,791
R-squared	0.0814	0.146	0.0679	0.0511	0.183	0.314	0.316	0.160	0.229	0.235	0.213	0.251	0.131	0.184	0.0587	0.0415
Med.Dev.IDXPublicUnitID FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre	0.920	5100	590.5	13.21	0.970	7512	623.3	14.99	0.247	2643	349.6	13.11	0.941	4260	591.8	12.54
Std.Dev.Exposure	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93	21.93

Notes: The table reports the effects of the exposure to the reference price policy on unitary prices paid, quantities ordered, expenses and delays for public health units at the order level. *All* includes includes in the estimation all devices. *Treated* includes in the estimation the treated medical devices with an average price before the policy above the reference price. *Semitreated* includes in the estimation the treated medical devices with an average price before the policy below the reference price. *Control* includes in the estimation the medical devices not subject to reference prices. *Unit.P.* is the unitary price of the order. *Q* is the quantity in the order. *Cost* is the expense. *Delays* represents the number of days of delivery of the ordered device. SEs are clustered at public buyer-by-medical device level. Significance at 10% (*), 5% (**), and 1% (***).

3.7.2 Suppliers analysis

The supply of medical devices (syringes, needles, cotton and bandages) to public health units is done by a small number of multinational and small local firms. Table 3.11 presents summary statistics of the suppliers. In this table, revenues of each firm are reported together with other variables, such as the share of revenues the supplier obtains by negotiating the provision of medical devices directly with the public health unit, the share of revenues the supplier makes by selling medical devices targeted by the reference price policy, and the total quantities the supplier sells. The total quantities are divided into subcategories. The treated devices are those subject to the policy whose average price before the policy lies above the reference price; the semi-treated devices are those subject to the policy whose average price before the policy lies below the reference price. All other devices are in the control group.

There are 41 distinct suppliers in the market; 6 of them entered the market after March 2016 and 6 suppliers exited the market. Firm 1 is the market leader with 30% of the market share and 60% of its revenues coming from the treated medical devices subject to the policy. Ten firms have 70% of the market. In particular, the three firms with the highest market shares possess more than 50% of the market. The market leader lost a significant amount of revenues after the policy was implemented. Among all the other big firms, the market leader has a relatively high share of revenues coming from the provision of treated medical devices. Firm 2 (the second highest in terms of market shares) had almost no exposure to the treated medical devices, and it was able to increase its revenues slightly.

Table 3.11 – Suppliers' summary statistics.

ID Supplier	Rev.(ShareTot)		Rev. (€1,000,000)		Rev.Sh.Negot.		Rev.Sh.Treated		Tot.Q (1,000,000)		Tot.Q.Tr.		Tot.Q.Semitr.		Tot.Q.Ctrl		DaysDeliv.	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	0.305	0.235	0.967	0.733	0.514	0.486	0.587	0.606	10.91	8.564	9.631	7.649	0.00339	0.0360	1.275	0.879	17.03	14.68
2	0.144	0.158	0.457	0.493	0.602	0.710	0.0208	0.00919	5.139	5.110	0.0669	0.0363	0.0144	0.131	5.058	4.943	12.51	12.42
3	0.0880	0.100	0.279	0.313	0.725	0.731	0.262	0.273	2.528	2.001	0.635	0.514	0.00660	0.0575	1.886	1.429	11.32	11.83
4	0.0752	0.0796	0.238	0.248	0.164	0.201	0.0637	0.546	5.525	5.656	0.0561	1.608	0.0672	0.366	5.402	3.682	10.05	12.94
5	0.0747	0.0210	0.236	0.0655	0.212	0.215	0.401	0.927	0.460	0.0707	0.421	0.0422	0.000600	0.0246	0.0377	0.00390	12.13	17.76
6	0.0532	0.0570	0.168	0.178	0	0	0	0	0.465	0.492	0	0	0	0	0.465	0.492	15.83	15.86
7	0.0385	0.0123	0.122	0.0384	0.00277	0.0160	0	0	0.354	0.119	0	0	0	0	0.354	0.119	16.62	14.75
8	0.0328	0.0237	0.104	0.0739	0.0489	0	0	0	0.0250	0.0190	0	0	0	0	0.0250	0.0190	8.903	8.638
9	0.0264	0.0283	0.0834	0.0884	0.0605	0	0.550	0.267	0.278	0.563	0.0138	0.00830	0	0	0.264	0.555	12.43	13.26
10	0.0200	0.0314	0.0634	0.0980	0.00463	0.226	0	0	0.0465	0.0710	0	0	0	0	0.0465	0.0710	7.032	9.221
11	0.0197	0.0205	0.0622	0.0638	0	0	0	0	0.230	0.241	0	0	0	0	0.230	0.241	11.52	12.34
12	0.0194	0.0228	0.0615	0.0712	0.0970	0.0277	1	1	0.0178	0.0206	0.0178	0.0206	0	0	0	0	16.31	14.23
13	0.0169	0.00925	0.0536	0.0289	0.335	0.150	1	1	0.217	0.128	0.00432	0.00288	0.213	0.125	0	0	12.09	11.30
14	0.0154	0.0381	0.0487	0.119	1	0.776	0.0420	0.194	0.0152	0.0386	0.00166	0.0115	0	0	0.0135	0.0272	13.98	14.69
15	0.0143	0.0146	0.0454	0.0454	0	0	0.755	0.789	0.0810	0.0734	0.00995	0.0104	0	0	0.0711	0.0630	22.39	16.51
16	0.0123	0.00341	0.0390	0.0107	0	0	0	0	0.00869	0.00180	0	0	0	0	0.00869	0.00180	10.29	9
17	0.0116	0.00199	0.0367	0.00621	0	0	0.255	0.181	0.0268	0.00408	0.00473	0.000444	0.00218	0	0.0199	0.00364	12.75	7.964
18	0.00630	0.00616	0.0199	0.0192	0.0615	0.320	0	0	0.112	0.117	0	0	0	0	0.112	0.117	12.88	13.14
19	0.00501	0	0.0159	0	0	0	0	0	0.0706	0	0	0	0	0	0.0706	0	10.91	0
20	0.00312	0.000559	0.00989	0.00175	1	0.872	1	0.171	0.200	0.136	0.100	0.00500	0.100	0	0	0.131	0	23
21	0.00304	0.0442	0.00961	0.138	0	0.0283	1	0.413	0.00267	2.817	0.00267	0.551	0	0.0153	0	2.251	0	15.84
22	0.00250	0.0186	0.00791	0.0581	0	0.571	0	0	0.00261	0.0166	0	0	0	0	0.00261	0.0166	6.278	9.420
23	0.00183	0	0.00580	0	0	0	1	0	0.0800	0	0.0800	0	0	0	0	0	19.50	0
24	0.00166	0.0106	0.00527	0.0330	0	0	0	0	0.00307	0.0224	0	0	0	0	0.00307	0.0224	10.70	12.14
25	0.00158	0.000154	0.00501	0.000480	0.198	0	0	0	0.00725	0.000600	0	0	0	0	0.00725	0.000600	12.14	8.333
26	0.00155	0.000189	0.00491	0.000589	0	0	0.777	1	0.0481	0.00190	0.0430	0.00190	0	0	0.00510	0	22	11
27	0.00154	0.00959	0.00488	0.0299	0.126	0.00466	0	0	0.00137	0.00692	0	0	0	0	0.00137	0.00692	13	9.300
28	0.00143	0.00395	0.00453	0.0123	0	0	0.808	0.288	0.0592	0.269	0.0467	0.200	0.00648	0.00251	0.00600	0.0663	17.38	19.48
29	0.00107	0.00497	0.00339	0.0155	0.644	0.180	0	0	0.00655	0.0205	0	0	0	0	0.00655	0.0205	6.958	14.26
30	0.000347	0.000352	0.00110	0.00110	0	0	0	0	0.0100	0.0110	0	0	0	0	0.0100	0.0110	11	4.500
31	0.000314	8.77e-05	0.000995	0.000274	0	0	0	0	0.00810	0.00190	0	0	0	0	0.00810	0.00190	36	17.67
32	0.000169	0	0.000535	0	0	0	0	0	0.000192	0	0	0	0	0	0.000192	0	8	0
33	0.000159	0	0.000504	0	1	0	0	0	0.0100	0	0	0	0	0	0.0100	0	49	0
34	6.79e-05	0	0.000215	0	0	0	0	0	0.000500	0	0	0	0	0	0.000500	0	17.50	0
35	1.77e-06	0	5.60e-06	0	1	0	0	0	0.000200	0	0	0	0	0	0.000200	0	24	0
36	0	0.000100	0	0.000313	0	0	0	0	0	0.00250	0	0	0	0	0	0.00250	0	6.857
37	0	0.0134	0	0.0419	0	0	0	0	0	0.125	0	0	0	0	0	0.125	0	14.50
38	0	0.0228	0	0.0711	0	0.576	0	0.494	0	0.610	0	0.546	0	0.00945	0	0.0540	0	16.77
39	0	0.000363	0	0.00113	0	0	0	0	0	0.00798	0	0	0	0	0	0.00798	0	14.13
40	0	0.000371	0	0.00116	0	0	0	0	0	0.00235	0	0	0	0	0	0.00235	0	12.19
41	0	0.00650	0	0.0203	0	0	0	0	0	0.0127	0	0	0	0	0	0.0127	0	38.34
Total	1	1	3.165	3.121	.	.	.	.	26.95	27.35	11.14	11.21	0.414	0.768	15.40	15.38	12.21	11.66
Total 17 largest	0.968	0.857	3.065	2.675	.	.	.	.	26.33	23.17	10.86	9.903	0.307	0.741	15.16	12.53	13.13	12.79

Notes: *ID Supplier* is the identifier of the firm, with $ID = 1$ being the firm with the highest total revenues before March 2016, $ID = 41$ being the firm with the lowest total revenues before March 2016. *Rev.(ShareTot)* are a firm's revenues as share of total revenues of all firms. *Rev. (€1,000,000)* represents the total revenues of the firm in €millions. *Rev.Sh.Negot.* represents the share of the revenues coming from direct negotiation between a public health unit and the firm. *Rev.Sh.Treated* represents the revenues (out of total revenues) from treated medical devices. *Tot.Q (1,000,000)* represents the total quantities (in millions). *Tot.Q.Tr.* represents the total quantities from treated devices whose average pre-policy price lies above the reference price. *Tot.Q.Semitr.* represents the total quantities (in millions) whose average pre-policy price lies below the reference price. *Tot.Q.Ctrl* represents the total quantities (in millions) of control medical devices. *DaysDeliv.* is the average number of days between the issue of the order and the delivery of the medical device.

To graphically understand the winners and losers from the policy, Figure 3.10 plots the total revenues (in €millions) for the biggest 17 suppliers, which own 97% of the market. Firm 1 is the firm losing the biggest amount of revenues (about €0.2 million). The decrease in total market shares of the largest 17 firms observed in Table 3.11 is mainly driven by the market leader. Figure 3.11 plots the share of revenues coming from the treated and control medical devices. Firm 1 lost revenues but remains exposed to the policy to the same extent as before March 2016. Thus, the decrease in revenues could be driven mainly by the lower unitary prices observed for the treated medical devices that are supplied to a large extent by the market leader and by the fact that the market leader did not adjust by selling more devices in the market of devices not subject to the policy.

Figure 3.10 – Firms selling medical devices (ID=1 firm with highest total revenue before policy)

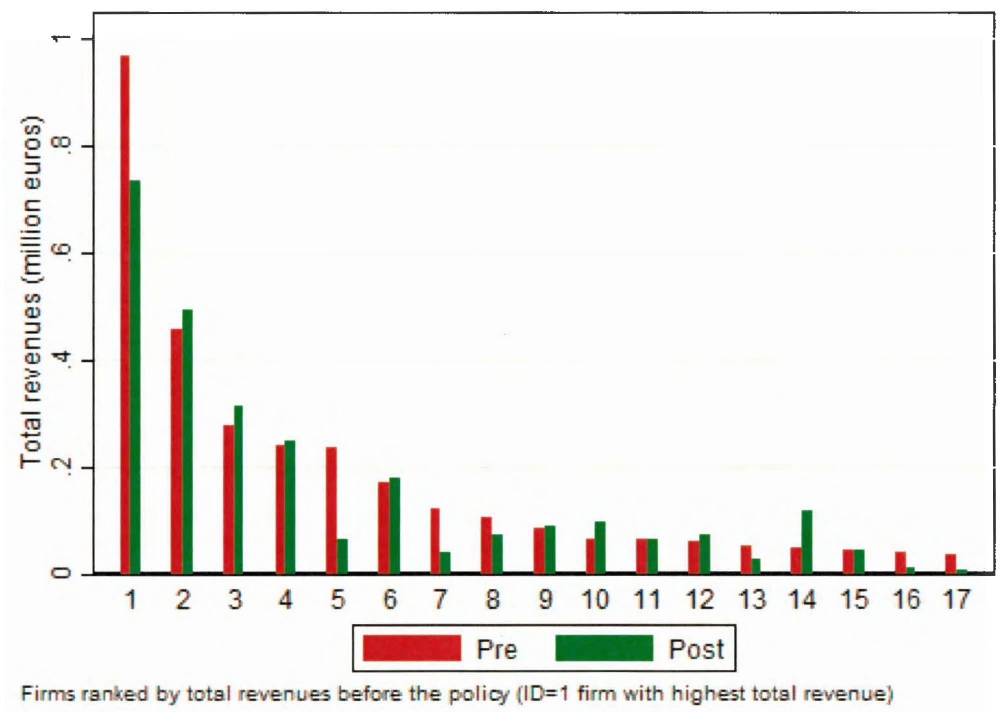
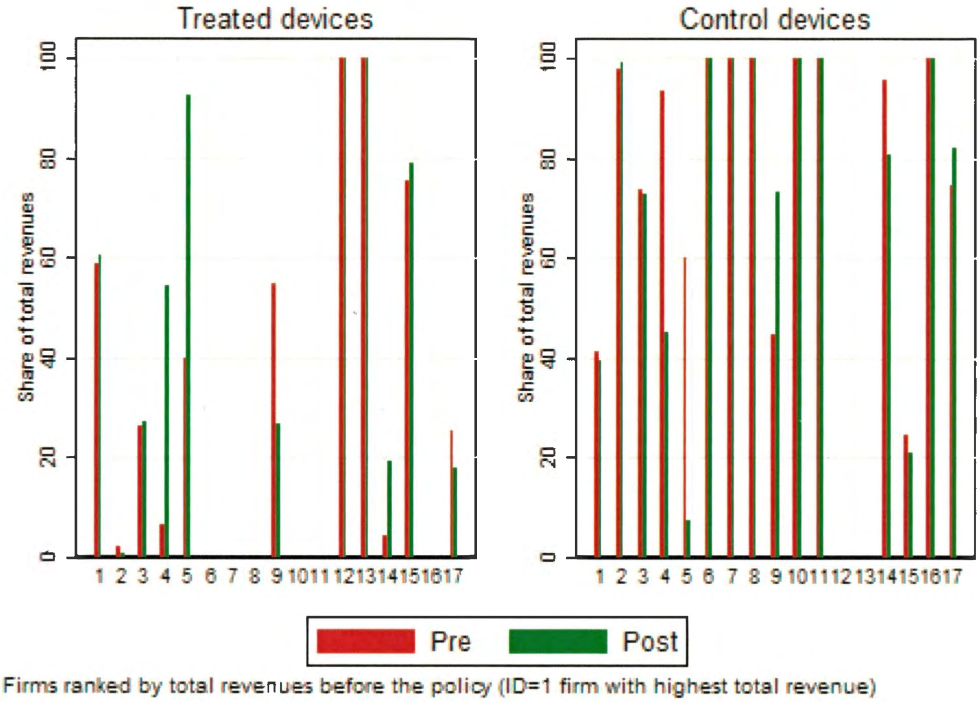


Figure 3.11 – Share of revenues from medical devices by supplier (ID=1 firm with highest total revenue before policy).



Tables 3.12 and 3.13 plot the quantities (in millions) sold by the 17 largest suppliers to the various public health units.[8] Firm 1 provided less quantities to almost every public health unit it was serving before March 2016.

To understand the impact of the exposure to the policy on the firms, we ran a parallel analysis to the one we did in subsection 3.7.1 for the public health units. The econometric model is the following:

$$Y_{sdt} = \beta_0 + \beta_1 Exp.Suppl._s X Post_t + \beta_2 Exp.Suppl._s + \beta_3 Post_t + \varepsilon_{hdt} \tag{3.4}$$

where Y_{sdt} is the price received (quantity sold, revenues, delays) by supplier s for order t, *Exp.Suppl.* is a continuous variable identifying the exposure of the supplier to the policy, represented by the revenues out of total revenues coming from the treated medical devices

[8]Note that public health units which merged or were renamed after 1st January 2016 have been treated as single entities in these tables.

before the policy was implemented, *Post* is equal to 1 if the order was made after 2nd March 2016. Regressions include supplier-by-medical device effects as well as month fixed effects.

Table 3.12 – Total quantities (millions) sold by the 17 largest suppliers to public health units before March 2016 (Pre reference prices)

	Public health units																	
ID supplier	S.And	S.Cam	S.Gio	AslFR	AslLT	AslRI	RM1	RM2	RM3	RM4	RM5	RM6	AslVT	IFO	Spall.	T.Verg.	UmbertoI	Total
1	1.337	3.104	0.330	0.259	0.000	0.177	0.272	1.113	0.520	0.042	1.008	1.337	1.386	0.000	0.000	0.019	0.005	10.909
2	1.027	0.301	0.202	0.000	0.000	0.003	0.289	0.308	0.239	0.001	0.229	0.361	0.856	0.337	0.318	0.061	0.608	5.139
3	0.562	0.071	0.011	0.219	0.176	0.410	0.007	0.005	0.274	0.096	0.215	0.121	0.034	0.000	0.000	0.025	0.302	2.528
4	0.061	0.462	0.171	0.371	0.000	0.000	0.013	0.203	0.040	0.135	0.412	0.218	0.082	0.000	0.000	2.948	0.409	5.525
5	0.010	0.110	0.000	0.000	0.000	0.000	0.003	0.155	0.000	0.006	0.030	0.000	0.000	0.000	0.013	0.014	0.118	0.460
6	0.000	0.000	0.000	0.465	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.465
7	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.105	0.117	0.000	0.127	0.000	0.000	0.000	0.005	0.000	0.354
8	0.002	0.002	0.000	0.000	0.000	0.000	0.001	0.010	0.005	0.000	0.000	0.001	0.000	0.000	0.000	0.003	0.000	0.025
9	0.003	0.006	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.001	0.260	0.005	0.278
10	0.001	0.000	0.004	0.000	0.000	0.002	0.000	0.018	0.010	0.003	0.000	0.000	0.006	0.000	0.000	0.001	0.000	0.046
11	0.000	0.008	0.000	0.000	0.000	0.000	0.000	0.222	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.230
12	0.000	0.000	0.002	0.000	0.000	0.000	0.002	0.007	0.000	0.000	0.000	0.000	0.007	0.000	0.000	0.000	0.000	0.018
13	0.010	0.024	0.004	0.003	0.000	0.000	0.022	0.021	0.000	0.011	0.030	0.006	0.063	0.000	0.006	0.018	0.000	0.217
14	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.000	0.014	0.000	0.000	0.000	0.000	0.000	0.015
15	0.000	0.000	0.000	0.081	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.081
16	0.000	0.000	0.000	0.005	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.009
17	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.023	0.001	0.000	0.001	0.000	0.001	0.000	0.000	0.000	0.000	0.027
Total	3.014	4.089	0.724	1.403	0.176	0.592	0.614	2.084	1.195	0.411	1.924	2.186	2.436	0.338	0.338	3.354	1.448	26.327

Table 3.13 – Total quantities (millions) sold by the 17 largest suppliers to public health units after March 2016 (Post reference prices)

	Public health units																	
ID supplier	S.And	S.Cam	S.Gio	AslFR	AslLT	AslRI	RM1	RM2	RM3	RM4	RM5	RM6	AslVT	IFO	Spall.	T.Verg.	UmbertoI	Total
1	1.113	2.379	0.257	0.263	0.000	0.029	0.084	0.716	0.320	0.036	1.389	0.866	1.106	0.000	0.000	0.006	0.000	8.564
2	1.109	0.021	0.140	0.000	0.000	0.001	0.205	0.395	0.285	0.029	0.316	0.775	0.901	0.060	0.231	0.014	0.629	5.110
3	0.487	0.000	0.031	0.314	0.212	0.194	0.063	0.022	0.260	0.088	0.078	0.000	0.049	0.000	0.003	0.065	0.133	2.001
4	0.230	1.003	0.410	0.398	0.000	0.000	0.299	0.538	0.159	0.123	0.432	0.224	0.072	0.000	0.002	1.594	0.173	5.656
5	0.000	0.020	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004	0.000	0.000	0.000	0.000	0.006	0.000	0.040	0.071
6	0.000	0.000	0.000	0.492	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.492
7	0.000	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.118	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.119
8	0.007	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.006	0.000	0.000	0.000	0.000	0.000	0.000	0.005	0.000	0.019
9	0.003	0.002	0.000	0.000	0.000	0.000	0.000	0.002	0.001	0.000	0.004	0.000	0.000	0.000	0.000	0.552	0.000	0.563
10	0.000	0.001	0.006	0.000	0.000	0.003	0.001	0.031	0.009	0.003	0.004	0.000	0.010	0.000	0.000	0.004	0.000	0.071
11	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.242	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.242
12	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.008	0.000	0.000	0.000	0.000	0.010	0.000	0.000	0.000	0.000	0.021
13	0.010	0.030	0.000	0.005	0.000	0.000	0.004	0.004	0.000	0.007	0.004	0.000	0.061	0.000	0.004	0.000	0.000	0.128
14	0.012	0.004	0.000	0.000	0.000	0.000	0.002	0.000	0.004	0.000	0.002	0.015	0.000	0.000	0.000	0.000	0.000	0.039
15	0.000	0.000	0.000	0.073	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.073
16	0.000	0.000	0.000	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.002
17	0.001	0.000	0.000	0.000	0.000	0.000	0.000	0.003	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.004
Total	2.973	3.461	0.846	1.547	0.212	0.228	0.657	1.962	1.043	0.408	2.227	1.880	2.208	0.060	0.246	2.240	0.974	23.174

Figure 3.12 plots the suppliers' exposure to the policy. The average exposure is equal to 23.22%, lower on average than the exposure of the public health units with a standard deviation of 37.29.

Figure 3.12 – Heterogeneity in firms' exposure to the reference price policy

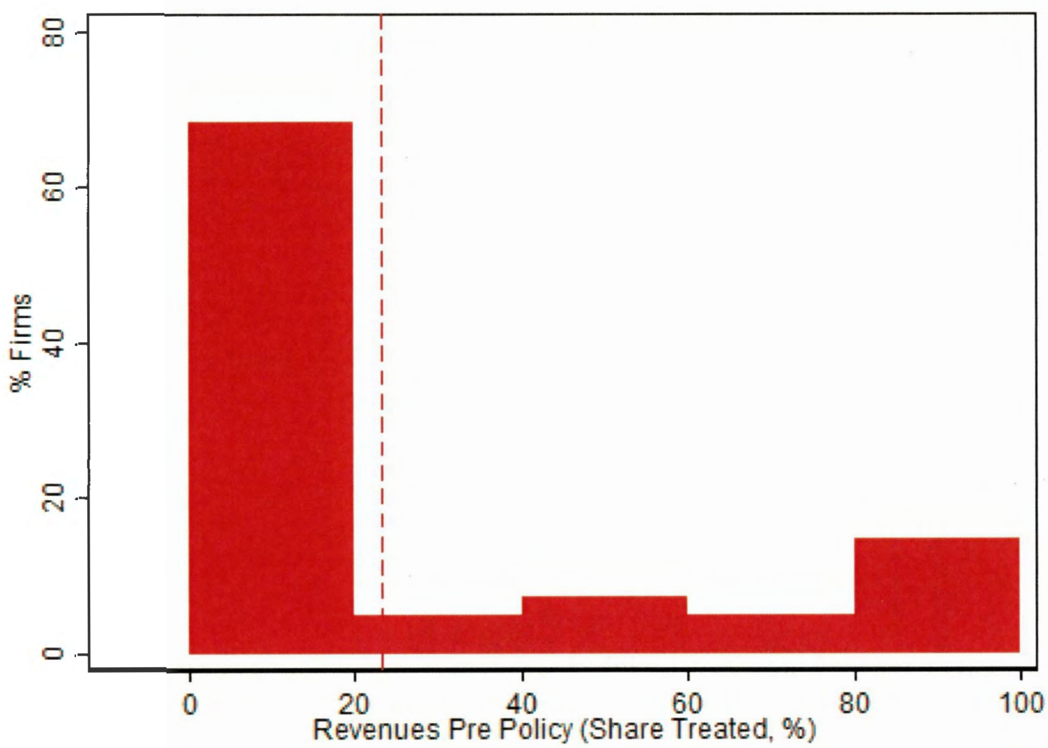


Table 3.14 presents the results of the estimation of equation 3.4. The only significant effect we find is on the days of delivery of the medical devices. According to column 4, one standard deviation of exposure to the reference price policy decreases delays by firms by 12%. This is computed by multiplying $37.29 * (-0.0433) = 1.6$, corresponding to 1.6 days, or 12% of the average days of delivery. This significant change in the days of delivery is driven mainly by the supply of medical devices not subject to the policy.

Table 3.14 – Effect of supplier's exposure to the reference price policy on main outcomes.

Devices	All				Treated				Semitreated				Control			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)
Dep.Variable	Unit.P.	Q	Cost	Delays	Unit.P.	Q.	Cost	Delays	Unit.P.	Q.	Cost	Delays	Unit.P.	Q.	Cost	Delays
Exp.Suppl.XPost	-0.000677	9.027	-0.668	-0.0433***	-4.28e-05	-9.645	-1.902	-0.0241	-0.000116	-38.32	-1.313	-0.0719	-0.000613	5.090	-2.352	-0.0798***
	(0.000439)	(8.048)	(0.879)	(0.0118)	(0.00153)	(12.95)	(1.138)	(0.0297)	(0.000149)	(24.94)	(1.494)	(0.0630)	(0.000482)	(10.89)	(3.176)	(0.0189)
ItemIDXSupplier FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Observations	10,632	10,632	10,632	6,868	2,970	2,970	2,970	1,803	443	443	443	279	7,215	7,215	7,215	4,785
R-squared	0.902	0.239	0.407	0.180	0.974	0.255	0.162	0.116	0.535	0.619	0.435	0.255	0.887	0.216	0.474	0.208
Mean Y Pre	0.920	5100	590.5	13.21	0.970	7512	623.3	14.99	0.247	2643	349.6	13.11	0.941	4260	591.8	12.54
Std.Dev.Exposure	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29	37.29

Notes: The table reports the effects of the exposure to the reference price policy on unitary prices received, quantities supplied, revenues, and delays for firms at the order level. *Treated* includes in the estimation the treated medical devices with an average price before the policy above the reference price. *Semitreated* includes in the estimation the treated medical devices with an average price before the policy below the reference price. *Control* includes in the estimation the medical devices not subject to reference prices. *Unit.P.* is the unitary price of the order. *Q* is the quantity in the order. *Cost* is the expense. *Delays* represents the number of days before the delivery of the ordered device. SEs are clustered at public buyer-by-medical device level. Significance at 10% (*), 5% (**), and 1% (***).

3.8 Conclusion

To study the effect of the introduction of statutory reference prices on the public procurement of medical devices, we used a newly collected dataset on the orders for medical devices in one Italian region between 2014 and 2018. To evaluate the impact of reference prices, we exploited their scattered implementation by the Italian Anti-corruption Authority. We documented that the unitary prices of treated medical devices complied with the reform.

We further evaluated the impact of the policy by looking at two margins of adjustment. First, we found that unitary prices increased for those devices with an average price before the policy lower than the reference price. Second, the quantities purchased and total spending did not change, indicating that the policy was not successful in reducing total spending for medical devices. Although the policy was effective in reducing the unitary prices for the sub-set of treated medical devices, it did not reduce total spending.

By ranking hospitals (suppliers) according to their exposure to the policy, i.e. the amount of expenses (revenues) coming from the treated medical devices before the introduction of reference prices, we found that i) one standard deviation of exposure to the reference price policy decreased unitary prices paid by hospitals by 15%, corresponding to a drop of €0.15, and ii) one standard deviation of exposure to the reference price policy decreased the number of days suppliers took to deliver the medical devices by 12%, corresponding to almost two additional days. Finally, we found that the scattered implementation of reference prices implies a redistribution of revenues from the market leader to smaller suppliers.

Understanding the impact of the introduction of reference prices on hospitals and suppliers is important for the optimal design of the policy. Our analysis provides one main suggestion for policy-makers. Statutory reference prices should not be common knowledge of hospitals and suppliers, especially if these policies aim at reducing healthcare costs by reducing the asymmetric information of the buyer *vis-à-vis* the supplier. Relatively efficient hospitals can end up paying higher prices because, following this policy, suppliers could adjust their behavior by extracting higher profits from them.

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General Conclusion

The findings of this thesis contribute to several streams of the literature related to competition in public procurement.

Evidence in my first chapter contributes to the literature on collusion in dimensions other than prices. Sullivan (2017) analyzes a situation of collusion in the products offered by two firms selling ice-cream in the US. The first chapter of this thesis investigates collusion on the degree at which firms compete against each other in the same auction (head-to-head competition). By using the start of the police investigation into collusion and corruption in the construction industry in the Canadian province of Quebec, the chapter shows that the two largest firms in the road paving market in Quebec submitted lower bids and competed head-to-head to a larger extent. With the help of structural econometrics techniques, this chapter is able to quantify the extent to which the average price increase observed between a competitive and a collusive regime is due to firms coordinating the degree of head-to-head competition. The chapter also includes a discussion on whether the end of a cartel causally affects the *ex-post* procurement performance, since previously colluding firms could use cost overruns as a margin of adjustment to compensate for the profit losses arising from the end of the cartel.

Second, the results in my second chapter provide tools for antitrust authorities to identify collusive behavior based on the difference in bids between the players. This chapter documents that clustering of the two lowest bids in an auction is a warning sign of collusion. Firms try to simulate competition by submitting close bids. By exploiting a cartel case in the construction industry in the City of Montreal, this chapter provides evidence that part of the cartel scheme involved colluding firms submitting close bids, in particular the two lowest. This chapter complements the analysis of recent papers that have found in the distance between winning and losing bids a red flag for collusion. The results in this chapter provide evidence that the submission of close bids is also consistent with collusion. This bidding pattern can be used as a simple screen to detect collusive behavior.

Finally, using a unique and very detailed dataset on orders made by public health units for medical devices, the third chapter documents that uniform pricing policies, such as reference pricing, could lower prices paid by public hospitals for medical devices while not affecting the overall public expenditure. These findings could inform policy-makers regarding the successful implementation of policies aimed at reducing public health expenditure and contribute to the debate on whether an increase in price transparency is effective in improving procurement performance.

Appendix A - Chapter 1

Other firms in the cartel?

The Canadian Competition Bureau is currently investigating 16 firms other than firms A and B. They are typically smaller firms.

Table A.1 – Summary statistics for suspected firms other than firms A and B

Variables	Pre 2007-2009	Post 2010-2015
Number of bids per contract (all contracts)	1.02	1.06
Number of bids per contract (contracts with at least firm A or firm B bidding)	1.08	1.08
Average bid (% mean value)	85.21	75
Average bid (contracts with at least firm A or firm B bidding)	82.88	74.38

Notes: *2007-2009* refers to the period before the start of the police investigations. *2010-2015* refers to the period after the start of the police investigations. *Number of bids per contract (%) (all contracts)* is the average number of bids of the suspected firms other than firms A and B out of total contracts. *Number of bids per contract (%) (contracts with at least firm A or B bidding)* is the average number of bids of the suspected firms other than firms A and B out of the contracts that received at least one bid from either firm A or firm B. *Average bid (%)* is the average bid expressed in % of the mean value of the contract submitted by suspected firms other than firms A and B. *Average bid when head-to-head (% mean value)* is the average bid expressed in % of the mean value of the contract submitted by the suspected firms other than firms A and B for those contracts where firms A and B are both bidding.

In Table A.2, I estimate a difference-in-difference by considering the suspected firms as the treated group and all other bidders in the control group. Firms A and B are excluded from the sample. While we observe a significant change in the average bid, the change in the winning bids is not significant.

Table A.2 – Diff-in-diff for bids over mean value of contract (%). Sample restricted to other 16 suspected firms. Firms A and B are excluded.

Sample	All bids excluding firms A and B					
Dependent variable	Bid over mean value of contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
SuspectsXPost	-8.042*	-8.718**	-9.362**	-4.124	-6.677	-7.671
	(4.300)	(4.197)	(4.069)	(7.606)	(7.750)	(7.848)
Suspects	2.258	3.942	4.258	3.154	5.907	6.188
	(3.718)	(3.516)	(3.536)	(6.786)	(6.864)	(7.520)
Post	-2.179	-0.950	8.577	-5.046	-4.716	10.29
	(4.156)	(3.866)	(9.441)	(4.176)	(4.041)	(12.28)
Distance(km)		0.0319*	0.0337*		0.0534*	0.0678*
		(0.0182)	(0.0188)		(0.0291)	(0.0357)
Capacity (%)		0.0581	0.0379		0.107	0.0247
		(0.0413)	(0.0419)		(0.0808)	(0.0877)
Value firm region (%)		-0.162*	-0.165*		-0.0679	0.0328
		(0.0888)	(0.0891)		(0.149)	(0.170)
N potential cartel bidders		-5.841**	-7.181**		-5.541**	-7.282**
		(2.608)	(3.032)		(2.321)	(3.155)
N potential non-cartel bidders		0.199	0.940		-0.263	0.742
		(0.699)	(1.065)		(0.686)	(1.127)
Demand (%)		0.0796*	0.0843*		-0.0351	-0.0148
		(0.0442)	(0.0457)		(0.0516)	(0.0552)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
N	1362	1362	1362	388	388	388
Average outcome Suspects Pre	85.21	85.21	85.21	80.71	80.71	80.71
R^2	0.0129	0.0353	0.0600	0.0115	0.0390	0.0753

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction a was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the % of value of contracts won up to auction a over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction a over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Test common trend

Figure A.1 – Average number of cartel bids (bids of firms A and B) in an auction by year.

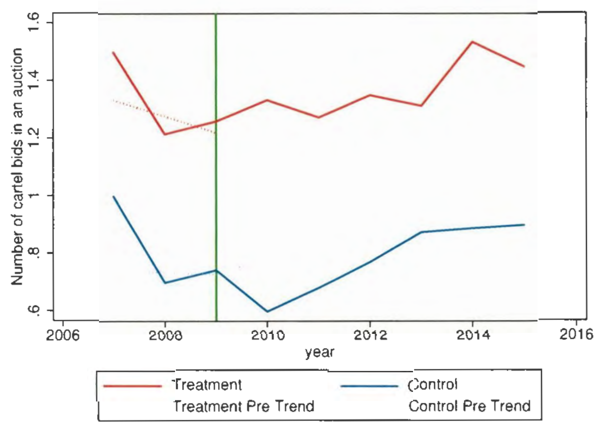

Table A.3 – Test of common trend for the number of cartel bids in an auction

Sample	All auctions pre-investigation			
Dependent variable	number of cartel bids in an auction			
	(1)	(2)	(3)	(4)
TreatedAuctionXYear	0.000263***	0.000254***		
	(5.72e-05)	(7.75e-05)		
TreatedAuctionX2008			0.367**	0.667***
			(0.168)	(0.169)
TreatedAuctionX2009			0.412**	0.609***
			(0.175)	(0.150)
Admin Region effects	No	Yes	No	Yes
Year effects	No	Yes	No	Yes
Size project effects	No	Yes	No	Yes
Observations	194	194	194	194
R-squared	0.166	0.475	0.0956	0.492
Average Outcome Treated Pre	1.260	1.260	1.260	1.260
P-value TreatedAuctionX2008=TreatedAuctionX2009			0.841	0.708

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *TreatedAuctionXYear* represents the interaction between *TreatedAuction* and a linear trend (*Year*). *TreatedAuctionX2008* represents the interaction between *TreatedAuction* and a dummy equal to 1 if the auction was published in 2008. *TreatedAuctionX2009* represents the interaction between *TreatedAuction* and a dummy equal to 1 if the auction was published in 2009. *p-value* is the p-value resulting from testing the equality of coefficients of *TreatedAuctionX2008* and *TreatedAuctionX2009*. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Figure A.2 – Average probability of head-to-head competition by year.

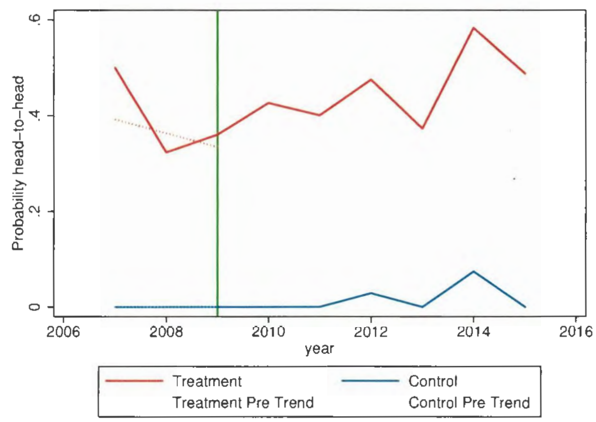

Table A.4 – Test of common trend for the probability of head-to-head competition

Sample	All auctions pre-investigation			
Dependent variable	probability of *head-to-head* competition			
	(1)	(2)	(3)	(4)
TreatedAuctionXYear	0.000176***	8.89e-05**		
	(3.16e-05)	(3.77e-05)		
TreatedAuctionX2008			0.247**	0.116
			(0.0982)	(0.0865)
TreatedAuctionX2009			0.284**	0.207**
			(0.126)	(0.0855)
Admin Region effects	No	Yes	No	Yes
Year effects	No	Yes	No	Yes
Size project effects	No	Yes	No	Yes
Observations	194	194	194	194
R-squared	0.159	0.353	0.0950	0.354
Average Outcome Treated Pre	0.354	0.354	0.354	0.354
P-value TreatedAuctionX2008=TreatedAuctionX2009			0.802	0.214

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *TreatedAuctionXYear* represents the interaction between *TreatedAuction* and a linear trend (*Year*). *TreatedAuctionX2008* represents the interaction between *TreatedAuction* and a dummy equal to 1 if the auction was published in 2008. *TreatedAuctionX2009* represents the interaction between *TreatedAuction* and a dummy equal to 1 if the auction was published in 2009. *p-value* is the p-value resulting from testing the equality of coefficients of *TreatedAuctionX2008* and *TreatedAuctionX2009*. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Table A.5 – Test of common trend for territorial allocation

Dependent variable	Number of cartel bids in an auction	
	(1)	(2)
TreatedAuctionXYear	2.88e-05	8.43e-05
	(3.22e-05)	(9.51e-05)
Admin Region effects	No	Yes
Year effects	No	Yes
Size project effects	No	Yes
Observations	96	96
R-squared	0.00758	0.436
Average Outcome Treated Pre	0.907	0.907

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *TreatedAuctionXYear* represents the interaction between *TreatedAuction* and a linear trend (*Year*). Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Table A.6 – Test common trend for bids over mean value of contract (%).

Sample	All auctions pre-investigation			
Dependent variable	Bid over mean value of the contract (%)			
	(1)	(2)	(3)	(4)
	all bids	all bids	winning bids	winning bids
TreatedAuctionXYear	0.00345	0.00729*	0.00259	0.00670
	(0.00218)	(0.00386)	(0.00213)	(0.00458)
Observations	589	589	194	194
R-squared	0.00964	0.0716	0.00628	0.0829
Admin Region effects	No	Yes	No	Yes
Year effects	No	Yes	No	Yes
Average Outcome Treated Pre	86.68	86.68	83.14	83.14

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *TreatedAuctionXYear* represents the interaction between *TreatedAuction* and a linear trend (*Year*). Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Robustness

Table A.7 – Diff-in-diff for bids over upper bound value of contract (%).

Sample	All auctions					
Dependent variable	Bid over upper bound value contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-10.38**	-10.15**	-11.82**	-9.030**	-8.014**	-9.975**
	(4.240)	(4.122)	(4.669)	(3.977)	(3.817)	(4.446)
TreatedAuction	6.431**	8.929***	11.81***	5.259	6.811**	10.69***
	(3.161)	(3.053)	(3.825)	(3.234)	(3.038)	(3.880)
Post	1.796	1.788	7.150	-1.014	-2.469	5.479
	(3.470)	(3.379)	(6.390)	(2.894)	(2.841)	(5.171)
Distance (km)		0.0270*	0.0305**		0.0353**	0.0382*
		(0.0139)	(0.0141)		(0.0178)	(0.0196)
Capacity (%)		0.0131	0.00817		0.0377	0.0256
		(0.0289)	(0.0294)		(0.0540)	(0.0609)
Value firm region		-0.0619	-0.0671		-0.00279	-0.0119
		(0.0432)	(0.0450)		(0.0789)	(0.0908)
N potential cartel bidders		-4.959**	-6.225**		-2.618	-3.456
		(2.010)	(2.425)		(1.650)	(2.103)
N potential non-cartel bidders		-0.228	0.312		-0.624	-0.318
		(0.445)	(0.755)		(0.385)	(0.671)
Demand (%)		0.0676*	0.0703*		0.0115	0.0177
		(0.0358)	(0.0369)		(0.0338)	(0.0353)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	2,230	2,230	2,230	751	751	751
R-squared	0.0166	0.0361	0.0517	0.0236	0.0399	0.0540
Average Outcome Treated Pre	60.66	60.66	60.66	58.56	58.56	58.56

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction *a* was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project.*Capacity (%)* is the percentage of total value of contracts won up to the auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Table A.8 – Diff-in-diff for bids over mean value of contract. Auctions with only one bidder are excluded (%)

Sample	Auctions with more than 1 bidder					
Dependent variable	Bid over mean value contract (%)					
	(1) all bids	(2) all bids	(3) all bids	(4) winning bids	(5) winning bids	(6) winning bids
TreatedAuctionXPost	-13.83**	-13.96**	-14.66**	-10.60*	-10.52*	-11.49*
	(5.968)	(5.819)	(6.147)	(5.703)	(5.607)	(5.933)
TreatedAuction	6.715	9.413**	11.87**	4.586	6.361	9.965*
	(4.502)	(4.297)	(5.247)	(4.507)	(4.366)	(5.274)
Post	2.472	3.042	10.45	-2.988	-3.369	5.996
	(5.030)	(4.878)	(8.196)	(4.216)	(4.119)	(6.788)
Distance (km)		0.0313*	0.0336*		0.0254	0.0291
		(0.0177)	(0.0181)		(0.0245)	(0.0280)
Capacity (%)		0.0302	0.0294		0.0530	0.0447
		(0.0377)	(0.0381)		(0.0791)	(0.0858)
Value firm region		-0.117**	-0.122**		-0.0374	-0.0499
		(0.0552)	(0.0580)		(0.119)	(0.136)
N potential cartel bidders		-5.792**	-7.263**		-3.373	-4.941*
		(2.681)	(3.096)		(2.436)	(2.775)
N potential non-cartel bidders		0.0526	0.784		-0.414	0.475
		(0.618)	(1.005)		(0.512)	(0.910)
Demand (%)		0.0852*	0.0847*		0.0193	0.0243
		(0.0461)	(0.0479)		(0.0463)	(0.0475)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	2,130	2,130	2,130	651	651	651
R-squared	0.0202	0.0372	0.0573	0.0327	0.0416	0.0626
Average Outcome Treated Pre	86.65	86.65	86.65	82.86	82.86	82.86

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction *a* was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage of total value of contracts won up to the auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Table A.9 – Diff-in-diff for bids over mean value of contract. Control for realized competition (%)

Sample	All auctions					
Dependent variable	Bid over mean value contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-13.12**	-12.03**	-13.36**	-11.12**	-8.647*	-10.88*
	(5.550)	(5.379)	(6.157)	(5.076)	(5.065)	(5.837)
TreatedAuction	6.923	8.485*	11.21**	5.205	6.779	10.99**
	(4.334)	(4.360)	(5.050)	(4.227)	(4.241)	(4.995)
Post	1.831	1.725	9.631	-1.993	-3.827	7.565
	(4.623)	(4.589)	(7.795)	(3.799)	(4.021)	(6.297)
Distance (km)		0.0321*	0.0339*		0.0277	0.0307
		(0.0172)	(0.0180)		(0.0233)	(0.0255)
Capacity (%)		0.0271	0.0229		0.0376	0.0294
		(0.0374)	(0.0385)		(0.0695)	(0.0779)
Value firm region		-0.110*	-0.117**		-0.0163	-0.0255
		(0.0568)	(0.0578)		(0.104)	(0.117)
n cartel bidders		-3.511	-3.903*		-3.723*	-3.567
		(2.308)	(2.312)		(2.028)	(2.237)
n non-cartel bidders		-0.0899	-0.0793		-1.714*	-1.690
		(1.137)	(1.568)		(0.953)	(1.310)
Demand (%)		0.0804*	0.0852*		0.00382	0.0110
		(0.0473)	(0.0484)		(0.0448)	(0.0470)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	2,230	2,230	2,230	751	751	751
R-squared	0.0186	0.0321	0.0493	0.0267	0.0402	0.0570
Average Outcome Treated Pre	86.68	86.68	86.68	83.14	83.14	83.14

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction a is published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project.*Capacity (%)* is the percentage of total value of contracts won up to the auction a over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction a over total value of contracts awarded in a given administrative region and year. *n cartel bidders* is the number of cartel bidders (firms A and B) bidding in the auction. *n non-cartel bidders* is the number of bidders (other than firms A and B) bidding in the auction. *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Other outcomes

Table A.10 reports the results for the estimation of a difference-in-difference model analyzing different auction outcomes, such as the number of bids coming from firms other than firms A and B (columns 1 and 2), the probability that an auction has only one bidder (columns 3 and 4), and the probability that firms other than A and B win an auction (columns 5 and 6). The number of bidders other than firms A and B increases in the treated group of auctions after the start of the police investigation and the probability of a one-bidder auction significantly decreases.

Table A.10 – Diff-diff for number of non-cartel bids, probability of one-bidder auction and probability of non-cartel bidders winning the auction

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	N non cartel bids	N non cartel bids	1 bidder auction	1 bidder auction	prob. non cartel win	prob. non cartel win
TreatedAuctionXPost	0.880**	0.733***	-0.215***	-0.128**	0.109	0.0234
	(0.423)	(0.145)	(0.0783)	(0.0557)	(0.0930)	(0.0651)
TreatedAuction	-0.109	-0.356**	-0.0423	0.0298	-0.0380	0.0934*
	(0.387)	(0.150)	(0.0466)	(0.0519)	(0.0744)	(0.0553)
Post	-0.771**	-0.699***	0.237***	0.182*	-0.146*	-0.274**
	(0.303)	(0.263)	(0.0802)	(0.0930)	(0.0802)	(0.118)
Admin Region effects	No	Yes	No	Yes	No	Yes
Year effects	No	Yes	No	Yes	No	Yes
Size project effects	No	Yes	No	Yes	No	Yes
Observations	751	751	751	751	751	751
R-squared	0.0577	0.630	0.113	0.278	0.00805	0.224
Average Outcome Treated Pre	1.921	1.921	0.0472	0.0472	0.559	0.559

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* is a dummy equal to 1 if the contract was published after October 2009. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Free capacity of cartel firms (%)* is the highest level of free capacity (%) of cartel firms in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), and 1% (***) $p < .01$.

Table A.11 shows the impact of the end of the cartel on the length of work and the renegotiations. The length of work (*delays*) is expressed as the difference between the day when the contract is terminated and the date on which the contract was signed. The cost overruns (*overrun*) are the difference between the total final expenses at the time when the contract is closed and the amount for which the contract was signed, expressed as % of the initial amount. The length of work decreases by about 8 months in the treatment in contrast to the control group of auctions, while there is no significant effect on the amount of cost overruns.

Table A.11 – Diff-in-diff for the time to complete a project and cost overruns

	(1)	(2)	(3)	(4)
	delays	delays	overrun	overrun
TreatedAuctionXPost	-250.9*	-202.1*	-0.922	1.983
	(130.2)	(101.8)	(4.560)	(1.942)
TreatedAuction	231.6*	95.17	-1.282	-1.472
	(123.9)	(111.4)	(4.378)	(1.856)
Post	-511.3***	-724.4***	-2.375	-21.60***
	(109.2)	(83.95)	(3.788)	(2.088)
Admin Region effects	No	Yes	No	Yes
Year effects	No	Yes	No	Yes
Size project effects	Yes	Yes	Yes	Yes
Observations	533	533	546	546
R-squared	0.315	0.465	0.0190	0.275
Average Outcome Treated Pre	1187	1187	1.533	1.533

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction *a* was published after October 2009. *delays* is the number of days between the day of the signing of the contract and the date on which the contract is terminated. *overruns* is the difference between the total final expenses at the time when the contract is terminated and the amount at which the contract is signed expressed as % of the amount for which the contract was signed. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Robustness: Identification strategy

- Both cartel firms are located within a 90 km radius of the project location.

Table A.12 – Diff-in-diff for the number of cartel bids in an auction and probability of head-to-head competition

Sample				All auctions		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	nbr cartel bids	nbr cartel bids	nbr cartel bids	prob. *head-to-head*	prob. *head-to-head*	prob. *head-to-head*
TreatedAuctionXPost	0.0675	0.164	0.218*	0.117	0.157**	0.236***
	(0.148)	(0.111)	(0.130)	(0.0817)	(0.0700)	(0.0573)
TreatedAuction	0.587***	0.358***	0.0705	0.369***	0.241***	-0.00612
	(0.129)	(0.0968)	(0.130)	(0.0634)	(0.0529)	(0.0570)
Post	0.0731	-0.0304	-0.0514	0.0140	-0.0260	-0.0292
	(0.106)	(0.0823)	(0.164)	(0.00994)	(0.0224)	(0.110)
N potential cartel bidders		0.403***	0.252***		0.224***	0.0917***
		(0.0425)	(0.0552)		(0.0372)	(0.0276)
N potential non-cartel bidders		-0.0436***	-0.0268		-0.0115	-0.00407
		(0.0131)	(0.0171)		(0.00743)	(0.00975)
Free capacity of cartel firms (%)		-0.00162*	-0.000450		-0.000634	-0.000117
		(0.000875)	(0.000792)		(0.000545)	(0.000423)
Demand (%)		-0.00240**	-0.00103		-0.00101	-0.000369
		(0.000977)	(0.000990)		(0.000615)	(0.000517)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Size project effects	No	No	Yes	No	No	Yes
Observations	751	751	751	751	751	751
R-squared	0.243	0.363	0.502	0.247	0.308	0.487
Average Outcome Treated Pre	1.295	1.295	1.295	0.369	0.369	0.369

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *nbr cartel bids* indicates the number of cartel bids in an auction. *prob head-to-head* is a binary variable indicating whether both cartel firms (firms A and B) bid in the auction. *Post* is a dummy equal to 1 if the contract was published after October 2009. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Free capacity of cartel firms (%)* is the highest level of free capacity (%) of cartel firms in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Table A.13 – Diff-in-diff for bids over mean value of contract (%)

Sample	All auctions					
Dependent variable	Bid over mean value of the contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-9.554*	-9.789*	-11.10*	-8.833*	-7.650	-9.848*
	(5.574)	(5.333)	(6.007)	(5.090)	(5.006)	(5.565)
TreatedAuction	2.820	5.298	7.039	2.090	3.477	7.071
	(4.485)	(4.230)	(5.267)	(4.329)	(4.255)	(4.991)
Post	-0.866	-0.348	8.414	-3.810	-5.322	6.453
	(4.481)	(4.301)	(8.456)	(3.644)	(3.677)	(6.786)
Distance (km)		0.0324*	0.0358**		0.0334	0.0357
		(0.0170)	(0.0176)		(0.0223)	(0.0249)
Capacity (%)		0.0281	0.0275		0.0330	0.0244
		(0.0373)	(0.0383)		(0.0684)	(0.0754)
Value firm region		-0.110**	-0.117**		0.00399	-0.00643
		(0.0537)	(0.0565)		(0.0974)	(0.111)
N potential cartel bidders		-4.658*	-6.145**		-2.211	-3.341
		(2.537)	(3.020)		(2.049)	(2.620)
N potential non-cartel bidders		0.0668	0.424		-0.634	-0.421
		(0.600)	(0.984)		(0.496)	(0.848)
Demand (%)		0.0825*	0.0839*		0.0103	0.0165
		(0.0451)	(0.0468)		(0.0449)	(0.0463)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Observations	2,230	2,230	2,230	751	751	751
R-squared	0.0179	0.0318	0.0488	0.0276	0.0364	0.0519
Average Outcome Treated Pre	85.47	85.47	85.47	82.12	82.12	82.12

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction a was published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage of total value of contracts won up to the auction a over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction a over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

- Both cartel firms are located within a 110 km radius of the project location.

Table A.14 – Diff-in-diff for the number of cartel bids in an auction and probability of head-to-head competition

Sample				All auctions		
	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	nbr cartel bids	nbr cartel bids	nbr cartel bids	prob. *head-to-head*	prob. *head-to-head*	prob. *head-to-head*
TreatedAuctionXPost	0.156	0.201**	0.241**	0.108	0.125*	0.190***
	(0.138)	(0.101)	(0.120)	(0.0802)	(0.0647)	(0.0461)
TreatedAuction	0.412***	0.189**	-0.158	0.324***	0.193***	-0.0651
	(0.113)	(0.0811)	(0.116)	(0.0622)	(0.0470)	(0.0416)
Post	0.00516	-0.0678	-0.0524	0.0118	-0.0139	0.00766
	(0.0887)	(0.0741)	(0.160)	(0.00822)	(0.0238)	(0.109)
N potential cartel bidders		0.460***	0.282***		0.254***	0.104***
		(0.0411)	(0.0554)		(0.0368)	(0.0283)
N potential non-cartel bidders		-0.0385***	-0.0350**		-0.00831	-0.00778
		(0.0141)	(0.0173)		(0.00795)	(0.00987)
Free capacity of cartel firms (%)		-0.00187*	-0.000656		-0.000813	-0.000165
		(0.000973)	(0.000810)		(0.000591)	(0.000427)
Demand (%)		-0.00275**	-0.00118		-0.00128*	-0.000389
		(0.00109)	(0.00102)		(0.000669)	(0.000520)
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Size project effects	No	No	Yes	No	No	Yes
Observations	751	751	751	751	751	751
R-squared	0.153	0.304	0.488	0.174	0.254	0.471
Average Outcome Treated Pre	1.194	1.194	1.194	0.324	0.324	0.324

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. *nbr cartel bids* indicates the number of cartel bids in an auction. *prob head-to-head* is a binary variable indicating whether both cartel firms (firms A and B) bid in the auction. *Post* is a dummy equal to 1 if the contract is published after October 2009. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Free capacity of cartel firms (%)* is the highest level of free capacity (%) of cartel firms in a given administrative region and year. *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), and 1% (***) $p < .01$.

Table A.15 – Diff-in-diff for bids over mean value of contract (%)

Sample	all auctions					
Dependent variable	Bid over mean value of the contract (%)					
	(1)	(2)	(3)	(4)	(5)	(6)
	all bids	all bids	all bids	winning bids	winning bids	winning bids
TreatedAuctionXPost	-11.73*	-11.42*	-12.39*	-11.10*	-10.27	-12.51*
	(6.665)	(6.664)	(7.126)	(6.260)	(6.300)	(6.893)
TreatedAuction	4.387	6.372	7.800	3.997	5.592	9.069
	(5.710)	(5.793)	(6.732)	(5.577)	(5.701)	(6.663)
Post	1.397	1.548	9.885	-1.455	-2.846	9.343
	(5.659)	(5.604)	(8.809)	(4.948)	(4.977)	(7.292)
Distance (km)		0.0330*	0.0365**		0.0338	0.0354
		(0.0167)	(0.0173)		(0.0227)	(0.0250)
Capacity (%)		0.0287	0.0293		0.0389	0.0332
		(0.0369)	(0.0380)		(0.0685)	(0.0756)
Value firm region		-0.109**	-0.119**		0.00359	-0.0137
		(0.0530)	(0.0559)		(0.0968)	(0.111)
N potential cartel bidders		-4.556*	-5.932*		-2.271	-3.308
		(2.579)	(3.046)		(2.239)	(2.726)
N potential non-cartel bidders		0.0421	0.383		-0.640	-0.440
		(0.599)	(0.956)		(0.487)	(0.822)
Demand (%)		0.0820*	0.0831*		0.00744	0.0127
		(0.0450)	(0.0465)		(0.0443)	(0.0456)
Observations	2,230	2,230	2,230	751	751	751
R-squared	0.0184	0.0324	0.0493	0.0281	0.0379	0.0538
Admin Region effects	No	No	Yes	No	No	Yes
Year effects	No	No	Yes	No	No	Yes
Average Outcome Treated Pre	85.66	85.66	85.66	82.47	82.47	82.47

Notes. Standard errors clustered by Quebec administrative region and year in parentheses. *Post* indicates whether the auction a is published after October 2009. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project.*Capacity (%)* is the percentage of total value of contracts won up to the auction a over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction a over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction a in a given administrative region of Quebec and year. Significance at 10%(*), 5% (**), 1%(***) $p < .01$.

The assumptions of the structural model: a discussion

The model has several assumptions. Modeling participation and bidding behavior in an auction require modeling an equilibrium selection mechanism. In discrete games, in fact, the equilibrium exists, but in general it is not unique. I assume in this case that all participation decisions of firms come from a unique equilibrium without explicitly modeling an equilibrium selection mechanism. Given the high number of firms in the market (although some firms are very small) adding an equilibrium selection makes the model almost intractable. On the other hand, Bajari et al. (2010) show that in games of incomplete information the number of equilibria decreases as the number of players increases.

A second assumption concerns the bid distribution. I assume, strictly following Athey et al. (2011) and Gugler et al. (2015), that bids are distributed according to a Weibull distribution. With asymmetric bidders and given the nature of the counterfactual experiment, having parametric assumptions on the bid distribution helps in generating counterfactual bids.

For the estimation of the model, I use data coming from the competitive period (after October 2009). In a competitive environment, bids reflect in fact the costs of firms; but in a collusive environment recovering costs could generate results that are biased. Finally, I assume independent private cost. To motivate this choice, I have to rule out the possibility that there is affiliation between costs of each firm. I provide evidence that my setting is different from that of Somaini (2011), who estimates a structural model of participation and bidding allowing for non-independent private information and common costs. Somaini (2011) justifies this choice by observing less aggressive bidding by firms when their main competitors are close to the auction's project. Using this reduced-form evidence, Somaini (2011) assumes non-independent costs in his structural model. In Table A.16, I justify why this is not the case in my setting. In columns 1-3 I run an OLS regression of bids on dummies indicating the closest competitor distance from the project (the base group are bids submitted when the closest bidder is more than 80 km away from the project), excluding the bidder closest to the project. Bidders farther from the project seem to bid more aggressively with respect to a case when the closest competitor is more than 80 km from the project. Columns 4-6 show that the probability of winning is inversely related to a bidder's distance from the project: a bidder closer to the project is more likely to win. Thus bidders are more likely to win in projects close to their plants and behave more aggressively for projects close to their competitors' plants. This is not consistent with the presence of affiliated or common costs.

Table A.16 – OLS estimation of bids and probability of winning on closest competitor's distance and firm's own distance from the project

	(1)	(2)	(3)	(4)	(5)	(6)
Dependent variable	bid over mean value contract (%)			probability of winning		
Competitor distance (0-10 km)	-16.81	-13.29	-11.46		-0.343***	-0.267***
	(10.31)	(12.02)	(10.63)		(0.0738)	(0.0737)
Competitor distance (10-20 km)	-22.62**	-19.26	-18.85*		-0.355***	-0.282***
	(10.36)	(12.04)	(10.41)		(0.0688)	(0.0701)
Competitor distance (20-40 km)	-23.02**	-19.82*	-21.18**		-0.250***	-0.197***
	(9.291)	(10.96)	(9.575)		(0.0668)	(0.0683)
Competitor distance (40-80 km)	-23.34**	-20.62*	-20.51*		-0.0651	-0.0405
	(10.42)	(11.69)	(10.36)		(0.0750)	(0.0768)
Distance (km)		0.0204	0.0130	-0.000618***	-0.00130***	-0.00134***
		(0.0218)	(0.0233)	(0.000227)	(0.000331)	(0.000331)
Capacity (%)			0.00462			-0.00250***
			(0.0531)			(0.000405)
Value firm region (%)			-0.102			0.00582***
			(0.0813)			(0.00109)
Demand (%)			0.126**			0.000480
			(0.0607)			(0.000315)
N potential cartel bidders			-11.17***			0.00553
			(3.937)			(0.0159)
N potential non cartel bidders			1.474			-0.00992***
			(1.346)			(0.00316)
Admin Region effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
N	1084	1084	1084	1553	1553	1553
R^2	0.0193	0.0201	0.0987	0.0044	0.0647	0.1007

Notes: Standard errors clustered by Quebec administrative region and year in parentheses. Only the auctions published in the period after the start of the police investigation (October 2009) are included. *Competitor distance (x-y)* is a dummy related to the competitor distance from the project (value equal to 1 if the closest competitor distance is between x and y). The base group is when the competitor distance is higher than 80 km. *Distance (km)* is the driving distance between the project location and the firm's closest plant to the project. *Capacity (%)* is the percentage of total value of contracts won up to the auction *a* over total value of contracts won in a given administrative region and year. *Value firm region (%)* is the value of contracts won by the bidder up to auction *a* over total value of contracts awarded in a given administrative region and year. *N potential cartel bidders* is the number of cartel bidders (firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *N potential non-cartel bidders* is the number of bidders (other than firms A and B) bidding in at least one auction in a given MRC (*municipalité régionale de comté*). *Demand (%)* is the % of number of contracts awarded up to auction *a* in a given administrative region of Quebec and year. Significance at 10% (*), 5% (**), 1% (***) $p < .01$.

Dataset

Two sources were used to construct the dataset: the official tendering website of the Quebec government (SEAO) and data from the open data portal of the Quebec government.

On the tendering website, I open "Advanced search" to look for contract between 2007 and 2015 with the code identifying paving job (72131701). The name of the public buyer is *Ministère des Transports du Quèbec* and I choose contracts awarded and concluded. Then, I scrape the contracts.

I use the open dataset to obtain information on whether the job is focused mainly on paving. If not, the contract is eliminated from the dataset.

Data cleaning

After the scraping part, I double check with the open data. I keep only contracts awarded by the *Ministère des transports du Quebec (service gestion contractuelle)*. In these data I only pay attention to contracts where 72131701 (paving) is the code. Out of the 747 contracts, I include the following:

- 401 where paving is the only code
- 253 (out of 329) where the codes are 72131701 and 72190000, but only 72131701 is principal
- 3 (out of 6) where there are 2 codes (7213701+other)
- 11 contracts misclassified (contracts where the only code is paving, but the job code reported is 72190000)

I have a total of 668 contracts from 2009 to 2015. For 2007-2008 (year not included in the open dataset), I found 132. Finally, I have 788 contracts, of which I drop 37 contracts because:

- Contracts were awarded in *Cote-Nord*

- Contracts on which one of the bidders bid 0
- Contracts on which the winning bid is the lowest bid
- Contracts for which the location involves more than 2 MRCs (the territorial units that identify the project location)
- Contracts for which paving is associated with a code different from construction of streets and highways
- Contracts on which the interval of estimated value is less than the 100,000 Canadian dollars (the threshold at which it is mandatory to publish).

Distance variable: This is the distance between the location of the project and the closest asphalt plant of each firm to the project. The location of the project is the first location announced in the contract. The location of the plant is found on the map given by the Ministry of Transport. From the addresses, I then construct a Python script that uses Google API to transform the addresses into coordinates (latitude and longitude). Then, using the Stata command globdist and georoute (georoute requires opening a HERE account), I find the shortest distance, the driving distance, and the time distance from the project.

Definition of the variables used in the dataset

Table A.17 – Definition of the variables used in the dataset

Variable	Definition	Notes
Outcomes		
Number of cartel bids	Number of cartel bids in an auction	Auction-level binary variable
Head-to-head competition	Probability that firms A and B bid in the same auction	Auction-level binary variable
Bid	Bid expressed as % of the mean value of the contract	Bidder and auction-level variable
Auction characteristics		
Treatment	Equal to 1 if both cartels are closer to the project than the furthest potential participant in the auction and both are within 100km of the auction	Auction-level binary variable
Post	Equal to 1 if the auction was published after 23rd October 2009	Auction-level binary variable
n cartel bidders	Number of actual cartel bidders (firms A and B)	Auction specific variable
n non-cartel bidders	Number of actual non cartel bidders (different from firms A and B)	Auction specific variable
N potential cartel bidders	Number of potential cartel bidders (firms A and B). A firm is a potential bidder if it bids at least once in a given MRC	For a given MRC, there is one value of this variable
N potential non-cartel bidders	Number of potential bidders different from firms A and B. A firm is a potential bidder if it bids at least once in a given MRC.	For a given MRC, there is one value of this variable
demand (%)	Value of contracts awarded up to auction *a* as % of the total value of contracts awarded in a given administrative region and year	The value of the contract is the amount for which the contracts are signed
Administrative region effects	Dummies for administrative region of location of the paving project	
Year effects	Dummies for year	
Size project effects	Dummies for project size	I use the upper bound of the value of the contract
Bidder characteristics		
Capacity (%)	Total value of contracts won in a given administrative region and year up to auction *a* as % of the total value of contracts won in a given administrative region and year	The value is the amount for which the contracts are signed. Bidder-auction specific
Value firm region (%)	Total value of contracts won in a given administrative region and year up to auction *a* as % of the total amount of contracts awarded in a given administrative region and year	The value is the amount for which the contracts are signed. Bidder-auction specific
Distance (km)	Driving distance in km from the closest asphalt plant of the firm to the paving project location	Stata command georoute. For paving project location I use the first location in the call for tender. Bidder-auction specific