Bid Rigging and Entry Deterrence in Public Procurement: Evidence from an Investigation into Collusion and Corruption in Quebec

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We study the impact of an investigation into collusion and corruption to learn about the organization of cartels in public procurement auctions. Our focus is on Montreal's asphalt industry, where there have been allegations of bid rigging, market segmentation, complementary bidding, and bribes to bureaucrats, and where, in 2009, a police investigation was launched. We collect procurement data and use a difference-in-difference approach to compare outcomes before and after the investigation in Montreal and in Quebec City, where there have been no allegations of collusion or corruption. We find that entry and participation increased, and that the price of procurement decreased. We then decompose the price decrease to quantify the importance of two aspects of cartel organization, coordination and entry deterrence, for collusive pricing. We find that the latter explains only a small part of the decrease.

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1. Introduction

In October 2009, Canadian news television show *Enquête* broadcast a program shedding light on the collusion and corruption allegedly rampant in the construction industry in the greater Montreal area (see Enquête, Radio Canada 2009). It detailed allegations of bid rigging, market segmentation, complementary bidding, and bribes to bureaucrats. The show sent shockwaves through the province and led to the creation on October 22, 2009, of a police task force, *Opération Marteau*, charged with investigating the allegations.[1]

The objective of this article is to study the impact of this police investigation on firm behavior in order to learn about the organization of cartels in public procurement auctions. Successful cartels depend on the ability of members to overcome two challenges: (1) *coordinating an agreement* amongst themselves (selecting and coordinating profitable collusive pricing strategies and monitoring behavior to prevent defection) and (2) *deterring the entry of other firms* into the market (see for instance Levenstein and Suslow 2006). While considerable attention has been paid to the impact of coordination, little has been directed at the distortion caused by entry deterrence, or to trying to separate the two effects. This is despite the fact that adverse participation effects could be economically as significant as other cartel-related sources of inefficiency and damages. By excluding potential rivals, the cartel might be able to charge higher prices than it otherwise would and earn greater profits. In this article we quantify the relative importance of these two challenges. Doing so is relevant for understanding the functioning of cartels, and also for evaluating the impact of collusion on municipal spending and for learning how to prevent it.

We collected detailed data for the municipal procurement of asphalt through *Access to Information* requests at the Municipal Clerk's offices for the period 2007–13. The provincial inquest into collusion and corruption in the construction industry that followed the police investigation revealed that a sophisticated cartel had existed since at least 2000 in this market. Testimony during the inquest provided detailed information on the organization of the cartel, characterized Montreal's asphalt market as *closed*, and documented sometimes violent behavior towards potential entrants.[2]

The data provide information on all public tenders, and the participating bidders before and after the investigation started. In order to estimate the

1. **Legal disclaimer:** This article 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.

2. See for instance pages 56–57 of the Final report of the Charbonneau Commission (Charbonneau and Lachance 2015).

causal impact of the investigation, we collected this information not only for Montreal, but also for Quebec City, which was not mentioned in the broadcast and was not the focus of the initial investigation. Moreover, to our knowledge, there have been no allegations of collusion or corruption in its asphalt industry.[3] These observations, and the fact that, prior to the investigation, bidding patterns were similar in the two markets (i.e., they have a common trend), qualify Quebec City as a suitable control and so we use a difference-in-difference approach comparing contracts in Montreal to those in Quebec City to estimate the effect of the investigation on bidding behavior. This approach has been used to study the impact of alleged price fixing in other markets (see for instance Clark and Houde 2014).

Our estimates indicate that entry and participation increased in Montreal following the investigation. Three new firms entered in Montreal, increasing the total number of firms in the market by 50%. These firms began bidding on contracts throughout the city. In contrast, no new firms entered in Quebec City. We estimate a 61% increase in the participation rate in Montreal relative to Quebec City, with 1.6 more bidders per auction after the investigation. We also find that the investigation led to an 18% decrease in the raw price (per ton) of asphalt in Montreal.

These results show that entry occurred and that prices fell, but do not inform as to the relative importance of entry versus coordination in explaining the price reduction. For this we consider calls for tender in which we restrict attention to auctions featuring no entrants. Our results imply that, even in auctions without entrants, prices were lower in Montreal after the investigation. These findings suggest that the price decrease can be mostly attributed to changes in bidding behavior by incumbent firms.

Since the participation decision is endogenous and this approach allows us to control only for the threat of entry but not the actual presence of an entrant, we also use a model-based approach to confirm our reduced-form results. We structurally estimate production costs from the post-cartel period in Montreal for all firms that were present (incumbents and entrants), and then use these cost estimates to decompose the reduced-form price change into coordination and entry-deterrence effects. Specifically, we simulate counter-factual prices under the scenario that the entrants had not in fact entered the market and compare these prices to the benchmark estimated using our difference-in-difference estimates. Our findings are consistent with those from our reduced-form estimates that control for entry. Specifically, they suggest that the inability of cartel members to deter entry explains only a small part of the price change (about 20%), with the majority of the change being explained by the loss of their ability to coordinate pricing.

3. More recently authorities have started to look into contracts in cities near to Quebec City, but as of the time of writing there have been no allegations of collusion or corruption in the asphalt market in Quebec City itself.

Our results shed light on the organization of cartels. Although entry deterrence is clearly part of the cartel mechanism, it is less important than the ability to coordinate pricing. These findings can have policy implications in terms of providing guidance regarding how governments and international organizations should allocate scarce resources in the fight against collusion and corruption. Academics and policymakers have emphasized the need to encourage the participation of a large number of bidders in the procurement process by eliminating policies that place restrictions on entry or participation (see for instance Coate 1985; OECD 2012).[4] However, at least in the case of the cartel we examine, our results suggest that less energy should be dedicated to ensuring that the tender process be designed to maximize participation, and more resources should be devoted to eliminating communication and coordination.

Related literature: Our article is related to a growing empirical literature on the organization of cartels. Some of this has focused on describing the inner workings of cartels and bidding behavior, for instance Pesendorfer (2000), Genesove and Mullin (2001), Roller and Steen (2006), Asker (2010), and Clark and Houde (2013). Other papers have focused on distinguishing collusion from competition, for instance Porter and Zona (1999), Bajari and Ye (2003), Conley and Decarolis (2016), Kawai and Nakabayashi (2014), and Chassang and Ortner (2015).

There is also a literature on cartel sustainability, whose focus has mostly been on the detection of cheating and retaliation to this behavior. See for instance Genesove and Mullin (2001) and Stigler (1964) regarding detection, and Green and Porter (1984) regarding retaliation. However, many cartels collapse because of pressures from firms outside the cartel. The role of entry deterrence and rivalry suppression in sustaining collusion is starting to receive more attention. Levenstein and Suslow (2006) point out that most successful cartels actively create barriers to entry either by engaging in predation (see Scott-Morton 1997; Podolny and Scott-Morton 1999; Asker 2010), by refusing to share production technology (Harrington 2006), by turning to the government to create regulations, or by using vertical exclusion (Heeb et al. 2009). Marshall et al. (2015) develop a model which allows them to consider the incentives for cartels to eliminate non-members from the market. What is less often discussed is the role that intimidation and violence can play. As pointed out by Porter (2005), illegal sanctions may be available for use in deterring entry, especially in industries linked to organized crime.

There is growing interest in the role of entry (participation) in auction outcomes (see for instance Li and Zheng 2009; Roberts and Sweeting 2013; Marmer et al. 2013; Coviello and Mariniello 2014). Participation is endogenous and not all potential bidders are observed to bid in every auction. We show that collusion is one factor preventing potential competitors not only from entering the market, but participating in and winning calls for tender.

4. For example, contracts should be well defined in terms of products and delivery times to encourage firms with excess capacity to bid (Coate 1985).

Finally, we are also related to a long literature on public procurement. See for instance Somaini (2011), Lewis and Bajari (2011), Krasnokutskaya and Seim (2011), Gil and Marion (2013), Bajari et al. (2014), and the survey by Dimitri et al. (2006). There has also been considerable attention paid to corruption in procurement. For examples, see Arozamena and Weinschelbaum (2009), Bandiera et al. (2009), Ferraz and Finan (2011), Lewis-Faupel et al. (2016) and Coviello and Gagliarducci (2017), or Fisman and Golden (2017) for a broader discussion of corruption.

Outline: The remainder of this article is structured as follows. A description of the market is presented in Section 2. Section 3 explains the alleged conspiracy and investigation. Section 4 describes the data and some descriptive statistics. The empirical strategy for examining the impact of the investigation, the estimation and the test results are presented and discussed in Section 5. Section 6 decomposes the estimated price change into an entry effect and a coordinated-behavior effect. Finally, Section 7 concludes. The Appendices contains a large number of robustness checks and details of the model.

2. The Markets and the Adjudication Process

Our focus is on the municipal procurement of asphalt in Montreal and Quebec City. The City of Montreal is composed of nineteen boroughs. Until 2009, Quebec City was composed of eight boroughs. In 2010, the boroughs of Quebec City were amalgamated bringing the total number to six. Figures A1 and A2, located in Appendix A, present maps of each city and their boroughs (before and after the amalgamation for Quebec City).

Montreal and Quebec City procure asphalt in the following way. When submitting their budgets, the boroughs each make predictions about the required amounts of asphalt to maintain their roads over the course of the upcoming year. The vast majority of contracts are for the *summer season*, with a small minority of contracts for work in the *winter season*. Our focus is on the summer-season contracts.[5]

Neither city has factories to produce asphalt, but each has the manpower required to repair roads with the asphalt provided. Interested firms are invited to submit bids for multiple boroughs and the results for each are announced simultaneously. In Montreal, produced asphalt can either be for delivery or for collection by the city. Delivered asphalt is taken to the borough's designated reception point, while collected asphalt is picked up by the city's trucks. Some types of asphalt are only delivered or only collected, while other asphalt types are both delivered and collected. These auctions are all performed separately. In contrast, in Quebec City, all

5. Only one percent of Montreal's contracts are for the winter season, and just six percent for Quebec City. These contracts are also auctioned at the city level, unlike summer contracts which are auctioned at the borough level. Finally, in Quebec City winter contracts can also vary in the period that they cover. For all these reasons, we omit these contracts from our analysis.

asphalt types are collected at the firms' plants by the city's trucks. In our empirical analysis we include all asphalt types, but our results are robust to focusing on a homogeneous set of contracts.

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). 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.[6]

Several different varieties of asphalt are available for paving work. Each of these types of asphalt has different characteristics and is suitable for specific work conditions (for instance some are better for the cold). During our sample period, eleven different asphalt types were ordered in Montreal, and five different types for Quebec City. In our empirical analysis we control for the different asphalt types.

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. In Montreal, firms are constrained to bid the same unit price for the same asphalt type in different boroughs, and to bid the same transport cost for delivery of all types within a given borough. Although most of the analysis abstracts from this constraint, in the robustness section we suppose that auctions are for types and investigate the impact of the investigation on type prices and find similar results.

Cities retain the right to reject any bid deemed non-compliant, but this is very rarely implemented. Indeed, in our data, this occurs only once, in Montreal in 2012. In this case, the city canceled the tender and called on all firms to resubmit. Once the auction is completed, the City must publish the results of all firms that bid.

In 2009, Quebec City introduced a by-law forbidding a firm from winning contracts in more than half the boroughs in any given year (more than four prior to 2010, more than three afterwards). Even if a firm was the lowest bidder on a call for tender, it only won the four (three after

6. In Montreal, firms are asked to submit a raw bid for each asphalt type. Firms must also take into account the transport cost they face and submit transport charges for each type in each borough. The sum of the raw bid plus transport charges is the final bid. For Québec City we do not have enough information to build a proper measure of transport charges and, therefore, of final bids. We know only raw bids per asphalt type per borough and the aggregated final bid of each firm per borough. Since the contracts are won at the borough level, not the asphalt type level as in Montreal, firms submit an aggregated transport charge for a borough. Since prices per type are usually different, it is impossible for us to map an accurate transport charge per asphalt type.

2010) calls on which there was the largest difference between the lowest and second lowest bidders. The second lowest bidder wins otherwise. Below we explain how we address this in the empirical analysis.

3. The Alleged Conspiracy and the 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 on October 11, 2011 to dig into the allegations of collusion and corruption first exposed in 2009 by Radio Canada and Opération Marteau. The Commission's mandate was to: (1) examine the existence of schemes and, where appropriate, to paint a portrait of activities involving collusion and corruption in the provision and management of public contracts in the construction industry (including private organizations, government enterprises and municipalities) and to include any links with the financing of political parties, (2) paint a picture of possible organized crime infiltration in the construction industry, and (3) examine possible solutions and make recommendations establishing measures to identify, reduce and prevent collusion and corruption in awarding and managing public contracts in the construction industry.[7]

Since the creation of the Commission, testimony has substantiated the allegations of corruption and collusive schemes in various construction-related industries in and around Montreal, including the asphalt industry in Montreal proper. According to testimony, collusion has existed in the construction industry in and around Montreal and for provincial contracts (with the Ministry of Transportation) at least as far back as the 1980's.[8] Contracts involving asphalt, sewers, aqueducts and sidewalks were all affected.[9]

Collusion involved market segmentation, complementary bidding and payoffs to bureaucrats. Before contracts were allocated by the municipalities or the Ministry of Transport, conspiring firms would acquire private information about the contracts (location, size, etc.) from officials.[10] Testimony during the Charbonneau Commission detailed bribes provided to city officials.[11]

Subsequently, representatives would meet to determine which firm would win which contracts based on the firms' capacities of production

7. See https://www.ceic.gouv.qc.ca/la-commission/mandat.html.

8. See paragraph 1118 of Piero Di Iorio's testimony from the Charbonneau Commission, November 26, 2012, Di Iorio (2012).

9. See paragraphs 788, 790, 804, 1038-1042 and 1134 of Gilles Théberge's testimony from the Charbonneau Commission, May 23, 2013, Théberge (2013a).

10. See paragraphs 684–686 and 724 of Jean Théoret's Testimony from the Charbonneau Commission, November 26, 2012, Théoret (2012).

11. These included invitations to fishing and yachting trips, wine and hockey tickets, and also political donations. See paragraphs 1226, and 185–206 of Gilles Théberge's testimonies from the Charbonneau Commission, May 23rd and May 24, 2013, Théberge (2013a) and Théberge (2013b).

and the location of their plants. The specified winner was then responsible for organizing all of the contracts (its bid and those of competitors). To do so, before the submission closing date, it would contact the other participants to provide instructions on complementary bidding.[12] According to dissidents interviewed during *Enquête*'s investigations, these complementary higher bids were submitted to simulate competition. In case their conversations were overheard, the participants used a coded vocabulary to exchange information. 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 4^{th} hole and we will be 9 players." This meant that the complementary bids must be over \$4 900 000 (4^{th} = \$4 000 000 and 9 players = \$900 000). The specified winner would bid just below this threshold.[13] The winner would reveal implicitly its bid. To our knowledge, no side payments were ever transferred between the colluding firms.

According to testimony during the Charbonneau Commission, while less structured collusion had existed since the 1980's, Montreal's asphalt cartel was formed in 2000, by four of the dominant construction firms active in and around Montreal (see Radio Canada 2013). The participating firms met to decide: (1) the quantity of asphalt to be produced by each member, (2) the territory of each member, and (3) the price of raw materials for the production of asphalt. The initial firms concluded partnership agreements for the asphalt market with other firms and extended the number of participants to include all six of the firms active in Montreal.[14]

Entry deterrence: Competition was deterred using threats and intimidation. The two dissidents interviewed during *Enquête*'s investigations, decided to remain anonymous for "fear of their physical integrity."[15] In order to prepare submissions, firms have to request plans from the municipal officials. If a non-cartel firm requested the plans, municipal informants would contact the cartel immediately.[16] Potential bidders would be informed that the contract did not belong to them, and that they either follow the rules of the cartel or remove their submission. Should they refuse, the cartel would harass potential bidders by calling unceasingly until the opening date of the submission. If they still would not join the cartel or leave, individuals would be sent to deliver a threat in person.[17] If, despite the threats, a firm participated in the call for tenders and won the contract, there was little chance it would be able to complete the necessary

12. See paragraphs 997–1009 ad 1060–1100 of Gilles Théberge's testimony from the Charbonneau Commission, May 23, 2013, Théberge (2013a).

13. See minute 7:25 of Enquête, Radio Canada (2009)

14. See paragraphs 575 and 677–696 of Gilles Théberge's testimony from the Charbonneau Commission, May 23, 2013, Théberge (2013a).

15. See minute 13:50 of Enquête, Radio Canada (2009).

16. See paragraphs 684–686 and 724 of Jean Théoret's Testimony from the Charbonneau Commission, November 26, 2012, Théoret (2012).

17. For an example of this behavior, see paragraphs 1102–1133 of Piero Di Iorio's testimony at the Charbonneau Commission, November 26, 2012, Di Iorio (2012).

work. According to a dissident, the cartel would tamper with equipment and materials, and would continue to exert physical violence.[18]

4. Data and Descriptive Statistics

We use borough-level asphalt contract data for Montreal and Quebec City, obtained through access to information requests at the Municipal Clerk's office. These requests yielded data on procurement auctions from 2007 to 2013 for both cities. Additional information was collected in the Cahiers d'appels d'offres (Call for tender books). We have information on all submitted bids (raw bids and transportation charges), and the identity of the winner. We also collected from the Quebec Ministry of Transportation the addresses of all the asphalt plants in Montreal and Quebec City, and we have called the addresses of the central point of reception for each neighborhood in the two cities. This allows us to calculate the distances for delivery of the asphalt for each tender. For Montreal the books also contain information on the capacity of each firm for each year.

4.1 Contracts

Table 1 describes the contracts awarded over the sample period in Montreal and Quebec City respectively. In Quebec City, from 2007 to 2013, there were 46 individual calls for tender to supply asphalt with an average of 3.47 bids per tender. In the 19 boroughs of Montreal, during the period 2007–13, there were 616 calls for tender, with an average of 3.41 bids per auction. From this table we can already see that there was a large increase in the number of bids per contract in Montreal post investigation. In contrast, the number of bids fell in Quebec City.[19]

We can also see that, prior to the investigation, raw bids in Montreal were \$75 per ton, but only \$57 in Quebec City. In the post-announcement sample the differences between Montreal and Quebec were considerably smaller. Note that this is due to changes both in Quebec City and in Montreal after the announcement. Prices increased by \$6 in Quebec City and fell by over \$8 in Montreal. As a preview of our empirical analysis below, we can already see that the difference-in-difference effect is \$14, suggesting the investigation had a large economic impact on bidding behavior in Montreal's asphalt market.

Table 2 breaks contract allocation down by firm for Montreal and Quebec City. Between 2007 and 2009, a total of six firms bid for contracts

18. See paragraphs 839–915 from Jean Théoret's testimony at the Charbonneau Commission, November 26, 2012, Théoret (2012).

19. The average number of tons per contract increases significantly in 2013, but this can largely be explained by one contract. In 2013, the district of Ville-Marie ordered 20,000 tons in a single contract. The average without this contract is 736.38 tons per contract. Overall, we observe that in 2010 and 2011 districts ordered smaller quantities of all asphalt types while in 2012 and 2013, they switched to fewer asphalt types but ordered in greater quantities.

Table 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				
2007–09	8.1	215	12	491	5.3	2.6	75
2010–13	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				
2007–09	5.9	22	7.3	3818	6.3	3.7	57
2010–13	10	24	6	5399	4.8	3.3	63

for the supply of asphalt in Montreal. We label these firms 1 through 6. Three other firms entered subsequently. Firms 7 and 8 placed bids for the first time in 2010 and firm 9 began bidding in 2012. These three entrants had been active in the private sector prior to 2010. Despite the fact that they each had the capacity to supply public contracts, they never placed bids in municipal auctions prior to this date.

We can see that in Montreal prior to the investigation one firm had a revenue share greater than half, and that three firms dominated the market. After the investigation the market share of two of these firms fell dramatically, but increased for the smallest of the three. Two of the three entrants pick up a little under a third of the market.

It is also worth pointing out that, both during the cartel period and afterwards, some firms participated often, but rarely won. During the cartel period this is consistent with the evidence suggesting that part of the cartel agreement involved complementary bids on the part of non-winning

Table 2. Firm statistics for Montreal and Quebec City

Firm	Nbr of auctions won	Winning rate	Nbr of submissions	Participation rate	Nbr auctions won/ Nbr submissions	Average share
Montreal						
2007–09						
1	146	67.90%	210	97.70%	69.50%	73.66%
2	41	19.10%	54	25.10%	75.90%	19.50%
3	2	0.90%	69	32.10%	2.90%	0.02%
4	21	9.80%	137	63.70%	15.30%	5.60%
5	1	0.50%	49	22.80%	2.00%	0.01%
6	4	1.90%	41	19.10%	9.80%	1.21%
Total	215	100.00%				
2010–2013						
1	178	44.40%	399	99.50%	44.60%	35.35%
2	12	3.00%	128	31.90%	9.40%	15.90%
3	18	4.50%	144	35.90%	12.50%	8.81%
4	93	23.20%	199	49.60%	46.70%	14.00%
5	9	2.20%	169	42.10%	5.30%	3.71%
6	3	0.70%	162	40.40%	1.90%	0.02%
7	65	16.20%	212	52.90%	30.70%	17.13%
8	20	5.00%	126	31.40%	15.90%	9.87%
9	3	0.70%	4	1.00%	75.00%	0.56%
Total	401	100.00%				
Quebec City						
2007–09						
1	13	59.10%	22	100.00%	59.10%	56.76%
2	0	0.00%	22	100.00%	0.00%	0.00%
3	0	0.00%	2	9.10%	0.00%	0.00%
4	0	0.00%	6	27.30%	0.00%	0.00%
5	0	0.00%	3	13.60%	0.00%	0.00%
6	8	36.40%	22	100.00%	36.40%	38.08%
7	1	4.50%	4	18.20%	25.00%	5.16%
Total	22	100.00%				
2010–13						
1	5	20.80%	18	75.00%	27.80%	20.14%
2	5	20.80%	23	95.80%	21.70%	23.95%
3	0	0.00%	4	16.70%	0.00%	0.00%
4	1	4.20%	9	37.50%	11.10%	6.17%
5	0	0.00%	1	4.20%	0.00%	0.00%
6	13	54.20%	24	100.00%	54.20%	49.74%
7	0	0.00%	0	0.00%	0.00%	0.00%
Total	24	100.00%				

firms. Although there is no mention of side-payments, there is some evidence that these cartel members were also present in other nearby (in geographic- or product-space) markets, and that the role of winners and complementary bidders may have been reversed in these other markets.

There were a total of seven firms that bid on tenders for the supply of asphalt in Quebec City in the 2007–13 period. We label these firms 1 through 7. Firms 1 and 6 won large fractions of the contracts in both time periods, while firms 7 and 2 were active in the early and late period, respectively.

4.1.1 Entry. As just mentioned, the three entrants in Montreal only began winning contracts in 2010, but then picked up a little less than a third of the market. While firm 9 participated in and won few auctions, the other two firms participated in and won across 16 of the 19 boroughs: firm 7 participated and won calls in 12 of the 19 boroughs, while firm 8 participated in 10 different boroughs and won calls in 9 of them. The two firms were more active in years 2010 and 2011 and so one might be concerned that it was the increased number of auctions that drove participation; however, our results regarding the impact of the investigation on both prices and participation are robust to controlling for the number of contracts and to restricting attention to boroughs that contract in every period.

5. Impact of the Police Investigation

In this section we evaluate the effect that the police investigation, Opération Marteau in October 2009, had on outcomes in Montreal. We employ a difference-in-difference strategy in which we compare changes in outcomes in the treatment market (Montreal) to those in a control market (Quebec City), before and after the start of the investigation. This approach hinges on a number of important assumptions. The first is that we are able to properly identify the cartel period. The second is that, after the investigation, bidding returned to competitive levels, and the third is that we are able to adequately control for market-specific developments during the operation of the cartel.

Since contracts in both our markets are negotiated only once a year in the spring, we establish our structural break in 2010, assuming that bidding in Montreal became competitive again starting at this point. Testimony during the Commission implied that the start of Opération Marteau caused collusion to abate. We use contracts in Quebec City as a competitive benchmark against which to compare the behavior of firms receiving the treatments, in the spirit of the test proposed by Porter and Zona (1999,1993) and in line with Clark and Houde (2014).[20] The choice

20. See also Igami (2015) and Miller and Weinberg (2017) for other examples in which the end or beginning of coordinated behavior is used to estimate the impact of collusion.

of Quebec City as a competitive benchmark is justified by the fact that, to our knowledge, its asphalt market has never been cited during Opération Marteau or the Charbonneau Commission. Our understanding is that the initial focus of Opération Marteau was on Montreal, based on the allegations in the *Enquête* broadcast. Quebec City is located a reasonable distance from the suspected markets (about 250 kms), which is important, since many markets surrounding Montreal have been cited and therefore, would not be reliable controls. Specifically, almost all the suburbs located on the North and South shores of the island of Montreal have been mentioned in the investigation. Furthermore, calls for tenders in the two cities are similar in many ways: (1) the auctions are held during the same period, (2) the auctions are designed per borough, and (3) the yearly budget for asphalt for the two cities is usually not too different. The latter condition may affect the number of auctions a firm wins and induce spurious drops in winning probabilities and prices.

On the other hand, one might point to factors that imply that Quebec City is not a perfect control. First, as alluded to above, the calls for tender are for very different quantities of asphalt, since in Montreal there are up to 11 auctions per borough per year (one per asphalt type), while in Quebec City there is just one per borough. Second, there was a municipal reorganization of the boroughs in Quebec City that coincided with the start of the investigation. Since the boroughs are now bigger, demand patterns for asphalt could change, possibly favouring larger firms that can satisfy bigger contracts. Finally, as mentioned above, there was a change in legislation that took place in Quebec starting in 2009 that established a limit on the number of contracts that a firm could win in any given year.

To alleviate these concerns we have carefully analyzed Quebec City contracts and performed several tests to learn about the impact of these factors on pricing and winning probability. In particular, we focus our attention on quantities in tons of asphalt, and we have run specifications in which we control for the type of asphalt being requested. This allows us to partial out demand effects. Regarding the change in legislation we define a winner as the lowest bidder even if the firm has already won half the contracts. Despite this correction, one might be concerned that bidders in Quebec City adjusted their behavior to this change in legislation, for instance by bidding more intensely on a smaller set of contracts. To address this, we regress winning bids and number of bidders on an indicator for whether the legislation was in place (and the same set of controls we use below). We find that the legislation has no impact on bidding. All this evidence suggests, albeit indirectly, that Quebec City is a valid control market.

As we explain in more detail in sub-Section 5.1.1 below, our analysis is robust to the inclusion of two additional cities (one treatment and one control), for which we have access to more limited data.

5.1 Prices

In this subsection we study the effect of the investigation on prices. Figure 1 plots the evolution of raw bids over time in Montreal and Quebec City. Prices were higher in Montreal than in Quebec City prior to the investigation, but the trends in the two cities were common with bids roughly following the price of the main input in the production of asphalt that we proxy with the price of crude oil (with a lag) until the start of the investigation at which point prices in Montreal diverged. This qualifies Quebec City as a valid comparison group for Montreal such that we can interpret the difference-in-difference estimates of the impact of the investigation presented above as causal.[21]

We investigate the extent to which our descriptive results are robust and not driven by other city- and/or borough-level factors that may act as confounding factors of our causal effect of interest. Our main econometric specification is:

$$B_{i,a} = \alpha + \delta_1 Mtl_{i,a} * Marteau_{i,a} + \delta_2 Marteau_{i,a} + \delta_3 Mtl_{i,a} + \beta X_{i,a} + \epsilon_{i,a}, \quad (1)$$

where $B_{i,a}$ is the raw bid of bidder i in auction a taking place in borough r, and where $X_{i,a}$ includes year, borough and asphalt-type fixed effects, and variables that capture (1) the proportion of contracts in borough r won by firm i in the previous year (CON), (2) the lagged average price of crude oil, (3) the distance between the production site and the delivery site (Distance), (4) the HHI, (5) the quantity of asphalt in the call for tender and (6) the firm's potential capacity defined as the maximum quantity ever bid on by the firms under competition (Capacity).[22] *Marteau* indicates the start of Opération Marteau in 2010 and *Mtl* is a dummy for Montreal. The parameter of interest is δ_1, which can be interpreted as the difference between the change in the price in Montreal relative to the change in price in Quebec from before to after the investigation started. Standard errors are clustered at the borough-year level, but our results are robust to different forms of clustering (for instance city, and city-year).[23]

Results from the estimation of equation (1) for raw bids are presented in Table 3. We present results for all raw bids and also for raw bids associated

21. Below we test formally for the similarities of trends and the robustness of our results to their inclusion. It should also be noted that, despite the evidence provided at the beginning of this section that there was no collusion in Quebec City in the pre-investigation period, the reader might nonetheless be concerned that collusion extended into this market. Given the similar trends experienced by the control, if there were in fact collusion, our findings would still provide causal estimates of the effect of the investigation on prices, since the investigation focused on Montreal initially. In this case our results would underestimate the effect of collusion on prices.

22. For Quebec City we use the HHI that would have prevailed had there been no change in legislation regarding the maximum number of contracts.

23. Note that we omit two time dummies: one for the constant and one for the (lagged) crude oil variable. This is because lagged crude oil shows a very high correlation with prices (See Figure 1). Furthermore, we omit one borough and one asphalt type from the specification.

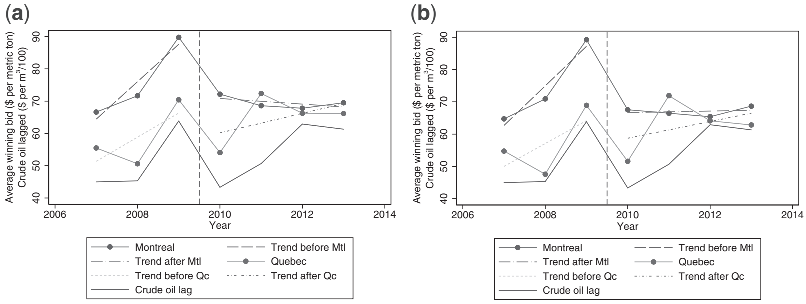

Figure 1. Average bids.
(a) Raw bids (all) (b) Raw bids (winning).

Table 3. Difference-in-difference for the submitted raw bids

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–10.677***	–8.679***	–8.693**	–13.670***	–10.770***	–10.231***
	(3.303)	(3.321)	(3.347)	(3.472)	(3.690)	(3.484)
Montreal	16.239***	9.411***	8.314***	18.078***	8.920***	6.141
	(2.953)	(1.913)	(2.991)	(3.104)	(1.822)	(4.766)
Marteau	4.760*	–5.678*	–6.042*	4.982*	–4.681	–5.472
	(2.674)	(3.188)	(3.633)	(2.862)	(3.623)	(3.960)
Crude oil lag		0.128***	0.133***		0.135***	0.132***
		(0.003)	(0.004)		(0.003)	(0.004)
Capacity			0.008			0.130***
			(0.023)			(0.036)
Quantity			–0.140			–0.217
			(0.135)			(0.155)
Distance			–0.017			–0.088**
			(0.025)			(0.036)
CON			–2.228***			1.389**
			(0.648)			(0.641)
HHI			–2.606			–7.747
			(4.423)			(4.921)
Borough effects	No	Yes	Yes	No	Yes	Yes
Year effects	No	Yes	Yes	No	Yes	Yes
Type effects	No	Yes	Yes	No	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.128	0.726	0.731	0.213	0.893	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

with winning bids. We focus our discussion on winning bids. Column (4) reproduces the findings from Table 1. From columns (5) and (6) we can see that adding controls yields only a slightly smaller estimate of the effect of the investigation of $10.23, or 13.51%. Overall, the results suggest that the police investigation led to a reduction in the prices paid for municipal procurement.[24]

5.1.1 Robustness. Perhaps the biggest concern is that there is a sizeable change in the number of auctions in 2010 and 2011 in Montreal (the number of contracts is more than double the number in other years). In 2010–11, boroughs requested smaller quantities of asphalt but for more types. In Table 4, we control for the number of auctions per year in each city. Results are similar to those reported above. In Appendix B we also report results when we restrict attention to *always-contracting* boroughs and find little change.

The other main concern is that the results may not be robust to the presence of city-wide shocks since our sample only includes two cities. To alleviate this concern we obtained limited information on procurement contracts in two other markets in the province of Quebec: Laval and Lévis.[25] Laval is a large suburb on Montreal, and has been frequently mentioned as a hub of collusive activities. Lévis is a suburb of Québec City and, to our knowledge, like Quebec City, has not been the subject of allegations of collusion for its municipal asphalt contracts. In Appendix B2 we present evidence showing that results are almost identical when extending the sample to four cities.

In the Appendix we have also analyzed the robustness of the effect of the investigation on prices with respect to the choice of controls, different windows around the start of the investigation, and concerns related to institutional features of the market. Overall, we conclude that the

24. The R-squared of the regressions suggests that the specification with controls does fairly well in explaining the variation in the bids and in the winning bids, 73.1% and 91.3%, respectively. In Appendix A we present formal tests for the presence of common trends in prices between Montreal and Quebec City before the investigation, which is the main identifying assumption of the difference-in-difference estimation method. A violation of this assumption would imply that our estimates are non-causal. Panel A of Table A1 shows that the hypothesis of common linear trends is strongly rejected in our data, whereas Panel B shows that the coefficients of *MontrealXYear*2008 and *MontrealXYear*2009 are very similar and not statistically different (i.e., large *p*-values of the difference) for the majority of our specifications. This evidence is compatible with the non-linearities in prices depicted in Figure 1. To assess the robustness of our results to the possible violation of the common trend assumption, in Table A2 we report estimates obtained with the same specification used in Table 3 but adding heterogenous linear (Panel A) and non-linear trends (Panel B). We conclude that our estimates are robust to this possible threat to the identification strategy since, once we control for heterogeneous trends, our estimates are comparable in sign and magnitude to our baseline estimates.

25. In the Appendix we explain in detail the dimensions in which these new data sets are inferior to those for Montreal and Quebec City.

Table 4. DID controlling for the number of auctions

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–10.26***	–10.26***	–10.42***	–11.14***	–11.14***	–10.83***
	(3.138)	(3.138)	(3.124)	(3.555)	(3.555)	(3.378)
Montreal	8.032***	8.032***	5.071	8.931***	8.931***	8.389***
	(2.495)	(2.495)	(3.621)	(2.879)	(2.879)	(2.535)
Marteau	17.85***	–2.714	–3.879	18.06***	–3.933	–4.728
	(3.440)	(3.231)	(3.692)	(3.886)	(3.666)	(4.123)
Nbr auctions	0.0429*	0.0429*	0.0495**	0.0109	0.0109	0.0186
	(0.0242)	(0.0242)	(0.0243)	(0.0269)	(0.0269)	(0.0270)
Crude oil lag		0.126***	0.133***		0.135***	0.133***
		(0.00328)	(0.00403)		(0.00324)	(0.00420)
Capacity			0.00756			0.129***
			(0.0230)			(0.0362)
Quantit			–0.113			–0.207
			(0.131)			(0.153)
Distance			–0.0210			–0.0912**
			(0.0248)			(0.0359)
CON			–2.231***			1.311**
			(0.648)			(0.643)
HHI			–6.900*			–9.556**
			(3.954)			(4.326)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.728	0.728	0.733	0.893	0.893	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6) *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. *Nbr auctions* is the number of auctions per year in each city. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

descriptive (and graphical) effect of the investigation on prices identified from Table 1 (and Figure 1) is robust to the specification of the empirical model, sample selection around the date of the investigation, and to different features of our market and data.

5.2 Entry and Participation

In this subsection we study the effect of the investigation on entry and participation. As mentioned above, in Montreal three new firms entered the market following the investigation. In contrast, in Quebec City, no firms enter and one firm no longer participates in any calls for tender. From Table 1 we also know that in Montreal the average number of participants increased following the investigation. Figure 2 presents the share of the dominant firm (as measured by total amounts of contracts won) in each borough in Montreal before and after the investigation. The incumbent firms win a smaller share of contracts after the investigation and in some cases are no longer the dominant firm in the borough afterwards.

Our main econometric specification for the entry analysis is similar to above:

$$I_a = \alpha + \delta_1 Mtl_a * Marteau_a + \delta_2 Marteau_a + \delta_3 Mtl_a + \beta X_a + \epsilon_a, \quad (2)$$

where I_a represents the following outcomes in auction a: (1) number of bidders, (2) number of incumbent bidders, and (3) share of the dominant firm (at the year level). The X_a includes the same variables and fixed effects as above.

Results from the estimation of equation (2) are presented in Table 5.[26] The investigation led to an increase in the number of bidders of 61.36%. The share of the dominant firm fell by 63.69% in Montreal relative to Quebec City. Overall, these findings suggest that Montreal's market structure appears to have become more competitive after the investigation, with entry taking place, with more participation and with the incumbents winning a smaller share of contracts.

It is important to note that the observed change in participation could reflect (1) an increase in the participation of entrants that were excluded by the cartel, (2) a change in the participation of incumbents, or (3) some combination of the two. Moreover, incumbents could participate less under competition because they are no longer required to submit complementary bids and preparation of bids is costly, or they could participate more because the cartel agreement may have limited the number of cover bids required. To shed light on these different effects, in column (2) of Table 5 we present regression results for incumbent participation only. This allows us to decompose the overall change in participation into an effect coming from entrants and an effect coming from incumbents. Our findings suggest that about half of the increase in participation is coming from an increase on the part of incumbents, with the remainder coming from the arrival of new entrants.

Related to this, one might be concerned about the impact that the simultaneous nature of the auctions in Montreal (across boroughs and types) has on participation and bidding behavior. In particular, if firms are capacity-constrained, then part of the observed change in participation from collusion to competition reflects the influence of capacity: under collusion firms might have participated in auctions for work exceeding their capacity knowing that they were not actually going to win; under

26. The market structure results are robust to the same set of robustness checks that we ran for the price outcome, and are available from the authors upon request.

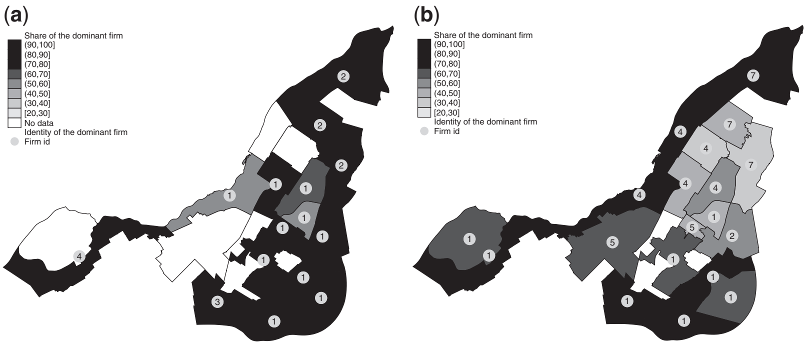

Figure 2. Dominance of firms and market-share in Montreal.
(a) Before the announcement (b) After the announcement.

Table 5. Difference-in-difference for market structure variables

Sample Dependent variables	All auctions Number of Bidders (1)	Number of Incumbents (2)	Share of the Dominant firm (3)
Montreal × Marteau	1.598***	0.775**	–37.022***
	(0.323)	(0.304)	(9.588)
Montreal	0.189	–0.438	–40.861
	(0.370)	(0.680)	(30.947)
Marteau	–0.902**	–6.163**	–8.644
	(0.449)	(3.052)	(13.007)
Crude oil lag	–0.001	0.032*	0.008
	(0.001)	(0.017)	(0.029)
Capacity	–0.016***	0.001	–1.396
	(0.006)	(0.006)	(1.757)
Quantity	0.021	0.025	–16.630
	(0.025)	(0.023)	(10.303)
Distance	–0.006	–0.006	2.174
	(0.007)	(0.006)	(1.685)
CON	–0.354***	–0.272**	
	(0.135)	(0.122)	
HHI	–0.464	–0.971	
	(0.819)	(0.760)	
Borough effects	Yes	Yes	No
Year effects	Yes	Yes	No
Type effects	Yes	Yes	No
Observations	662	662	14
R-squared	0.697	0.592	0.796
Average outcome	3.418	3.418	49.64

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on the number of bidders (1), the number of incumbents (2), the share of the yearly dominant firm (3). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels, except for column (3) where the SEs are clustered at city and year level. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

competition, bidding strategies would be affected by capacity and risk preferences. This is not a problem in our particular case, since the capacities for the cartel firms appear to significantly exceed demand. We have information on the actual capacities for some of the firms in Montreal, which suggests that they could individually supply all of Montreal's needs simply by running their plants for less than two weeks.

6. Cartel Organization: Coordination versus Entry Deterrence

We have shown that, following the investigation, raw bids fell in Montreal relative to Quebec City. We have also described how, after the investigation, three new players entered the Montreal market, which led to a significant increase in the number of bidders per auction. In this section we investigate the role that entry played in explaining the observed price change in order to learn about the organization of the cartel. To collude, cartel members must overcome two main organizational challenges: (1) coordinating an agreement amongst themselves and (2) entry deterrence. In what follows we quantify the relative importance of these two activities.

6.1 Reduced-form Approach

We start by estimating the same difference-in-difference specification as above, but this time controlling for whether there was an entrant present in the auction (in Montreal). Results are presented in Table 6. Columns (1)–(4) restrict attention to auctions featuring no entrants in Montreal after the investigation (columns (1) and (2) consider all bids, whereas columns (3) and (4) look at winning bids). Following the investigation the entrants began participating in calls for tender. Despite this, it is possible to find a set of auctions in which they did not take part, and to redo our price regressions for this subset of auctions. Our results imply that, even in auctions without entrants, prices were much lower in Montreal after the investigation. These findings suggest that the price decrease is mostly due to changes in bidding behavior by incumbent firms, which appears to be more competitive following the investigation.

The problem with this approach is that participation may be endogenous, and controlling for it in our regression introduces endogeneity bias. Moreover, this specification does not allow us to control for the threat of entry, but only the presence of an actual entrant in an auction. To address these issues, and confirm our reduced-form findings, we turn to a model-based approach.

6.2 Model-based Approach

In order to disentangle the entry-deterrence and coordination effects we simulate what bidding would have looked like had entry not occurred after the investigation. Our approach is to estimate bidding strategies during the post-cartel period in Montreal when all $N = 9$ firms (incumbents and entrants) are present in the market to back out the costs of each

Table 6. Difference-in-difference in calls featuring no entry

Variables	(1) All bids No entrants	(2) All bids No entrants	(3) Winning bids No entrants	(4) Winning bids No entrants
Montreal × Marteau	–9.883***	–7.312**	–11.834***	–8.680**
	(3.339)	(3.035)	(3.510)	(3.378)
Montreal	16.239***	8.050*	18.078***	9.443
	(2.958)	(4.185)	(3.112)	(5.753)
Marteau	4.760*	–6.151*	4.982*	–5.985
	(2.679)	(3.391)	(2.869)	(3.883)
Crude oil lag		0.131***		0.132***
		(0.004)		(0.006)
Capacity		–0.033		0.115**
		(0.031)		(0.045)
Quantit		–0.205		–0.438
		(0.444)		(0.442)
Distance		–0.039		–0.032
		(0.034)		(0.071)
CON		–1.851***		1.147
		(0.509)		(1.066)
HHI		–4.057		–8.027
		(4.097)		(4.914)
Borough effects	No	Yes	No	Yes
Year effects	No	Yes	No	Yes
Type effects	No	Yes	No	Yes
Observations	1,052	1,052	393	393
R-squared	0.200	0.848	0.216	0.912
Average outcome	72.21	72.21	71.59	71.59

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1 and 2), winning bids (columns 3 and 4). For Montreal we restrict attention to auctions with no entrants after the investigation. *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

firm. We then simulate counter-factual bids under the scenario that the three entrants had not in fact entered the market. Finally, we compare these prices to those estimated using our difference-in-difference approach in order to quantify the two effects.

Since our objective is only to confirm the validity of the reduced-form results, we consider a simple model that captures the main features of the market, but abstracts from certain specific elements that would make the setup too cumbersome to analyze. Details of the model and our approach are provided in Appendix C. The model consists of two stages. In a first stage, firms choose whether or not to participate in an auction. In the second stage, participating firms bid.

We use techniques developed by Guerre et al. (2000) (GPV) to estimate production costs in the bidding stage assuming that n firms have chosen to participate. The GPV approach is to back out costs based on the observed distribution of bids under the assumption of equilibrium behavior. We consider the standard model with n symmetric bidders who each draw their costs iid from some distribution $F(\cdot)$. Using the first order condition and the observed distribution of bids, we can nonparametrically estimate the cost distribution. Ideally, all firms would be modelled asymmetrically. This, however, would create two kinds of difficulties. First, asymmetric auctions with entry are difficult to solve. Second, and more importantly, auction asymmetries would lead to an asymmetric participation game with multiple equilibria, necessitating an involved econometric analysis that would address equilibrium selection as, for example, in Bajari et al. (2010). But since we are also considering a counterfactual scenario with fewer firms, we would need to address equilibrium selection directly.

For the participation stage, we assume that one of the firms always participates in the auction. We are motivated in this assumption by the fact that in our dataset, there is a single firm (firm 1) with a participation rate close to 100% in both the collusive and competitive phases. This is a very large firm, active in many sectors. For the other firms, there are a number of different endogenous participation models proposed in the literature, and results are known to be sensitive to the magnitude of the participation cost.

To address this difficulty, we assume, as in Moreno and Wooders (2011), that the participation costs are potentially heterogeneous in that they vary from auction to auction even for the same bidder. As the distribution of the participation cost is not identifiable with our data, we adopt a partial identification approach. We develop and estimate nonparametric bounds on the entry deterrence effect that hold across the participation-cost distributions compatible with the data. The intuition is the following. When N falls there are two conflicting effects on prices: a *competition effect* and a *participation effect* (see Levin and Smith 1994; Li and Zheng 2009). With fewer potential bidders the competition effect suggests that prices should rise, since bidding is less aggressive. However, the participation effect works in the opposite direction, as bidders will be more inclined to participate when they face fewer potential rivals.

Our bounds are pinned down by considering the two extreme cases for the participation effect. The upper bound is computed under the assumption of exogenous participation. By this we mean that the probability that a fraction x of firms participates is the same when $N = 6$ as when $N = 9$ (and where the latter is estimated as the empirical frequency using the Montreal data over the competitive phase). In other words, the participation effect is zero. The lower bound is computed assuming homogeneous participation costs, which yields the maximum participation effect. If instead participation costs were heterogeneous, then marginal participants would have higher participation costs, and hence the increase in participation would be smaller. We show that the bounds are sharp, in the sense that each can arise for a certain distribution of the participation cost.

6.2.1 Results. Recall from Table 3 that the difference-in-difference effect is –\$13.67.[27] Our estimation results reveal what part of this price decrease can be attributed to entry deterrence and what part to coordination.

From the data, we can calculate that the participation probability amongst the fringe firms was 0.38 in Montreal/After. Using this information and the fact that firm 1 participates in almost every auction, we can understand the participation patterns across auctions. Table 7 displays the distribution of auctions of different sizes in Montreal/After. The table shows that the most common auction sizes are those with three and four participants.

Using the GPV method, we then estimate costs. Figure 3 presents these along with bids and markups, and in each case their bootstrapped confidence intervals, as a function of the number of participants. We can see from the figure that bids are falling in the number of participants, while costs are, for the most part, not statistically different across different N (as expected from the model). As a result, markups are strictly decreasing in the number of participants in the auction.

We use the estimated production costs to perform the counterfactual variation in prices (P) as explained above. The upper bound on the entry deterrence effect is estimated to be \$2.78 per metric ton, with a 95% confidence interval of [2.54, 2.95]. The lower bound on the entry deterrence effect is estimated to be –\$0.29 per metric ton, with a 95% confidence interval of [−0.28, −0.23].[28] Thus the bound on the entry deterrence effect is estimated to be:

$$P(6) - P(9) \in [-0.29,\ 2.78].$$

The 5% bootstrap percentile of the lower bound is computed as –0.27, while the 95% percentile of the upper bound is 2.92. Combining these two percentiles, we obtain

$$P(6) - P(9) \in [-0.27, 2.92],$$

the Manski–Imbens 95% bootstrap confidence interval for the entry deterrence effect. These results imply that the entry deterrence effect accounts for no more than 22% of the overall price change, with the

27. For simplicity, we present results in this section using difference-in-difference estimates derived without controls, but have also performed the estimation and simulation using normalized bids. Results from the decomposition are very similar and are available from the authors upon request.

28. These confidence intervals are computed by taking 2.5% and 97.5% percentiles of the bootstrap samples.

Table 7. Number of auctions of each size in Montreal/After with N = 9

	Number of bidders					
	2	3	4	5	6	7
Number of auctions	52	81	110	78	52	4

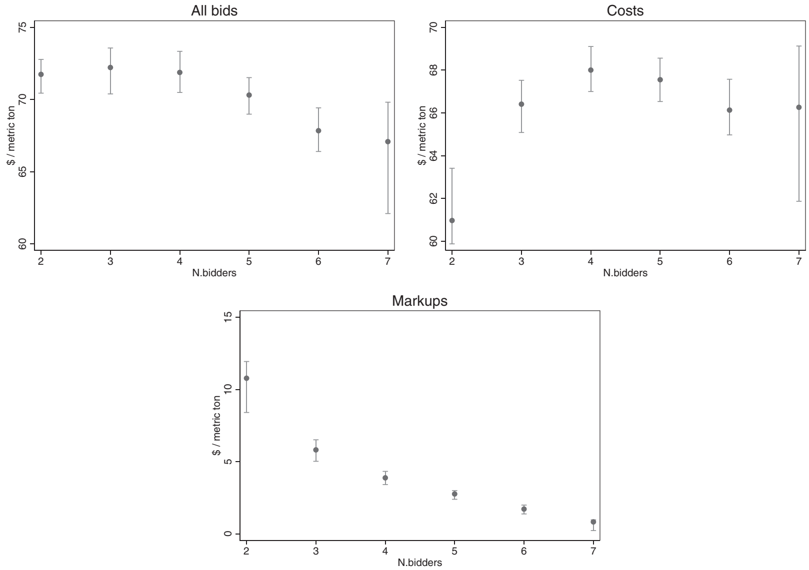

Figure 3. Bids, costs and markups.

remainder attributed to the fact that the firms can no longer coordinate their bidding.

The lower bound, which is negative, corresponds to the counterfactual participation probability estimated according to the Levin and Smith model. It is negative because the counterfactual participation probability with $N = 6$ bidders, estimated to be $\hat{\rho}(6) = 0.61$ ([0.58, 0.64]), is higher than the observed participation probability with $N = 9$, $\hat{\rho}(9) = 0.38$ ([0.36, 0.40]). In other words, although there are fewer bidders, each one is more likely to participate in any given auction. This results in a participation effect, which is strong enough to offset the competition effect.

The upper bound on the entry deterrence effect, 2.78, corresponds to exogenous participation. Recall that this assumes that participation occurs with the same probability as for $N = 9$, such that $\rho(6) = \hat{\rho}(9) = 0.38$. In this case, the competition effect will dominate the participation effect, such that price will fall because of the decrease in the number of bidders.

It should be noted that our model assumes symmetry, but that one of the entrants, firm 9, participates in only 1% of auctions, while all of the other fringe firms participate with similar probability (between about 30% and 50%). Therefore, as a robustness check we drop this firm (and the four auctions in which it participates) and redo the analysis modeling only the behavior of the 7 remaining fringe firms and the always-participating firm. With this setup the upper bound on the entry deterrence effect falls by about a third to 14%, while the lower bound remains negative.

7. Discussion

We have documented that following the investigation prices fell and entry and participation increased. Our results imply that coordinating a profitable and stable agreement was the main function of this particular cartel. The relatively small role of entry deterrence may be at least in part due to the fact that there are already six firms in the industry and so, absent collusion, a fairly competitive outcome can be achieved. However, in other contexts even larger numbers of firms did not guarantee the competitive outcome. For instance, Elsinger et al. (2015) find that when Austria joined the European Union and Europe-wide competitors were allowed to bid in their treasury auction the number of participants moved from 15 to 25 and bond yields fell.

Disentangling the coordination and entry-deterrence activities is important for understanding the organization of cartels, for evaluating the impact of collusion on municipal procurement spending, and for designing effective policies for fighting collusion and corruption. In particular, we might be interested in thinking about how to allocate resources for fighting collusion. By quantifying the relative importance of entry deterrence and bidders' coordination, our approach can shed light on where additional resources should be devoted. When describing how best to fight against bid rigging in public procurement, academics and policy-makers have proposed the need to encourage the participation of many bidders by removing or restricting policies that place limits on entry or participation (see Coate 1985; OECD 2012). In the case of Montreal's construction cartel, our findings imply that less energy should be dedicated to ensuring that the tender process maximizes participation, and more to eliminating communication and coordination.

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Appendix A
Additional Tables and Figures

Table A1. Test of the common-trend assumption

Dependent Variable Sample	Raw bids All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
	Panel A: Linear trend					
Montreal × Year	3.602***	5.993***	7.863***	4.957*	6.692**	8.285***
	(1.214)	(2.201)	(2.404)	(2.607)	(2.798)	(2.666)
Year effects	No	No	No	No	No	No
Type effects	No	Yes	Yes	No	Yes	Yes
Borough effects	No	Yes	Yes	No	Yes	Yes
R-squared	0.716	0.948	0.953	0.754	0.971	0.978
	Panel B: Non-linear trend					
Montreal × Year 2008	9.919***	11.393***	12.051***	13.355***	14.971***	13.758***
	(2.310)	(3.564)	(3.550)	(4.661)	(4.594)	(3.953)
Montreal × Year 2009	8.230***	11.950***	12.589***	10.341**	13.818**	12.468**
	(2.248)	(4.247)	(4.198)	(4.675)	(5.335)	(4.693)
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	No	Yes	Yes	No	Yes	Yes
Borough effects	No	Yes	Yes	No	Yes	Yes
p-value	0.0774	0.804	0.809	0.001	0.669	0.629
R-squared	0.786	0.951	0.953	0.817	0.977	0.978
Observations	641	641	641	237	237	237
Average outcome	73.89	73.89	73.89	74.03	74.03	74.03

Notes: Coefficient (standard error in parenthesis) of the interaction term between *Montreal* and a linear trend (*Year*) on raw bids: all bids (columns 1–3), winning bids (columns 4–6) for all the observations prior to the announcement of the *Marteau* investigation (2007–2009 included). *Montreal* is a dummy variable = 1 if the call is in Montreal. In Panel B, the trend is specified with two dummy variables for the years 2008 and 2009. *p-value* is the p-value for the F-test *MontrealXYear*2008 = *MontrealXYear*2009. The columns include the same variables as in Table 3. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table A2. Heterogeneous trends

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
	Panel A: Linear heterogenous trend					
Montreal × Marteau	–7.376	–6.188	–6.704	–13.386**	–13.148**	–11.867**
	(4.834)	(5.162)	(5.286)	(5.150)	(5.668)	(5.562)
Year effects	No	Yes	Yes	No	Yes	Yes
Type effects	No	Yes	Yes	No	Yes	Yes
Borough effects	No	Yes	Yes	No	Yes	Yes
R-squared	0.426	0.726	0.731	0.589	0.893	0.912
	Panel B: Non-linear heterogenous trend					
Montreal × Marteau	–17.825***	–15.636***	–15.944***	–19.031***	–17.173***	–16.228***
	(1.176)	(1.778)	(1.766)	(1.198)	(1.968)	(1.940)
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	No	Yes	Yes	No	Yes	Yes
Borough effects	No	Yes	Yes	No	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.453	0.753	0.759	0.618	0.921	0.938
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announce of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call is in Montreal. The model includes heterogenous trends: in Panel A, an interaction term between *Montreal* and a linear trend (*Year*); in Panel B, interaction terms between *Montreal* and year indicators (2007–2013). The columns include the same variables as in Table 3. SEs are clustered at the borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table A3. Variables, descriptions and sources

Dependent variables

Variable	Description	Source/Calculation
Raw bid	Is the bid per metric ton of asphalt submitted by a firm.	Data from calls for tender obtained through access to information requests. This bid does not include transport charges.
Number of bidders	Is the number of firms participating in an auction.	Calculated as the number of unique participants in the auction.
Number of incumbents	Is the number of incumbent firms participating in an auction.	Calculated as the number of unique participants in the auction, who participated at least once in the pre-announcement period.
Share of the dominant firm	Is the share of the dominant firm and is measured at the year and city level.	The share of a firm is the value of contracts awarded to the firm in a year weighted by the total value of awarded contracts. The firm with the largest share is the dominant one.

Explainatory variables

Variable	Description	Source/Calculation
Montreal	Is a dummy variable equal 1 if the call was in Montreal and 0 otherwise.	
Marteau	Is a dummy variable equal 1 if the observations are from after 2009 and 0 otherwise.	
Montreal × Marteau	Is a dummy variable equal 1 if the observations are those of Montreal and from after 2009.	
Crude oil lag	Is the yearly average price of crude oil lagged by one period.	Data from the website of Natural Resources Canada: http://www.nrcan.gc.ca/energy/crude-petroleum/4541. We take the average of all crude oils listed.
Capacity	Is the number of tons a year that a firm can produce. It is measured at the auction level.	Calculated as the maximum among all years, of all the quantity a firm will bid on.
Distance	Is the round trip distance between the production site of a firm and the contract's delivery site. It is measured at the auction level.	For Montreal, the distance comes from the calls for tender obtained through access to information requests. For Quebec, it was calculated using Google maps.
CON	Is the experience of a firm in a borough and is measured at the year, company and borough level.	Based on the proportion of auctions won by a firm in a borough during the previous year. In Quebec, there is a change in the boroughs in 2010. The new borough of La Cite-Limoilou is the union of of two previous boroughs; La Cite and Limoilou. A firm that won 100% of the contracts in La Cite in 2009 but 0% in Limoilou has an experience of 50% in the new borough. The new borough Sainte-Foy-Sillery-Cap-Rouge is the union of the previous borough of Sainte-Foy-Sillery and half of the previous borough of Laurentien. A firm that won all auctions in Laurentien in 2009 and none elsewhere, has an experience of 25% in the new borough, since the new borough is formed with 25% of the borough of Laurentien.
HHI	Is the Herfindahl index and is measured at the year and city level.	The share of a firm is its value of awarded contracts during a year weighted by the total value of awarded contracts.

Figure A1. Map of Montreal boroughs.
Source: Cartes de Montreal, Services aux citoyens, Ville de Montreal.

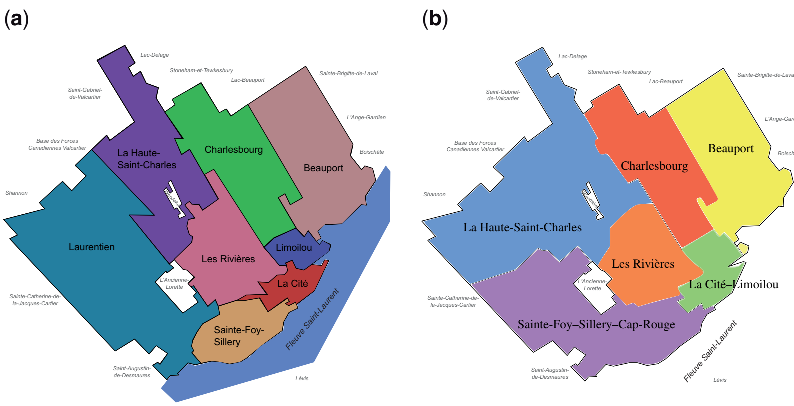

Figure A2. Map of Quebec City boroughs before and after amalgamation.
(a) Before amalgamation (b) After amalgamation.
Source: https://fr.wikipedia.org/wiki/Arrondissements_de_Québec.

Appendix B
Robustness

In this section we describe the various robustness checks we have performed. Overall, we conclude that the descriptive (and graphical) effect of the investigation on prices identified from Table 3 (and Figure 1) is robust to the inclusion of additional cities, the specification of the empirical model, sample selection around the date of the investigation, and different features of our market and data.

B1 Robustness checks

Additional cities: In Section B2, we consider whether our results are robust to the inclusion of additional cities. Figure B1 presents the evolution of average and winning bids in the suspect (Montreal and Laval) and non-suspect (Quebec City and Lévis) cities. The figures show that Laval bids look very similar to those in Montreal.[29] In particular they fall sharply after the start of Operation Marteau. In contrast there is no fall in the prices in either Quebec City or Lévis.

Different explanatory variables: In Section B3, we consider different explanatory variables that have sometimes been used in the literature, but which we do not include in our main specification. Our results are robust to the inclusion of the square of the capacity variable (Table B3), which is sometimes included to account for non-linearities in the effect of firms' capacities on bidding. We also consider a specification that includes the square of quantity (Table B4). Our results are also robust to the inclusion of a variable that indicates the number of bidders in the auction (Table B5). We also present results from a specification in which we omit *Con* and *HHI*, since there may be some concern that these are endogenous variables. Our results are robust to this change too (B6).

Different measures of crude oil prices: In Section B4, we include different measures of crude oil prices (Table B7) and consider the use of the current, rather than lagged price (Table B8), and both current and lagged values (Table B9). Our results are also robust to these variations from the baseline model.

Different time windows: In Section B5, we repeat our analysis considering different time windows around the date of the start of the investigation. We consider the following windows: 2009–2010 (Table B10), 2008–2011 (Table B11) and 2007–2012 (Table B12). In every case the interaction coefficient is statistically significant, and, except for the shortest window, the estimated investigation effect is very similar. For the shortest window the effect is smaller.

Addressing market particularities: Next we consider a number of specifications to address particularities of the markets and/or bidding processes. Since in Montreal the firms are constrained to submit one price per type per year, there could be concern that firms were not bidding to maximize profits in each auction, but rather for each type. To address this concern, we suppose that auctions are for types and investigate the impact of the investigation on type prices. In Table B13 we still observe a significant decrease in price of around 16%, depending on the exact specification. In Table B14, we also test the effect of the investigation on the quantity demanded of these types and find no significant change in demand. This also allows us to rule out the possibility that our price

29. Note that there are only three data points on the Laval curve, since (as mentioned above) contracts in Laval are for multiple years.

effect is driven by changes in demand of asphalt in Montreal versus Quebec City from before to after the investigation.

Another particularity of Montreal's market is that two of the firms are owned by the same consortium, but bid as separate firms. These two firms actually share the same production plants. We consider a specification where we treat these two firms as one. Table B15 shows that the estimated results are similar to our main results and are still statistically significant.

We also consider the fact that some boroughs do not request asphalt in every period. In Table B16 we restrict attention to boroughs requesting asphalt every year. Finally, we consider the fact that the winner of a particular auction in Montreal is determined at the type/borough level, while in Quebec City, there is one auction per borough and a firm bids for all the types needed in that borough. The firm with the lowest total submission wins the auction. In Table B17 we also verify what happens when we treat every type in an auction in Quebec as an individual auction, like in Montreal. Once again the results are consistent.

Delivery versus pickup: In Section B7, we consider that in Quebec all the asphalt produced is collected by the city, while in Montreal some types are collected and others are delivered by the firms. Results are robust to using a sample consisting only of delivered or picked-up types and to controlling for the nature of the transport (see Tables B18 and B19).

B2 Additional cities

We have managed to obtain information for two additional cities: Laval and Lévis. We consider Laval to be a *suspect* cities, and add it to the treatment group. We consider Lévis' municipal asphalt market to be *collusion-free*, and add it to the control group. Relative to our original data set, the new data have a number of limitations:

1. In Laval the contracts are sometimes for multiple years. Specifically, there were three-year contracts up for auction in 2006 (so 2006–2008), 2009 (2009–2011) and 2012 (2012–2014). We treat the 2006 and 2009 contracts as *before* the investigation, and the 2012 contract as *after*.
2. Information regarding firm capacity (hourly capacity) is not available in the data and must be estimated for Laval and Lévis (as it is for Quebec City). In contrast, this information is available for Montreal.
3. Information on the type of asphalt purchased by the city of Lévis is missing. As a result, we cannot control for asphalt-type FEs (as in our main specification).
4. The original documents given to us by the City of Laval do not contain information on bids for one company for some years. The firm does not win in periods when the data are missing, and so this represents a problem only for the average bid calculation, but not the winning bid.
5. To obtain the data from Laval we were required to sign a non-disclosure agreement preventing us from presenting any information that might reveal the identities of the bidders. This would for instance

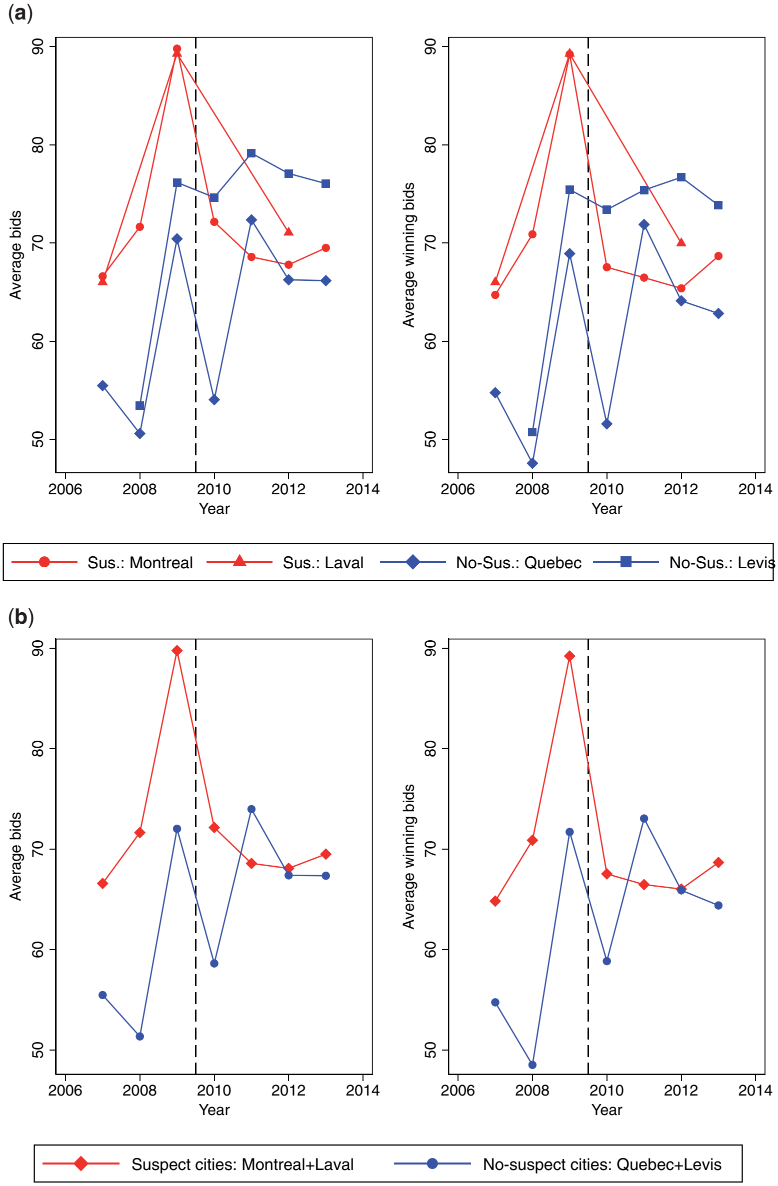

Figure B1. Average and wining bids.
(a) Four cities.
(b) Suspect vs Control.

Table B1. DID with extra cities

VARIABLES	(1) All bids	(2) All bids	(3) All bids	(4) Winning bids	(5) Winning bids	(6) Winning bids	(7) N. of bidders	(8) N. of bidders	(9) N. of bidders
Suspect ×	-11.500***	-13.329***	-13.503***	-13.956***	-16.203***	-15.924***	1.605***	1.854***	1.775***
Mart	(3.164)	(2.634)	(2.732)	(3.448)	(2.599)	(2.404)	(0.341)	(0.259)	(0.250)
Suspect	14.892***	10.528***	25.252***	15.413***	12.227***	6.469	-0.784***	0.515	-8.772**
	(2.810)	(2.532)	(9.115)	(3.102)	(2.217)	(34.012)	(0.237)	(0.448)	(3.834)
Marteau	5.552**	33.728***	45.129***	5.200*	42.460***	45.254***	-0.290	-4.549	-4.479
	(2.534)	(10.220)	(11.739)	(2.906)	(12.468)	(15.289)	(0.245)	(3.258)	(3.514)
Crude oil lag		–0.108*	–0.168**		–0.145**	-0.167*		0.021	0.022
		(0.059)	(0.069)		(0.071)	(0.088)		(0.019)	(0.020)
Quantity			–0.918***			–0.978***			0.021
			(0.285)			(0.291)			(0.024)
Capacity			–0.000			–0.004			–0.001***
			(0.000)			(0.005)			(0.000)
Distance			–0.021			–0.202***			–0.002
			(0.021)			(0.053)			(0.007)
CON			–1.756***			3.682***			–0.419***
			(0.567)			(0.833)			(0.134)
HHI			0.002**			0.003***			0.000
			(0.001)			(0.001)			(0.000)
Borough effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Year effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Type effects	No	No	No	No	No	No	No	No	No
Observations	2,331	2,331	2,322	700	700	697	700	700	697
R-squared	0.119	0.457	0.467	0.196	0.629	0.681	0.195	0.694	0.710
Avg outcome	75.98	75.98	75.98	75.82	75.82	75.82	2.507	2.507	2.507
Eff.Suspect (%)	–15.13	–17.54	–17.77	–17.81	–21.37	–21	64.03	73.97	70.81

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids and the number of bidders: all bids (columns 1–3), winning bids (columns 4–6), number of bidders (columns 7–9). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Suspect* is a dummy variable = 1 if the call was in Montreal or Laval. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B2. DID Montreal/Quebec City using same specification

VARIABLES	(1) All bids	(2) All bids	(3) All bids	(4) Winning bids	(5) Winning bids	(6) Winning bids	(7) N. of bidders	(8) N. of bidders	(9) N. of bidders
Montreal × Marteau	–10.677***	–10.458***	–11.180***	–13.670***	–12.624***	–12.251***	1.633***	1.760***	1.654***
	(3.303)	(3.348)	(3.288)	(3.472)	(3.736)	(3.228)	(0.329)	(0.322)	(0.322)
Montreal	16.239***	16.128***	12.636**	18.078***	16.668***	13.242**	–1.077***	0.060	0.077
	(2.953)	(5.497)	(5.431)	(3.104)	(5.139)	(5.526)	(0.215)	(0.493)	(0.588)
Marteau	4.760*	32.274***	39.429***	4.982*	42.443***	44.249***	–0.390*	–4.859	–5.363
	(2.674)	(10.701)	(12.755)	(2.862)	(13.044)	(15.168)	(0.222)	(3.372)	(3.568)
Crude oil lag		–0.116*	–0.149**		–0.166**	–0.182**		0.023	0.027
		(0.061)	(0.074)		(0.074)	(0.085)		(0.019)	(0.020)
Quantity			–0.939***			–1.026***			0.023
			(0.296)			(0.316)			(0.023)
Capacity			0.026			0.207***			–0.018***
			(0.021)			(0.062)			(0.006)
Distance			–0.010			–0.134**			–0.007
			(0.022)			(0.060)			(0.007)
CON			–1.860***			3.155***			–0.377***
			(0.639)			(0.800)			(0.132)
HHI			–3.306			–9.561***			–0.039
			(3.411)			(3.651)			(0.744)
Borough effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Year effects	No	Yes	Yes	No	Yes	Yes	No	Yes	Yes
Type effects	No	No	No	No	No	No	No	No	No
Observations	2,263	2,263	2,263	662	662	662	662	662	662
R-squared	0.128	0.447	0.462	0.213	0.612	0.686	0.181	0.671	0.690
Average outcome	75.94	75.94	75.94	75.71	75.71	75.71	2.605	2.605	2.605
Eff.Suspect (%)	–14.06	–13.77	–14.72	–14.77	–16.68	–16.18	62.71	67.57	63.48

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on and the number of bidders: all bids (columns 1–3), winning bids (columns 4–6), nbr bidder (columns 7–9). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

prevent us from showing the participation rates, winning rates and market share for bidders in Laval before and after the police investigation like we do in Table 2. Given the limited number of bidders a similar table would allow firms to be identified.

Our analysis of these data reveals patterns that are consistent with our results from the original data covering only Montreal and Quebec City. Focusing our attention on the before-investigation period, we also note that the parallel-trend assumption appears to be satisfied even when we include the two additional cities. Table B1 confirms these patterns, displaying regression results. Comparing the results presented here to those in the text, it is clear that adding Laval and Lévis has little quantitative impact on results. Table B1 also presents results for the number of bidders per auction. These findings too look much like those that we observe when using just Montreal as treatment and Quebec City as control. The results presented in columns 3, 6 and 9 in Table B1 are obtained with a specification slightly different from the specification used in the text. The difference is that we cannot include fixed effects for the type of asphalt, since there is no information on types for Lévis (as discussed above). To be sure that this is not affecting results, we also present findings using only Montreal and Quebec City, but without type fixed effects. Results are presented in Table B2. The findings suggest that there is little change from the results presented in the article when using just the two cities.

B3 Different explanatory variables

Table B3. D-i-D controlling for square of the capacity

Dependent variable Sample	Raw bids All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.762*** (3.339)	–8.762*** (3.339)	–8.738** (3.361)	–9.759*** (3.609)	–9.759*** (3.609)	–9.725*** (3.440)
Montreal	9.126*** (1.920)	9.126*** (1.920)	8.033*** (2.983)	8.432*** (1.460)	8.432*** (1.460)	8.180*** (1.437)
Marteau	15.262*** (3.405)	–5.555* (3.204)	–5.957 (3.641)	16.746*** (3.774)	–4.449 (3.532)	–6.272 (3.884)
Capacity	–0.183 (0.140)	–0.183 (0.140)	–0.179 (0.138)	–0.744*** (0.166)	–0.744*** (0.166)	–0.673*** (0.181)
Capacity2	0.003 (0.002)	0.003 (0.002)	0.003 (0.002)	0.014*** (0.002)	0.014*** (0.002)	0.012*** (0.003)
Crude oil lag		0.128*** (0.003)	0.132*** (0.004)		0.130*** (0.003)	0.130*** (0.004)
Quantity			–0.138 (0.134)			–0.200 (0.151)
Distance			–0.014 (0.026)			–0.025 (0.032)
CON			–2.250*** (0.665)			1.583** (0.637)
HHI			–2.599 (4.434)			–7.405 (4.816)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.727	0.727	0.731	0.914	0.914	0.918
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Capacity2* is its square. *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B4. D-i-D controlling for square of the quantity

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.776***	–8.776***	–8.691***	–10.939***	–10.939***	–10.223***
	(3.246)	(3.246)	(3.325)	(3.590)	(3.590)	(3.475)
Montreal	9.228***	9.228***	8.332**	8.412***	8.412***	6.274
	(2.131)	(2.131)	(3.202)	(2.150)	(2.150)	(4.716)
Marteau	15.420***	–5.422*	–6.042*	17.741***	–4.289	–5.470
	(3.293)	(3.074)	(3.638)	(3.754)	(3.487)	(3.976)
Quantity	–0.132	–0.132	–0.132	–0.095	–0.095	–0.161
	(0.381)	(0.381)	(0.385)	(0.393)	(0.393)	(0.357)
Quantity2	–0.000	–0.000	–0.001	–0.012	–0.012	–0.004
	(0.018)	(0.018)	(0.019)	(0.019)	(0.019)	(0.017)
Crude oil lag		0.128***	0.133***		0.135***	0.132***
		(0.003)	(0.004)		(0.003)	(0.004)
Capacity			0.008			0.130***
			(0.023)			(0.036)
Distance			–0.017			–0.088**
			(0.025)			(0.036)
CON			–2.228***			1.388**
			(0.649)			(0.646)
HHI			–2.603			–7.724
			(4.456)			(4.964)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.727	0.727	0.731	0.894	0.894	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Quantity2* is its square. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B5. D-i-D controlling for number of bidders

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–9.200***	–9.200***	–9.123***	–9.736***	–9.736***	–9.721***
	(3.400)	(3.400)	(3.424)	(3.716)	(3.716)	(3.492)
Montreal	9.299***	9.299***	8.287***	9.387***	9.088***	9.811***
	(1.969)	(1.969)	(3.033)	(2.439)	(1.746)	(1.628)
Marteau	15.526***	–5.492*	–5.853	16.717***	–5.088	–5.760
	(3.451)	(3.230)	(3.689)	(3.853)	(3.597)	(3.959)
N.bidders	0.327	0.327	0.267	–0.616**	–0.616**	–0.319
	(0.251)	(0.251)	(0.247)	(0.252)	(0.252)	(0.230)
Crude oil lag		0.129***	0.133***		0.134***	0.132***
		(0.003)	(0.004)		(0.003)	(0.004)
Capacity			0.011			0.125***
			(0.023)			(0.036)
Quantity			–0.142			–0.210
			(0.135)			(0.154)
Distance			–0.019			–0.090**
			(0.025)			(0.036)
CON			–2.195***			1.277*
			(0.650)			(0.653)
HHI			–2.465			–7.896
			(4.492)			(4.909)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.727	0.727	0.731	0.895	0.895	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *N.bidders* is the number of bidders that submitted an offer. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B6. D-i-D omitting *Con* and *HHI*

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.679***	–8.679***	–8.804***	–10.770***	–10.770***	–10.565***
	(3.321)	(3.321)	(3.281)	(3.690)	(3.690)	(3.566)
Montreal	9.411***	9.411***	9.182***	8.920***	8.920***	9.843***
	(1.913)	(1.913)	(1.999)	(1.822)	(1.822)	(1.659)
Marteau	15.197***	–5.678*	–5.385*	17.389***	–4.681	–3.081
	(3.391)	(3.188)	(3.091)	(3.861)	(3.623)	(3.429)
Crude oil lag		0.128***	0.128***		0.135***	0.130***
		(0.003)	(0.003)		(0.003)	(0.003)
Capacity			–0.014			0.138***
			(0.023)			(0.034)
Quantity			–0.135			–0.226
			(0.134)			(0.163)
Distance			0.001			–0.103***
			(0.023)			(0.032)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.726	0.726	0.727	0.893	0.893	0.910
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

B4 Different measures of crude oil prices

Table B7. D-i-D with the average of the Maya and Lloyd blend as our crude oil measure

Dependent variable Sample	Raw bids All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.729***	–8.679***	–8.693**	–11.390***	–10.770***	–10.231***
	(3.293)	(3.321)	(3.347)	(3.689)	(3.690)	(3.484)
Montreal	9.334***	9.411***	8.314***	5.777	4.555	6.218
	(1.923)	(1.913)	(2.991)	(4.034)	(4.318)	(4.591)
Marteau	15.026***	14.915***	15.576***	14.873***	13.260***	12.846***
	(3.460)	(3.532)	(3.563)	(3.896)	(3.931)	(3.821)
Crude oil lag (Maya)		0.006	0.001		0.085***	0.066*
		(0.016)	(0.029)		(0.021)	(0.034)
Capacity			0.008			0.130***
			(0.023)			(0.036)
Quantit			–0.140			–0.217
			(0.135)			(0.155)
Distance			–0.017			–0.088**
			(0.025)			(0.036)
CON			–2.228***			1.389**
			(0.648)			(0.641)
HHI			–2.606			–7.747
			(4.423)			(4.921)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.726	0.726	0.731	0.893	0.893	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag Maya* is the price of Maya crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B8. D-i-D controlling for the contemporaneous price of crude oil

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.679***	–8.679***	–8.693**	–10.770***	–10.770***	–10.231***
	(3.321)	(3.321)	(3.347)	(3.690)	(3.690)	(3.484)
Montreal	9.411***	9.411***	8.314***	8.920***	4.929	6.141
	(1.913)	(1.913)	(2.991)	(1.822)	(3.969)	(4.766)
Marteau	15.197***	11.301***	10.619***	17.389***	12.470***	10.948***
	(3.391)	(3.087)	(3.694)	(3.861)	(3.538)	(4.001)
Crude oil		0.022***	0.028***		0.028***	0.029***
		(0.003)	(0.005)		(0.004)	(0.005)
Capacity			0.008			0.130***
			(0.023)			(0.036)
Quantity			–0.140			–0.217
			(0.135)			(0.155)
Distance			–0.017			–0.088**
			(0.025)			(0.036)
CON			–2.228***			1.389**
			(0.648)			(0.641)
HHI			–2.606			–7.747
			(4.423)			(4.921)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.726	0.726	0.731	0.893	0.893	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil* is the price of crude oil. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B9. D-i-D controlling for the contemporaneous and lagged price of crude oil

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.679***	–8.679***	–8.693**	–10.770***	–10.770***	–10.231***
	(3.321)	(3.321)	(3.347)	(3.690)	(3.690)	(3.484)
Montreal	9.411***	9.411***	8.314***	8.920***	4.929	9.673***
	(1.913)	(1.913)	(2.991)	(1.822)	(3.969)	(3.057)
Marteau	15.197***	–9.506***	–11.084***	17.389***	–9.605***	–10.629**
	(3.391)	(2.929)	(3.816)	(3.861)	(3.336)	(4.080)
Crude oil		0.020***	0.026***		0.025***	0.027***
		(0.003)	(0.005)		(0.004)	(0.005)
Crude oil lag		0.130***	0.136***		0.138***	0.135***
		(0.004)	(0.004)		(0.003)	(0.005)
Capacity			0.008			0.130***
			(0.023)			(0.036)
Quantit			–0.140			–0.217
			(0.135)			(0.155)
Distance			–0.017			–0.088**
			(0.025)			(0.036)
CON			–2.228***			1.389**
			(0.648)			(0.641)
HHI			–2.606			–7.747
			(4.423)			(4.921)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,263	2,263	2,263	662	662	662
R-squared	0.726	0.726	0.731	0.893	0.893	0.913
Average outcome	70.92	70.92	70.92	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil* is the price of crude oil and *Crude oil lag* is its lag. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

B5 Different time windows

Table B10. D-i-D from 2009 to 2010

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–2.086***	–2.086***	–2.422***	–5.722***	–5.722***	–4.761***
	(0.524)	(0.524)	(0.557)	(0.407)	(0.407)	(0.532)
Montreal	11.317***	11.317***		10.930***	10.930***	14.529***
	(1.102)	(1.102)		(0.638)	(0.638)	(1.141)
Marteau	–16.122***			–17.477***		
	(0.167)			(0.168)		
Crude oil lag		0.079***	0.078***		0.085***	0.081***
		(0.001)	(0.001)		(0.001)	(0.003)
Capacity			–0.098**			0.159**
			(0.040)			(0.061)
Quantity			–0.052			0.256
			(0.320)			(0.173)
Distance			–0.014			–0.116*
			(0.038)			(0.058)
CON			–0.853			1.684***
			(1.159)			(0.495)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	No	No	No	No	No	No
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	872	872	872	269	269	269
R-squared	0.756	0.756	0.763	0.961	0.961	0.980
Average outcome	75.55	75.55	75.55	73.76	73.76	73.76

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. All regressions include borough and asphalt types effects. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B11. D-i-D from 2008 to 2011

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–10.028***	–10.028***	–10.143**	–14.036***	–14.036***	–12.604***
	(3.780)	(3.780)	(3.888)	(3.740)	(3.740)	(3.717)
Montreal	–2.888	–2.888	–1.669	–4.399	–4.399	–5.686
	(4.032)	(4.032)	(4.178)	(3.616)	(3.616)	(3.975)
Marteau	9.236**	3.521	3.318	11.429***	5.627	4.905
	(3.778)	(3.783)	(4.051)	(3.761)	(3.757)	(3.759)
Crude oil lag		0.107***	0.106***		0.108***	0.105***
		(0.002)	(0.003)		(0.002)	(0.002)
Capacity			–0.003			0.140***
			(0.031)			(0.035)
Quantit			0.136			0.195
			(0.325)			(0.241)
Distance			–0.039			–0.074**
			(0.030)			(0.036)
CON			–2.858***			0.818
			(0.882)			(0.556)
HHI			–0.680			–3.443
			(2.977)			(2.738)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,726	1,726	1,726	492	492	492
R-squared	0.756	0.756	0.763	0.941	0.941	0.954
Average outcome	72.16	72.16	72.16	70.80	70.80	70.80

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. All regressions include borough, year and asphalt types effects. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B12. D-i-D from 2007 to 2012

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.702**	–8.702**	–8.796**	–11.601***	–11.601***	–11.148***
	(3.697)	(3.697)	(3.636)	(3.969)	(3.969)	(3.568)
Montreal	6.684	6.684	5.698	6.432	6.432	4.703
	(4.061)	(4.061)	(4.262)	(6.947)	(6.947)	(7.644)
Marteau	13.116***	14.830***	15.599***	15.153***	14.438***	13.625***
	(3.767)	(3.847)	(3.837)	(4.056)	(4.165)	(3.924)
Crude oil lag		–0.010*	–0.011*		0.004	0.002
		(0.005)	(0.006)		(0.005)	(0.006)
Capacity			–0.005			0.150***
			(0.025)			(0.033)
Quantity			–0.096			–0.194
			(0.347)			(0.331)
Distance			–0.020			–0.053
			(0.027)			(0.037)
CON			–2.386***			1.976***
			(0.701)			(0.701)
HHI			–3.311			–6.985
			(4.517)			(4.825)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,140	2,140	2,140	621	621	621
R-squared	0.732	0.732	0.738	0.902	0.902	0.921
Average outcome	71.04	71.04	71.04	69.47	69.47	69.47

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. All regressions include year, borough and asphalt types effects. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

B6 Addressing market particularities

Since in Montreal the firms are constrained to submit one price per type per year, there could be concern that firms were not bidding to maximize profits in each auction, but rather for each type. In Table B13, we suppose that auctions are for types and investigate the impact of the investigation on type prices. We still observe a significant decrease in price of around 16%, depending on the exact specification.

In Table B14 we see that the size of the contracts in terms of quantity (i.e., demand) seems to be different (the *p*-value of *MontrealXMarteau* is 10.4%). In Montreal before the investigation the average quantity of asphalt auctioned is 184 tons versus 201 tons after the investigation. This difference between the means is not statistically different from 0 (*p*-value 68.95%). However, Quebec City reduced its number of boroughs but not

Table B13. D-i-D for the price of types

Dependent variable Sample	Price of types All types (1)	(2)	(3)	(4)
Montreal × Marteau	–12.25***	–12.55***	–12.24***	–12.70***
	(3.994)	(3.970)	(3.995)	(3.908)
Montreal	17.86***	17.51***	17.67***	17.39***
	(1.570)	(1.630)	(1.567)	(1.560)
Marteau	16.23***	16.92***	17.92***	18.05***
	(3.261)	(3.312)	(3.176)	(3.151)
Median Quantity		–0.812		
		(0.593)		
Maximum Quantity			–0.541**	
			(0.207)	
Average Quantity				–1.376**
				(0.558)
Borough effects	No	No	No	No
Year effects	Yes	Yes	Yes	Yes
Type effects	No	No	No	No
Observations	95	95	95	95
R-squared	0.678	0.681	0.692	0.688
Average outcome	68.38	68.38	68.38	68.38

Notes: Coefficient (standard error in parenthesis) of the effect of the announce of the Marteau investigation on the yearly average price of asphalt articles. *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Median Quantity* is the yearly median quantity of asphalt auctioned for contracts of a given type. *Maximum Quantity* is the yearly maximum quantity of asphalt auctioned for contracts of a given type. *Average Quantity* is the yearly mean quantity of asphalt auctioned for contracts of a given type. All regressions include year effects. SEs are clustered at the city and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B14. D-i-D for the quantity of asphalt types

Dependent variable Sample	Quantity All types (1)
Montreal × Marteau	–200.0
	(122.8)
Montreal	–342.8
	(223.7)
Marteau	237.1*
	(137.6)
Borough effects	Yes
Year effects	Yes
Type effects	Yes
Observations	1,570
R-squared	0.331
Average outcome	306.9

Notes: Coefficient (standard error in parenthesis) of the effect of the announce of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. The regression includes borough, year and asphalt-type effects. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

the surface of its road system. Therefore, the average quantity auctioned of each asphalt type is bound to increase. In fact, the average demand for types goes from 711 tons to 1121 tons. The change in Quebec City explains the large negative interaction coefficient.

We have treated all firms as separate even though in Montreal firm 4 is owned by firm 2 and each will sometimes use the other's plant to produce asphalt. They do not compete in auctions prior to 2009, but do so afterwards. In the following table, we treat these firms as one and assume that firm 4 is a plant of firm 2. We consider the lowest bid of these two firms as the *serious* bid.

In Table B16 we restrict attention to boroughs requesting asphalt every year. There are 9 such boroughs in Montreal (out of 19).

The winner of a particular auction in Montreal is determined at the type/borough level, while in Quebec City, the firm with the lowest total submission for all types needed by the borough wins. In Table B17 we treat every type in an auction in Quebec as an individual auction, like in Montreal.

Table B15. D-i-D when treating firm 2 and 4 as one firm

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.667***	–8.667***	–9.623***	–10.770***	–10.770***	–10.234***
	(3.321)	(3.321)	(3.349)	(3.690)	(3.690)	(3.692)
Montreal	6.437	6.437	7.392*	8.920***	8.920***	8.818***
	(3.960)	(3.960)	(3.966)	(1.822)	(1.822)	(1.988)
Marteau	15.202***	–5.683*	–4.458	17.389***	–4.681	–5.471
	(3.392)	(3.188)	(3.511)	(3.861)	(3.623)	(4.083)
Crude oil lag		0.128***	0.129***		0.135***	0.131***
		(0.003)	(0.004)		(0.003)	(0.005)
Capacity			–0.119***			0.021
			(0.014)			(0.021)
Quantity			–0.132			–0.223
			(0.132)			(0.163)
Distance			–0.059***			–0.131***
			(0.021)			(0.029)
CON			–1.518**			1.493**
			(0.607)			(0.582)
HHI			0.336			–3.291
			(4.022)			(4.542)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,261	2,261	2,261	662	662	662
R-squared	0.726	0.726	0.744	0.893	0.893	0.906
Average outcome	70.93	70.93	70.93	69.37	69.37	69.37

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B16. D-i-D for boroughs always contracting

Dependent variable Sample	Raw bids All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–8.809***	–8.809***	–8.827**	–10.861***	–10.861***	–9.863***
	(3.326)	(3.326)	(3.389)	(3.675)	(3.675)	(3.386)
Montreal	9.490***	9.490***	1.151	3.857	3.857	4.031
	(1.667)	(1.667)	(6.670)	(3.932)	(3.932)	(6.642)
Marteau	14.648***	–6.238**	–7.169*	16.980***	13.386***	–5.946
	(3.364)	(3.144)	(3.807)	(3.866)	(3.914)	(3.954)
Crude oil lag		0.128***	0.136***		0.022***	0.125***
		(0.003)	(0.005)		(0.007)	(0.005)
Capacity			0.032			0.131***
			(0.025)			(0.033)
Quantit			–0.140			–0.207
			(0.140)			(0.153)
Distance			–0.022			–0.044
			(0.031)			(0.037)
CON			–2.813***			3.160***
			(0.713)			(0.933)
HHI			–3.938			–8.365
			(5.255)			(5.515)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,725	1,725	1,725	477	477	477
R-squared	0.744	0.744	0.750	0.893	0.893	0.914
Average outcome	70.98	70.98	70.98	69.48	69.48	69.48

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Table B17. D-i-D treating asphalt types separately in Quebec City

Dependent variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–11.572***	–11.572***	–11.765***	–13.192***	–13.192***	–12.909***
	(2.514)	(2.514)	(2.445)	(2.324)	(2.324)	(2.029)
Montreal	17.423***	17.423***	18.031***	9.159**	8.066*	14.369***
	(1.483)	(1.483)	(2.142)	(4.088)	(4.447)	(3.689)
Marteau	17.221***	–1.439	–0.308	17.814***	–1.266	0.125
	(2.036)	(2.064)	(1.983)	(2.073)	(2.107)	(2.057)
Crude oil lag		0.114***	0.113***		0.117***	0.118***
		(0.004)	(0.004)		(0.006)	(0.005)
Capacity			–0.015			0.153***
			(0.020)			(0.037)
Quantit			–0.046			–0.088
			(0.130)			(0.152)
Distance			–0.007			–0.016
			(0.017)			(0.027)
CON			–0.852**			2.165***
			(0.405)			(0.592)
HHI			4.811			3.327
			(2.963)			(3.633)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,796	2,796	2,796	840	840	840
R-squared	0.734	0.734	0.735	0.862	0.862	0.901
Average outcome	68.89	68.89	68.89	66.98	66.98	66.98

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

B7 Picked-up and delivered asphalt types

In Quebec City, all asphalt types are picked by the city's trucks. In contrast, in Montreal some articles of asphalt are delivered by the firms to the boroughs' reception points.[30] In Table B18 we run the difference-in-difference regression only on collected articles.

In Table B19, we run the difference-in-difference regression only for Montréal's delivered articles, while we keep all of Québec's asphalt auctions as a control.

Table B18. D-i-D for picked up asphalt types

Dependent variable	Raw bids					
Sample	All bids	All bids	All bids	Winning bids	Winning bids	Winning bids
	(1)	(2)	(3)	(4)	(5)	(6)
Montreal × Marteau	–10.627***	–10.627***	–10.181***	–13.077***	–13.077***	–12.517***
	(3.395)	(3.395)	(3.127)	(3.645)	(3.645)	(3.164)
Montreal	12.575***	12.575***	11.733***	14.728***	14.728***	
	(3.913)	(3.913)	(4.018)	(1.209)	(1.209)	
Marteau	14.451***	–4.686	–4.874	16.541***	–3.499	–4.484
	(3.743)	(3.159)	(3.099)	(4.289)	(3.546)	(3.500)
Crude oil lag		0.117***	0.121***		0.123***	0.124***
		(0.008)	(0.008)		(0.008)	(0.008)
Capacity			0.046			0.090*
			(0.030)			(0.051)
Quantity			–0.046			–0.143
			(0.701)			(0.773)
Distance			0.063*			–0.088*
			(0.036)			(0.051)
CON			–1.872***			1.380
			(0.635)			(0.999)
HHI			–0.290			–5.890
			(4.571)			(4.814)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,148	1,148	1,148	319	319	319
R-squared	0.603	0.603	0.612	0.859	0.859	0.870
Average outcome	68.20	68.20	68.20	66.35	66.35	66.35

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

30. Some types are both collected and delivered. In this case, two auctions will be held.

Table B19. D-i-D for delivered types

Dependent Variable	Raw bids					
Sample	All bids (1)	All bids (2)	All bids (3)	Winning bids (4)	Winning bids (5)	Winning bids (6)
Montreal × Marteau	–6.359*	–6.359*	–6.413*	–8.445**	–8.445**	–7.850**
	(3.266)	(3.266)	(3.327)	(3.843)	(3.843)	(3.553)
Montreal	5.883	5.883	4.307	8.825***	8.825***	8.764***
	(4.023)	(4.023)	(4.322)	(1.759)	(1.759)	(1.433)
Marteau	14.375***	11.911***	–6.910*	15.009***	12.034***	–8.244**
	(3.361)	(3.481)	(3.509)	(4.049)	(4.088)	(3.884)
Crude oil lag		0.015**	0.132***		0.018*	0.129***
		(0.007)	(0.004)		(0.011)	(0.005)
Capacity			–0.031			0.145***
			(0.022)			(0.036)
Quantity			–0.206			–0.267
			(0.129)			(0.169)
Distance			–0.067**			–0.041
			(0.026)			(0.037)
CON			–1.711***			2.046**
			(0.654)			(0.913)
HHI			–5.992			–11.340**
			(4.117)			(4.782)
Borough effects	Yes	Yes	Yes	Yes	Yes	Yes
Year effects	Yes	Yes	Yes	Yes	Yes	Yes
Type effects	Yes	Yes	Yes	Yes	Yes	Yes
Observations	1,275	1,275	1,275	389	389	389
R-squared	0.826	0.826	0.831	0.905	0.905	0.926
Average outcome	72.26	72.26	72.26	70.76	70.76	70.76

Notes: Coefficient (standard error in parenthesis) of the effect of the announcement of the Marteau investigation on raw bids: all bids (columns 1–3), winning bids (columns 4–6). *Marteau* is a dummy variable = 1 if the observations are from after the announcement of the investigation. *Montreal* is a dummy variable = 1 if the call was in Montreal. *Crude oil lag* is the price of crude oil lagged. *Capacity* is the firm's potential capacity, defined as the maximum quantity ever bid on by the firm (for Montreal it is based only on post-cartel years). *Quantity* is the number of tons in the call. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *HHI* is the yearly Herfindahl index of each city. For Quebec City we use the one that would have prevailed without the change in legislation in 2009. SEs are clustered at borough and year levels. Significance at the 10% (*), at the 5% (**), and at the 1% (***).

Appendix C

Coordination versus Entry Deterrence: Model-Based Approach

C1 Model

It is important to note at the outset that we are assuming that auctions are independent despite the fact that firms in Montreal are constrained to bid the same price for each asphalt type in each borough. In this section, we simply work with bids per metric ton of asphalt. It should be noted that this means that, like most of the empirical auctions literature, we also ignore the fact that the auctions are run simultaneously and bidders may have preferences over combinations of auction outcomes, for instance because of capacity limitations.[31] As discussed in the main text, the firms in Montreal appear to have sufficient capacity to individually cover all of Montreal's needs and so this should be less of a concern in our context.

The model consists of two stages. In a first stage, firms choose whether or not to participate in an auction. In the second stage, participating firms bid. Since our objective is to characterize the post-cartel period in Montreal, in setting up our model we take into account the observed behavior in this period as described in Table 2. Specifically, we note that firm 1 always participates and so we assign a participation cost of 0 to this firm, and only model the participation decisions of the other *fringe* firms.

We follow the literature and assume that the preparation of bids requires time and effort and so is costly. Following Athey et al. (2011), we assume that the participation cost is heterogeneous, and distributed according to some distribution $H(\cdot)$. This model includes as a special case the homogenous participation cost model as in Levin and Smith (1994), Li and Zheng (2009), Bajari et al. (2014) and Krasnokutskaya and Seim (2011). We first describe the equilibrium of the participation and bidding game, following Athey et al. (2011). In our model, participation and bidding stages are independent in the sense that participation only affects bidding inasmuch as it affects the number of fringe firms participating in the auction.

We begin with the bidding stage assuming there are n firms that have chosen to participate. The bidders draw their costs iid from some distribution $F(\cdot)$. This is true for both the always-participating firm and the fringe firms, so there are no asymmetries in the bidding game. This is motivated by the fact that in our data, while the always-participating firm participates in almost all auctions, its winning rate is not significantly different from that of some other firms during the competitive phase.

At the bidding stage, the bidders who have chosen to participate know how many rivals they face.[32] In the unique symmetric Bayesian–Nash equilibrium of the bidding game with n participants, the firms bid according to

$$B(c) = c + \frac{\int_c^{\infty}(1 - F(u))^{n-1}du}{(1 - F(c))^{n-1}},$$

31. Recently, Gentry et al. (2015) have developed and estimated a model in which bidders have preferences over combinations.

32. The fact that one firm always participates in the auction means that we cannot easily allow for the possibility that the number of participants is unobservable. This would result in an asymmetric model that would be difficult to estimate.

and derive expected profit of

$$u(c, n) = (B(c) - c)(1 - F(c))^{n-1}.$$

We now consider the participation stage. At the participation stage, N–1 fringe firms draw their participation costs e_i, simultaneously and independently from distribution $H(\cdot)$. For simplicity, we assume that $H(\cdot)$ has full support R_+. A fringe firm chooses to participate if and only if its participation cost is below a cutoff $\overline{e}(N)$. This cutoff is found by solving the game backwards, as follows. If all rival fringe firms adopt this cutoff, then each will participate with probability

$$\rho(N) = H(\overline{e}(N)),$$

so a given fringe firm will expect to earn profit equal to $\Pi(\rho(N), N)$, where

$$\Pi(\rho, N) = \sum_{n=0}^{N-2} \binom{N-2}{n} \rho^n (1-\rho)^{N-2-n} Eu(c, n+2).$$

This formula reflects the fact that a given fringe firm has N–2 rival fringe firms, and that the leading firm always participates. If there are m rival firms participating, the total number of participants is $m + 2$, which includes both the leading firm and the given fringe firm that contemplates participating. In a perfect Bayesian equilibrium, a fringe firm will participate if and only if $e_i \leqslant \Pi(\rho, N)$. This means that the participation cutoff $\overline{e}(N)$ is equal to the above expected profit,

$$\overline{e}(N) = \Pi(\rho(N), N).$$

This equation will be fundamental in our bounding approach for the counterfactual price. It can be equivalently stated in terms of the participation probability only, as

$$\Pi(\rho(N), N) = H^{-1}(\rho(N)). \tag{C1}$$

This equation is derived from the fact that the participation cutoff must be equal to the $\rho(N)$th *quantile* of the participation cost distribution, $H^{-1}(\rho)$. Since the expected profit $Eu(c, n)$ is decreasing in n, the l.h.s. of the above equation is decreasing in the probability of rival participation $\rho(N)$, while the r.h.s. is increasing in this probability. This implies that there is a unique equilibrium entry probability $\rho(N)$, and a unique symmetric equilibrium of the complete participation and bidding game.

By *revenue equivalence*, the expected profit of a bidder in the auction with n participants is equal to

$$E[u(c, n)] = \frac{1}{n} E[c_{2:n} - c_{1:n}] \equiv u_*(n). \tag{C2}$$

Using this fact, and denoting the binomial weights by

$$\pi(n, \rho, N) = \binom{N-2}{n} \rho^n (1-\rho)^{N-2-n},$$

allows us to rewrite the expression for the ex-ante expected profit function as

$$\Pi(\rho, N) = \sum_{n=0}^{N-2} \pi(n, \rho, N) u_*(n).$$

C2 Identification

Identification of the production cost

As in Guerre, Perrigne and Vuong (GPV; 2000), we identify the production costs c_i in each auction by applying the inverse strategy transformation. The conditional CDF of b_i is denoted by $G(\cdot|n)$ and the PDF by $g(\cdot|n)$, and these are directly identifiable from the data. In the auction with n bidders, the inverse bidding strategy is given by

$$\phi(b|n) = b - \frac{1}{n-1} \frac{1 - G(b|n)}{g(b|n)}. \tag{C.3}$$

So the distribution $F(\cdot)$ is identifiable according to

$$F(c) = G[\phi^{-1}(c|n)|n].$$

Bounds on the counterfactual price

Our ultimate goal is to identify the entry-deterrence effect, defined as the difference

$$\Delta p = p(N') - p(N),$$

where $p(N)$ is the actual competitive price with N firms, $p(N')$ is the counterfactual competitive price with $N' < N$ firms. Here, N is the actual number of firms in Montreal after the breakup of the cartel, and N' is the number of firms in the cartel before the breakup. In our application, $N = 9$ and $N' = 6$. The key is to identify the counterfactual price $p(N')$. In our model the counterfactual price is driven solely by the entry probability $\rho(N')$.

The participation probability $\rho(N)$ is directly identifiable from the data. But the distribution of the participation cost is *not* identifiable in our model. Indeed, from (C1), we are only able to identify its $\rho(N)^{\text{th}}$ quantile, $H^{-1}(\rho(N))$.[33] But for our application, we are not interested per se in the distribution of the participation cost, but only to the extent that it affects

33. Identification of the participation cost can be enhanced if there is an instrument that affects the participation cost but not the production cost. Alternatively, variation in N can

the counterfactual price with $N' < N$ potential bidders. We are interested in the prices conditional on *buying*. In our model, these prices depend only on the participation probability ρ and are given by

$$P(\rho, N) = \sum_{n=1}^{N-1} w(\rho, n, N) p_*(n)$$

where, invoking revenue equivalence again, the expected price in an auction with n participants is given by the expected second-lowest cost,

$$p_*(n) = E[c_{2:n}],$$

and the weight function is given by

$$w(n, \rho, N) = \frac{\binom{N-1}{n} \rho^n (1-\rho)^{N-1-n}}{1-(1-\rho)^{N-1}}.$$

(The denominator in the weight reflects conditioning on there being at least one fringe firm participating.) The equilibrium price is then given by

$$p(N) = P(\rho(N), N).$$

As N is reduced to $N' < N$, the counterfactual price $p(N')$ will also change, but only because the participation probability $\rho(N)$ will change and the prices $p_*(n)$ get re-weighted. $\prec$One can easily show that the weights $w(\rho, n, N)$ and $\pi(\cdot, \rho, N)$ satisfy the stochastic dominance conditions

$$w(\cdot, \rho, N) \succ w(\cdot, \rho, N'), w(\cdot, \rho, N) \succ w(\cdot, \rho', N), N' < N, \rho' < \rho \qquad \text{(C4)}$$

$$\pi(\cdot, \rho, N) \succ \pi(\cdot, \rho, N'), \pi(\cdot, \rho, N) \succ \pi(\cdot, \rho', N), N' < N, \rho' < \rho. \qquad \text{(C5)}$$

Intuitively, increasing N leads to higher weights being put on higher realizations of the number of participants n in the Binomial distribution, both unconditionally (for the $\pi(\cdot)$), and conditional on at least one firm participating (for the $w(\cdot)$).

These stochastic dominance conditions imply the following monotonicity facts concerning the ex-ante profit $\Pi(\rho, N)$ and the expected price $P(\rho, N)$. First, the ex-ante bidder profit $\Pi(\rho, N)$ must be decreasing in ρ. This is intuitive as a higher participation probability implies more weight put on larger n. Since $u_*(n)$ is decreasing in n, this implies that the ex-ante profit is smaller. Second, $\Pi(\rho, N)$ must be decreasing in N as higher N implies, keeping ρ fixed, more weight put on larger n. Similar considerations imply that the expected price $P(\rho, N)$ is also decreasing in ρ and N.

also aid identification. Unfortunately, neither source of variation is available in our application.

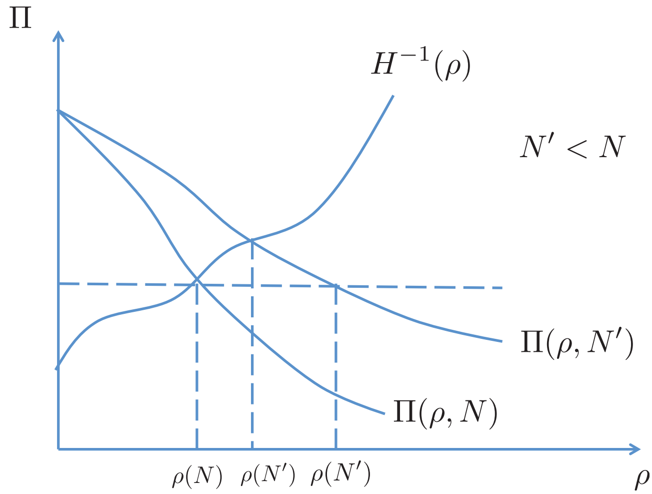

Figure C1. Counterfactual bounds.

The fact that $\Pi(\rho, N)$ is decreasing in both arguments implies that the participation probability, as the solution to (C1), increases as N falls to N' (see Figure C1). The counterfactual participation probability is given by the intersection of the ex-ante profit curve $\Pi(\rho, N')$ and the participation cost quantile curve $H^{-1}(\rho)$. As this figure illustrates, the exogenous entry probability $\rho(N)$ is a lower bound for the counterfactual entry probability $\rho(N')$,

$$\rho(N') > \rho(N), N' < N.$$

Since we do not know $H(\cdot)$, $\rho(N')$ is not identifiable. However, as Figure C1 illustrates, the counterfactual probability can be bounded in an informative way. Specifically, we have

$$\rho(N') \in [\rho(N), \overline{\rho}(N')], \tag{C6}$$

where $\overline{\rho}(N')$ is the participation probability in the (original) Levin and Smith model with homogeneous participation cost (given by the dashed line in Figure C1). That is, $\overline{\rho}(N')$ is determined as the probability that would equate the ex-ante profits with N and N' firms,

$$\Pi(\overline{\rho}(N'), N') = \Pi(\rho(N), N). \tag{C7}$$

The counterfactual price $p(N')$ can be either lower or higher than $p(N)$. Under exogenous entry, the participation probability does not change, and the price would be unambiguously higher. Under endogenous entry, however, the participation probability will be higher with fewer bidders, N'. This is Li and Zheng's *participation effect* that works in the opposite direction. So the overall effect is in general ambiguous. But in a model with distributed participation costs as here, the participation effect could conceivably be small. This would be the case if the distribution $H(\cdot|x)$ put very small (think 0 in the limit) weight on the interval of participation costs

$$[\Pi(\rho(N), N),\ \Pi(\rho(N), N')],$$

so that there is in effect virtually no additional participation when N is reduced to N'. On the other hand, the participation effect is strongest for the atomic distribution of the participation cost, which results in the participation probability $\overline{\rho}(N')$. This case corresponds to the original endogenous participation model introduced in Levin and Smith (1993) and estimated in Li and Zheng (2009). The intuition here is that when the participation costs are heterogeneous, the marginal participants have higher participation costs, and hence there is less participation.

The bounds on the participation probability imply the following identifiable bounds on the counterfactual price

$$p(N') \in [P(\overline{\rho}(N'), N'),\ P(\rho(N), N')]. \tag{C8}$$

In the next subsection, we develop nonparametric estimators for these bounds.

C3 Estimation

The sample consists of T auctions, with individual auctions indexed by $t = 1, .., T$. The number of potential bidders is N, including the leading firm $i = 1$. We index the individual bidders by $i = 1, \ldots, N$. The data generating process takes the following form.

1. The participation costs e_i are drawn from $H(\cdot)$ for all fringe firms. The participation decision of firm i is denoted as $y_{it} \in \{0, 1\}$. The leading firm always participates, so $y_{1t} = 1$ in all auctions t. Fringe firm i participates if and only if $e_i \leqslant \overline{e}(N)$,

$$y_{it} = \begin{cases} 1, & e_i \leqslant \overline{e}(N_t) \\ 0, & \text{otherwise}. \end{cases}$$

This participation process results in a binomially distributed number of participants $n_t = \sum_{i=1}^{N} y_{it}$.

2. Those firms that have chosen to participate, discover their production costs c_{it}, where c_{it} are iid and are distributed according to a cumulative distribution $F(\cdot)$, the same across all the firms. The participants bid in the auction according to

$$b_{it} = B(c_{it}|n_t). \tag{C9}$$

If the leading firm is the sole participant, so that $n_t = 1$, then the auction is declared uncompetitive and is cancelled.

As in GPV, the c_{it}'s can be estimated by the plug-in method. The CDF $G(\cdot|n)$ of the bids can be estimated as the empirical CDF, and $g(\cdot|n)$ can be estimated by the kernel method:

$$\hat{G}(b|n) = \frac{\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it} I[b_{it} \leqslant b, n_t = n]}{\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it} I[n_t = n]}, \tag{C10}$$

$$\hat{g}(b|n) = \frac{\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it} \frac{1}{h} K\left(\frac{b_{it}-b}{h}\right) I[n_t = n]}{\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it} I[n_t = n]}, \tag{C11}$$

where $I[\mathcal{A}]$ is the indicator function of the event $\mathcal{A}$, $K(\cdot)$ is a suitable kernel function, and h is the bandwidth chosen as in GPV, $h = 1.06\hat{\sigma}_b L^{-1/5}$. The costs c_{it} are now estimated by the plug-in

$$\hat{c}_{it} = \hat{\phi}(b_{it}|n_t),$$

and their distribution is estimated as an empirical CDF

$$\hat{F}(c) = \frac{\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it}\tau_{it} I[\hat{c}_{it} \leqslant c]}{\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it}\tau_{it}}.$$

In order to account for boundary effects, we adopt the same trimming approach as in GPV, and only use the trimmed sample of the estimated costs, removing those that are close to boundaries. The parameter $\tau_{it} \in \{0, 1\}$ in the above formula reflects this trimming:

$$\tau_{it} = \begin{cases} 1, & B_{min} + 2h \leqslant b_{it} \leqslant B_{Max} - 2h \\ 0, & \text{otherwise} \end{cases}$$

We now turn to the participation stage. The expected profits and prices in auctions with n participants can be estimated, for a typical project, by replacing the distribution $F(\cdot)$ with the estimate $\hat{F}(\cdot)$. This gives us the estimates

$$\hat{u}(n) = \frac{1}{n}\left(\int c d\hat{F}_{(2:n)}(c) - \int c d\hat{F}_{(1:n)}(c)\right), \hat{p}_*(n) = \int c d\hat{F}_{(2:n)}(c).$$

The integrals with respect to the empirical distributions $\hat{F}_1(\cdot)$ and $\hat{F}_2(\cdot)$ that appear above are actually weighted averages of the ordered sample of cost estimates,

$$\hat{c}_{(1:NT)} \leqslant \ldots \leqslant \hat{c}_{(NT:NT)},$$

given that the overall sample size is NT. The distributions of the order statistics $\hat{F}_{(1:n)}(c)$ and $\hat{F}_{(2:n)}(c)$ are discrete distributions concentrated on the (ordered) sample of estimated costs $\{\hat{c}_{(k)}\}_{k=1}^{NT}$, with

$$\hat{F}_{(1:n)}(\hat{c}_{(k)}) = \hat{F}(\hat{c}_{(k)})^n = \left(\frac{k}{NT}\right)^n,$$

and

$$\hat{F}_{(2:n)}(c) = n\hat{F}_{1:n-1}(c) - (n-1)\hat{F}_{1:n}(c).$$

This yields the estimates[34]

$$\hat{u}_*(n) = \frac{1}{n}\sum_{k=1}^{NT} \hat{c}_{(k)} \Delta \hat{F}_{(2:n)}(\hat{c}_{(k)}) - \frac{1}{n}\sum_{k=1}^{NT} \hat{c}_{(k)} \Delta \hat{F}_{(1:n)}(\hat{c}_{(k)}),$$

$$\hat{p}_*(n) = \sum_{k=1}^{NT} \hat{c}_{(k)} \Delta \hat{F}_{(2:n)}(\hat{c}_{(k)}).$$

These estimates are then plugged in to derive the estimates of the ex ante profit function and the expected price,

$$\hat{\Pi}(\rho, N) = \sum_{n=0}^{N-2} \pi(n, \rho, N)\hat{u}_*(n),\ \hat{P}(\rho, N) = \sum_{n=1}^{N-1} w(\rho, n, N)\hat{p}_*(n).$$

We next use these estimates to obtain the counterfactual bounds on the participation probability $\hat{\rho}(N)$ and $\hat{\overline{\rho}}(N')$, and the corresponding bounds on the counterfactual price. For $N = 9$, we estimate the participation probability $\rho(N)$ as the empirical frequency,

$$\hat{\rho}(N) = \frac{1}{NT}\sum_{t=1}^{T}\sum_{i=1}^{N} y_{it},$$

while the counterfactual participation probability $\overline{\rho}(N')$ is estimated as the solution to the estimated analogue of (C7),

$$\hat{\Pi}(\hat{\overline{\rho}}(N'), N') = \hat{\Pi}(\hat{\rho}(N), N).$$

We then obtain the estimated bound for the counterfactual price difference

$$P(N') - P(N) \in [\hat{P}(\hat{\overline{\rho}}(N'), N') - \hat{P}(N),\ \hat{P}(\hat{\rho}(N), N') - \hat{P}(N)],$$

exactly as described previously.

34. In the estimates below, we adopt the notation $\Delta\hat{F}(\hat{c}_{(k)}) = \hat{F}_{(2:n)}(\hat{c}_{(k)}) - \hat{F}_{(2:n)}(\hat{c}_{(k-1)})$, with $\hat{c}_{(0)} = 0$.

C3.1 Confidence intervals of the bounds. To compute confidence intervals around our estimated bounds for the entry effect we follow the bootstrap approach taken in Marmer and Shneyerov (2012). In a first step we create a bootstrap sample of T auctions by drawing the auctions (as blocks) from the original sample with replacement. Next, we redo the entire estimation procedure for this bootstrap sample, including recomputing the costs. This will generate a new value for each of the bounds. We then repeat this step 500 times, which yields a bootstrap sample of 500 values for each bound. Finally, in order to determine a confidence interval $[\Delta, \overline{\Delta}]$ that covers the true price difference with probability 95%, we follow Imbens and Manski (2004) and compute the lower 5% (for Δ) and upper 95% (for $\overline{\Delta}$) percentiles of these samples.