Complementary bidding and the collusive arrangement: Evidence from an antitrust investigation*

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Abstract

Clustered bids and a missing mass of nearly tied bids have both been proposed as markers of collusion. We present causal empirical evidence from an actual procurement cartel that bidding involves both clustering and a gap around the winning bid. We support these results with information from testimony of cartel participants that explain how both patterns arise naturally as part of an arrangement featuring complementary bidding. Based on these findings, we develop an easy-to-implement screen for collusive arrangements featuring complementary bidding.

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1 Introduction

Collusion involves groups of firms that explicitly agree on coordinating prices, thereby earning higher profits at the expense of consumers. This behaviour led former EU commissioner Mario Monti to describe cartels as "cancers on the open market economy."[1] Since a sizeable share of investigated cartels arises in public procurement auctions and since procurement represents an important component of total general government expenditures (on average 30% in OECD countries in 2015, OECD, 2017), bidding rings impose a significant cost on taxpayers. Understanding the functioning of bidding rings and identifying patterns and behaviour associated with them is therefore of importance for antitrust authorities. Many have started to take into consideration behaviours linked with collusion to guide their searches for suspicious bidding patterns. For example, instances of high correlation in the residuals of the bidding function (Bajari and Ye, 2003) and low bid variance across auctions (Froeb et al., 1993; Harrington, 2008; Abrantes-Metz et al., 2006) are thought to imply coordinated efforts of industry participants and are being used to provide guidance about which markets antitrust authorities should target for investigation with their limited resources.

Clustering of bids within auctions, especially of the two lowest bids, has also been suggested as indicative of collusion.[2] As pointed out in Chassang et al. (2022), clustering can occur because firms designated to submit complementary losing bids should bid just above the assigned winner so that the latter has no incentive to raise its bid. An extreme form of clustering in which identical bids are submitted may also occur when cartel members are unable to make cash transfers and so use the seller as their randomization device to determine allocation (see McAffee and McMillan, 1992).

However, in the presence of antitrust oversight, cartel members may try to avoid submitting bids that are too clustered, since authorities often flag such auctions. Therefore, a cartel concerned about detection may want to leave a margin of safety between the designated winner's bid and the closest losing bid. Furthermore, leaving a margin of safety between the winning and closest losing bids helps to guarantee that the designated winner obtains the contract even in the event of small mistakes (trembles) in how firms bid. Such behaviour has been documented in cartels operating in Switzerland, where large gaps were left between winning and losing bids (see Imhof et al., 2018). However, the gap cannot not be too large, since this would imply that the designated winner could have increased its bid and therefore its profits (Ortner et al., 2020 and Chassang et al., 2022).

In this paper, we present causal empirical evidence from an actual procurement cartel that bidding involves a high degree of clustering, but also a gap around the winning bid. We support these results with information from testimony of alleged participants in the

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

[2] See for instance Marshall and Marx (2007), Porter and Zona (1993), and Harrington (2008), and also Feinstein et al. (1985), LaCasse (1995), and Ishii (2009).

cartels that explain how both patterns arise naturally together as part of a cartel arrangement featuring complementary bidding. Finally, based on these findings, we develop a simple and easy-to-implement screen for a collusive arrangement featuring complementary bidding.

Our study is centered on the construction industry in Montreal, where the existence of cartels in some sectors was discovered in October 2009, following an investigation by a news show, *Enquête*, that shed light on collusive practices in this industry, namely bid-rigging, complementary bidding, and market-sharing agreements. Immediately after the show, the Quebec government launched a police investigation called *Opération Marteau* and then a formal inquiry, known as the Charbonneau Commission, in order to verify the reported allegations.[3]

Our empirical analysis examines bidding data from calls for tender in Montreal's asphalt industry, one of the industries suspected of being collusive. We study the distribution of bid differences (the difference between a given bid and the next most competitive bid), which capture bidders' margins of victory or defeat. Bid differences are negative when the bidder won the auction, and positive otherwise. We start by calculating bid differences during the infringement period and find a low mass at zero and a significant mass of bid differences just to the right and left of zero, suggesting the existence of isolated winning bids and bid clustering. Together these two forces generate what appear to be twin peaks (a bimodal pattern) centered around zero in the distribution of bid differences.

To provide causal evidence that clustering and isolated winning bids were part of the collusive arrangement, we adopt a difference-in-differences approach in which we compare the extent of winning-bid isolation and clustering in Montreal's asphalt industry before and after the police investigation to patterns over the same time span in Quebec City, whose asphalt industry has not been the subject of collusion allegations. More specifically we use techniques related to the distributional regression approach developed by Fortin et al., 2021, and Chernozhukov et al., 2013 to compare the distribution of bid differences in Montreal and Quebec City before and after the investigation. Our findings provide causal evidence that the collusive arrangement featured isolated winning bids and clustering. The pattern of isolated winning bids and bid clustering (the twin peaks in the distribution of bid differences) observed during the infringement period disappears in Montreal after the start of the police investigation and is much less pronounced in Quebec City before and after the investigation.

Interviews from the news program and testimony from the Commission help us to understand how these bid patterns are associated with a collusive scheme. The cartel

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

arrangement involved market segmentation and complementary bidding. Representatives from each of the cartel firms would get together to decide which of them would be assigned a given contract as a function of the firms' production capacities and their plant locations. The designated winner would then organize the bidding for the contract by contacting the other cartel members and giving instructions on complementary bidding, often using coded language.[4] According to the Enquête news program, complementary bids were submitted in order to give the appearance of competition, thereby providing incentive for clustering. Furthermore, there is evidence that the Ministry of Transportation flagged tied bids, and that bidders were concerned about oversight and about mistakes in the bidding process, and as result, a gap was left between the winning bid and the closest losing bid.

This testimonial evidence is consistent with cartel behaviour described in Chassang et al. (2022) and in Ortner et al. (2020). They find isolated winning bids in their sample of Japanese procurement auctions, but they also point out that bids are somewhat clustered with a large mass of bids within 2% of the winning bid. They explain that firms instructed to provide complementary losing bids should be incentivized not to undercut the designated winner, and that losing bidders should bid just above the designated winner so that the latter has no incentive to raise its bid. This leads to clustering of bids. Regarding isolated bids, the authors propose two possible collusive explanations. First, if the possibility of antitrust scrutiny is added to the framework just described, and if highly clustered (and, in particular, identical) bids attract antitrust scrutiny, then the cartel could want to ensure that identical or nearly-identical bids are not submitted. Second, isolated winning bids may facilitate the assignment of the contract to the designated winner, thereby improving allocative efficiency. They point out that isolation of winning bids can guarantee that the designated winner comes away with the contract in cases where precise bids cannot be assigned to losers and/or if bids can be perturbed by small trembles. Our empirical findings can be viewed as providing causal and testimonial evidence in support of these arguments.

It is also related to the model proposed in LaCasse (1995). Hers is a model of a first-price sealed-bid auction in which an all-inclusive cartel decides whether to rig bids in the face of antitrust oversight. Firms endogenously choose whether or not to collude, knowing there is some chance their conspiracy will be detected. This knowledge influences the form that the collusive arrangement takes. LaCasse shows that the chosen arrangement has two features that line up with behaviour described in the testimony. First, the frequency of identical bids should be very low, since these identify collusion. Second, losing bids give the appearance of competition, but are derived from a truncated bid distribution, since they must be higher than the designated winning bid.

[4] See paragraphs 997-1009 ad 1060-1100 of Gilles Théberge's testimony from the Charbonneau Commission, May 23rd 2013, Théberge (2013a).

Motivated by our findings, we propose a local screen for a collusive arrangement featuring complementary bidding. Note that our results so far were based on a difference-in-differences setup that requires data from one or more control markets and being able to identify the beginning or end of collusive activity. Authorities interested in screening for collusion will not necessarily have access to such data. We therefore propose a screen that is based only on data from the suspect calls for tender.

Our screen builds on the theoretical results of Chassang et al. (2022) and Kawai et al. (2023). To implement the screen, we construct a new set of bid differences, this time excluding the winning bid. There is no reason to expect this new distribution of bid differences to exhibit the same sort of bimodal distribution as the original distribution that includes the winning bids, and so it can serve as a control group that does not rely on having information on other markets or knowing the end date of the cartel. The key condition for the screen is that, under competition, bids have a smooth density. This condition is satisfied for instance in sealed-bid first-price auctions in IPV environments, where bidders are symmetric and their costs are drawn iid from a distribution with differentiable density on its bounded support. Smoothness of the bid density implies smoothness of the densities of the bid-differences. The screen involves the comparison of the distributions of these new bid differences that exclude the winning bid, and the original ones that do not, conditional on these differences taking values in a small interval around zero. Since under competition the densities of the two bid differences are smooth, the conditional distributions should be approximately equivalent in this small interval. This result forms the basis of our testable null hypothesis; rejecting the equality of the conditional distributions of the two bid differences in a small interval around zero implies rejecting the null that bidders submit competitive bids.

The screen can be empirically implemented both non-parametrically and parametrically using the distributions of the two bid differences conditional on them taking values in the same small interval around zero. We apply it to calls for tender in Montreal during the collusive period, rejecting the null of competition. To evaluate the performance of our screen we repeat the exercise for three other samples: (i) Montreal post-investigation, (ii) Quebec pre-investigation, and (iii) Quebec post-investigation. In each case, there is no reason to suspect that collusion was taking place and so the null should not be rejected. This is the case and so we conclude that our screen is a useful tool for detecting a collusive arrangement featuring complementary bidding.

To further investigate the external validity of our screen, we apply it to other procurement settings where collusion is either known to have, or not to have, taken place. Specifically, we apply it to the Ohio school milk cartel analysed by Porter and Zona (1999) and to the Japanese procurement cartels studied by Chassang et al. (2022), and in each case our test correctly rejects the null of competition. We also apply it to procurement auctions in Georgia that are believed to be competitive (see Kawai et al., 2022) and our screen does not reject the null of competition. Finally, our test has been applied by authorities in Finland and Sweden to investigate cartels operating in those two countries, and in each case it correctly rejects the null of competition (see Buri et al., 2023).

This paper relates to the literature on the detection of cartels in procurement auctions. In addition to the papers mentioned above see also Porter and Zona (1999), Pesendorfer (2000), Conley and Decarolis (2016), Aryal and Gabrielli (2013), Marmer et al. (2016), Schurter (2017), Chassang and Ortner (2019), kaw, and Kawai et al. (2023). We contribute to this literature by providing a new screen that builds on the theoretical results of Chassang et al. (2022) and Kawai et al. (2023). Compared to these papers, our test has the following advantages: a) it is simple to implement as it involves the estimation of a series of OLS regressions or the implementation of a Kolmogorov-Smirnov test, b) it can be applied in settings where the researcher or antitrust authority has no knowledge of which markets or firms are collusive, c) it allows for the control of market and auction heterogeneity, and (d) it focuses on more than just the presence of tied bids, zooming out from bid differences of zero.

This study also relates to the literature on explicit cartels and their functioning.[5] See for instance Roeller and Steen (2006), Asker (2010), Genesove and Mullin (2001), Clark and Houde (2013), Chilet (2018), Igami and Sugaya (2022), and Byrne and deRoos (2019).[6] Relative to these papers, here we provide new evidence on the role of complementary bidding. Using the same data, Clark et al. (2018) study the impact of the investigation into collusion in Montreal's construction industry and provide causal evidence of the impact of the investigation on procurement costs and entry deterrence. With the help of a model, the paper quantifies the importance of entry deterrence for sustaining high prices during collusive periods. In this paper, we use testimonial and descriptive evidence to understand the role of complementary bidding for the collusive arrangement, and based on this, we develop a simple to implement screen for collusion.

The paper is structured as follows. In the next section we discuss the adjudication process of the contracts, the police investigation and the special Commission appointed by the Quebec government to examine collusion and corruption in Quebec's construction industry. Section 3 presents a framework for understanding how clustering of bids and isolated winning bids could coexist as part of a collusive arrangement. Section 4 describes the data. In Section 5 we present descriptive evidence motivating our empirical analysis, which is laid out in Section 6. Section 7 discusses the screen that we propose based on our analysis. Finally, Section 8 concludes.

[5]Ross (2004) reviews cartels in Canada.

[6]A separate literature studies tacit coordination. See for instance Slade (1987), Slade (1992), Miller and Weinberg (2017), and Ciliberto and Williams (2014).

2 The markets and the investigation

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

2.1 The markets

The focus of the analysis is on municipal contracts for the procurement of asphalt in Montreal and Quebec City. Montreal is made up of 19 boroughs, while Quebec is composed of six boroughs.[7] When procuring asphalt, each borough in Montreal makes predictions about the amount required for the maintenance of their roads for the coming year. Due to the weather conditions, most contracts are awarded for the spring and summer seasons. There were ten different asphalt types ordered in Montreal, and slightly fewer in Quebec City. 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. Submissions are invited for all boroughs requiring asphalt simultaneously. 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.

Montreal does not have any factories for producing asphalt, but does have the personnel necessary to make use of the procured asphalt for road repair. Asphalt can either be delivered to the borough's designated reception point or collected by the city using their trucks. Certain asphalt types are both delivered and collected, while others are only delivered or only collected. Auctions for all types and all boroughs are all performed separately.

Firms propose bids with two components. First, firms submit a unit price per metric ton for each type of asphalt required (raw bid). Second, firms submit a bid that represents the total price, which is a function of the unit price multiplied by the quantity required for each type of asphalt plus mechanically inputed shipping costs and taxes (total bid). Auctions are first-price, sealed-bid and single-attribute (cost), such that the firm offering the lowest total bid wins the contract. In our main empirical analysis we focus on raw bids without the transportation cost, because, as discussed below, the testimonial evidence suggests that in some of the cartelized markets in Montreal, collusion took place at the level of the unit price. It is also the case that during our sample period there were changes to the way transport charges were calculated in Montreal, and in Quebec City it is not possible to properly separate out transportation costs. In Appendices A.11 and A.12, we consider instead total bids, and a restricted set of raw bids for which the firm with the

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

lowest raw bid also has the lowest total bid, and we find that our results are consistent with those derived using raw bids.

2.2 The investigation into collusion

The *Commission of Inquiry on the Awarding and Management of Public Contracts in the Construction Industry* (known as the Charbonneau Commission) was established on October 11th 2011 to investigate allegations of collusion and corruption initially revealed in 2009 by Radio Canada and through the police investigation, Opération Marteau.[8] Testimony heard throughout the Commission substantiated the allegations of collusion in various construction-related industries in and around Montreal, including the asphalt industry in Montreal proper. According to testimony, collusion has existed in and around Montreal and for provincial contracts (with the Ministry of Transport) at least as far back as the 1980's.[9] Contracts involving asphalt, sewers, aqueducts and sidewalks were all affected.[10]

Testimony also revealed that, although less structured collusion had existed as far back as the 1980's, the cartel in Montreal's asphalt market was formed in 2000, by four of the dominant construction firms in Montreal (see Radio Canada, 2013). The firms coordinated (i) the quantity of asphalt to be produced by each member, (ii) the territory of each member, and (iii) the price of raw materials for the production of asphalt. Two other firms were added to the initial four, such that six firms actively participated in the market. All six were involved in the cartel.[11]

The collusive arrangement was characterized by market segmentation, complementary bidding and payoffs to bureaucrats. Prior to the allocation of contracts by the municipalities or the Ministry of Transport, conspiring firms would acquire private information about other participants in the auction and possibly about the timing, location and size of other upcoming calls for tender from officials.[12]

The police task force, Opération Marteau, was launched on October 22nd 2009. The task force comprised 60 members and had support from the Competition Bureau of

[8] The Commission's mandate was to: (i) 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, (ii) paint a picture of possible organized crime infiltration in the construction industry, and (iii) 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. See https://www.ceic.gouv.qc.ca/la-commission/mandat.html.

[9] See paragraph 1118 of Piero Di Iorio's testimony from the Charbonneau Commission, November 26th 2012, Di Iorio, 2012.

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

[11] See paragraphs 575 and 677-696 of Gilles Théberge's testimony from the Charbonneau Commission, May 23rd 2013, Théberge (2013a).

[12] See paragraphs 684-686 and 724 of Jean Théoret's Testimony from the Charbonneau Commission, November 26th 2012, Théoret (2012).

Canada, the Ministry of Transportation, the Régie du Bâtiment, and the Commission de la construction du Québec. In our empirical analysis we will assume that the police investigation and the Radio Canada news show caused collusive activity to cease and bidding to return to more competitive levels.

3 Complementary bidding, isolated winning bids and clustered bidding

In this section we describe how isolated winning bids and clustered bidding can be part of a collusive arrangement featuring complementary bidding. Clustering can arise for a variety of reasons. As pointed out in Chassang et al. (2022), it might occur because firms designated to submit complementary losing bids will bid just above the assigned winner so that the latter has no incentive to raise its bid. It might also occur if the designated winner proposes a minimum bid under which the complementary bidders are told not to bid, since this will help to give the appearance of collusion. Clustering may also arise in the form of identical bids submitted when cartel members are unable to make cash transfers and so use the seller as their randomization device to determine allocation (see McAffee and McMillan, 1992). Chassang et al. (2022) propose two potential explanations as to why winning bids might be isolated when collusion is involved. First, if nearly-identical bids attract antitrust scrutiny, then a cartel may want to prevent the submission of clustered bids. Second, isolated winning bids may make it easier to assign the contract to the designated winner and, in so doing, improve allocative efficiency. The authors argue that winning-bid isolation can help to secure the victory of the designated winner when exact bids cannot be assigned to losers and/or if small trembles can perturb bids. In their sample of procurement auctions from Japan, Chassang et al. (2022) find evidence that winning bids are isolated, but that at the same time bids are somewhat clustered with a large mass of bids within 2% of the winning bid.

This is related to the model developed by LaCasse (1995) of collusion in first-price sealed-bid auctions subject to antitrust oversight. Firms can choose whether or not to collude, knowing that the antitrust authority can detect collusive behavior upon investigation. The possibility of antitrust oversight affects the likelihood that collusion arises and the form that it takes. In particular, if identical bids attract antitrust scrutiny, then the cartel will avoid this sort of bidding. LaCasse proposes a bid rotation scheme featuring an incentive-compatible communication mechanism for determining bidding. The mechanism assigns to the designated winner a bid that maximizes expected cartel profits and to other cartel members bids below that level. The designated winner's bid must be close to the second highest bid in order to avoid leaving money on the table.

These explanations provide a framework for understanding why bids within an auction can feature both clustering and isolated winning bids. Moreover, they are consistent with testimonial evidence from the Charbonneau Commission and the *Enquête* news report. According to these sources, after having acquired confidential information about the contracts from officials of the municipality, firms' representatives then met to establish the winner of the contract and to settle on complementary bids to be submitted by the designated losers. This decision was based on attributing a certain amount of the overall work to each firm and was a function of location and distance to particular jobs. Trying to understand the arrangement, the president of the Charbonneau Commission interrogated a former high ranking executive at a Montreal construction company, Gilles Theberge, asking:

Do I understand correctly that it is the location, that it is not only the volume that it is determined for who will supply the City in asphalt, but also the location where the work was to be done?[13]

To which Gilles Theberge responded in the affirmative, and elaborated:

We filled the submissions as they came, we filled them in groups, we filled that particular submission in accordance with a participant that had say 40 000 tons, he was sure to have at least 40 000 tons, another 30 000 tons, another 10 000 tons. So then just based on transportation, we knew roughly how many each would have in volume.[14]

These sources also make clear that complementary bidding was part of the collusive arrangement:

Well, one has to enter a complementary bid as well when you want to bid. You cannot just withdraw them for the sake of withdrawing them. At calls for tender, you have to bid, we submit a complementary bid.[15]

The final report of the Commission into collusion and corruption in Montreal describes the general purpose of complementary bidding as being to provide the impression that the market was competitive:

Complementary bids are an instrument of collusion. They give the illusion of healthy competition. The tactic is illegal, but it is almost undetectable.[16]

[13]Translated from *Est-ce que je comprends que c'est le lieu où, que c'est non seulement la tonne qui était où s'en était rendu à qui pour fournir la Ville en asphalte, mais aussi le lieu d'où se tenait les travaux?* Paragraph 1084 of Théberge (2013b).

[14]Translated from *On les a remplies comme tel, on les a remplies en groupe, on a rempli cette soumission-là en étant, en étant d'accord avec un participant avait quoi quarante mille (40 000) tonnes, il était sûr d'avoir au moins quarante mille (40 000) tonnes, l'autre trente mille (30 000) tonnes, l'autre dix mille (10 000) tonnes. Ça fait que juste avec les questions de transport, on savait combien à peu près chacun aurait de tonnes.* Paragraph 1081 of Théberge (2013b).

[15]Translated from *Bien il faut rentrer, il faut rentrer une soumission de complaisance aussi quand tu veux soumissionner. Il ne faut pas juste retirer des soumissions pour retirer. Les appels d'offres il faut soumissionner, on remplit une soumission de complaisance.* Paragraph 1075 of Théberge (2013b).

[16]Translated from *Les soumissions de complaisance font partie de l'attirail du réseau de collusion. Elles donnent l'illusion d'une saine concurrence. L'artifice est illégal, mais il est presque indétectable.* Page 193 of Charbonneau and Lachance, 2015.

The designated winner was responsible for managing the complementary bids that each of the cartel firms would submit in the auction. Most of the evidence suggests that this was achieved by the designated winner directly informing the complementary bidders of a price below which they should not bid (or sometimes even of an exact bid they should target), but sometimes telling them what the designated winner will bid:

Well, the designated winner had to give each the starting number. Well, the bid amount that he had to enter, including taxes.[17]
and

Well, either at the meeting he has already prepared his price for me because he knows I am invited to bid on the same project, or if not, he calls me to give me his price.[18]

This was even more clearly outlined in testimony related to Montreal's water and sewer cartel that featured many of the same players as the asphalt cartel:

When an entrepreneur knows that a contract is reserved for him, it is his responsibility to call the other members of the cartel in order to reassure himself that his bid will be lowest. Essentially there are two ways for him to request complementary bids. The first: he indicates the minimum price at which his competitor accomplices must bid. The second: he provides them with his tender slip, that outlines his unit prices. In other words, every member of the cartel adjusts its unit prices slightly higher, [...].[19]

Note that this quote also highlights the fact that the collusive arrangement was centered around raw bids (unit price per metric ton).[20]

Sometimes, worried that their phone conversations might be overheard, the participants would employ a coded vocabulary when communicating how the complementary bidding should take place. For instance, the specified winner would claim to be organizing a round of golf. He would call other firms saying, for example, "we will start from the 4th hole and we will be 9 players." This meant that the complementary bids must be over $4 900 000 (4th = $4 000 000 and 9 players = $900 000). The specified winner would bid just below this threshold (Théberge, 2013b; *Enquête*, Radio Canada, 2009).

[17]Translated from *Bien, celui qui était gagnant devait remettre à chacun le départ. Bien, le numéro de la soumission qui devait rentrer, incluant les taxes.* Paragraphs 1139-1140 of Théberge (2013b).

[18]Translated from *Bien, soit qu'à la réunion il a déjà préparé son prix pour moi parce qu'il sait que je suis invité sur le même projet ou, sinon, il m'appelle pour me donner son prix.* Paragraph 701 of Théberge (2013b).

[19]Translated from *Lorsqu'un entrepreneur sait qu'un contrat lui est réservé, il est de sa responsabilité d'appeler les autres membres du cartel afin de s'assurer que sa propre soumission soit la plus basse. Essentiellement, deux façons s'offrent à lui pour demander des soumissions de complaisance. La première: il indique le prix minimum auquel ses concurrents complices doivent soumissionner. La deuxième: il fournit à ces derniers son bordereau de soumission, qui ventile ses prix unitaires. En d'autres mots, chaque membre du cartel ajuste ses prix unitaires légèrement à la hausse, [...]* Page 34 of Charbonneau and Lachance, 2015.

[20]Theberge also talks about coordinating on prices per tonne. See paragraph 701 of Théberge (2013b).

Testimony during the Charbonneau Commission also provides evidence of behaviour leading to isolated winning bids. Despite the incentive to bid as close to the next lowest bid as possible, the designated winner would, according to testimony, allow a small margin between the assigned lowest losing bid and its bid to guard against any mistake in bidding. When asked to describe the complementary bidding procedure Gilles Theberge responded:

It was a custom like this. The others did not report their bids to me, me also I did not tell them my bid. Why should I have told my bid to him? If my bid was $2.310M, I would have told him: listen, you can submit $2.380M. I kept for myself a small margin in case the secretary made a mistake in typing, but never more than that (Théberge, 2013b).[21]

The result was a very small gap between the two lowest bids – in other words, isolated winning bids.

There is also evidence that cartel members were concerned about antitrust oversight, which may explain the gap that was left between the winning bid and the next closest bid. As mentioned, cartel members explicitly referred to complementary bidding being employed because it was difficult to detect. Moreover, bidders sometimes spoke in code for fear of being caught. This makes sense, since authorities explicitly targeted identical bids when monitoring for collusion as captured by the following statement from the Report of the anticollusion Unit at the Ministry of Transportation of Quebec (Duschesneau, 2011):

The following elements might reveal collusion: competitors submit identical offers or the offers increase by constant amount.[22]

In Sections 5 and 6 we provide causal evidence that the collusive arrangement involved both isolated winning bids and clustered bidding, and in Section 7 we develop a screen based on these observations.

4 Data

The dataset, described in Clark et al. (2018), consists of borough-level asphalt contracts for Montreal and Quebec City, obtained through access to information requests at the Municipal Clerk's office. The dataset covers procurement auctions from 2007 to 2013 for both cities.[23] The data contain information on all submitted bids (raw bids and transportation charges) and the identity of the winner. Addresses for all asphalt plants in Montreal and Quebec City were also collected from the Quebec Ministry of Transportation, and we gathered addresses of the central point of reception for each neighborhood

[21]Translated from *C'était une coutume comme ça. Les autres ne me le donnaient pas, moi Je ne le donnais pas non plus. Pourquoi Je lui aurais donné mon prix? Lui, si ma soumission était 2,310 M$, Je lui disais, écoute, tu peux rentrer à 2,380 M$. Je me gardais un peu de marge en cas que sa secrétaire fasse une erreur en dactylographiant, mais il n'avait jamais plus que ça.*

[22]Translated from *Les éléments suivants peuvent révéler de la collusion : - Des concurrents présentent des offres identiques, ou bien les offres de prix des soumissionnaires augmentent par paliers réguliers.*

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

in the two cities. Together these allow us to determine delivery distances for each tender. Capacity information is also available for Montreal. Finally, we also collected information on the price of crude oil, since this is the main input into the production of asphalt.[24]

The dataset has information on 662 contracts. The median and mean number of participants are 3.00 and 3.42, respectively. The mean winning raw bid (unit price per ton) is $68.73 per ton with a standard deviation of 10.32. Table 1 presents summary statistics for Montreal and Quebec City.[25] Before the start of the police investigation, there is a remarkable difference in the winning bid between the two municipalities, equal to $18 per ton. The winning bid in Montreal decreases after the start of the investigation by $8 per ton. In contrast, in Quebec City it increases by $6 per ton, such that the overall difference after the investigation is just $4 per ton. As documented in Clark et al. (2018), part of the cartel scheme in Montreal involved the deterrence of some firms from bidding in auctions. In Montreal, after the police investigation was launched, The number of firms bidding increased from 6 to 9 in Montreal from before to after the investigation, resulting in an increase in the mean number of bidders from 2.6 before the start of the police investigation to 3.6 after. On the other hand, in Quebec City, we observe that the mean number of bidders is between 3 and 4 in both periods.

Table 1: Descriptive statistics for Montreal and Quebec City

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

Since the focus of our analysis is on the firms alleged to be part of the collusive arrangement in Montreal, and given that part of the cartel scheme involved the deterrence

[24]These data are 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, and lag one period.

[25]Table 1 replicates exactly Table 1 in Clark et al. (2018).

of other players from entering the market (Clark et al., 2018), we exclude firms that entered in Montreal's asphalt market following the launch of the investigation. In particular, to ensure that the entry of new firms does not contaminate the analysis, in our main specification we drop auctions in which new entrants participated. By doing so, we analyze only the differences in bids from the six firms suspected of having joined the cartel in both periods. We therefore drop 269 auctions. Table 2 reports summary statistics for Montreal for the restricted sample (nothing changes in Quebec City). Dropping the auctions without entrants reduces the number of auctions in Montreal after the start of the investigation to 132. The average reduction in the winning bids is also slightly lower, falling from \$8 per ton to \$6 per ton. In the appendix we present results in which we do not drop the entrants and our results are largely unchanged. We also show that results are unchanged if we drop auctions from 2010, which features more contracts than in other years in the full sample with entrants. See Appendices A.5 to A.7.

Table 2: Descriptive statistics for Montreal – restricted sample

Year	\$ awarded (millions)	Nbr contracts		Nbr bidding boroughs	Avg tons of asphalt	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	.39	42	.	8	126	5	1.9	70
2011	.48	40	.	6	166	5	2.6	67
2012	1.7	28	.	10	825	6	3.4	67
2013	1	22	.	10	641	5	2.4	71
	Total					Average		
2007-2009	8.1	215	.	12	491	5.3	2.6	75
2010-2013	3.5	132	.	8.5	440	5.3	2.6	69

5 Motivating facts

Chassang et al. (2022) document *missing bids* around 0 in the distribution of bid differences for public works procurement auctions in Japan. The measure they focus on is the difference between a given bidder's own bid and the most competitive bid in the auction. In particular, they denote the bid for any firm i bidding in auction a by $b_{i,a}$, and by $\wedge \mathbf{b}_{-i,a}$ the minimum bid by i's rivals. Consider, for example, an auction with three bidders. Suppose further that bids submitted by bidders 1, 2, and 3 are, respectively, \$60, \$75, and \$78 per ton. Then the difference between bidder 1's bid and the most competitive bid is -15 (since bidder 1 wins the auction, the most competitive bid is the second lowest bid), the difference between bidder 2's bid and the most competitive bid is +15, and the difference between bidder 3's bid and the most competitive bid is 18. In other words, bid differences capture bidders' margins of victory or defeat. Chassang et al.

(2022) are interested in the distribution of

$$\Delta_{i,a}^{CKNO} = \frac{b_{i,a} - \wedge \mathbf{b}_{-i,a}}{r}, \tag{1}$$

where r is the reserve price in auction a. Given the way in which this measure is constructed, the difference between the winning bid and the most competitive bid (the second lowest bid) in the distribution appears to the left of 0, while the difference between a losing bid and the most competitive bid (the lowest bid) appears to the right of 0.

We construct the same measure of bid differences for our sample of auctions from the known cartel period in Montreal. Since auctions in Montreal do not have a reserve price and since the bids are already in dollars per ton, there is no need to normalize.[26] We are interested in the following measure of bid differences:

$$\Delta_{i,a}^{1} = b_{i,a} - \wedge \mathbf{b}_{-i,a}. \tag{2}$$

In Figure 1 we plot the distribution of bid differences in Montreal before the investigation on a range plus or minus 10% of the average winning bid in this period. Like Chassang et al. (2022), we find that there is much less mass at 0 than in a small neighborhood around 0, suggesting that our winning bids are also isolated. The figure also provides our first evidence that there is clustering of bids, with most bid differences falling within about 3% of the average winning bid. Together, clustering and missing bids generate a bimodal, or twin-peaked, distribution of bid differences, centered around zero.

While this figure provides suggestive evidence of a pattern of clustered bids and isolated winning bids, it remains to show that this pattern is related to the collusive arrangement. This is what we turn to in the following section.

6 Empirical analysis

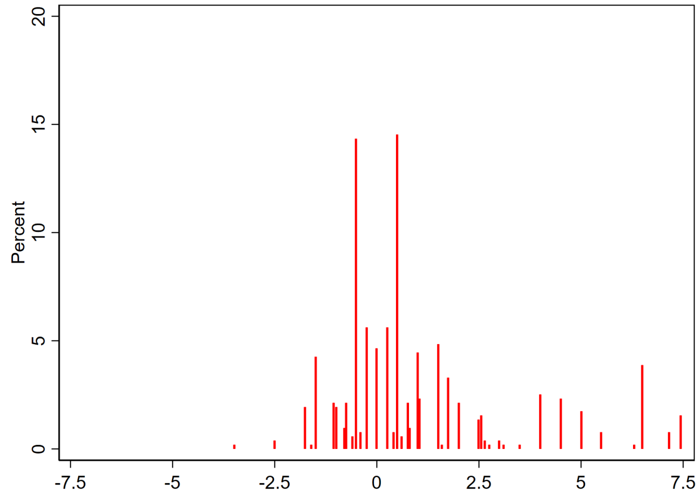
6.1 Descriptive analysis

We start by plotting bid differences, $\Delta_{i,a}^{1}$, in Figure 2, this time not just for Montreal during the cartel period, but also for Montreal post-investigation and Quebec City both pre- and post-investigation.[27] As already seen, in Montreal before the investigation, there is evidence of isolated winning bids and clustering. There is much less mass directly at 0 than in a small neighborhood around 0, and bid differences are overall quite clustered

[26] In Appendix A.2, we investigate the robustness of the definition of bid difference, plotting $\Delta_{i,a}^{1}$ as fraction of the average winning bid in Montreal pre-investigation.

[27] We plot these on a range of +/- 10% of the average winning bid observed in Montreal before the start of the investigation. In the Appendix we plot this for alternative ranges to illustrate robustness (Figure A.3 and Figure A.4) and for alternative bin size (Figure A.5).

Figure 1: Differences between own bid and most competitive bid ($\Delta^1_{i,a}$) – Montreal asphalt industry.



This figure plots the differences between own bid and most competitive bid in auctions for asphalt procurement contracts in Montreal during the cartel period. Bid differences in $ per ton. Number of bins equal to 500.

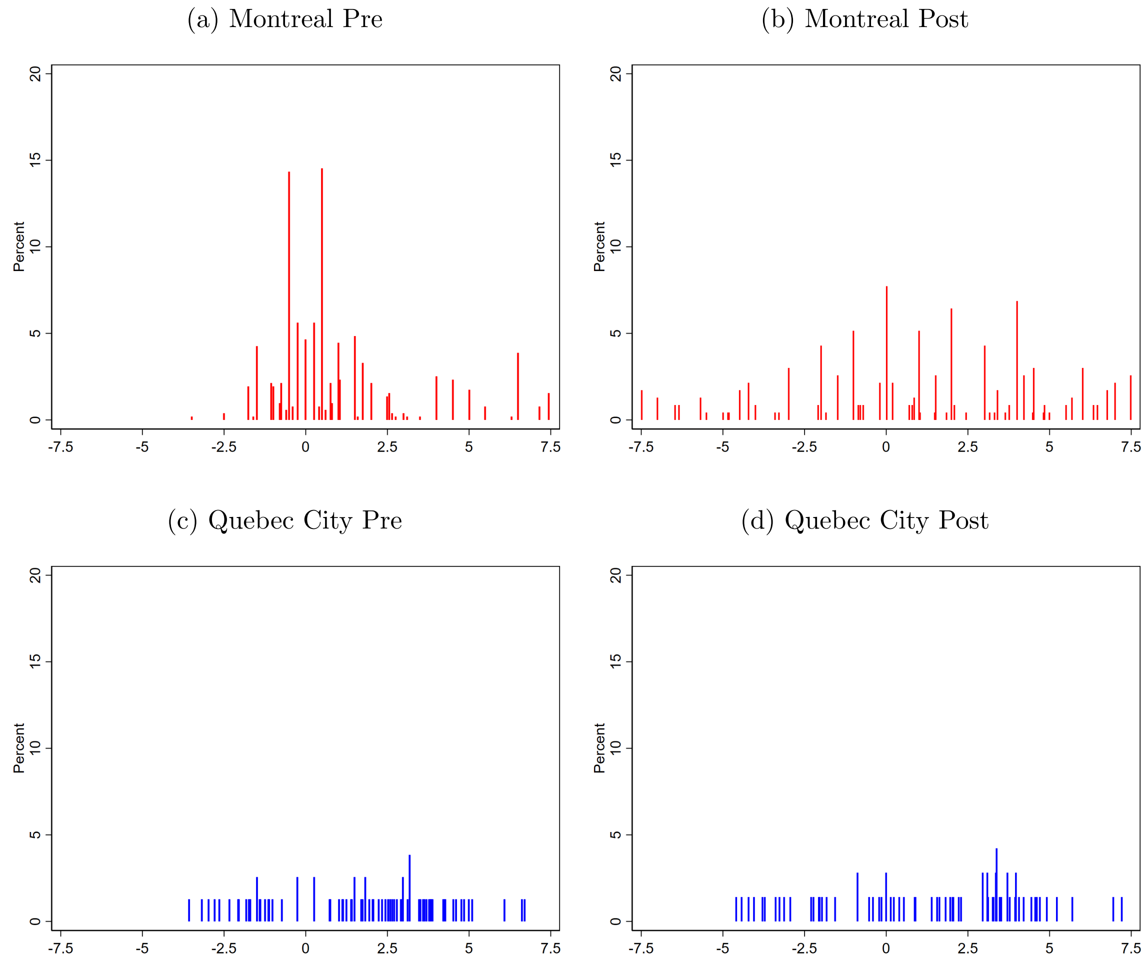
around 0. There is a bimodal, or twin-peaked, distribution of bid differences centered at zero.

Comparing this distribution to the one in Montreal after the investigation we see that after the investigation bid differences are much more dispersed and that there is more mass directly at 0 and less mass immediately nearby.[28] The twin peaks are gone and the distribution is much smoother. Together these results suggest that clustering and isolated winning bids were part of the collusive arrangement and that this behaviour ceased following its collapse. To confirm that other confounding factors were not behind this change we look at what happened in Quebec City. Here, bid differences are much more spread out, although there is again less mass at 0 in the pre period and slightly

[28]The mass right at zero can be explained by the round-number bidding that is observed to take place. All of the ties that we observe in Montreal post-investigation are for whole dollar amounts (i.e., bids ending in 0 or 0.5.).

more later on, but the increase is much smaller than in Montreal, as is the decrease in mass in the region immediately next to 0.[29,30]

Figure 2: $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation.



Bid differences in \$ per ton. The interval of bid differences is ±10% of the average winning bid in Montreal before the start of the investigation (\$7.5 per ton). The number of bins is equal to 500.

[29] One might be concerned that the fact that there is no mass at 0 for Quebec City in the pre-period is suggestive of collusion. To our knowledge, there have been no allegations of collusion for this market, despite extensive investigation over a number of years of all construction markets in the province. The observed increase in tied bids is very small and can be explained instead by the fact that Quebec City has a much smaller number of contracts than Montreal. In the pre-period in Quebec City there were just 22 calls for tender and out of these, none featured tied winning bids. In contrast, in the post period there were 24 calls for tender of which one had tied bids (at a round number). So, there is indeed an increase in the number of tied bids from pre to post, but it is hard to interpret this as representing a meaningful change given the small sample. To provide further confirmation that Quebec City's overall distribution did not change significantly from pre to post, we formally test the equality of the two distributions in Figures 2c and 2d using a Kolmogorov-Smirnov test. The *p-value* is .760, implying that the null hypothesis of the equality of the two distributions is not rejected. On the other hand, applying the same test in Montreal, yields a *p-value* of the Kolmogorov-Smirnov test of .0001.

[30] Appendices A.11 and A.12 present the same results but using total bids, and a restricted set of raw bids for which the firm with the lowest raw bid also has the lowest total bid, respectively, and we find that our results are consistent with those derived using raw bids.

To be more precise about the patterns observed in Figure 2, we provide statistics characterizing the changes in the distribution of bids observed from before to after the investigation in Montreal and Quebec City. We run a t-test for the equality of means in Montreal Pre against Montreal Post, and Quebec Pre against Quebec Post, under the assumption of unequal variances. For Montreal Post and Montreal Pre, we find a mean difference of \$0.79 per ton with standard error of 0.35 (t-stat equal to 2.26). For Quebec Post and Quebec Pre, we find no statistical difference in mean bid differences (\$0.14 per ton with standard error of 0.54, t-stat equal to 0.25).

6.2 Regression analysis

Figure 2 provides suggestive evidence of the causal impact of collusion on clustering and the isolation of winning bids, pooling all bids from all auctions together. To confirm that these patterns are robust to changes in other variables we turn to regression analysis at the auction level.

To understand the causal effect of the investigation on the distribution of bid differences, we use an approach related to the distributional regression techniques described by Chernozhukov et al. (2013), and more recently used by Fortin et al. (2021) to understand the effect of the minimum wage at different points of the wage distribution using a difference-in-differences setup. Consistent with this literature, we estimate a linear probability model where the outcome variable is a binary variable equal to 1 if the bid difference in auction a falls within a given interval of values. We estimate separate linear probability regressions, one for each interval. More specifically, the linear probability model that we estimate is the following:

$$y_{i,a,q} = \alpha_q + \beta_{1,q} Mtl_a \times Marteau_a + \beta_{2,q} Mtl_a + \beta_{3,q} Marteau_a + \gamma_q Z_a + \epsilon_{i,a,q}, \quad (3)$$

for $q = 1, 2, ..., Q$. Where $y_{i,a,q}$ is an indicator equal to 1 if bidder i's bid difference in auction a ($\Delta^1_{i,a}$) falls in interval q, and 0 otherwise. We divide the bid-difference distribution into 10 intervals of width 0.5 (\$ per ton), and one extra bin for values exactly equal to 0, for a total of eleven bins.[31] Allowing bid differences of 0 to get their own bin permits us to zoom in on bid isolation by studying the impact on identical bids. Since this might give the appearance of us arbitrarily choosing intervals, in the appendix we show that results are the same if we assign zero to a bin on the interval -0.5 to 0. Mtl_a is a dummy equal to 1 if the auction is run for the procurement of asphalt in Montreal, $Marteau_a$ is a dummy equal to 1 if the contract is awarded after the start of the investigation in October 2009, and Z_a represents auction characteristics such as the lagged (one period) average price of crude oil, the quantity of asphalt in the call for tender,

[31] For graphical purposes, we only show these 11 intervals. The results on additional intervals are available upon request.

and the Herfindahl index (city-specific). These are the same auction-level characteristics as in Clark et al. (2018). We include also borough, asphalt type, and year fixed effects, and we cluster standard errors at the borough and year levels.[32,33] We are interested in the coefficients $\beta_{1,q}$. Studying these coefficients will inform as to how the collapse of the cartel shifted the distribution of bid differences in Montreal relative to Quebec City.

Table 3: Distributional effect of the investigation on clustering & isolation

Dep.Var	(1) Pr(-2.5 -2]	(2) Pr(-2-1.5]	(3) Pr(-1.5-1]	(4) Pr(-1 -.5]	(5) Pr(-.5 -0)	(6) Pr[0]	(7) Pr(0 .5)	(8) Pr[.5 1)	(9) Pr[1 1.5)	(10) Pr[1.5 2)	(11) Pr[2 2.5)
					Panel A: Without controls						
Mtl×Marteau	0.0252	-0.0394	0.0987***	-0.1784***	-0.0582*	-0.0115	-0.0582*	-0.1647***	0.0666**	-0.0394	0.0425
	(0.033)	(0.032)	(0.029)	(0.033)	(0.031)	(0.032)	(0.031)	(0.035)	(0.032)	(0.044)	(0.039)
Mtl	-0.0370*	0.0241	-0.0599**	0.1599***	0.0364	0.0444***	0.0364	0.1494***	-0.0340	0.0179	-0.0414
	(0.021)	(0.024)	(0.027)	(0.025)	(0.022)	(0.015)	(0.022)	(0.027)	(0.027)	(0.033)	(0.027)
Marteau	0.0136	0.0009	-0.0988***	0.0256	0.0133	0.0253	0.0133	0.0133	-0.0861***	-0.0111	-0.0111
	(0.031)	(0.029)	(0.026)	(0.024)	(0.026)	(0.025)	(0.026)	(0.026)	(0.029)	(0.042)	(0.035)
Constant	0.0370*	0.0370*	0.0988***	0.0123	0.0247	0.0000	0.0247	0.0247	0.0988***	0.0617**	0.0617**
	(0.021)	(0.020)	(0.026)	(0.012)	(0.017)	(0.000)	(0.017)	(0.016)	(0.026)	(0.030)	(0.025)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0226	0.00691	0.0103	0.0621	0.0104	0.00587	0.0104	0.0585	0.00680	0.00889	0.00805
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2
					Panel B: With controls						
Mtl×Marteau	-0.0076	-0.0484	0.0945**	-0.1312***	-0.0642	-0.0282	-0.0642	-0.1251***	0.0554	-0.0457	0.0022
	(0.038)	(0.046)	(0.037)	(0.044)	(0.043)	(0.047)	(0.043)	(0.046)	(0.041)	(0.061)	(0.038)
Mtl	-0.1756*	-0.0036	-0.0334	0.1992*	0.1082	0.1902	0.1082	0.2473**	-0.0964	0.0388	0.0137
	(0.106)	(0.062)	(0.083)	(0.101)	(0.089)	(0.147)	(0.089)	(0.113)	(0.112)	(0.102)	(0.113)
Marteau	-0.1023	-0.5933**	-0.2074	1.1732***	-0.3230	-0.5791	-0.3230	1.0470***	-0.2460	-0.3983	-0.6855**
	(0.332)	(0.227)	(0.293)	(0.375)	(0.234)	(0.353)	(0.234)	(0.380)	(0.316)	(0.352)	(0.316)
Crude oil lag	0.0009	0.0035***	0.0006	-0.0066***	0.0020	0.0032	0.0020	-0.0059***	0.0010	0.0023	0.0044**
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Quantity	-0.0000	0.0000	-0.0000	-0.0000	0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	-0.0568	-0.1406	0.0550	0.2678***	-0.3949***	-0.0709	-0.3949***	0.2232***	0.0912	-0.1986	-0.0460
	(0.119)	(0.106)	(0.091)	(0.071)	(0.097)	(0.087)	(0.097)	(0.082)	(0.095)	(0.132)	(0.117)
Constant	-0.1954	-1.5494***	-0.2556	2.9355***	-0.8663	-1.5622*	-0.8663	2.6085**	-0.3772	-0.9576	-1.8277**
	(0.826)	(0.527)	(0.739)	(0.988)	(0.595)	(0.898)	(0.595)	(0.997)	(0.799)	(0.857)	(0.786)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0877	0.0991	0.105	0.176	0.169	0.151	0.169	0.169	0.0796	0.125	0.118
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2

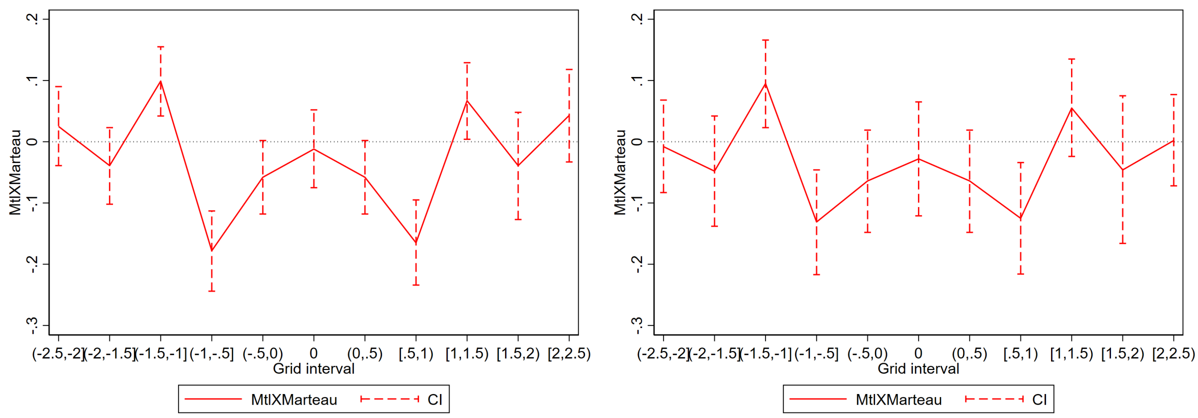
Dep. variable is the probability that bid differences fall in a given interval. *Marteau* is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Mtl* indicates that the contract was for Montreal. Panel A without controls. Panel B includes controls as well as borough, year and asphalt type effects. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

[32] In Table A.6 and Figure A.15 of Appendix A.9, we report results including as well bidder-level covariates.

[33] Whether $\Delta^1_{i,a}$ falls into a particular bin depends on the other bids submitted in auction a, i.e., $\{\mathbf{b_{-i,a}}\}$. This means that there could be correlation in the errors, $\epsilon_{i,a,q}$ across i within the same auction, and that one might instead cluster standard errors at the auction level. Figure A.23 assesses the robustness of our results to this alternative level of clustering and shows that our key results are not affected.

Figure 3: Graphical representation of the distributional effect of the investigation on clustering & isolation

(a) No controls (b) Controls



This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table 3. Confidence intervals are computed with standard errors clustered at the borough and year levels.

Results are presented in Table 3 and show that there is no impact of the collapse of the cartel on bid differences right at 0, and very little impact immediately on either side. In contrast, there is a big decrease in probability that bid differences fall in the range -1.0 to -0.5 and 0.5 to 1.0. Together these findings imply a decrease in isolation as a result of the investigation – during the collusive time period there was much less mass at 0 than just outside of 0, but this changes after the collapse. The results also reveal that the mass that leaves the -1.0 to -0.5 and 0.5 to 1.0 ranges is relocated to intervals further removed from 0. This pattern is confirmed in Figure 3, which plots the difference-in-differences coefficient from the first row of Table 3.

6.3 Robustness checks and identification assumption

We replicate the analysis in this section for the sample including entrants in Montreal (Figure A.6, Table A.1, and Figure A.7). We also replicate the analysis for the sample excluding the year following the investigation (Figure A.8, Table A.2, and Figure A.9) and for the sample including entrants and excluding the year following the investigation (Figure A.10, Table A.3, and Figure A.11).

In the appendix (Table A.4 and Figure A.13) we also show results for the entire distribution of bid differences (i.e., including values to the left of -\$2.5 and to the right of \$2.5). We see that density losses in a neighborhood of 0 are relocated to the tails of the distribution of $\Delta^1_{i,a}$ in Montreal, as compared to Quebec City.

In Table A.5 of the appendix we repeat the exercise but this time we assign bid differences of 0 to the -0.5 to 0 bin (Table A.5 and Figure A.14). Results are unchanged.

There is almost no effect of the collapse on bid differences right around 0, but there is a big decrease in the probability that bid differences fall in the range -1.0 to -0.5, confirming the decrease in isolation caused by the investigation. We also see the same patterns that confirm that clustering also fell after the collapse. In the appendix we also present results narrowing and widening the grid intervals (Table A.7 and Table A.8, respectively).

It is important to note that our difference-in-differences approach relies on the existence of common trends in the distribution of bid differences in Montreal and Quebec City. To confirm the existence of common trends, we use an event-study design approach and find that 19 out of 22 coefficients are not statistically different from zero at 10% significance level suggesting that there are parallel trends in each of the eleven intervals of the bid differences. Results are reported in Figure A.12.

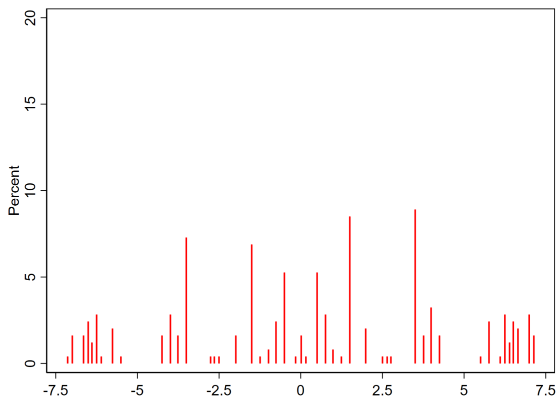
7 An easy-to-implement screen for collusion

In this section we propose a simple local screen for collusion that builds on the evidence that the mutual occurrence of isolated winning bids and clustered bidding is related to collusion. If antitrust authorities flag procurement auctions that feature tied, or nearly tied bids, cartel firms may benefit by adjusting their behaviour, leaving a gap between the winning bid and other bids. A gap facilitates if it helps to guarantee that the designated winner comes away with the contract in cases where precise bids cannot be assigned to losers and/or if bids can be perturbed by small trembles. At the same time clustering may be present, since the cartel will want to keep the second lowest bid relatively close to the first in order to lower the designated winner's temptation to increase its bid. We found evidence of these behaviors in Montreal's asphalt industry during the cartel period. In contrast, these behaviors disappear in Montreal after the investigation and are never present in Quebec City, suggesting that they are not associated with competition.

Our results so far then are based on a difference-in-differences setup that requires data from one or more control markets and being able to identify the beginning or end of collusive activity. Authorities interested in screening for collusion will not necessarily have access to such data. We therefore propose a screen that is based only on data from the suspected calls for tender.

Building on the theoretical results of Chassang et al. (2022) and Kawai et al. (2023), we begin by constructing a new set of bid differences, $\Delta^2_{i,a}$, that excludes the winning bid ($\Delta^2_{i,a}$ is the difference between bidder i's bid, provided that i did not win the auction, and the most-competitive losing bid). There is no reason to expect the distribution of $\Delta^2_{i,a}$ to exhibit the same sort of bimodal distribution as $\Delta^1_{i,a}$, and so $\Delta^2_{i,a}$ can serve as a control group that does not rely on having information on other markets or knowing the end date of the cartel. Figure 4 plots the distribution of $\Delta^2_{i,a}$ in Montreal pre-investigation, which can be compared to the distribution of $\Delta^1_{i,a}$ for the same period that was presented above in Panel A of Figure 2. We can see that, unlike for $\Delta^1_{i,a}$, there are no twin peaks around zero for $\Delta^2_{i,a}$. This visual inspection of the distributions provides heuristic evidence of a lack of competition in Montreal prior to the investigation, however, it does not constitute a formal statistical test. This is what we turn to next.

Figure 4: $\Delta^2_{i,a}$ for Montreal before the start of the police investigation, excluding winning bids.



Bid differences in \$ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation (\$7.5 per ton). The number of bins is equal to 500.

The formal screen involves the comparison of the distributions $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$, conditional on these distributions taking values in a small interval around zero. It requires that under competition, bids have a smooth density, which in turn, implies that the densities of the two bid-differences will be smooth, and therefore, their conditional distributions should be approximately equivalent in this small interval. We formalize this argument in the following proposition:

Proposition 1. *Suppose that under competition bids have a smooth density, and define $f^k(\Delta^k_{i,a}|\Delta^k_{i,a} \in [-H,+H])$, $(k = 1,2)$, as the density of $\Delta^k_{i,a}$ conditional on $\Delta^k_{i,a}$ taking values in $[-H,+H]$. Then, for $H > 0$ and $H \to 0$, $f^1(\Delta^1_{i,a}|\Delta^1_{i,a} \in [-H,+H])$ and $f^2(\Delta^2_{i,a}|\Delta^2_{i,a} \in [-H,+H])$ can be approximated by the same distribution.*

Proof: The assumption that, under competition, bids have a smooth density implies smoothness of the densities of each of the n order statistics, which, in turn, implies smoothness of the densities of the differences, Δ^k $(k = 1,2)$. Then, the approximation of $f^k(\Delta^k_i|\Delta^k_i \in [-H,+H])$ for $k = 1,2$, can be written as:

$$f^k(\Delta^k_i|\Delta^k_i \in [-H,+H]) \approx \frac{2H * f(H)}{Prob(-H < \Delta^k_i \leq +H)}.$$

Note that this formula represents the area of the rectangle with base $2H$ and height $f(H)$, and because we are approximating the distribution of Δ^k_i conditional on Δ^k_i taking values in $[-H,+H]$ we scale this area by $Prob(-H < \Delta^k_i \leq +H)$. This approximation equals 1 for $H > 0$ and $H \to 0$, because $f(H)$ is equal $Prob(-H < \Delta_i^k \leq +H)/2H$ by the definition of a density function. This result implies that for $H > 0$ and $H \to 0$ in $[-H, +H]$ the conditional distributions $f^1(\Delta_{i,a}^1 | \Delta_{i,a}^1 \in [-H, +H])$ and $f^2(\Delta_{i,a}^2 | \Delta_{i,a}^2 \in [-H, +H])$ can both be approximated by the same rectangular bin, and therefore that they share the same distribution on this interval. □

Local screen for competition Based on the predictions of Proposition 1, we formulate the following testable null hypothesis of competition:

$$H_0 : f^1(\Delta_{i,a}^1 | \Delta_{i,a}^1 \in [-H, +H]) = f^2(\Delta_{i,a}^2 | \Delta_{i,a}^2 \in [-H, +H]) \; for \; H > 0 \; and \; H \to 0.$$

According to our test, a rejection of H_0 implies a rejection of the predictions of Proposition 1 and therefore a rejection of competition.

The assumption that, under competition, bids have a smooth density is crucial to our argument. It is satisfied for instance in sealed-bid first-price auctions in IPV environments, where bidders are symmetric and their costs are drawn iid from a distribution with differentiable density f on its bounded support $[\underline{c}, \overline{c}]$.[34] This is because in the competitive equilibrium of the sealed-bid first-price auction, each bidder uses the same strictly increasing bidding function β.

7.1 Implementation of the screen in Montreal

We empirically implement our screen in two ways: non-parametrically and parametrically. The non-parametric version is based on a Kolmogorov–Smirnov test of H_0. Large *p-values* imply that the empirical distributions of $f^1(\Delta_{i,a}^1 | \Delta_{i,a}^1 \in [-H, H])$ and $f^2(\Delta_{i,a}^2 | \Delta_{i,a}^2 \in [-H, H])$ for $H \to 0$ are the same, such that we would not reject the null of competition.

For the parametric version of the test, we discretize $f^1(\Delta_{i,a}^1 | \Delta_{i,a}^1 \in [-H, H])$ and $f^2(\Delta_{i,a}^2 | \Delta_{i,a}^2 \in [-H, H])$ using Q intervals. We then use a regression approach in which we estimate a linear probability model for each of the Q intervals of bid differences. The advantage of the parametric test is that these regressions allow us to test whether the conditional distribution of $\Delta_{i,a}^1$ is statistically different from the conditional distribution of $\Delta_{i,a}^2$ in each interval q. Specifically, the model we estimate is the following:

$$y_{i,a,q} = \alpha_q + \beta_q \mathbb{1}(f(\Delta_{i,a}^1)) + \gamma_q Z_a + \epsilon_{i,a,q}, \quad \text{for} \quad q = 1, 2, ..., Q, \; q \in [-H, +H], \tag{4}$$

where, as above, $y_{i,a,q}$ is an indicator equal to 1 if bidder i's bid difference in auction a, $\Delta_{i,a}$, falls in interval q or zero if it is not in q but is in $[-H, +H]$. $\mathbb{1}(f(\Delta_{i,a}^1))$ is an

[34] On the other hand, bids would not have a smooth density in cases where procurement costs are publicly observable. In this context the distributions of $\Delta_{i,a}^1$ and $\Delta_{i,a}^2$ do not have smooth densities and $f^1(\Delta^1 | \Delta^1 \in [-H, H])$ and $f^2(\Delta^2 | \Delta^2 \in [-H, H])$ would be different even under competition and for $H > 0$ and $H \to 0$.

indicator variable equal to 1 if the observation is derived from the distribution of $\Delta^1_{i,a}$ and 0 if derived from the distribution of $\Delta^2_{i,a}$, and Z_a includes the same variables as in equation 3. We test H_0 with standard two-sided t-tests. As in Section 6.2, we compute standard errors clustered at the borough and year levels.

Before describing the results of our test when applied to Montreal pre-investigation, let us first comment on the choice of H. H must be small for our proposition to apply, but the question is, how small. Again, we are motivated by collusive arrangements featuring (i) a missing mass of nearly tied bids, and (ii) an excess mass of close bids, implying large mass around, but not at, zero. So, as our guiding principle we choose H large enough to include zero and the extra mass around it. In the case of Montreal's asphalt cartel, we take H to be approximately 3 percent, or \$2.5 per tonne, based on the patterns we see in the data, but in other contexts it might be slightly different.

The results of our non-parametric test are presented in Table 4. The top left panel presents results for Montreal pre-investigation and reveals a *p-value* of 0.058, implying that the null hypothesis of equal distributions of $f^1(\Delta^1_{i,a}|\Delta^1_{i,a} \in [-H, H])$ and $f^2(\Delta^2_{i,a}|\Delta^2_{i,a} \in [-H, H])$ is rejected.[35,36]

Table 4: Nonparametric implementation of the screen

	Pre Anti-Collusion Investigation	Post Anti-Collusion Investigation
Montreal	0.058	0.971
Quebec City	0.992	0.549

Values are the *p-values* from the Kolmogorov–Smirnov test of $H_0 : f^1(\Delta^1|\Delta^1 \in [-H, H]) = f^2(\Delta^2|\Delta^2 \in [-H, H])\, for\, H > 0\, and\, H \to 0$.

Next we report results for the parametric version of the screen. We use the same number of intervals, Q, that we adopted in our difference-in-differences analysis (see Section 6). These intervals are of width \$0.5 per ton, and we consider 0 as an isolated bin. This gives a total of eleven intervals with five intervals between \$0 and \$2.5, five intervals between -\$2.5 and \$0, and a separate bin for 0. Our findings are presented in Panel A of Table 5 and Panel A of Figure 5 for Montreal pre-investigation. What we see is that, compared to Δ^2, the conditional distribution of Δ^1 features more mass just to the left and right of zero.

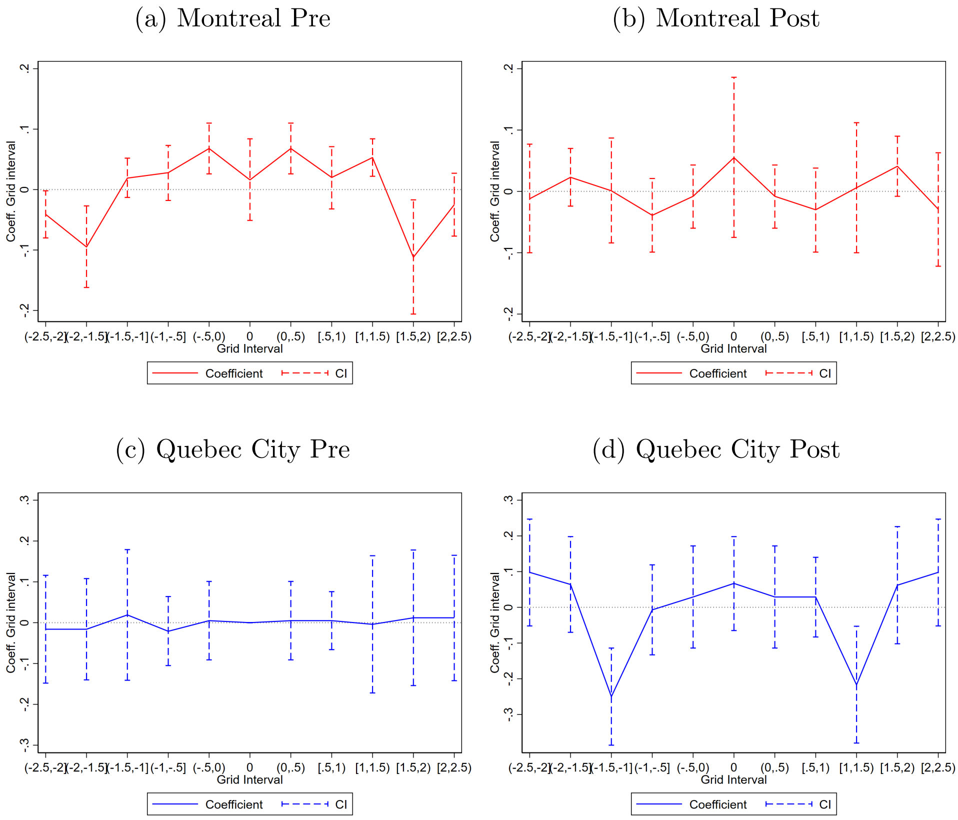
Based on the evidence from the non-parametric and parametric tests, we conclude that in Montreal pre-investigation we reject that the conditional distributions are the same,

[35]Appendices A.11 and A.12 present the same results but using total bids, and a restricted set of raw bids for which the firm with the lowest raw bid also has the lowest total bid, respectively, and we find that our results are consistent with those derived using raw bids.

[36]Note that we could also test whether $f^1(\Delta^1_{i,a}|\Delta^1_{i,a} \in [-H, H])$ and $f^2(\Delta^2_{i,a}|\Delta^2_{i,a} \in [-H, H])$ are both uniform between $[-H, +H]$. We reject that these distributions are uniform in Montreal during the pre-investigation period (*p-values* 0.0001 and 0.013 for $f^1(\Delta^1_{i,a}|\Delta^1_{i,a} \in [-H, H])$ and $f^2(\Delta^2_{i,a}|\Delta^2_{i,a} \in [-H, H])$, respectively) and we do not reject that they are uniform in Montreal post-investigation (*p-values* 0.761 and 0.699, respectively) or in Quebec City pre- and post-investigation (*p-values* 0.752 and 0.525, and 0.239 and 0.186, respectively).

which implies that we can reject competition. These results are all consistent with the complementary bidding arrangement we described above, where bids are clustered, but exactly tied bids are avoided.

Figure 5: Graphical representation of the parametric screen



This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals, obtained separately for each city/time period. Confidence intervals are computed with standard errors clustered at the borough and year levels.

Table 5: Estimation of the parametric screen (equation 4) comparing bid differences $\Delta^1_{i,a}$ with respect to $\Delta^2_{i,a}$ in Montreal and Quebec City before and after the investigation.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0)	Pr[0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
						Panel A: Montreal Pre					
$\mathbb{1}(\Delta^1_{i,a})$	-0.0408**	-0.0949***	0.0194	0.0276	0.0684***	0.0163	0.0684***	0.0197	0.0527***	-0.1119**	-0.0248
	(0.020)	(0.034)	(0.017)	(0.023)	(0.021)	(0.034)	(0.021)	(0.026)	(0.016)	(0.048)	(0.027)
Constant	0.0408**	0.1735***	0.0306**	0.1939***	0.0102	0.0408	0.0102	0.2041***	0.0306**	0.2143***	0.0510**
	(0.020)	(0.032)	(0.013)	(0.026)	(0.010)	(0.027)	(0.010)	(0.028)	(0.013)	(0.042)	(0.021)
Observations	518	518	518	518	518	518	518	518	518	518	518
R-squared	0.0334	0.0158	0.00130	0.000687	0.0117	0.000800	0.0117	0.000348	0.00627	0.0177	0.00316
Controls	No	No	No	No	No	No	No	No	No	No	No
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No
						Panel B: Montreal Post					
$\mathbb{1}(\Delta^1_{i,a})$	-0.0119	0.0231	0.0014	-0.0393	-0.0083	0.0555	-0.0083	-0.0303	0.0061	0.0411	-0.0292
	(0.045)	(0.024)	(0.044)	(0.031)	(0.026)	(0.066)	(0.026)	(0.035)	(0.054)	(0.025)	(0.047)
Constant	0.1200***	0.0400*	0.1067***	0.0933***	0.0533**	0.1067***	0.0533**	0.0933***	0.1200***	0.0400*	0.1733***
	(0.033)	(0.021)	(0.026)	(0.023)	(0.021)	(0.038)	(0.021)	(0.023)	(0.032)	(0.021)	(0.043)
Observations	186	186	186	186	186	186	186	186	186	186	186
R-squared	0.000340	0.00252	5.21e-06	0.00571	0.000359	0.00616	0.000359	0.00317	8.33e-05	0.00673	0.00156
Controls	No	No	No	No	No	No	No	No	No	No	No
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No
						Panel C: Quebec Pre					
$\mathbb{1}(\Delta^1_{i,a})$	-0.0161	-0.0161	0.0191	-0.0209	0.0048		0.0048	0.0048	-0.0042	0.0119	0.0119
	(0.067)	(0.063)	(0.082)	(0.043)	(0.049)		(0.049)	(0.036)	(0.086)	(0.085)	(0.078)
Constant	0.0930**	0.0930**	0.1860***	0.0465	0.0465		0.0465	0.0465	0.2093***	0.1163**	0.1163**
	(0.044)	(0.044)	(0.053)	(0.032)	(0.032)		(0.032)	(0.032)	(0.052)	(0.046)	(0.046)
Observations	82	82	82	82	82		82	82	82	82	82
R-squared	0.000828	0.000828	0.000578	0.00308	0.000122		0.000122	0.000122	2.64e-05	0.000331	0.000331
Controls	No	No	No	No	No		No	No	No	No	No
Borough FE	No	No	No	No	No		No	No	No	No	No
Year FE	No	No	No	No	No		No	No	No	No	No
Type FE	No	No	No	No	No		No	No	No	No	No
						Panel D: Quebec Post					
$\mathbb{1}(\Delta^1_{i,a})$	0.0976	0.0643	-0.2500***	-0.0071	0.0286	0.0667	0.0286	0.0286	-0.2167**	0.0619	0.0976
	(0.076)	(0.068)	(0.069)	(0.064)	(0.073)	(0.067)	(0.073)	(0.057)	(0.083)	(0.084)	(0.076)
Constant	0.0357	0.0357	0.2500***	0.1071*	0.0714	0.0000	0.0714	0.0714	0.2500***	0.0714	0.0357
	(0.036)	(0.036)	(0.069)	(0.057)	(0.048)	(0.000)	(0.048)	(0.048)	(0.069)	(0.048)	(0.036)
Observations	58	58	58	58	58	58	58	58	58	58	58
R-squared	0.0302	0.0161	0.147	0.000137	0.00259	0.0333	0.00259	0.00259	0.0986	0.0103	0.0302
Controls	No	No	No	No	No	No	No	No	No	No	No
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No

The outcome is the probability that bid differences fall in a given interval of values. $\mathbb{1}(\Delta^1_{i,a})$ is an indicator variable equal to 1 if the observation is derived from the distribution of $\Delta^1_{i,a}$ and 0 if derived from the distribution of $\Delta^2_{i,a}$. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

7.2 Advantages of our screen

Our screen offers several advantages. The first is that it is simple to implement, either nonparametrically or parametrically. In both cases, $f^1(\Delta^1_{i,a}|\Delta^1_{i,a} \in [-H, H])$ and $f^2(\Delta^2_{i,a}|\Delta^2_{i,a} \in [-H, H])$ must be determined and then compared either via a Kolmogorov–Smirnov test or using a set of linear probability models. In Appendix A.14, we describe the steps in detail required for implementation of the screen.

Second, for both the non-parametric and parametric tests, auction and market heterogeneity can be controlled for. In the nonparametric test, auction-level characteristics, Z_a, can be included as controls running a Kolmogorov–Smirnov test comparing the distribution of the residuals $\hat{\epsilon}_{\Delta^1_{i,a}}$ and $\hat{\epsilon}_{\Delta^2_{i,a}}$ in $[-H, +H]$, which are the residuals obtained regressing $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$ on Z_a. In the parametric test, Z_a are included in equation 4 as controls. In our application we include observable characteristics such as market concentration and input prices, along with borough, asphalt-type and year fixed effects. Results are reported in Appendix A.10. We find no significant differences with our main estimates (see Table A.9 and Figure A.16).

Third, our screen can be easily applied in other contexts as it does not require knowing the structure of the cartel. Moreover, it uses only data from the suspect calls for tender and so does not require a control group or period. That is, it is not necessary to know the identity of the suspected collusive firms, nor the exact timing of the collusive activity.

Finally, we provide both heuristic and formal versions of our test. The former involves the visual inspection of the unconditional distributions of $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$, while the latter requires that the bid density be smooth and tests for the statistical difference of the conditional distributions of $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$ in a small interval around zero.

7.3 Assessing the performance of our screen using the police investigation

An advantage of our setting and data set is the existence of multiple markets/periods where collusion was not suspected after the investigation took place: (i) Montreal after the collapse of the cartel, (ii) Quebec during the collusive period and (ii) Quebec after the start of the investigation. These markets that are assumed to be competitive allow us to evaluate the performance of our screen. We apply our test to each of the three other cases and report results in the top right, and bottom two panels of Table 4, and in Panels B, C and D of Table 5 and Figure 5.[37] The main takeaway is that, in cases where the market is assumed to be competitive, our screen does not reject competition. Based on this evidence we conclude that our screen has sufficient predictive power and it is not systematically rejecting the null of competition when the null is true.

[37]Figure A.24 reports the same tests clustering standard errors at the auction level and shows that the predictions of our screen are not affected by the choice of the clustering approach.

7.4 External applications of the screen

To further test the performance of our screen, we apply it to other procurement settings where collusion is known to have either taken place or not. We first implement our screen in the context of the Ohio school milk auctions analyzed by Porter and Zona (1999) and find that our null hypothesis of equality of the conditional distributions of $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$ between $[-H, H]$ is rejected between 1980 and 1990, which, according to testimony, is the period in which a partial cartel operated in this market. Results are reported in Appendix A.15.[38]

We have also applied our screen to Japanese procurement auctions studied in Chassang et al. (2022). These auctions are first-price sealed bid with public reserve price (city auctions sample) and first-price sealed bid auctions with secret reserve price (national auctions sample). The test rejects the null of competition in both samples, consistent with the findings in Chassang et al. (2022). Results are presented in Appendix A.16.

We also provide empirical evidence that in environments that are known to be competitive, the null of competition is not rejected according to our screen. Specifically, we also applied the screen to first-price auctions with a public reserve price in the country of Georgia. Kawai et al. (2022) examine this market and find no evidence of collusion. We use publicly available data from Wachs and Kertész (2019) and apply our screen, and are also unable to reject the null of competition. Results are reported in Appendix A.17. This falsification exercise offers the means to assess the performance of our screen. Based on this assessment of the performance of our screen, we conclude that it has good statistical power to reject the null of competition when there is no competition, but does reject the null when collusion has been ex-post verified by anti-collusion investigations.

Furthermore, our screen has already been implemented successfully by antitrust authorities in Sweden and Finland, analysing competition in the procurement of asphalt. Results are reported in Buri et al. (2023) and they reveal that our test has detection power. The authors reject competition during a collusive period, but do not after Sweden and Finland launched two anti-collusion investigations and the cartels allegedly collapsed.

In all of these cases, procurement auctions are first-price sealed bid and can reasonably be considered IPV settings. We therefore believe that, under competition, they are characterized by $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$ having smooth densities, and that according to our Proposition 1 the conditional distributions $f^1(\Delta^1_{i,a}|\Delta^1_{i,a} \in [-H, H])$ and $f^2(\Delta^2_{i,a}|\Delta^2_{i,a} \in [-H, H])$ for $H > 0$ and $H \to 0$ are the same, such that our screen can be applied. Reassuringly, the application of our screen in these contexts reveals that it has predictive power, rejecting the null of competition in markets where collusion is thought to have taken place, and failing to do so in markets that are assumed to be competitive.

[38] See the court case *State of Ohio v. Louis et al.* for details on the functioning of the cartel.

8 Conclusion

In this paper, we provided evidence from an actual procurement cartel that clustered bidding and isolated winning bids are associated with collusive arrangements that feature complementary bidding. Using a difference-in-differences approach, we compared the extent of winning-bid isolation and clustering of bids in Montreal's asphalt industry before and after the investigation to isolation and clustering patterns over the same time span in Quebec City, whose asphalt industry has not been the subject of collusion allegations. We used an approach related to the distributional regression techniques of Chernozhukov et al. (2013) and Fortin et al. (2021) to compare the distribution of bid differences (differences between own and most competitive bids) in Montreal and Quebec City before and after the investigation. Our findings provide causal evidence that the collusive arrangement featured both clustered bids and isolated winning bids.

Interviews from the news program and testimony from the Commission help us understand how these observations fit together. The cartel arrangement involved market segmentation and complementary bidding. Representatives from each of the cartel firms would get together to decide which of them would be assigned a given contract as a function on the firms' production capacities and their plant locations. The designated winner would then organize the bidding for the contract by contacting the other cartel members and giving instructions on complementary bidding. Complementary bids were submitted in order to mimic competition. The designated winner would provide guidance as to what it was bidding or what should be the complementary bids. Despite this incentive to bid as close to the next lowest bid as possible, the designated winner would, according to testimony, allow a small margin between the assigned lowest losing bid and its bid. It would do so to guard against antitrust oversight or any mistake in the bidding, such as a secretary making a typing mistake. The result was a very small gap between the two lowest bids, or isolated winning bids.

Based on our findings we propose an easy-to-implement local screen that can be implemented non-parametrically or using techniques related to the distributional regression approach. Since a competitive control market may not be available for comparison, our screen involves the comparison of the conditional distributions of bid differences including and excluding the winning bid in a small interval around zero, and requires that under competition bids have a smooth density. We evaluate the performance of our screen and show that it successfully rejects the null of competition in markets where collusion took place and does not in markets where there is no evidence of collusion. Further, it has already been implemented with success by antitrust authorities in a number of jurisdictions.

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A Appendix

A.1 Transport charges and final bids

We concentrate our main analysis on raw bids, but contract allocation is based on final bids. 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 on transport charges is the final bid. In Québec City however, we do not have enough information to build a perfect measure of transport charges and thus, 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. More precisely, for each aggregated auction we have:

$$\sum_{k=1}^{K} (\mathbf{P}_k + t_k) * \mathbf{Quantity}_k = \mathbf{Aggregated\ final\ bid}$$

where k is the asphalt type, t is the unknown transport charge and P is the raw bid (what we know is in bold text). We can rewrite the equation above as:

$$\sum_{k=1}^{K} (\mathbf{P}_k * \mathbf{Quantity}_k + t_k * \mathbf{Quantity}_k) = \mathbf{Aggregated\ final\ bid}$$

$$\sum_{k=1}^{K} (t_k * \mathbf{Quantity}_k) = \mathbf{Aggregated\ final\ bid} - \sum_{k=1}^{K} (\mathbf{P}_k * \mathbf{Quantity}_k)$$

$$\sum_{k=1}^{K} (t_k * \mathbf{Quantity}_k) = \mathbf{Aggregated\ transport\ charge}$$

since t_k is unknown for all k, the best we can do is compute the average transport charge:

$$\overline{T} = \frac{\mathbf{Aggregated\ transport\ charge}}{\sum_{k=1}^{K} (\mathbf{Quantity}_k)}$$

Similarly, we cannot compute final bids per type for Québec City.[39] This measure is imperfect, but we believe it is relevant to estimate DiD for transport charges and final bids.

[39] Note that since there is one winner per borough, we know that the firm that bids the lowest aggregated final bid, which we observe, is the actual winner.

A.2 Normalization with average winning bid in Montreal pre-investigation

Chassang et al. (2022) are interested in the distribution of

$$\Delta_{i,a}^{CKNO} = \frac{b_{i,a} - \wedge \mathbf{b}_{-i,a}}{r}, \tag{5}$$

where $b_{i,a}$ is bidder i's bid in auction a, $\wedge \mathbf{b}_{-i,a}$ is the minimum bid by i's rivals, and r is the reserve price in auction a. Since our auctions are for a homogeneous good, bid are in dollars per ton, and there is no reserve price, there is no need to normalize by the reserve price they way Chassang et al. (2022) do. This is why in the text, we focus on the following measure of bid differences:

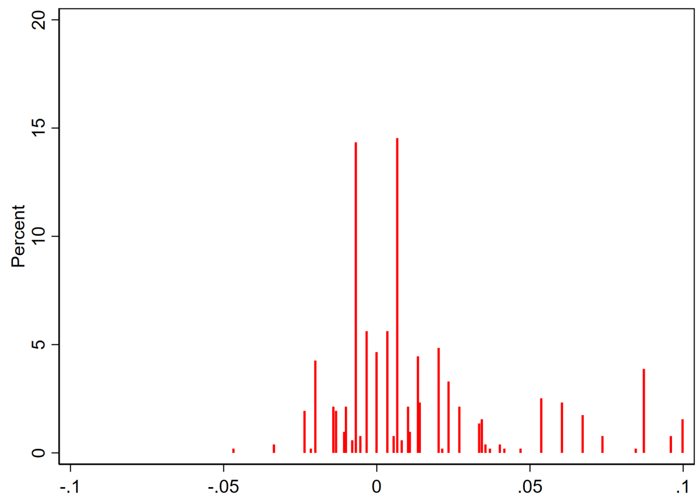
$$\Delta_{i,a}^{1} = b_{i,a} - \wedge \mathbf{b}_{-i,a}. \tag{6}$$

As a check on this specification, here we present results in which we normalize by the average winning bid observed in Montreal in the period before the start of the investigation ($\bar{b}_{mtl,pre}$). The measure of bid differences is then:

$$\Delta_{i,a}^{1,norm} = \frac{b_{i,a} - \wedge \mathbf{b}_{-i,a}}{\bar{b}_{mtl,pre}}. \tag{7}$$

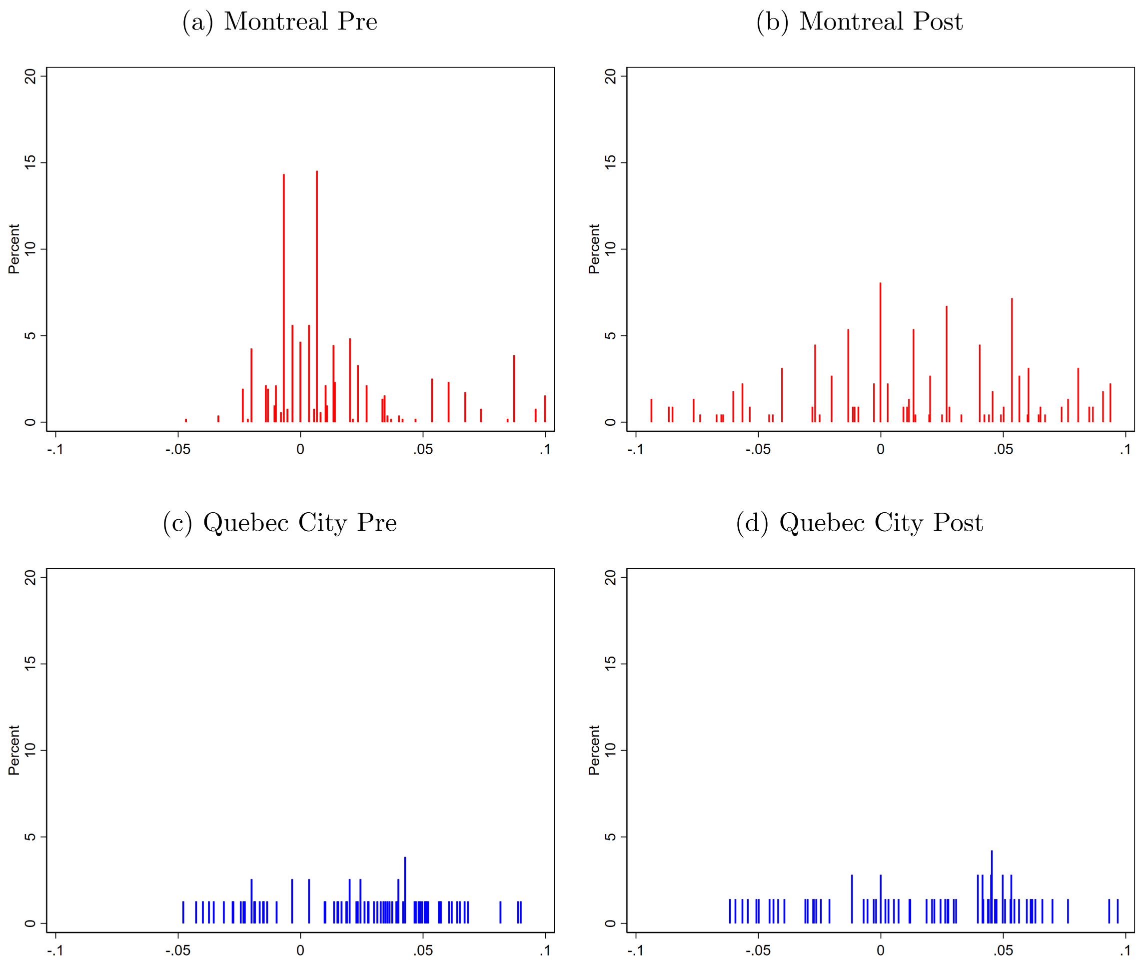
Figures A.1 and A.2 replicate Figures 1 and 2 using this new definition of bid differences.

Figure A.1: Differences between own bid and most competitive bid (bid differences)



This figure plots the differences between own bid and the most competitive bid in auctions as a fraction of the average winning bid in the period before the investigation, for asphalt procurement contracts in Montreal during the cartel period. Bid differences in \$ per ton.

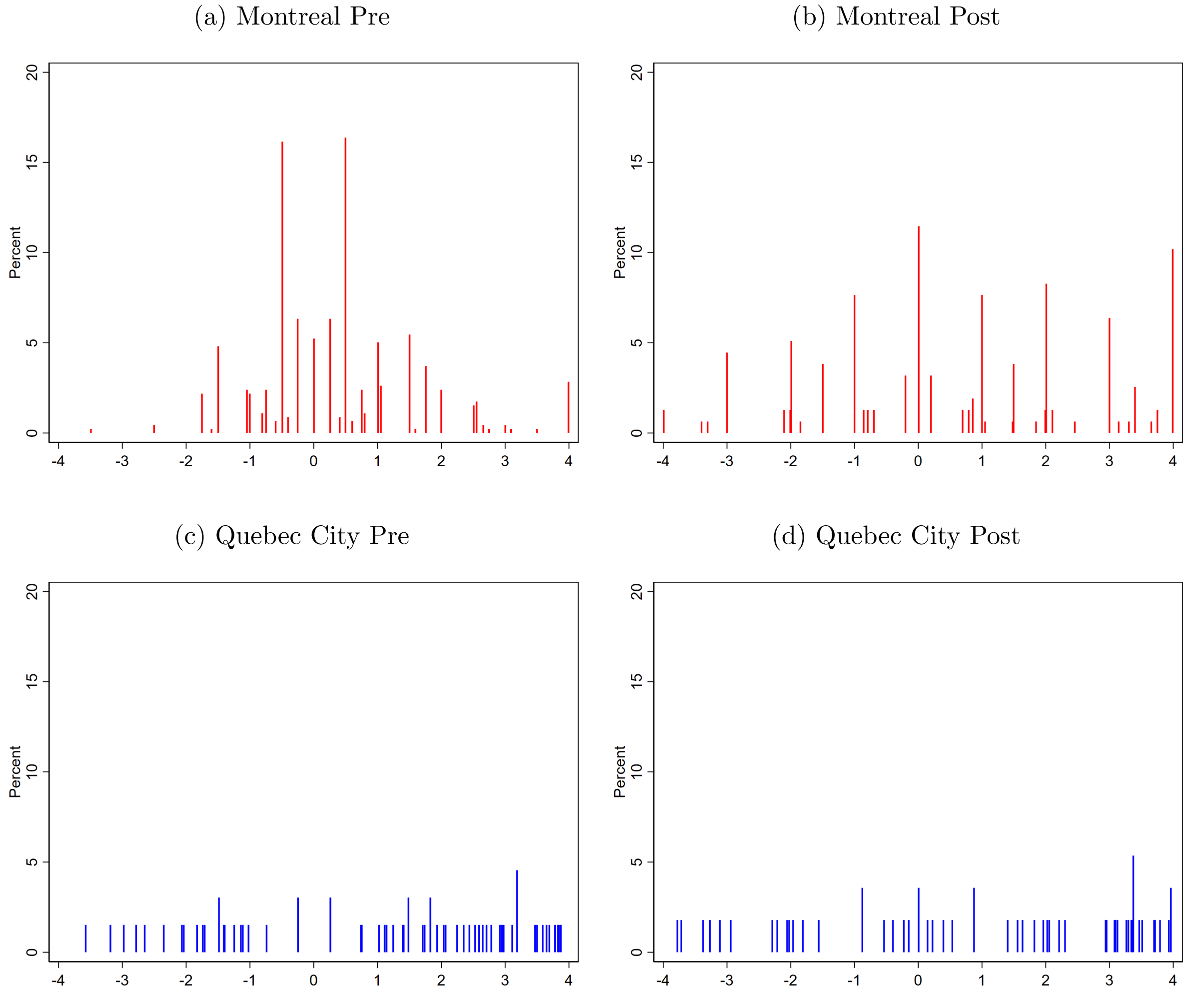
Figure A.2: $\Delta_{i,a}^{1,norm}$ for Montreal and Quebec City before and after the start of the police investigation.



Differences between own bid and the most competitive bid in auctions as a fraction of the average winning bid in the period before the investigation, for asphalt procurement contracts in Montreal during the cartel period. Bid differences in \$ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation (\$7.5 per ton).

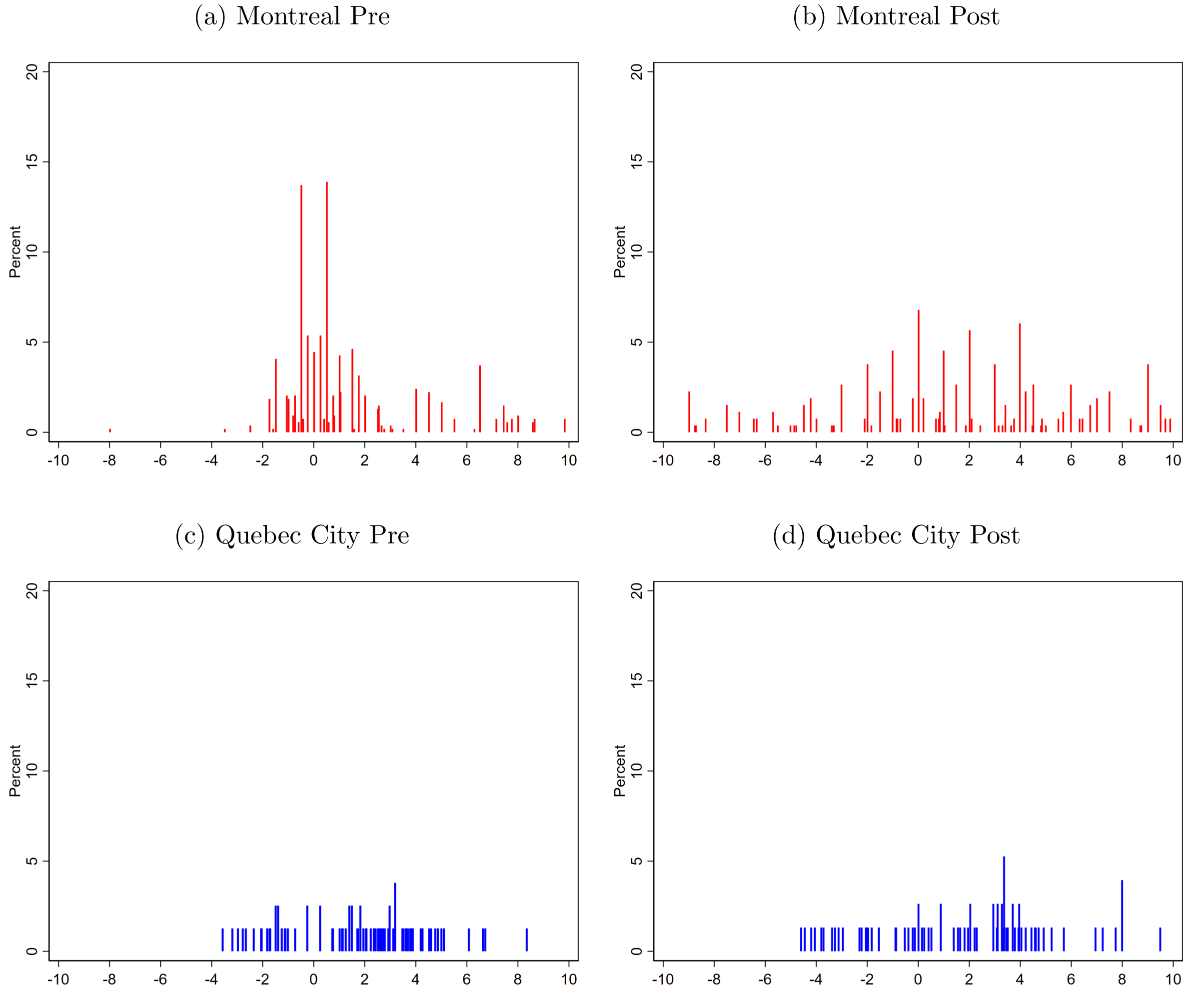
A.3 Different intervals for bid differences

Figure A.3: Distribution of $\Delta^1_{i,a}$. Difference in \$ per ton. Interval of \$4 per ton.



Differences between own bid and the most competitive bid in auctions. Bid differences in \$ per ton. The interval of bid differences is ± 4 dollars per ton.

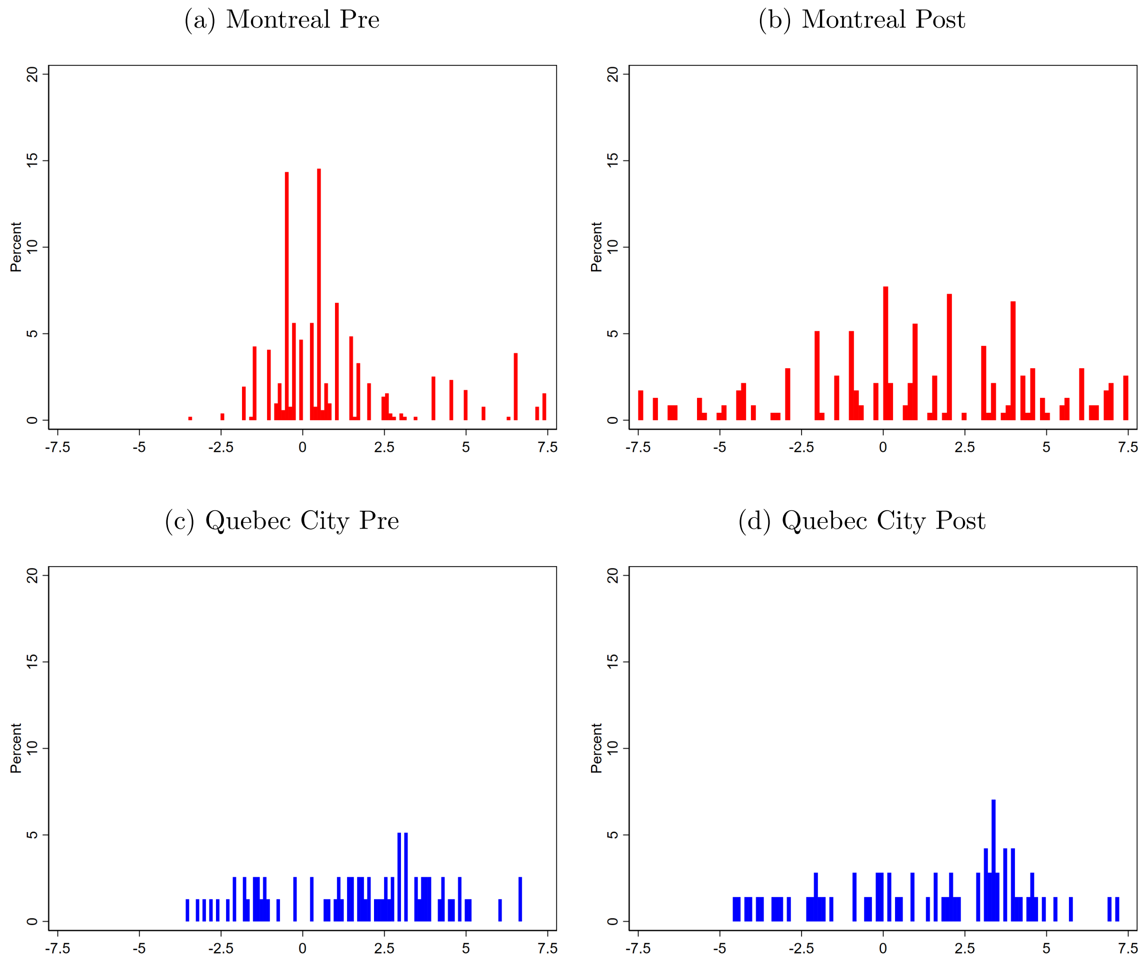
Figure A.4: Distribution of $\Delta^1_{i,a}$. Difference in \$ per ton. Interval of \$10 per ton.



Differences between own bid and the most competitive bid in auctions. Bid differences in \$ per ton. The interval of bid differences is ± 10 dollars per ton.

A.4 Different bin size

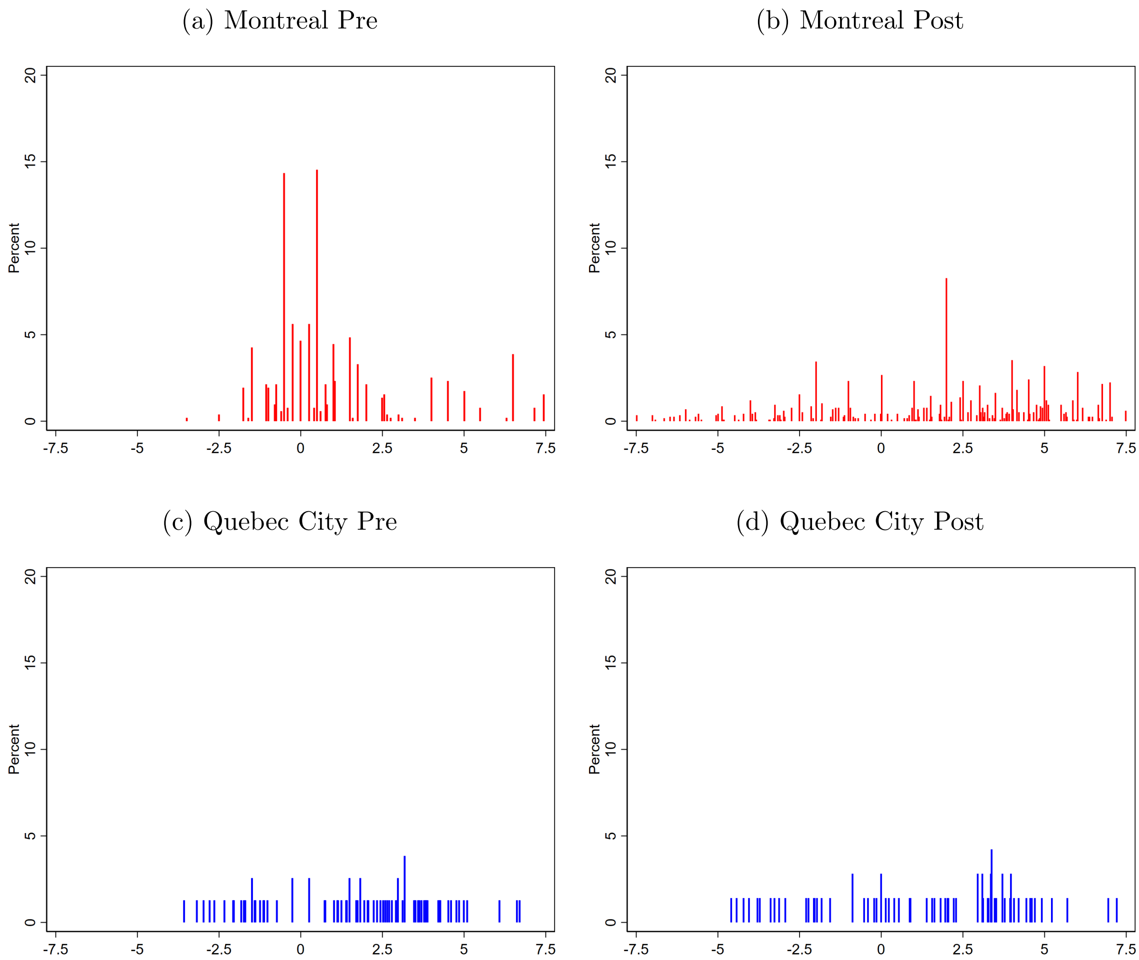
Figure A.5: Distribution of $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation. The number of bins is equal to 100.



Bid differences in $ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation ($7.5 per ton). The number of bins is equal to 100.

A.5 Sample of auctions: Original sample plus auctions with entrants

Figure A.6: Distribution of $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation. Original sample plus auctions with entrants.



Bid difference in bids in \$ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation (\$7.5 per ton).

Table A.1: Distributional effect of the investigation on clustering & isolation. Original sample plus auctions with entrants.

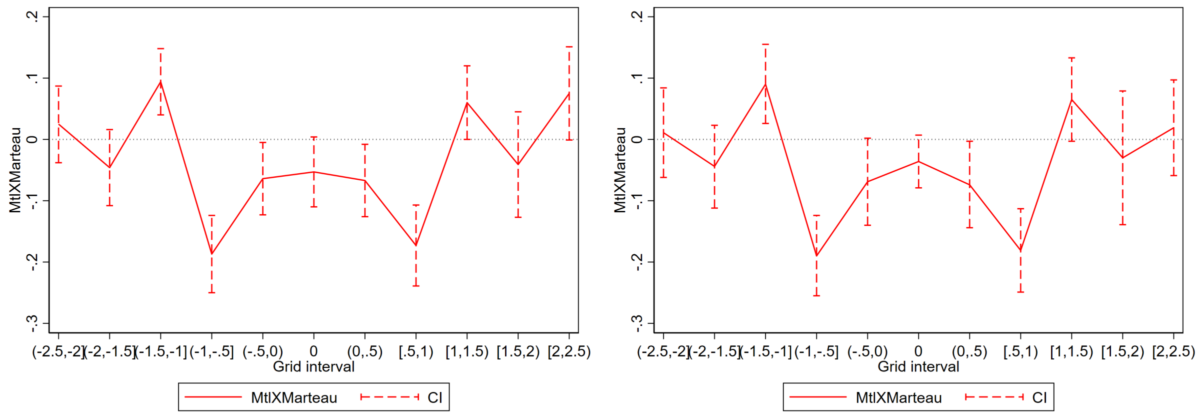
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0)	Pr[0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
						Panel A: Without controls					
Mtl×Marteau	0.0246	-0.0463	0.0941***	-0.1873***	-0.0639**	-0.0527*	-0.0672**	-0.1729***	0.0601*	-0.0409	0.0749*
	(0.032)	(0.032)	(0.028)	(0.032)	(0.030)	(0.029)	(0.030)	(0.034)	(0.031)	(0.044)	(0.039)
Mtl	-0.0370*	0.0241	-0.0599**	0.1599***	0.0364	0.0444***	0.0364	0.1494***	-0.0340	0.0179	-0.0414
	(0.021)	(0.024)	(0.027)	(0.025)	(0.022)	(0.015)	(0.022)	(0.027)	(0.027)	(0.032)	(0.027)
Marteau	0.0136	0.0009	-0.0988***	0.0256	0.0133	0.0253	0.0133	0.0133	-0.0861***	-0.0111	-0.0111
	(0.031)	(0.029)	(0.026)	(0.024)	(0.026)	(0.025)	(0.026)	(0.026)	(0.029)	(0.042)	(0.035)
Constant	0.0370*	0.0370*	0.0988***	0.0123	0.0247	0.0000	0.0247	0.0247	0.0988***	0.0617**	0.0617**
	(0.021)	(0.020)	(0.026)	(0.012)	(0.017)	(0.000)	(0.017)	(0.016)	(0.026)	(0.030)	(0.025)
Observations	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220
R-squared	0.00988	0.0136	0.00551	0.0985	0.0196	0.00677	0.0246	0.0896	0.00593	0.0124	0.0119
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2
						Panel B: With controls					
Mtl×Marteau	0.0109	-0.0443	0.0903***	-0.1895***	-0.0692*	-0.0357	-0.0735**	-0.1810***	0.0652*	-0.0303	0.0187
	(0.037)	(0.034)	(0.033)	(0.033)	(0.036)	(0.022)	(0.036)	(0.035)	(0.035)	(0.056)	(0.040)
Mtl	-0.1710	0.0222	-0.0150	0.1543	0.1521*	0.2206	0.1542*	0.2006*	-0.0687	0.0647	-0.0542
	(0.112)	(0.057)	(0.081)	(0.105)	(0.089)	(0.139)	(0.089)	(0.119)	(0.110)	(0.100)	(0.130)
Marteau	-0.8581***	-0.2941*	0.1216	0.6156**	-0.2917*	-0.5082**	-0.3002*	0.5422**	0.1292	0.0073	-1.5008***
	(0.292)	(0.171)	(0.282)	(0.243)	(0.159)	(0.211)	(0.155)	(0.251)	(0.305)	(0.261)	(0.298)
Crude oil lag	0.0053***	0.0017*	-0.0013	-0.0031**	0.0018**	0.0028**	0.0019**	-0.0028**	-0.0012	-0.0003	0.0091***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
Quantity	-0.0000*	0.0000	0.0000	-0.0000***	0.0000	0.0000	0.0000	-0.0000*	0.0000	0.0000	-0.0000**
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	-0.0813	-0.1503	0.0116	0.2658***	-0.3646***	-0.0661	-0.3663***	0.2237***	0.0541	-0.2336*	-0.0799
	(0.120)	(0.101)	(0.089)	(0.071)	(0.096)	(0.072)	(0.096)	(0.079)	(0.093)	(0.132)	(0.121)
Constant	-2.1675***	-0.7101*	0.6632	1.3556**	-0.8196**	-1.4145***	-0.8483**	1.1670*	0.6573	0.1988	-3.9196***
	(0.721)	(0.363)	(0.710)	(0.609)	(0.347)	(0.532)	(0.333)	(0.624)	(0.775)	(0.601)	(0.736)
Observations	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220	2,220
R-squared	0.0560	0.0610	0.0723	0.167	0.116	0.0874	0.123	0.152	0.0605	0.0763	0.0974
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2

Dep. variable is the probability that bid differences fall in a given interval. *Marteau* is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Mtl* indicates that the contract was for Montreal. Panel A without controls. Panel B with controls. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.7: Graphical representation of the distributional effect of the investigation on clustering & isolation. Original sample plus auctions with entrants.

(a) No controls

(b) Controls

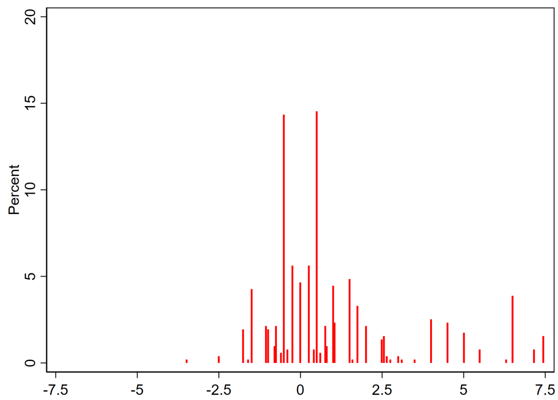


This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table A.1. Confidence intervals are computed with standard errors clustered at the borough and year levels.

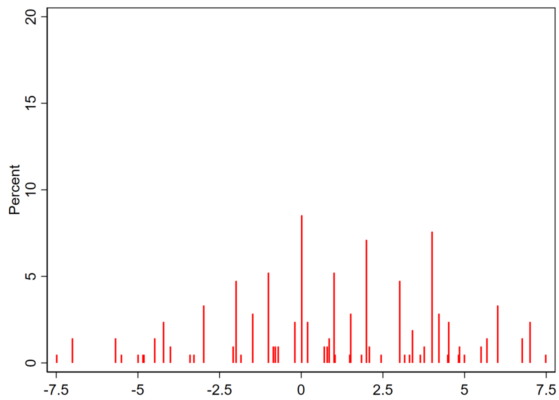
A.6 Sample of auctions: Original sample minus year 2010

Figure A.8: Distribution of $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation. Original sample minus year 2010

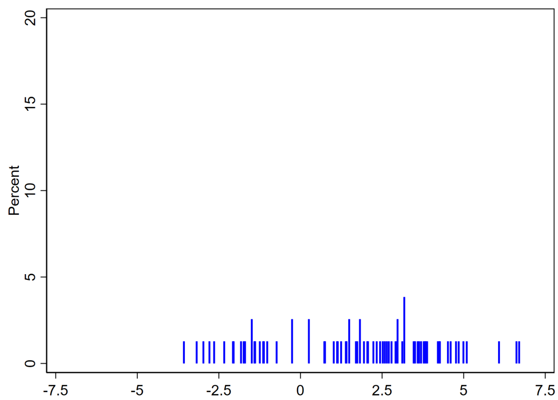
(a) Montreal Pre



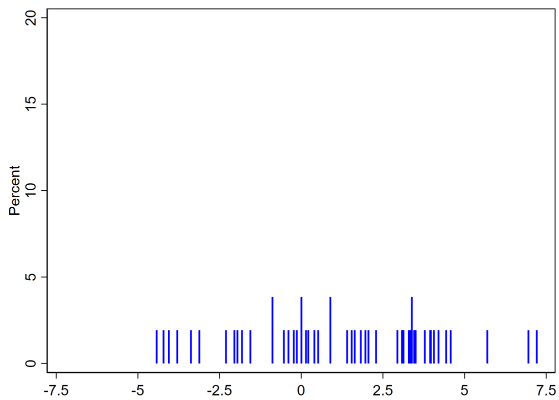
(b) Montreal Post



(c) Quebec City Pre



(d) Quebec City Post



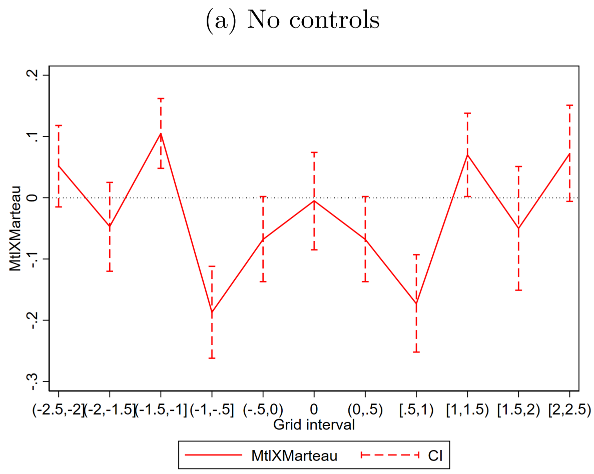
Bid difference in bids in $ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation ($7.5 per ton).

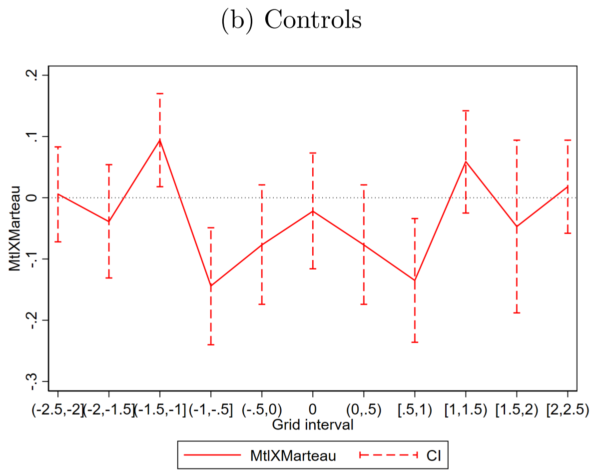
Table A.2: Distributional effect of the investigation on clustering & isolation. Original sample minus year 2010.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0)	Pr[0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
	Panel A: Without controls										
MtlXMarteau	0.0515	-0.0472	0.1048***	-0.1871***	-0.0677*	-0.0055	-0.0677*	-0.1725***	0.0698**	-0.0501	0.0722*
	(0.034)	(0.037)	(0.029)	(0.038)	(0.036)	(0.041)	(0.036)	(0.041)	(0.035)	(0.052)	(0.040)
Mtl	-0.0370*	0.0241	-0.0599**	0.1599***	0.0364	0.0444***	0.0364	0.1494***	-0.0340	0.0179	-0.0414
	(0.021)	(0.024)	(0.027)	(0.025)	(0.022)	(0.015)	(0.022)	(0.027)	(0.027)	(0.033)	(0.027)
Marteau	-0.0026	0.0147	-0.0988***	0.0394	0.0270	0.0345	0.0270	0.0270	-0.0815**	0.0072	-0.0272
	(0.031)	(0.034)	(0.026)	(0.030)	(0.032)	(0.033)	(0.032)	(0.032)	(0.031)	(0.050)	(0.035)
Constant	0.0370*	0.0370*	0.0988***	0.0123	0.0247	-0.0000	0.0247	0.0247	0.0988***	0.0617**	0.0617**
	(0.021)	(0.020)	(0.026)	(0.012)	(0.017)	(.)	(0.017)	(0.016)	(0.026)	(0.030)	(0.026)
Observations	924	924	924	924	924	924	924	924	924	924	924
R-squared	0.0273	0.00441	0.00964	0.0530	0.00786	0.00866	0.00786	0.0491	0.00466	0.00548	0.0121
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2
	Panel B: With controls										
MtlXMarteau	0.0056	-0.0387	0.0937**	-0.1445***	-0.0765	-0.0215	-0.0765	-0.1350**	0.0586	-0.0471	0.0180
	(0.040)	(0.047)	(0.039)	(0.048)	(0.050)	(0.048)	(0.050)	(0.051)	(0.043)	(0.072)	(0.039)
Mtl	-0.0956	-0.0031	-0.0174	0.1737	0.1143	0.2079	0.1143	0.2173*	-0.1113	0.0551	0.0890
	(0.071)	(0.061)	(0.083)	(0.118)	(0.099)	(0.149)	(0.099)	(0.126)	(0.129)	(0.101)	(0.084)
Marteau	-0.2007	-0.6248**	-0.2121	1.0774***	-0.3068	-0.5243	-0.3068	0.9424**	-0.2721	-0.5305	-0.6600**
	(0.335)	(0.242)	(0.315)	(0.391)	(0.236)	(0.364)	(0.236)	(0.396)	(0.333)	(0.370)	(0.312)
Crude oil lag	0.0014	0.0037***	0.0007	-0.0060**	0.0019	0.0028	0.0019	-0.0053**	0.0012	0.0030	0.0041**
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Quantity	-0.0000	0.0000	-0.0000	-0.0000	0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	-0.0482	-0.1530	0.0676	0.2608***	-0.4029***	-0.0578	-0.4029***	0.2142**	0.1019	-0.2063	-0.0395
	(0.124)	(0.111)	(0.094)	(0.070)	(0.102)	(0.086)	(0.102)	(0.082)	(0.097)	(0.141)	(0.122)
Constant	-0.5004	-1.6094***	-0.2894	2.6990**	-0.8583	-1.4368	-0.8583	2.3621**	-0.4219	-1.3153	-1.8026**
	(0.828)	(0.565)	(0.793)	(1.038)	(0.602)	(0.916)	(0.602)	(1.046)	(0.842)	(0.902)	(0.772)
Observations	924	924	924	924	924	924	924	924	924	924	924
R-squared	0.104	0.106	0.110	0.171	0.171	0.154	0.171	0.163	0.0800	0.131	0.127
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2

Dep. variable is the probability that bid differences fall in a given interval. *Marteau* is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Mtl* indicates that the contract was for Montreal. Panel A without controls. Panel B with controls. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.9: Graphical representation of the distributional effect of the investigation on clustering & isolation. Original sample minus year 2010.

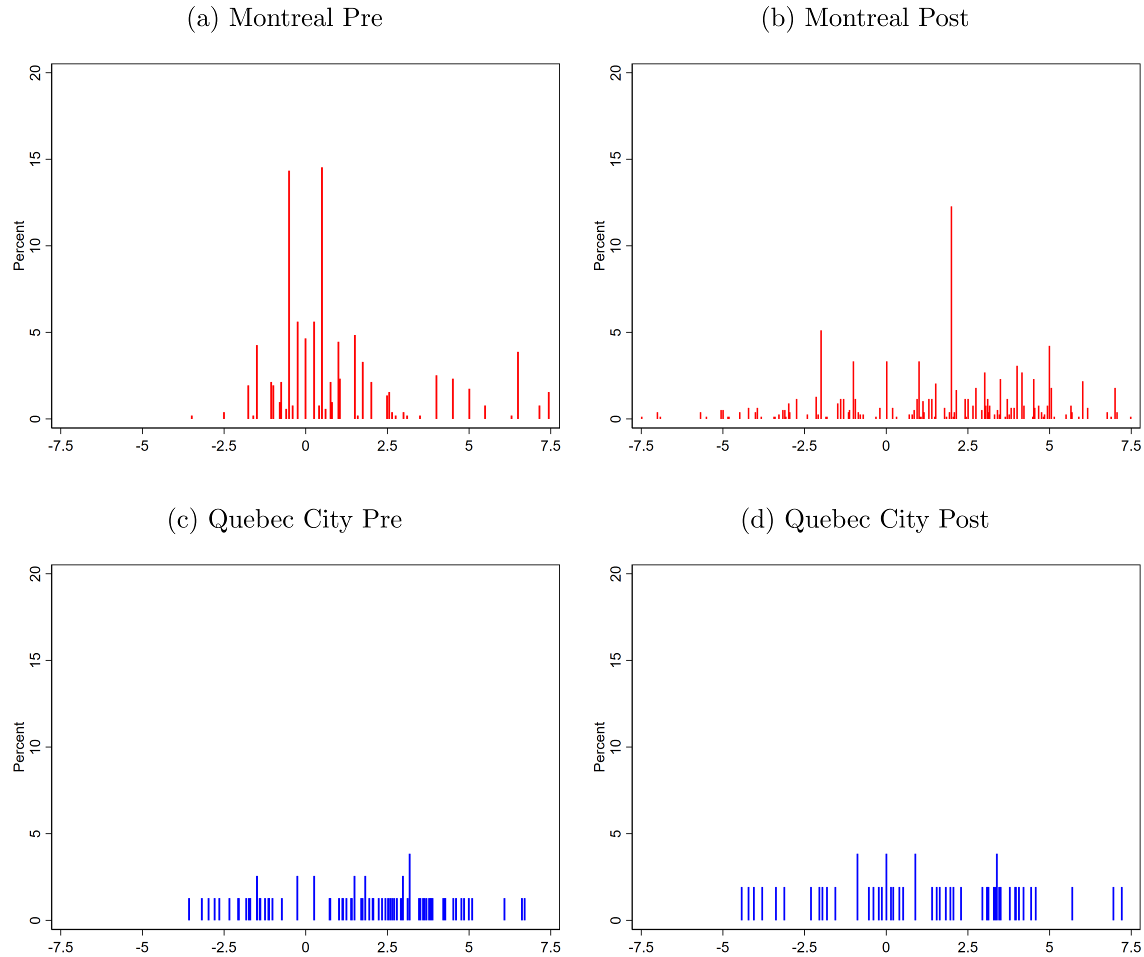




This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table A.2. Confidence intervals are computed with standard errors clustered at the borough and year levels.

A.7 Sample of auctions: Original sample plus auctions with entrants, minus year 2010

Figure A.10: Distribution of $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation. Original sample plus auctions with entrants, minus year 2010.



Bid difference in bids in \$ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation (\$7.5 per ton).

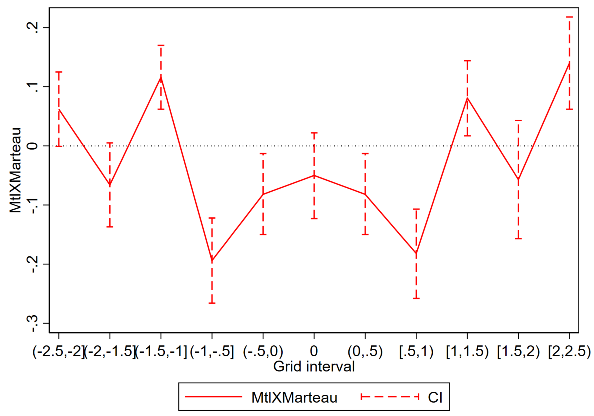
Table A.3: Distributional effect of the investigation on clustering & isolation. Original sample plus auctions with entrants, minus year 2010

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0)	Pr[0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
						Panel A: Without controls					
Mtl×Marteau	0.0620*	-0.0659*	0.1160***	-0.1940***	-0.0815**	-0.0503	-0.0815**	-0.1824***	0.0806**	-0.0571	0.1401***
	(0.032)	(0.036)	(0.028)	(0.037)	(0.035)	(0.037)	(0.035)	(0.038)	(0.033)	(0.051)	(0.040)
Mtl	-0.0370*	0.0241	-0.0599**	0.1599***	0.0364	0.0444***	0.0364	0.1494***	-0.0340	0.0179	-0.0414
	(0.021)	(0.024)	(0.027)	(0.025)	(0.022)	(0.015)	(0.022)	(0.027)	(0.027)	(0.032)	(0.027)
Marteau	-0.0026	0.0147	-0.0988***	0.0394	0.0270	0.0345	0.0270	0.0270	-0.0815**	0.0072	-0.0272
	(0.031)	(0.034)	(0.026)	(0.030)	(0.032)	(0.033)	(0.032)	(0.032)	(0.031)	(0.049)	(0.035)
Constant	0.0370*	0.0370*	0.0988***	0.0123	0.0247	-0.0000	0.0247	0.0247	0.0988***	0.0617**	0.0617**
	(0.021)	(0.020)	(0.026)	(0.012)	(0.017)	(0.000)	(0.017)	(0.016)	(0.026)	(0.030)	(0.025)
Observations	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587
R-squared	0.0211	0.0198	0.00577	0.0802	0.0243	0.00350	0.0243	0.0782	0.00236	0.0117	0.0359
Borough FE	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2
						Panel B: With controls					
Mtl×Marteau	0.0310	-0.0567	0.1026***	-0.1998***	-0.0985**	-0.0410	-0.0985**	-0.1943***	0.0803**	-0.0447	0.0481
	(0.036)	(0.040)	(0.035)	(0.039)	(0.042)	(0.030)	(0.042)	(0.040)	(0.036)	(0.071)	(0.035)
Mtl	-0.0749	0.0047	0.0005	0.1438	0.1295	0.2231	0.1295	0.1871	-0.0904	0.0626	0.0614
	(0.073)	(0.059)	(0.081)	(0.131)	(0.096)	(0.141)	(0.096)	(0.140)	(0.131)	(0.105)	(0.090)
Marteau	-0.8824***	-0.3503**	0.1168	0.5520**	-0.3304**	-0.4854**	-0.3304**	0.4622*	0.1155	-0.0824	-1.4782***
	(0.304)	(0.175)	(0.291)	(0.265)	(0.152)	(0.218)	(0.152)	(0.267)	(0.314)	(0.266)	(0.318)
Crude oil lag	0.0053***	0.0021**	-0.0014	-0.0027*	0.0021***	0.0027**	0.0021***	-0.0023	-0.0012	0.0004	0.0087***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)
Quantity	-0.0000*	0.0000	0.0000	-0.0000***	0.0000	0.0000	0.0000	-0.0000***	0.0000	0.0000	-0.0000***
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	-0.0737	-0.1693	0.0318	0.2545***	-0.3908***	-0.0524	-0.3908***	0.2081**	0.0689	-0.2438*	-0.0788
	(0.124)	(0.107)	(0.092)	(0.071)	(0.098)	(0.073)	(0.098)	(0.081)	(0.096)	(0.143)	(0.125)
Constant	-2.2529***	-0.8679**	0.6496	1.2188*	-0.9615***	-1.3889**	-0.9615***	0.9915	0.6686	-0.0810	-3.8404***
	(0.752)	(0.368)	(0.733)	(0.675)	(0.327)	(0.541)	(0.327)	(0.673)	(0.797)	(0.611)	(0.793)
Observations	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587	1,587
R-squared	0.0708	0.0801	0.0804	0.161	0.151	0.0983	0.151	0.155	0.0604	0.105	0.112
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2

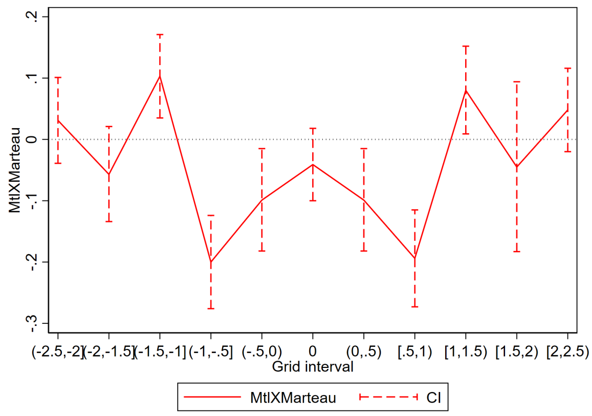
Dep. variable is the probability that bid differences fall in a given interval. $Marteau$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. Mtl indicates that the contract was for Montreal. Panel A without controls. Panel B with controls. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.11: Graphical representation of the distributional effect of the investigation on clustering & isolation. Original sample plus auctions with entrants, minus year 2010

(a) No controls



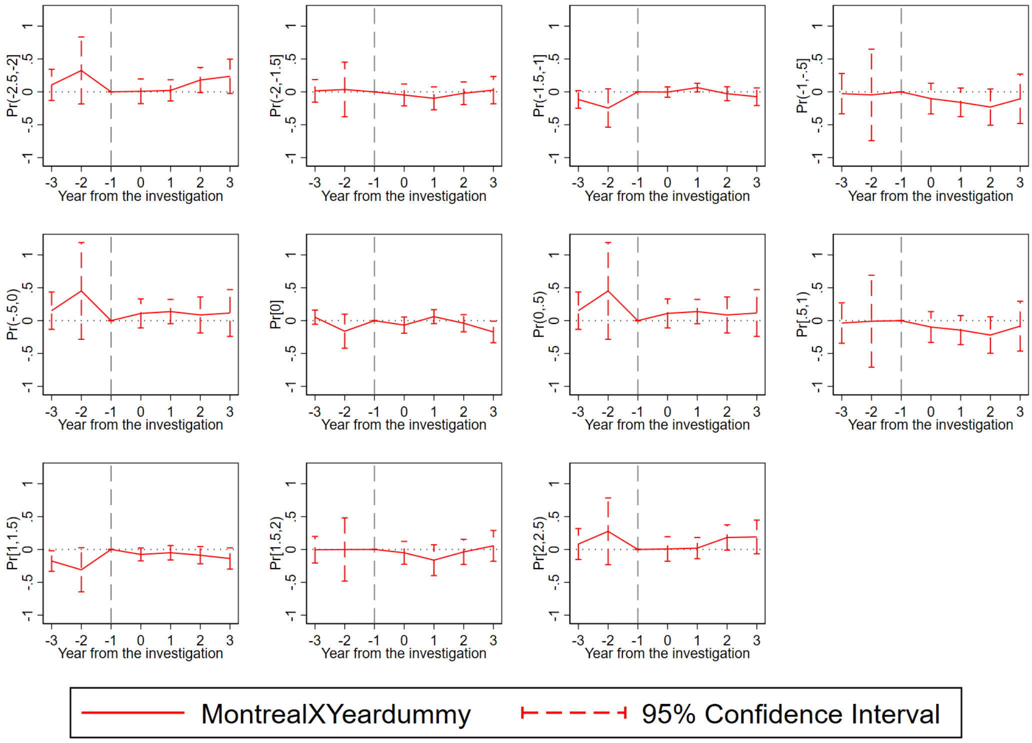
(b) Controls



This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table A.3. Confidence intervals are computed with standard errors clustered at the borough and year levels.

A.8 Parallel trend

Figure A.12: Event study graphs.



Notes: Plot of the coefficients (red line) and the associated confidence intervals of the interaction term between the dummy *Mtl* equal to 1 if the auctions is in Montreal and a dummy indicating whether the call for tender is published x years to/from the investigation, with x=-3,-2,0,1,2,3. The base group is the year 2009. The model includes also year, asphalt type and borough effects, together with auction-level controls (number of tons in the call, lagged price of crude oil and the Herfindahl index of each city at the year level). SEs are clustered at the borough-year level. *CI* are 95% confidence intervals.

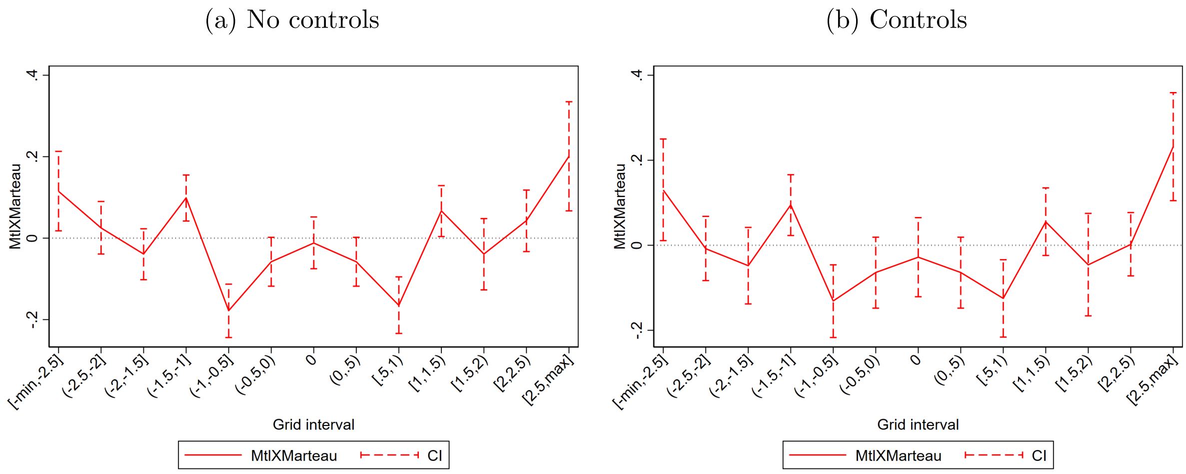
A.9 Main results – robustness

Table A.4: Distributional effect of the investigation on clustering & isolation – entire distribution

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)
Dep.Var.	Pr[min -2.5]	Pr(-2.5 -2)	Pr(-2 -1.5)	Pr(-1.5 -1)	Pr(-1 -.5)	Pr(-.5 0)	Pr[0]	Pr(0 .5)	Pr(.5 1)	Pr(1 1.5)	Pr(1.5 2)	Pr(2 2.5)	Pr[2.5 max]
							Panel A: Without controls						
Mtl×Marteau	0.1154**	0.0252	-0.0394	0.0987***	-0.1784***	-0.0582*	-0.0115	-0.0582*	-0.1647***	0.0666**	-0.0394	0.0425	0.2014***
	(0.050)	(0.033)	(0.032)	(0.029)	(0.033)	(0.031)	(0.032)	(0.031)	(0.035)	(0.032)	(0.044)	(0.039)	(0.068)
Mtl	-0.0543**	-0.0370*	0.0241	-0.0599**	0.1599***	0.0364	0.0444***	0.0364	0.1494***	-0.0340	0.0179	-0.0414	-0.2420***
	(0.026)	(0.021)	(0.024)	(0.027)	(0.025)	(0.022)	(0.015)	(0.022)	(0.027)	(0.027)	(0.033)	(0.027)	(0.049)
Marteau	0.0649	0.0136	0.0009	-0.0988***	0.0256	0.0133	0.0253	0.0133	0.0133	-0.0861***	-0.0111	-0.0111	0.0369
	(0.041)	(0.031)	(0.029)	(0.026)	(0.024)	(0.026)	(0.025)	(0.026)	(0.026)	(0.029)	(0.042)	(0.035)	(0.060)
Constant	0.0617**	0.0370*	0.0370*	0.0988***	0.0123	0.0247	0.0000	0.0247	0.0247	0.0988***	0.0617**	0.0617**	0.4568***
	(0.025)	(0.021)	(0.020)	(0.026)	(0.012)	(0.017)	(0.000)	(0.017)	(0.016)	(0.026)	(0.030)	(0.025)	(0.042)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0930	0.0226	0.00691	0.0103	0.0621	0.0104	0.00587	0.0104	0.0585	0.00680	0.00889	0.00805	0.0685
Borough FE	No	No	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	-4.12	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2	5.6
							Panel B: With controls						
Mtl×Marteau	0.1304**	-0.0076	-0.0484	0.0945**	-0.1312***	-0.0642	-0.0282	-0.0642	-0.1251***	0.0554	-0.0457	0.0022	0.2319***
	(0.061)	(0.038)	(0.046)	(0.037)	(0.044)	(0.043)	(0.047)	(0.043)	(0.046)	(0.041)	(0.061)	(0.038)	(0.065)
Mtl	-0.2163	-0.1756*	-0.0036	-0.0334	0.1992*	0.1082	0.1902	0.1082	0.2473**	-0.0964	0.0388	0.0137	-0.3802**
	(0.130)	(0.106)	(0.062)	(0.083)	(0.101)	(0.089)	(0.147)	(0.089)	(0.113)	(0.112)	(0.102)	(0.113)	(0.187)
Marteau	1.0891**	-0.1023	-0.5933**	-0.2074	1.1732***	-0.3230	-0.5791	-0.3230	1.0470***	-0.2460	-0.3983	-0.6855**	0.1486
	(0.497)	(0.332)	(0.227)	(0.293)	(0.375)	(0.234)	(0.353)	(0.234)	(0.380)	(0.316)	(0.352)	(0.316)	(0.644)
Crude oil lag	-0.0061**	0.0009	0.0035***	0.0006	-0.0066***	0.0020	0.0032	0.0020	-0.0059***	0.0010	0.0023	0.0044**	-0.0012
	(0.003)	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)	(0.004)
Quantity	0.0000	-0.0000	0.0000	-0.0000	-0.0000	0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	0.0000*
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	0.3268***	-0.0568	-0.1406	0.0550	0.2678***	-0.3949***	-0.0709	-0.3949***	0.2232***	0.0912	-0.1986	-0.0460	0.3387**
	(0.111)	(0.119)	(0.106)	(0.091)	(0.071)	(0.097)	(0.087)	(0.097)	(0.082)	(0.095)	(0.132)	(0.117)	(0.163)
Constant	2.8442**	-0.1954	-1.5494***	-0.2556	2.9355***	-0.8663	-1.5622*	-0.8663	2.6085**	-0.3772	-0.9576	-1.8277**	1.0696
	(1.277)	(0.826)	(0.527)	(0.739)	(0.988)	(0.595)	(0.898)	(0.595)	(0.997)	(0.799)	(0.857)	(0.786)	(1.696)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.183	0.0877	0.0991	0.105	0.176	0.169	0.151	0.169	0.169	0.0796	0.125	0.118	0.132
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	-4.12	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2	5.6

Dep. variable is the probability that bid differences fall in a given interval. $Marteau$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. Mtl indicates that the contract was for Montreal. Panel A without controls. Panel B with controls. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.13: Graphical representation of the distributional effect of the investigation on clustering & isolation. Entire distribution.



This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table A.4. Confidence intervals are computed with standard errors clustered at the borough and year levels.

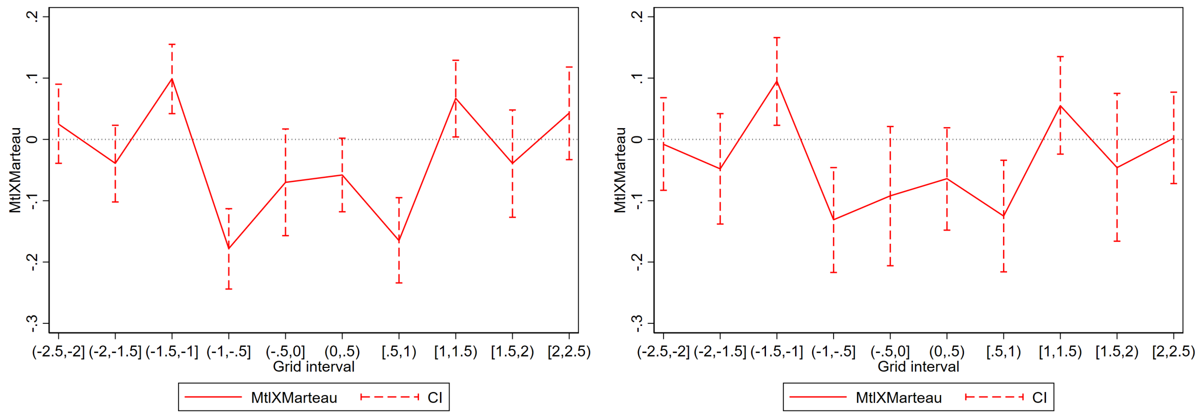
Table A.5: Distributional effect of the investigation on clustering & isolation – no separate bin for 0.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
	Panel A: Without controls									
Mtl×Marteau	0.0252	-0.0394	0.0987***	-0.1784***	-0.0697	-0.0582*	-0.1647***	0.0666**	-0.0394	0.0425
	(0.033)	(0.032)	(0.029)	(0.033)	(0.044)	(0.031)	(0.035)	(0.032)	(0.044)	(0.039)
Mtl	-0.0370*	0.0241	-0.0599**	0.1599***	0.0809***	0.0364	0.1494***	-0.0340	0.0179	-0.0414
	(0.021)	(0.024)	(0.027)	(0.025)	(0.026)	(0.022)	(0.027)	(0.027)	(0.033)	(0.027)
Marteau	0.0136	0.0009	-0.0988***	0.0256	0.0386	0.0133	0.0133	-0.0861***	-0.0111	-0.0111
	(0.031)	(0.029)	(0.026)	(0.024)	(0.035)	(0.026)	(0.026)	(0.029)	(0.042)	(0.035)
Constant	0.0370*	0.0370*	0.0988***	0.0123	0.0247	0.0247	0.0247	0.0988***	0.0617**	0.0617**
	(0.021)	(0.020)	(0.026)	(0.012)	(0.017)	(0.017)	(0.016)	(0.026)	(0.030)	(0.025)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0226	0.00691	0.0103	0.0621	0.00746	0.0104	0.0585	0.00680	0.00889	0.00805
Borough FE	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.16	.27	.55	1.02	1.6	2
	Panel B: With controls									
Mtl×Marteau	-0.0076	-0.0484	0.0945**	-0.1312***	-0.0924	-0.0642	-0.1251***	0.0554	-0.0457	0.0022
	(0.038)	(0.046)	(0.037)	(0.044)	(0.058)	(0.043)	(0.046)	(0.041)	(0.061)	(0.038)
Mtl	-0.1756*	-0.0036	-0.0334	0.1992*	0.2984**	0.1082	0.2473**	-0.0964	0.0388	0.0137
	(0.106)	(0.062)	(0.083)	(0.101)	(0.129)	(0.089)	(0.113)	(0.112)	(0.102)	(0.113)
Marteau	-0.1023	-0.5933**	-0.2074	1.1732***	-0.9021**	-0.3230	1.0470***	-0.2460	-0.3983	-0.6855**
	(0.332)	(0.227)	(0.293)	(0.375)	(0.382)	(0.234)	(0.380)	(0.316)	(0.352)	(0.316)
Crude oil lag	0.0009	0.0035***	0.0006	-0.0066***	0.0051**	0.0020	-0.0059***	0.0010	0.0023	0.0044**
	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Quantity	-0.0000	0.0000	-0.0000	-0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	-0.0568	-0.1406	0.0550	0.2678***	-0.4657***	-0.3949***	0.2232***	0.0912	-0.1986	-0.0460
	(0.119)	(0.106)	(0.091)	(0.071)	(0.101)	(0.097)	(0.082)	(0.095)	(0.132)	(0.117)
Constant	-0.1954	-1.5494***	-0.2556	2.9355***	-2.4285**	-0.8663	2.6085**	-0.3772	-0.9576	-1.8277**
	(0.826)	(0.527)	(0.739)	(0.988)	(0.965)	(0.595)	(0.997)	(0.799)	(0.857)	(0.786)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0877	0.0991	0.105	0.176	0.180	0.169	0.169	0.0796	0.125	0.118
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.16	.27	.55	1.02	1.6	2

Dep. variable is the probability that bid differences fall in a given interval. $Marteau$ is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. Mtl indicates that the contract was for Montreal. Panel A without controls. Panel B with controls. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.14: Graphical representation of the distributional effect of the investigation on clustering & isolation.

(a) No controls (b) Controls



This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table A.5. Confidence intervals are computed with standard errors clustered at the borough and year levels.

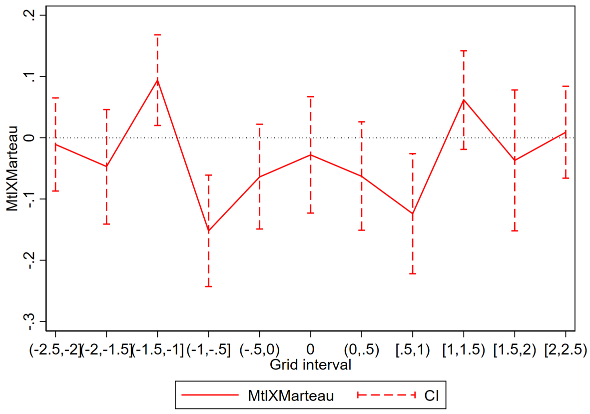
Table A.6: Distributional effect of the investigation. The estimation includes all controls in Clark et al. (2018).

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0)	Pr[0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
	Panel A: With controls										
Mtl×Marteau	-0.0109	-0.0474	0.0940**	-0.1520***	-0.0636	-0.0277	-0.0626	-0.1242**	0.0617	-0.0372	0.0089
	(0.039)	(0.048)	(0.038)	(0.046)	(0.044)	(0.048)	(0.045)	(0.050)	(0.041)	(0.059)	(0.038)
Mtl	-0.1709	-0.0204	-0.0425	0.1902*	0.0766	0.1907	0.1243	0.2956**	-0.1047	0.0410	-0.0017
	(0.106)	(0.062)	(0.085)	(0.104)	(0.088)	(0.148)	(0.087)	(0.115)	(0.111)	(0.101)	(0.114)
Marteau	-0.1330	-0.5994**	-0.2169	1.1662***	-0.3079	-0.5957	-0.4530*	0.8665***	-0.1924	-0.4469	-0.6552**
	(0.329)	(0.232)	(0.301)	(0.413)	(0.239)	(0.361)	(0.244)	(0.312)	(0.308)	(0.354)	(0.325)
Crude oil lag	0.0011	0.0035***	0.0007	-0.0065***	0.0018	0.0032	0.0027**	-0.0048***	0.0007	0.0025	0.0041**
	(0.002)	(0.001)	(0.002)	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.002)	(0.002)	(0.002)
Capacity	0.0000	-0.0000***	-0.0000*	-0.0000***	-0.0000***	0.0000	0.0000***	0.0000***	-0.0000	0.0000***	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Quantity	-0.0000	0.0000	-0.0000	-0.0000	0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Distance	-0.0004	0.0007	0.0003	-0.0017	0.0011	0.0001	0.0001	-0.0009	0.0007	0.0009	0.0011
	(0.001)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
CON	0.0119	0.0355	0.0243	0.0662	0.0569**	0.0056	0.0241	-0.0173	-0.0211	0.0003	0.0033
	(0.017)	(0.035)	(0.021)	(0.043)	(0.027)	(0.009)	(0.032)	(0.039)	(0.022)	(0.023)	(0.020)
HHI	-0.0519	-0.1480	0.0514	0.2591***	-0.4120***	-0.0687	-0.3723***	0.2671***	0.0827	-0.1902	-0.0554
	(0.119)	(0.112)	(0.090)	(0.072)	(0.096)	(0.086)	(0.100)	(0.095)	(0.094)	(0.126)	(0.118)
Constant	-0.2808	-1.4603**	-0.2150	3.1751***	-0.6138	-1.6163*	-1.3516**	1.7696**	-0.2312	-1.1869	-1.7020**
	(0.830)	(0.571)	(0.760)	(1.082)	(0.633)	(0.929)	(0.608)	(0.830)	(0.785)	(0.861)	(0.793)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0908	0.111	0.109	0.203	0.219	0.151	0.213	0.253	0.0827	0.135	0.125
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.58	-1.03	-.55	-.27	0	.27	.55	1.02	1.6	2

The outcome is the probability that bid differences fall in a given interval of values. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. *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). *CON* is the percentage of all contracts won in a borough by a firm in the previous year. *Distance* is the distance from the firm to the delivery point of the borough where the job is located. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.15: Graphical representation of the distributional effect of the investigation on clustering & isolation. The estimation includes all controls in Clark et al. (2018)

(a) All controls



This figure reports the estimated coefficient for $Mtl \times Marteau$ in Table A.6 along with confidence intervals. Confidence intervals are computed with standard errors clustered at the borough-year level.

Table A.7: Distributional effect of the investigation on clustering & isolation. Finer grid – 0.25

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)
Dep.Var.	Pr(-2.25 -2]	Pr(-2 -1.75]	Pr(-1.75 -1.5]	Pr(-1.5 -1.25]	Pr(-1.25 -1]	Pr(-1 -.75]	Pr(-.75 -.5]	Pr(-.5 -.25]	Pr(-.25 0)	Pr[0]	Pr(0 .25)	Pr[.25 .5)	Pr[.5 .75)	Pr[.75 1)	Pr[1 1.25)	Pr[1.25 1.5)	Pr[1.5 1.75)	Pr[1.75 2)	Pr[2 2.25)
									Panel A: Without controls										
Mtl×Marteau	0.0256	-0.0283	-0.0111	0.0494**	0.0493**	-0.0420**	-0.1364***	-0.0491*	-0.0091	-0.0115	-0.0091	-0.0491*	-0.1383***	-0.0264	0.0266	0.0400	-0.0294	-0.0101	0.0272
	(0.029)	(0.022)	(0.025)	(0.022)	(0.024)	(0.020)	(0.030)	(0.025)	(0.018)	(0.032)	(0.018)	(0.025)	(0.030)	(0.025)	(0.024)	(0.026)	(0.033)	(0.027)	(0.034)
Mtl	-0.0247	0.0062	0.0179	-0.0494**	-0.0105	0.0296***	0.1302***	0.0364	-0.0000	0.0444***	-0.0000	0.0364	0.1321***	0.0173	0.0154	-0.0494**	0.0235	-0.0056	-0.0167
	(0.017)	(0.013)	(0.021)	(0.022)	(0.022)	(0.007)	(0.027)	(0.022)	(0.000)	(0.015)	(0.000)	(0.022)	(0.026)	(0.014)	(0.022)	(0.022)	(0.021)	(0.021)	(0.022)
Marteau	0.0133	0.0130	-0.0120	-0.0494**	-0.0494**	0.0253	0.0003	-0.0120	0.0253	0.0253	0.0253	-0.0120	0.0003	0.0130	-0.0494**	-0.0367	0.0006	-0.0117	0.0009
	(0.027)	(0.021)	(0.021)	(0.022)	(0.021)	(0.017)	(0.017)	(0.021)	(0.017)	(0.025)	(0.017)	(0.021)	(0.017)	(0.021)	(0.021)	(0.026)	(0.030)	(0.026)	(0.029)
Constant	0.0247	0.0123	0.0247	0.0494**	0.0494**	-0.0000	0.0123	0.0247	0.0000	0.0000	0.0000	0.0247	0.0123	0.0123	0.0494**	0.0494**	0.0247	0.0370*	0.0370*
	(0.017)	(0.012)	(0.017)	(0.022)	(0.021)	(.)	(0.012)	(0.017)	(0.000)	(0.000)	(0.000)	(0.017)	(0.012)	(0.012)	(0.021)	(0.022)	(0.017)	(0.020)	(0.020)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0205	0.00414	0.00463	0.0456	0.00346	0.00450	0.0606	0.0229	0.0119	0.00587	0.0119	0.0229	0.0616	0.00201	0.00675	0.0298	0.00530	0.00437	0.00524
Borough FE	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	-1.75	-1.75	-1.5	.	-1.03	-.77	-.5	-.27	.	-1.75	.	.27	.5	.77	1.02	.	1.5	1.75	2
									Panel B: With controls										
Mtl×Marteau	0.0164	0.0043	-0.0527	0.0604**	0.0341	-0.0296	-0.1015***	-0.0365	-0.0277	-0.0282	-0.0277	-0.0365	-0.1087***	-0.0163	-0.0095	0.0649**	-0.0810	0.0353*	0.0239
	(0.034)	(0.011)	(0.046)	(0.028)	(0.029)	(0.027)	(0.036)	(0.029)	(0.026)	(0.047)	(0.026)	(0.029)	(0.036)	(0.030)	(0.031)	(0.028)	(0.059)	(0.020)	(0.035)
Mtl	-0.1834*	-0.0095	0.0059	0.1430**	-0.1764**	0.0060	0.1932***	0.0621	0.0461	0.1902	0.0461	0.0621	0.1900***	0.0573	-0.1398**	0.0434	0.0365	0.0023	0.0176
	(0.099)	(0.020)	(0.057)	(0.068)	(0.071)	(0.085)	(0.072)	(0.072)	(0.042)	(0.147)	(0.042)	(0.072)	(0.072)	(0.088)	(0.070)	(0.108)	(0.061)	(0.057)	(0.109)
Marteau	-0.2241	-0.4231***	-0.1702	0.0403	-0.2477	0.1640	1.0091***	-0.4181***	0.0951	-0.5791	0.0951	-0.4181***	0.9657***	0.0813	-0.1502	-0.0958	-0.2318	-0.1665	-0.7839***
	(0.294)	(0.143)	(0.174)	(0.074)	(0.287)	(0.221)	(0.320)	(0.157)	(0.152)	(0.353)	(0.152)	(0.157)	(0.312)	(0.228)	(0.284)	(0.114)	(0.198)	(0.260)	(0.291)
Crude oil lag	0.0014	0.0025***	0.0010	-0.0005	0.0012	-0.0011	-0.0054***	0.0023***	-0.0003	0.0032	-0.0003	0.0023***	-0.0052***	-0.0007	0.0008	0.0002	0.0015	0.0008	0.0048***
	(0.002)	(0.001)	(0.001)	(0.000)	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)	(0.001)	(0.001)	(0.002)
Quantity	-0.0000	0.0000	-0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	0.0000	0.0000	0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	-0.1497**	-0.1321***	-0.0085	0.0995	-0.0446	0.0235	0.2443***	-0.4565***	0.0616	-0.0709	0.0616	-0.4565***	0.2286***	-0.0054	0.0130	0.0782	-0.0388	-0.1598***	-0.1064
	(0.066)	(0.036)	(0.095)	(0.065)	(0.092)	(0.033)	(0.069)	(0.073)	(0.046)	(0.087)	(0.046)	(0.073)	(0.072)	(0.042)	(0.095)	(0.065)	(0.105)	(0.061)	(0.071)
Constant	-0.3960	-1.1128***	-0.4366	0.0697	-0.3253	0.6549	2.2806***	-0.9370**	0.0707	-1.5622*	0.0707	-0.9370**	2.1701***	0.4384	-0.2004	-0.1768	-0.6414	-0.3162	-1.9944***
	(0.753)	(0.361)	(0.373)	(0.156)	(0.731)	(0.604)	(0.815)	(0.377)	(0.403)	(0.898)	(0.403)	(0.377)	(0.792)	(0.622)	(0.724)	(0.264)	(0.452)	(0.654)	(0.741)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0988	0.181	0.103	0.135	0.103	0.112	0.183	0.193	0.0771	0.151	0.0771	0.193	0.180	0.115	0.0847	0.106	0.103	0.222	0.125
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	.	-1.75	-1.5	.	-1.03	-.77	-.5	-.27	.	-1.75	.	.27	.5	.77	1.02	.	1.5	1.75	2

Dep. variable is the probability that bid differences fall in a given interval. *Marteau* is a dummy equal to 1 if the contract is awarded after the start of the investigations in October 2009. *Mtl* indicates that the contract was for Montreal. Panel A without controls. Panel B with controls. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Table A.8: Distributional regression doubling intervals around 0.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Dep.Var	Pr(-4 -3]	Pr(-3 -2]	Pr(-2 -1]	Pr(-1 0)	Pr[0]	Pr(0 1)	Pr[1, 2)	Pr[2 3)	Pr[3 4)
					Panel A: Without controls				
MtlXMarteau	-0.0113	0.0459	0.0593	-0.2366***	-0.0115	-0.2229***	0.0272	0.0950*	-0.0133
	(0.031)	(0.039)	(0.040)	(0.039)	(0.032)	(0.044)	(0.048)	(0.048)	(0.045)
Mtl	-0.0228	-0.0704**	-0.0358	0.1963***	0.0444***	0.1858***	-0.0160	-0.1191***	-0.1531***
	(0.017)	(0.028)	(0.031)	(0.027)	(0.015)	(0.034)	(0.033)	(0.037)	(0.035)
Marteau	0.0386	-0.0108	-0.0978***	0.0389	0.0253	0.0266	-0.0972**	-0.0969**	0.0674
	(0.030)	(0.038)	(0.035)	(0.033)	(0.025)	(0.039)	(0.044)	(0.045)	(0.044)
Constant	0.0247	0.0741***	0.1358***	0.0370*	0.0000	0.0494*	0.1605***	0.1728***	0.1605***
	(0.017)	(0.028)	(0.028)	(0.019)	(0.000)	(0.028)	(0.031)	(0.036)	(0.034)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0205	0.0252	0.00849	0.0739	0.00587	0.0707	0.0128	0.0177	0.0880
Borough FE	No	No	No	No	No	No	No	No	No
Year FE	No	No	No	No	No	No	No	No	No
Type FE	No	No	No	No	No	No	No	No	No
Mean Y Pre Montreal	-3.5	-2.5	-1.36	-.48	0	.48	1.34	2.34	3.15
					Panel B: With controls				
Mtl×Marteau	0.0074	0.0462	0.0462	-0.1954***	-0.0282	-0.1893***	0.0098	0.0595	0.0299
	(0.029)	(0.050)	(0.061)	(0.058)	(0.047)	(0.059)	(0.068)	(0.060)	(0.047)
Mtl	-0.2071**	-0.1490	-0.0370	0.3074**	0.1902	0.3555**	-0.0576	-0.0749	-0.2152*
	(0.095)	(0.107)	(0.090)	(0.129)	(0.147)	(0.155)	(0.116)	(0.129)	(0.121)
Marteau	0.3332	0.0002	-0.8007**	0.8502**	-0.5791	0.7240*	-0.6443	-1.2761***	0.1004
	(0.272)	(0.351)	(0.366)	(0.414)	(0.353)	(0.424)	(0.437)	(0.406)	(0.326)
Crude oil lag	-0.0018	0.0000	0.0042**	-0.0046*	0.0032	-0.0040	0.0033	0.0070***	-0.0004
	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)	(0.002)
Quantity	0.0000	-0.0000	0.0000	-0.0000	0.0000	-0.0000	-0.0000	0.0000	-0.0000
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
HHI	0.1062	0.1027	-0.0857	-0.1270	-0.0709	-0.1717	-0.1074	-0.1542	0.1718*
	(0.065)	(0.107)	(0.121)	(0.116)	(0.087)	(0.128)	(0.128)	(0.168)	(0.102)
Constant	0.9857	0.1151	-1.8050**	2.0691*	-1.5622*	1.7422	-1.3348	-2.8787***	0.3601
	(0.721)	(0.885)	(0.905)	(1.093)	(0.898)	(1.112)	(1.098)	(0.979)	(0.822)
Observations	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009	1,009
R-squared	0.0891	0.0951	0.115	0.152	0.151	0.149	0.137	0.0865	0.145
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Mean Y Pre Montreal	-3.5	-2.5	-1.36	-.48	0	.48	1.34	2.34	3.15

The outcome is the probability that bid differences fall in a given interval of values. *Quantity* represents the number of tons in the call. *Crude oil lag* represents the lagged price of crude oil. *HHI* is the Herfindahl index of each city at the year level. Significance at 10% (*), 5% (**), and 1% (***).

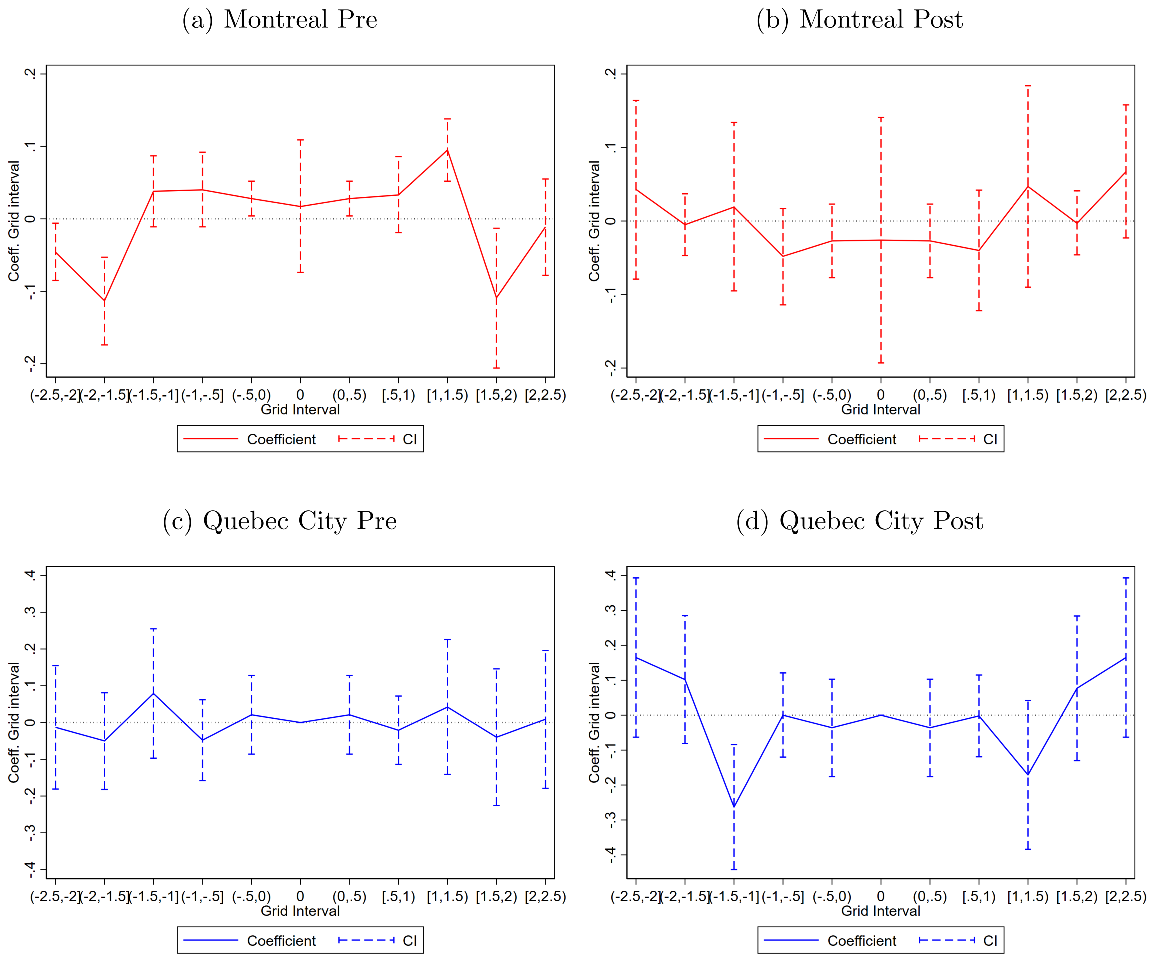
A.10 Test adding controls

Table A.9: Estimation of the parametric screen (equation 4) comparing bid differences $\Delta^1_{i,a}$ with respect to $\Delta^2_{i,a}$ in Montreal and Quebec City before and after the investigation. Controls are added in this specification.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Dep.Var	Pr(-2.5 -2]	Pr(-2-1.5]	Pr(-1.5-1]	Pr(-1 -.5]	Pr(-.5 -0)	Pr[0]	Pr(0 .5)	Pr[.5 1)	Pr[1 1.5)	Pr[1.5 2)	Pr[2 2.5)
						Panel A: Montreal Pre					
$\mathbb{1}(\Delta^1_{i,a})$	-0.0455**	-0.1132***	0.0379	0.0402	0.0279**	0.0174	0.0279**	0.0334	0.0947***	-0.1094**	-0.0113
	(0.020)	(0.031)	(0.025)	(0.026)	(0.012)	(0.047)	(0.012)	(0.027)	(0.022)	(0.049)	(0.034)
Constant	0.0889***	-0.1794	0.1302***	0.1495	0.0657	0.4545***	0.0657	0.1823	0.0112	-0.0829	0.1143***
	(0.032)	(0.127)	(0.043)	(0.115)	(0.058)	(0.095)	(0.058)	(0.123)	(0.075)	(0.132)	(0.034)
Observations	518	518	518	518	518	518	518	518	518	518	518
R-squared	0.115	0.125	0.136	0.111	0.219	0.266	0.219	0.104	0.107	0.128	0.0816
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
						Panel B: Montreal Post					
$\mathbb{1}(\Delta^1_{i,a})$	0.0426	-0.0046	0.0193	-0.0483	-0.0270	-0.0263	-0.0270	-0.0401	0.0468	-0.0029	0.0674
	(0.062)	(0.021)	(0.058)	(0.033)	(0.026)	(0.085)	(0.026)	(0.042)	(0.070)	(0.022)	(0.046)
Constant	0.1178	-0.1820	-0.7902***	1.2452***	0.3637	-0.3398	0.3637	1.3908***	-0.8285***	0.4858	-0.8267
	(0.541)	(0.277)	(0.216)	(0.373)	(0.246)	(0.760)	(0.246)	(0.428)	(0.214)	(0.379)	(0.775)
Observations	186	186	186	186	186	186	186	186	186	186	186
R-squared	0.158	0.302	0.206	0.158	0.273	0.299	0.273	0.149	0.233	0.276	0.235
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
						Panel C: Quebec Pre					
$\mathbb{1}(\Delta^1_{i,a})$	-0.0126	-0.0503	0.0793	-0.0477	0.0207		0.0207	-0.0211	0.0423	-0.0400	0.0088
	(0.086)	(0.067)	(0.090)	(0.056)	(0.055)		(0.055)	(0.047)	(0.094)	(0.095)	(0.096)
Constant	0.1204	-0.1695	0.9796***	-0.0647	-0.5158**		-0.5158**	-0.1352	1.1370***	0.0279	0.1362
	(0.242)	(0.266)	(0.337)	(0.114)	(0.204)		(0.204)	(0.146)	(0.270)	(0.291)	(0.163)
Observations	82	82	82	82	82		82	82	82	82	82
R-squared	0.106	0.164	0.123	0.122	0.171		0.171	0.152	0.112	0.124	0.0795
Controls	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Borough FE	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes		Yes	Yes	Yes	Yes	Yes
						Panel D: Quebec Post					
$\mathbb{1}(\Delta^1_{i,a})$	0.1650	0.1020	-0.2629**	0.0003	-0.0365	-0.0000	-0.0365	-0.0020	-0.1713	0.0770	0.1650
	(0.117)	(0.093)	(0.092)	(0.061)	(0.071)	(0.000)	(0.071)	(0.060)	(0.109)	(0.106)	(0.117)
Constant	-1.0604***	-0.4438	0.2031	0.6112	0.7708	1.0000***	0.7708	0.8829	0.2199	-0.8942	-1.0604***
	(0.331)	(0.376)	(0.482)	(0.926)	(0.668)	(0.000)	(0.668)	(0.921)	(0.570)	(0.601)	(0.331)
Observations	58	58	58	58	58	58	58	58	58	58	58
R-squared	0.158	0.161	0.226	0.133	0.261	1	0.261	0.161	0.193	0.218	0.158
Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Borough FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

The outcome is the probability that bid differences fall in a given interval of values. $\mathbb{1}(\Delta^1_{i,a})$ is an indicator variable equal to 1 if the observation is derived from the distribution of $\Delta^1_{i,a}$ and 0 if derived from the distribution of $\Delta^2_{i,a}$. Controls include *Quantity* which represents the number of tons in the call, *Crude oil lag* which represents the lagged price of crude oil and *HHI* which represents the Herfindahl index of each city at the year level.Standard errors are clustered at the borough and year levels. Significance at 10% (*), 5% (**), and 1% (***).

Figure A.16: Graphical representation of the parametric screen. Controls are added in this specification.



This figure reports the coefficients β_q estimated from equation (4), along with confidence intervals, obtained separately for each city/time period. Confidence intervals are computed with standard errors clustered at the borough and year levels.

Table A.10: Nonparametric implementation of the screen

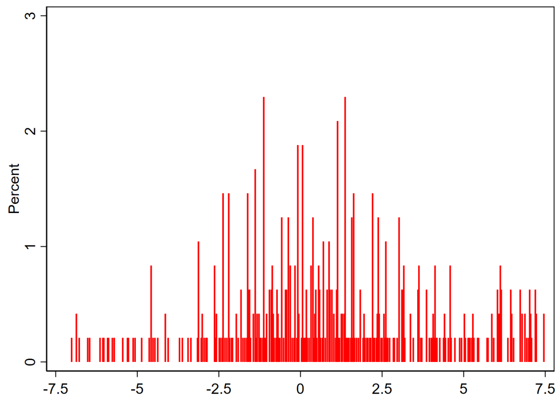
	Pre Anti-Collusion Investigation	Post Anti-Collusion Investigation
Montreal	0.008	0.709
Quebec City	0.946	0.531

Values are the *p-values* from the Kolmogorov–Smirnov test of $H_0 : f^1(\Delta^1|\Delta^1 \in [-H, H]) = f^2(\Delta^2|\Delta^2 \in [-H, H])$ *for* $H > 0$ *and* $H \to 0$.

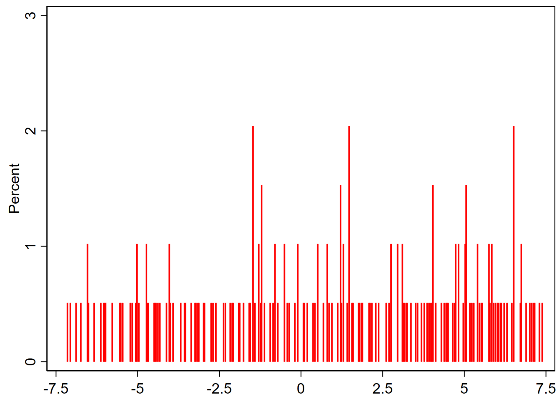
A.11 Total bids

Figure A.17: $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation.

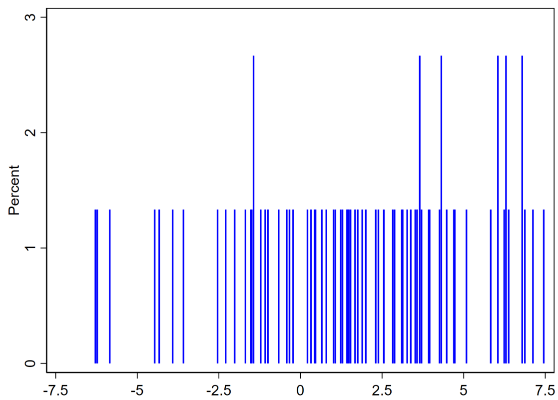
(a) Montreal Pre



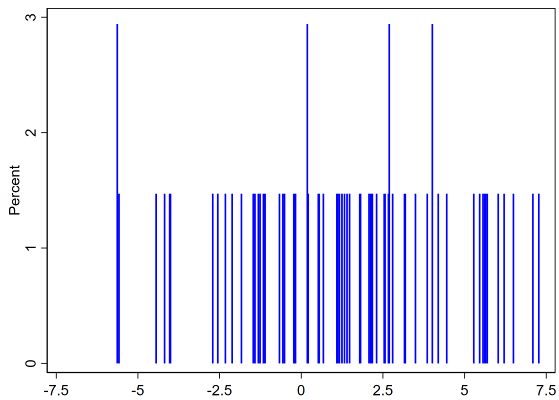
(b) Montreal Post



(c) Quebec City Pre

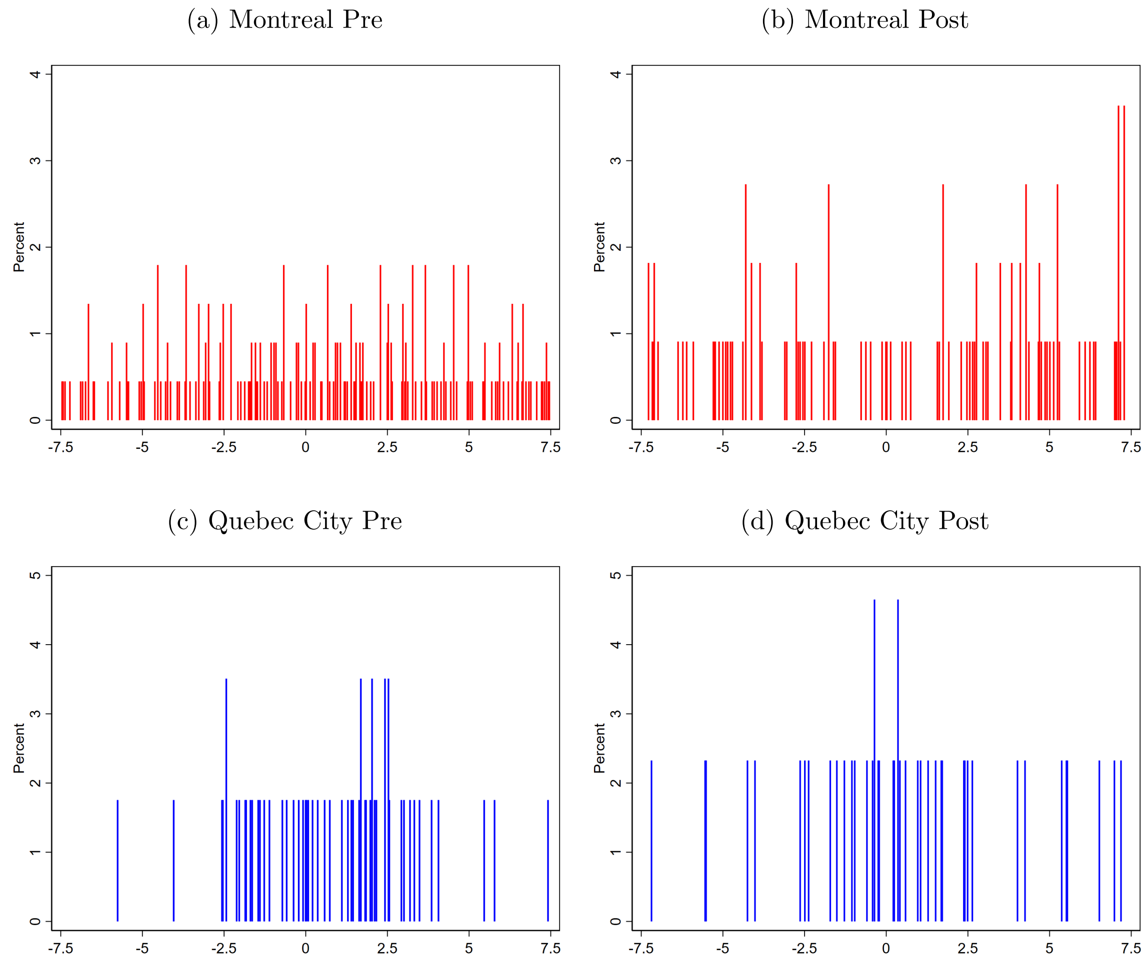


(d) Quebec City Post



Bid differences in \$ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation (\$7.5 per ton). The number of bins is equal to 500.

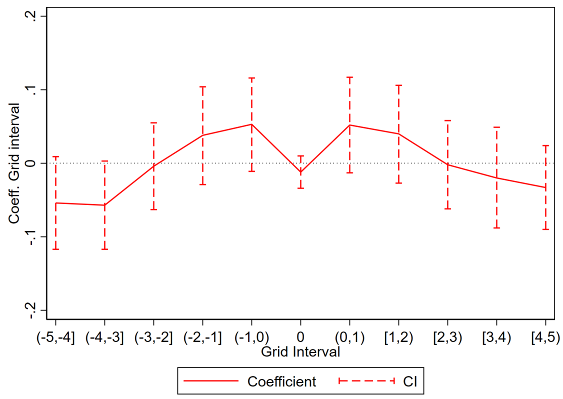
Figure A.18: $\Delta^2_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation.



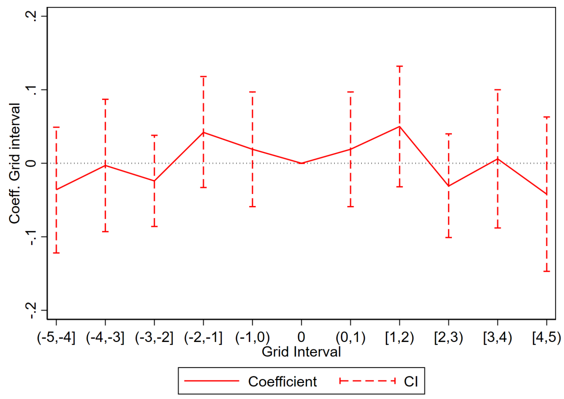
Bid differences in \$ per ton. The interval of bid differences is $\pm 10\%$ of the winning bid in Montreal before the start of the investigation (\$7.5 per ton). The number of bins is equal to 500.

Figure A.19: Graphical representation of the parametric screen on total bids

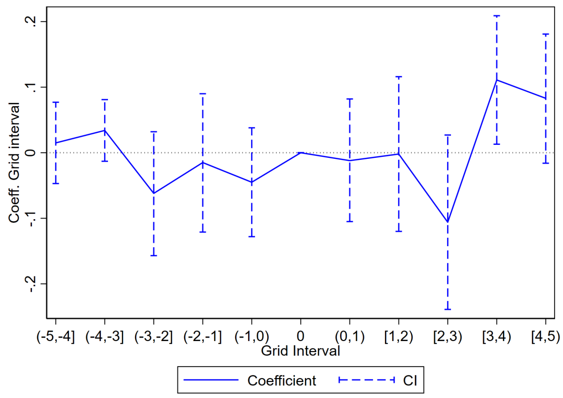
(a) Montreal Pre



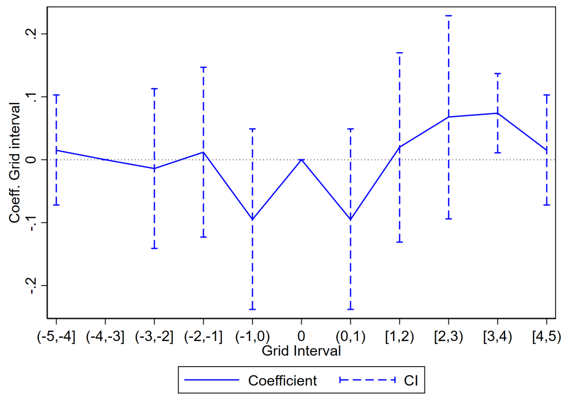
(b) Montreal Post



(c) Quebec City Pre



(d) Quebec City Post



This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals, obtained separately for each city/time period. Confidence intervals are computed with standard errors clustered at the borough and year levels.

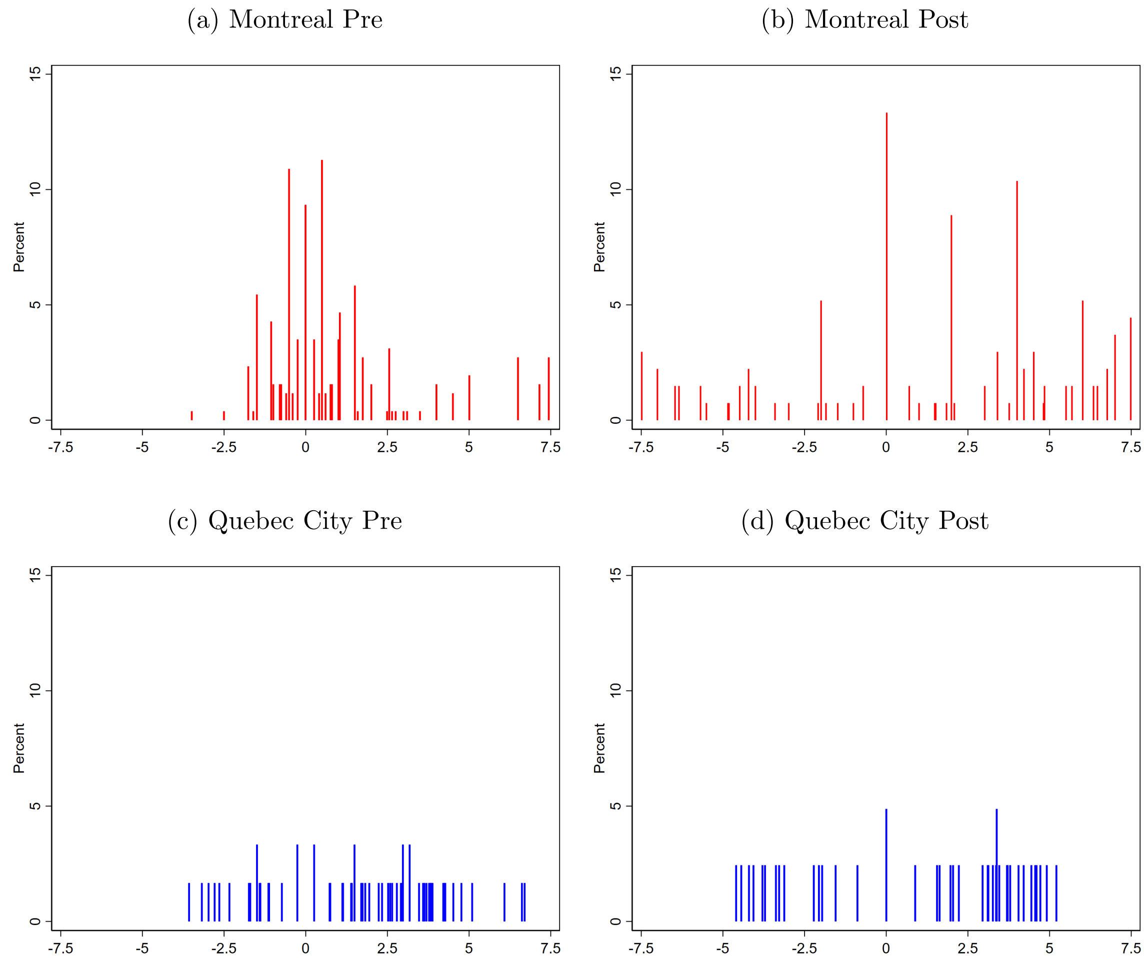
Table A.11: Nonparametric implementation of the screen on total bids

	Pre Anti-Collusion Investigation	Post Anti-Collusion Investigation
Montreal	0.011	0.488
Quebec City	0.207	0.289

Values are the *p-values* from the Kolmogorov–Smirnov test of $H_0 : f^1(\Delta^1|\Delta^1 \in [-H,H]) = f^2(\Delta^2|\Delta^2 \in [-H,H])$ *for* $H > 0$ *and* $H \to 0$.

A.12 Lowest raw bidder = final winner

Figure A.20: $\Delta^1_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation.



(a) Montreal Pre

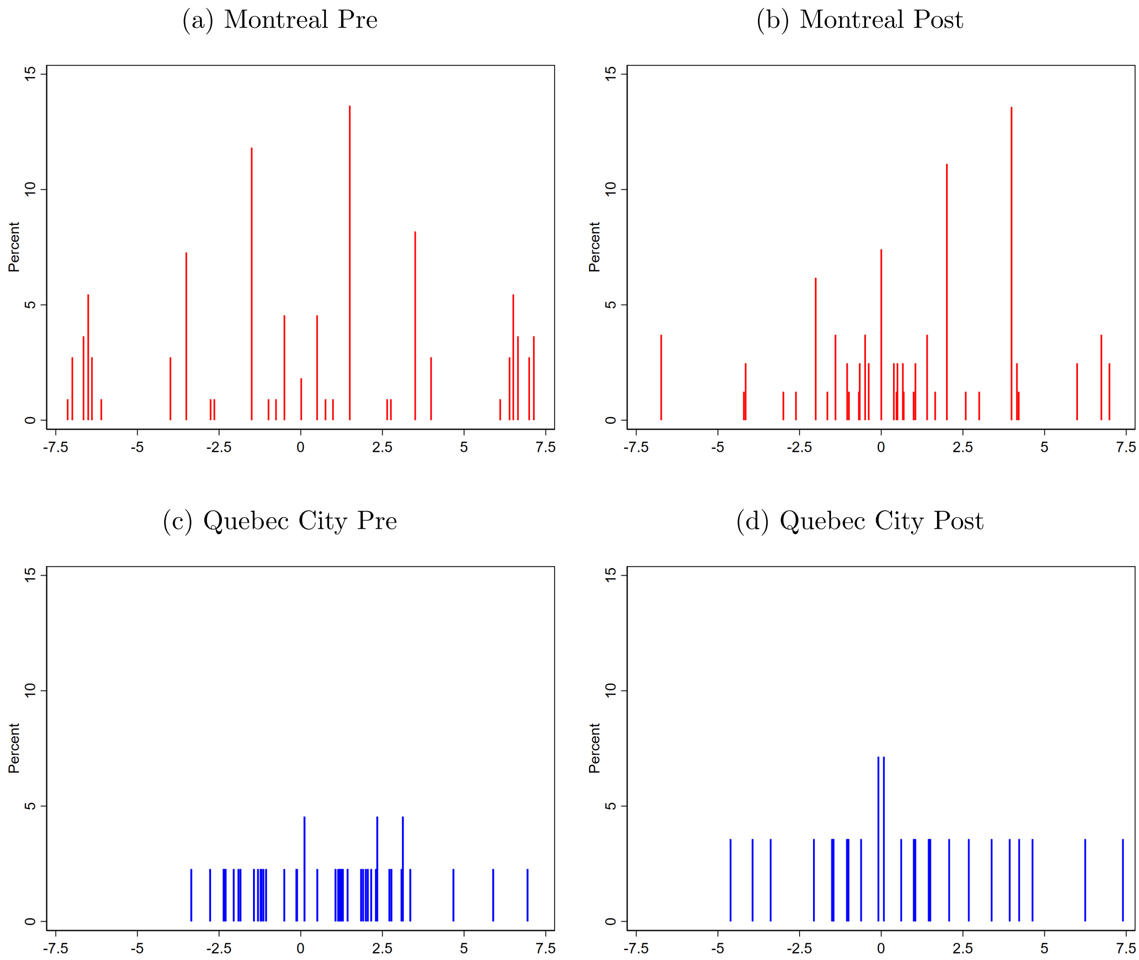
(b) Montreal Post

(c) Quebec City Pre

(d) Quebec City Post

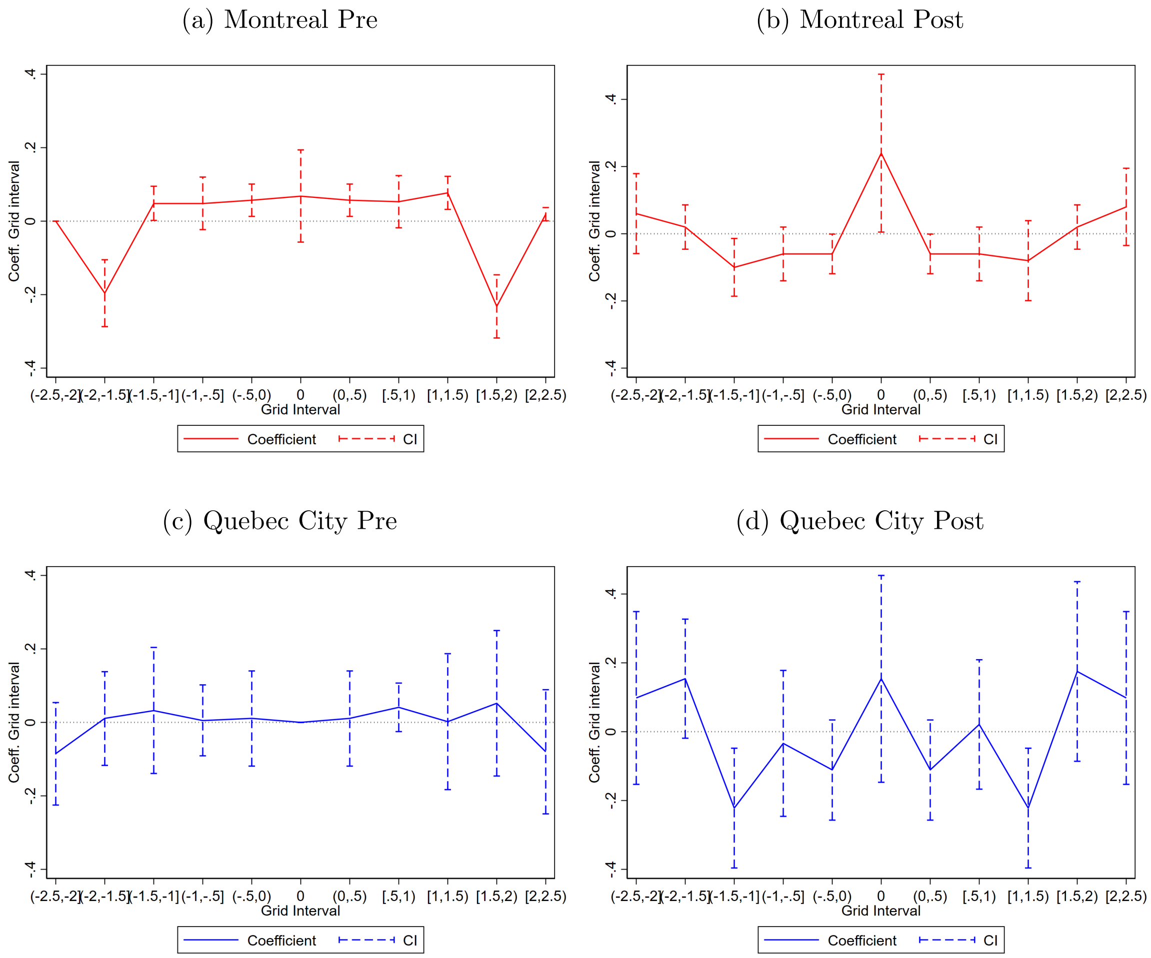
Bid differences in \$ per ton. The interval of bid differences is ±10% of the winning bid in Montreal before the start of the investigation (\$7.5 per ton). The number of bins is equal to 500.

Figure A.21: $\Delta^2_{i,a}$ for Montreal and Quebec City before and after the start of the police investigation.



Bid differences in $ per ton. The interval of bid differences is $\pm 10\%$ of the winning bid in Montreal before the start of the investigation ($7.5 per ton). The number of bins is equal to 500.

Figure A.22: Graphical representation of the parametric screen on auctions in which lowest raw bidder = final winner



This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals, obtained separately for each city/time period. Confidence intervals are computed with standard errors clustered at the borough and year levels.

Table A.12: Nonparametric implementation of the screen

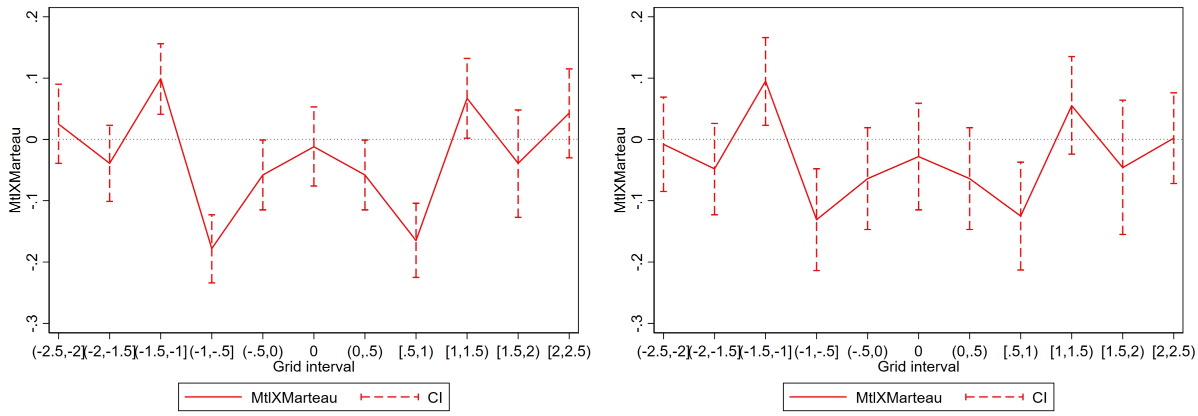
	Pre Anti-Collusion Investigation	Post Anti-Collusion Investigation
Montreal	0.062	0.717
Quebec City	0.842	0.304

Values are the *p-values* from the Kolmogorov–Smirnov test of $H_0 : f^1(\Delta^1|\Delta^1 \in [-H, H]) = f^2(\Delta^2|\Delta^2 \in [-H, H])$ *for* $H > 0$ *and* $H \to 0$.

A.13 Clustering of Standard Errors at the auction level

Figure A.23: Graphical representation of the distributional effect of the investigation on clustering & isolation. Standard errors are clustered at the auction level.

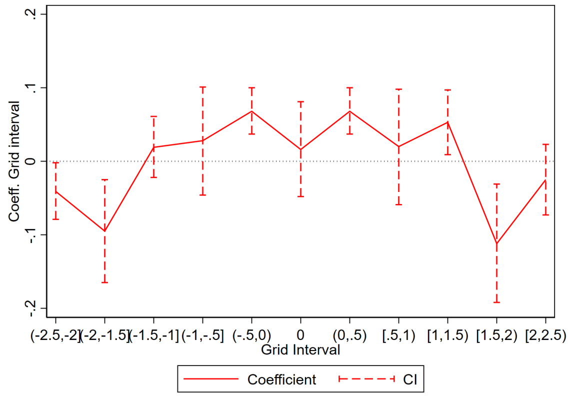
(a) No controls (b) Controls



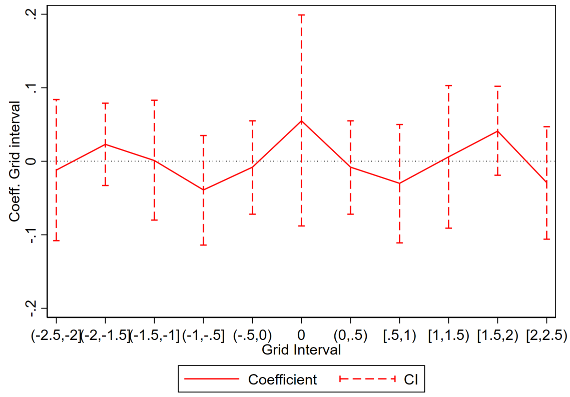
This figure reports the estimated coefficient for $Mtl \times Marteau$, along with confidence intervals, from Table 3. Confidence intervals are computed with standard errors clustered at the auction level.

Figure A.24: Graphical representation of the parametric screen. Standard errors are clustered at the auction level.

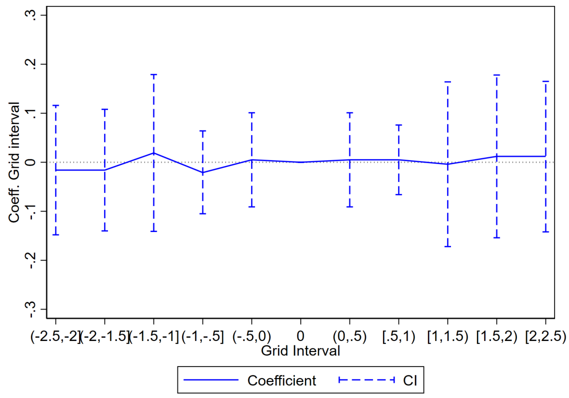
(a) Montreal Pre



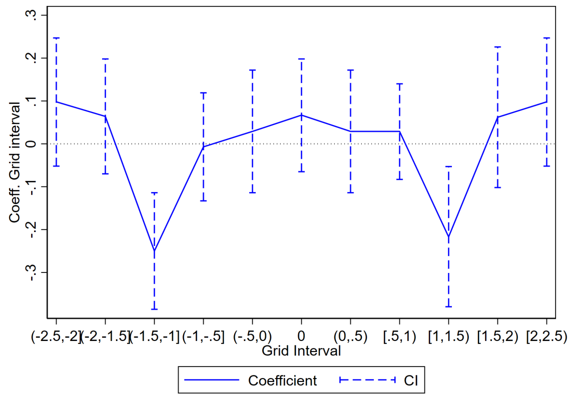
(b) Montreal Post



(c) Quebec City Pre



(d) Quebec City Post



This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals, obtained separately for each city/time period. Confidence intervals are computed with standard errors clustered at the auction level.

A.14 Implementation of the test

Parametric version (with and without controls) The steps required for the implementation of the screen are:

1. Construct $\Delta^1_{i,a}$, using the entire sample of contracts and bids.
2. Construct $\Delta^2_{i,a}$, using the same approach as for $\Delta^1_{i,a}$ but excluding winning bids.
3. Append the two sets of bid differences constructed in steps 1 and 2. This will be the sample of $\Delta_{i,a}$ that we will use for the screen.
4. Generate an indicator variable $\mathbb{1}(f(\Delta^1_{i,a}))$ equal to 1 when bid differences $\Delta_{i,a}$ are from the distribution of $\Delta^1_{i,a}$, and equal to 0 when they come from the distribution of $\Delta^2_{i,a}$.
5. Generate an indicator variable $y_{i,a,q}$ equal to 1 if a bid difference $\Delta_{i,a}$ is within a given interval q, and to 0 otherwise but still in the interval $[-H, H]$
6. Run Q linear probability models, represented by equation (4), in the market suspected of collusion.
7. Check the statistical significance of coefficients β_q, which indicate a statistical significant difference between the distributions of $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$ in the interval q. Under the null of competitive behavior the two distributions should not be statistically different for intervals q within $-H$ and H.
8. Repeat steps 6 and 7 adding controls

Non-parametric version (no controls)

The steps required for the implementation of the screen are:

1. Construct $\Delta^1_{i,a}$, using the entire sample of contracts and bids.
2. Construct $\Delta^2_{i,a}$, using the same approach as for $\Delta^1_{i,a}$ but excluding winning bids.
3. Append the two sets of bid differences constructed in steps 1 and 2. This will be the sample of $\Delta_{i,a}$ that we will use for the screen.
4. On the samples of $\Delta_{i,a}$ within $-H$ and H, implement the two-sample KS test to check the statistical difference between the two distribution of $\Delta_{i,a}$s within $-H$ and H
5. Extract the *p-value* of the test

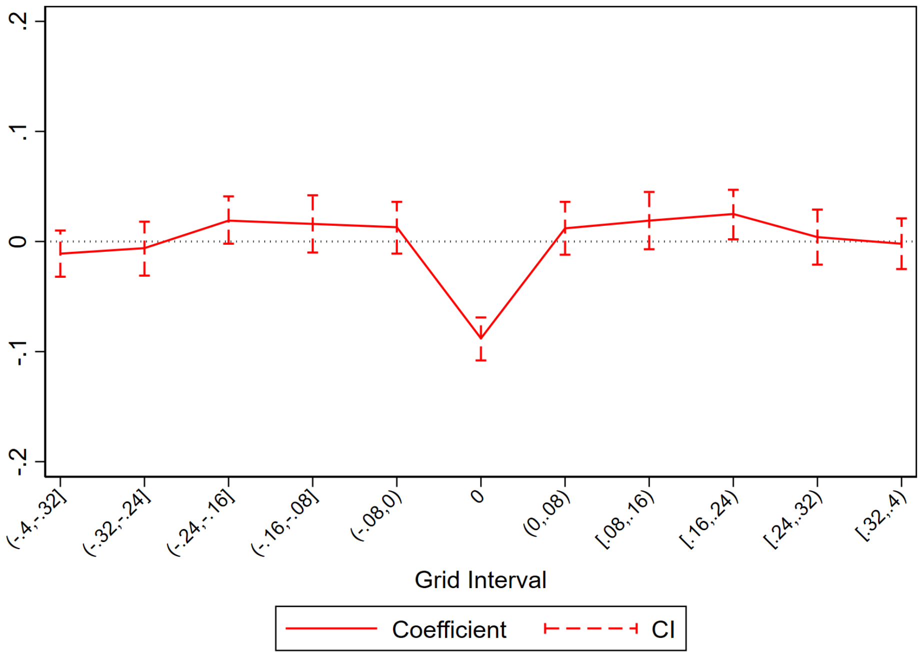
Non-parametric version (with controls) The steps required for the implementation of the screen are:

1. Construct $\Delta^1_{i,a}$, using the entire sample of contracts and bids.
2. Construct $\Delta^2_{i,a}$, using the same approach as for $\Delta^1_{i,a}$ but excluding winning bids.
3. Append the two sets of bid differences constructed in steps 1 and 2. This will be the sample of $\Delta_{i,a}$ that we will use for the screen.
4. Run an OLS regression of $\Delta^1_{i,a}$ and $\Delta^2_{i,a}$ on auction characteristics to obtain residuals.
5. Implement the two-sample KS test on the residuals to check the statistical difference between the residualized distribution of $\Delta_{i,a}$s within $-H$ and H
6. Extract the *p-value* of the test

A.15 Ohio school milk cartel

According to Porter and Zona (1999), the Ohio school milk cartel featured collusion. We apply our screen in the Ohio school milk dataset made publicly available by Wachs and Kertész (2019). Results for the parametric test are reported in Figure A.25. The *p-value* of the KS test is 0.044. The *p-value* is from the Kolmogorov–Smirnov test of $H_0 : f^1(\Delta^1|\Delta^1 \in [-H, H]) = f^2(\Delta^2|\Delta^2 \in [-H, H]) \; for \; H > 0 \; and \; H \to 0$. Both tests reject the null of competition.

Figure A.25: Graphical representation of the parametric screen between [-H,H]. Ohio school milk public procurement auctions.

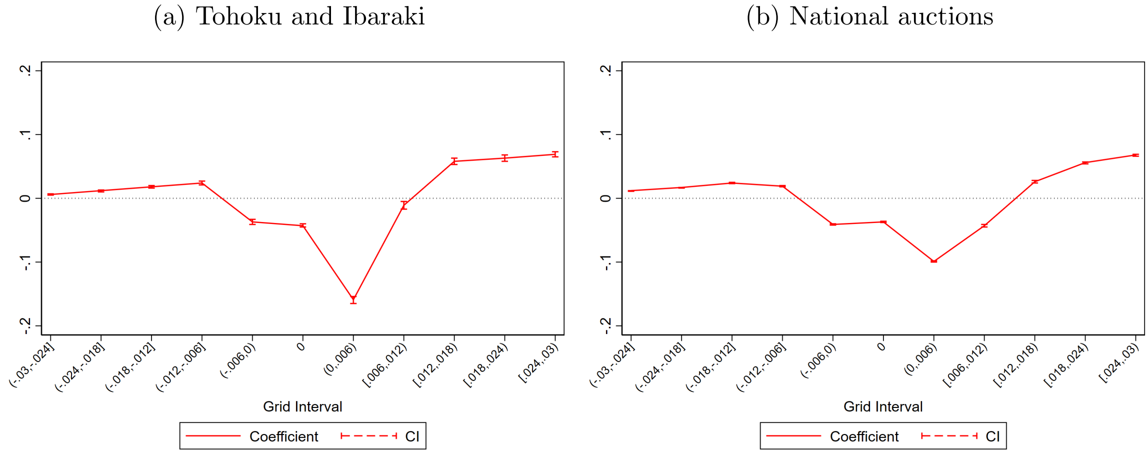


This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals. Confidence intervals are computed with robust standard errors.

A.16 Japanese auctions

According to Chassang et al. (2022), Japanese auctions featured collusion. The dataset is in the replication package by Chassang et al. (2022). We have repeated our test on the following samples: (i) the entire sample of city auctions, and (ii) the entire sample of national auctions. Bid differences are expressed as fraction of the reserve price. Results are reported in Figure A.26 and Table A.13. The tests reject the null of competition.

Figure A.26: Graphical representation of the parametric screen between [-H,H]. Japanese public procurement auctions.



This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals. Confidence intervals are computed with robust standard errors.

Table A.13: KS test on [-H,H]

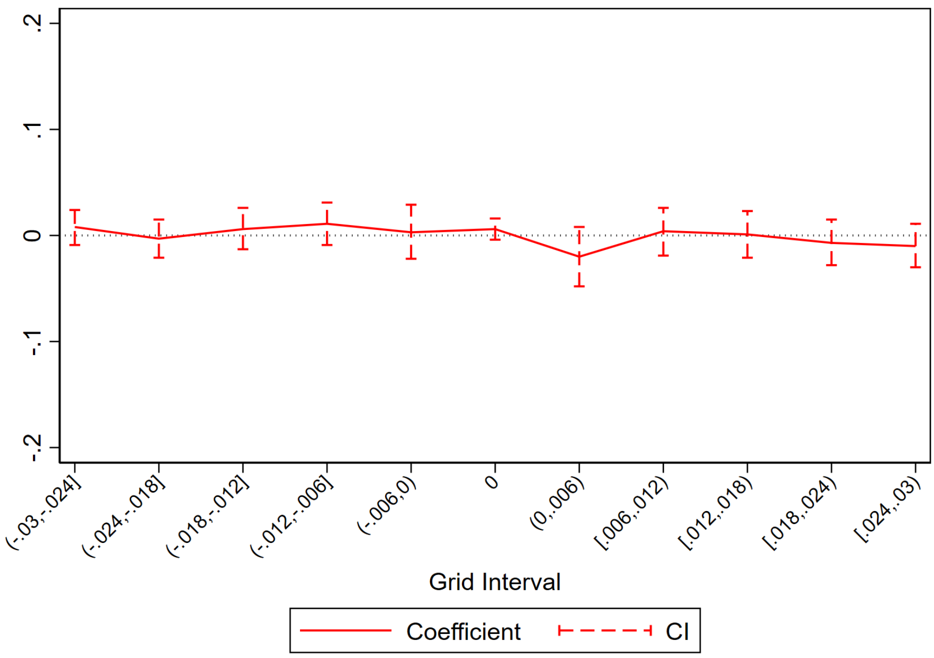
	p-value KS test
	Pre
Tohoku and Ibaraki	0.000
National auctions	0.000

Values are the *p-values* from the Kolmogorov–Smirnov test of $H_0 : f^1(\Delta^1|\Delta^1 \in [-H,H]) = f^2(\Delta^2|\Delta^2 \in [-H,H])$ *for* $H > 0$ *and* $H \to 0$.

A.17 Georgian first-price auctions

Wachs and Kertész (2019) also provided a dataset on Georgian public procurement auctions. Kawai et al. (2022) examine this market and find no evidence of collusion. We also applied our screen in this context. To the best of our knowledge, the Georgian antitrust authority up to now did not pursue any firm with bid-rigging. Thus, we apply the test using the first-price auctions observed in the dataset. Bid differences are expressed as fraction of the reserve price. We should expect no statistical significant differences in the distribution of $\Delta^1_{i,a}$ with respect to $\Delta^2_{i,a}$ around 3% of the reserve price. Figure A.27 provides the results for the parametric test. The *p-value* of the KS test is 0.425. Both tests do not reject the null of competition.

Figure A.27: Graphical representation of the parametric screen between [-H,H]. Georgian public procurement auctions.



This figure reports the coefficients β_q estimated from equation 4, along with confidence intervals. Confidence intervals are computed with robust standard errors.