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Scaling Auctions as Insurance:
A Case Study of the Massachusetts Department of Transportation

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INTRODUCTION

Infrastructure investment underlies nearly every part of the American economy and constitutes hundreds of billions of dollars in public spending each year. However, infrastructure projects are often complex and subject to unexpected changes. This uncertainty can be challenging for government estimates of project needs and costly for the firms that bid and ultimately implement the projects.

In the paper this brief is based on, we study the mechanism by which contracts for construction work are allocated by the Highway and Bridge Division in the Massachusetts Department of Transportation (MassDOT or "the DOT"). Along with DOTs in 40 other states, MassDOT uses a scaling auction, whereby bidders submit unit price bids for each item in a comprehensive list of tasks and materials required to complete a project. The winning bidder is determined by the lowest sum of unit bids multiplied by item quantity estimates produced by DOT project designers. The winner, however, is paid based on the actual quantities ultimately used in completing the project, not the estimates.

This process creates an incentive for firms to skew their bids by bidding high on items they believe will over-run the government's quantity estimates, and vice-versa. This strategy not only allows a firm to increase its chances of winning the contract due to a low total bid, but also allows it to realize greater profits when MassDOT pays high prices on underestimated items. Understandably, this strategy concerns officials and policymakers, as bid-skewing behavior that takes advantage of government inaccuracies may result in a markup to the DOT, and, in turn, in a higher bill for taxpayers.

Our model of bidding behavior demonstrates that the markup charged to the DOT depends not only on the level of competition between bidders, but also on 1) uncertainty about ultimate project needs, and 2) the degree of risk aversion faced by competing firms. We find evidence that bidders competing for MassDOT projects are risk averse. Unlike risk neutral bidders, for example, risk averse bidders may want to use bid skewing to balance the uncertainty in a project across the different items involved. The incentive to raise bids on items predicted to over-run is dampened for risk adverse bidders by the uncertainty in the prediction of the item quantities. Moreover, the risk lowers the value of a project to bidders, making the project less desirable and resulting in firms bidding less aggressively. Such a

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negative effect on competition between bidders contributes to higher prices for the DOT.

Working with a rich and detailed dataset from MassDOT's Highway and Bridge Division, we analyzed bridge construction and maintenance projects undertaken in Massachusetts from 1998 to 2015. As part of our analysis, we evaluate the cost incurred by the DOT due to uncertainty in its project specifications. We estimate the level of risk in each project and the degree of risk aversion exhibited by bidders who participated in bridge procurement auctions. Using these estimates, we simulate a counterfactual scenario in which the level of uncertainty about item quantities is driven down to zero. We then compare the outcome of each procurement auction under this scenario against the auction as it was observed in the data. These calculations reveal that the DOT could save $172,513 (13.7 percent) on average per project from the elimination of risk from incorrect quantity estimates. Thus, there may be substantial cost savings to the DOT from improving projects' quantity estimates.

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We also find that scaling auctions provide substantial savings to MassDOT relative to lump-sum auctions, suggesting that changes in policy to favor lump-sum auctions would not be advisable. In a lump-sum auction, bidders do not have the ability to skew their bids. Firms bid on the total price for a project, without any item quantity breakdown. Additionally, the winning bidder is simply paid the amount that they bid, and bidders are not further compensated if the costs of the project change or if quantities used are higher than the estimates. Lump-sum auctions are therefore riskier and less desirable to risk averse bidders, decreasing competition and resulting in the submission of less aggressive (and therefore higher) bids. More concretely, we estimate that lump-sum auctions would increase realized costs to the DOT by 128 percent on average over scaling auctions.

It is important to note that our model is predicated on the assumption that MassDOT officials are able to effectively monitor the decisions to increase or decrease item quantities as needed, so that contractors may not simply use more of the items on which they have placed higher bids. This assumption is in line with MassDOT operations for standardized projects such as bridge maintenance and highway resurfacing, for instance, but may not be suitable for more custom projects where contractors have more control over design and implementation.

Finally, we suggest some policies that might improve on the status quo. Improvements to quantity estimates would result in cost savings for the DOT, but making these improvements may be challenging. Efforts to increase competition more directly may offer an additional channel to improve DOT cost efficiency. We estimate that the DOT could save $82,583 (8.9 percent) by having one additional contractor bid on an average project.

BID SKEWING AND MATERIAL LOSS TO THE DOT

Scaling Auctions in Highway and Bridge Procurement

Massachusetts manages the construction and maintenance for its highways and bridges through its Department of Transportation (DOT). To develop a new project, MassDOT engineers assemble a detailed specification of what the project will entail. This specification includes an itemized list of every task and material (item) that is necessary to complete the project, the engineers' estimates of the amount (quantity) of each item that will be needed, and a market unit cost for each item. The itemized list of quantities is then advertised to prospective contractors who may want to bid on the project. To submit a bid, a contractor posts a per-unit price for each of the items specified by the DOT. All bids are private until the completion of the auction.

Once the auction is complete, each contractor is given a score, computed by the sum of the product of each item's estimated quantity and the contractor's unit-price bid for it. The bidder with the lowest score is then awarded the rights to implement the project. In the process of construction, it is common for items to be used in quantities that deviate from the DOT engineer's specification. The winning contractor is ultimately paid the sum of their unit price bid multiplied by the *actual* quantity of each item used. Since all changes must be approved by an on-site DOT manager, a contractor's ability to influence the quantities of items that are ultimately used is limited and the possibility of deceit by the bidders is low. However, bidders may be able to predict which items will over/under-run the DOT's estimates and construct their bids using this information in a process called bid skewing.

Bid Skewing in Practice

Bid Skewing Across Industries

The practice of bid skewing — also sometimes called unbalanced bidding —in scaling auctions appears, in the words of one review, "to be ubiquitous" (Skitmore and Cattell (2013)). References to bid skewing in operations research and construction management journals date as far back as 1935. Previous work on timber auctions (Athey and Levin (2001)) and highway construction (Bajari, Houghton, and Tadelis (2014)) has demonstrated evidence that bidders skew correctly on average and that the most competitive bidders skew in a similar way. This suggests that competitive bidders are similarly able to predict which items will over/underrun and optimize accordingly. To manage the complexities of bid selection, contractors often employ experts and software geared for statistical prediction and optimization. In a survey on construction management software trends, Capterra (a web platform that facilitates research for business software buyers) estimates that contractors spend an average of $2,700 annually on software.

DOT Challenges to Bid Skewing

In Massachusetts, a bid is considered mathematically unbalanced if it contains any line-item for which the unit bid is (1) over (under) the office cost estimate and (2) over (under) the average unit bid of bidders ranked 2-5 by more than 25 percent. In principle, a mathematically unbalanced bid elicits a flag for DOT officials to examine the possibility of material unbalancedness. However, in practice, such bids are ubiquitous, and substantial challenges by the DOT are very rare.

DATA AND SETTING

Data

Our data come from MassDOT and cover highway and bridge construction and maintenance projects undertaken by the state from 1998 to 2015. There are 4,294 construction and maintenance projects in the DOT's digital records, although the coverage is sparse prior to the early 2000s. If we keep only the projects for which MassDOT has digital records on 1) identities of the winning and losing bidders; 2) bids for the winning and losing bidders; and 3) data on the actual quantities used for each item, we are left with 2,513 projects, 440 of which are related to bridge construction and maintenance. We focus on bridge projects alone for this paper, as these projects are particularly prone to item quantity adjustments.

For each auction in our study, we observe the full set of items involved in the project, along with ex-ante estimates and ex-post realizations of item quantities. Additionally, the data contain a blue book DOT estimate of the market unit rate for each item and the unit price bid that each bidder who participated in the auction submitted. The winner of each auction is determined entirely by the expected cost of the project given the bidder's unit bids. Participating bidders are all pre-qualified by the DOT and neither historical performance, nor external quality considerations, play a role in contract allocation.

Table 1 provides summary statistics for the bridge projects in our data set, as well as preliminary evidence of the costs of bid skewing. We measure the extent to which MassDOT overpays the projected project cost in two ways. First, we consider the difference between what the DOT ultimately pays the winning bidder (the sum of actual quantities used multiplied by the winning bidder's unit bids) and the DOT's initial estimate (the sum of the DOT's quantity estimates multiplied by the DOT's estimate for each item's unit cost). Summary statistics for this measure are presented in the "Net Over-Cost (DOT Quantities)" row in Table 1.

While it appears that the DOT is saving money on net, this is a misrepresentation of the costs of bid skewing. The DOT's estimate, which can be thought of as the score evaluated using the DOT's unit costs as bids, is not representative of the ex-post amount to be paid at those bids. Rather, a more appropriate metric is to compare the amount ultimately spent against the sum of the product of the DOT's unit cost estimates and the actual quantities used. This is presented in the "Net Over-Cost (Ex-Post Quantities)" row of Table 1. The median over-payment by this metric is about $15,000, but the 25th and 75th percentiles are about -$210,000 and $275,000, respectively. Figure 1 shows the spread of over-payment across projects. As we will show in the counterfactual section, this over-payment suggests potential savings from the elimination of risk.

The Bidders

There are 2,883 unique project-bidder pairs (e.g., total bids submitted) across the 440 bridge projects that we analyze. 116 unique firms participate in these auctions, albeit to different degrees. We distinguish firms that are rare participants by dividing firms into two groups: "common" firms, which participate in at least 30 auctions within our data set, and "rare firms", which participate in fewer than 30 auctions. We retain the individual identifiers for each of the 24 common firms, but group the 92

Table 1: Summary Statistics

Statistic	Mean	St. Dev.	25th Percentile	Median	75 Percentile
Project Length (Estimated)	1.53 years	0.89 years	0.88 years	1.48 years	2.01 years
Project Value (DOT Estimate)	$2.72 million	$3.89 million	$981,281	$1.79 million	$3.3 million
# Bidders	6.55	3.04	4	6	9
# Types of Items	67.8	36.64	37	67	92
Net Over-Cost (DOT Quantities)	-$286,245	$2.12 million	-$480,487	-$119,950	$167,933
Net Over-Cost (Ex-Post Quantities)	$26,990	$1.36 million	$208,554	$15,653	$275,219
Extra Work Orders	$298,796	$295,173	$78,775	$195,068	$431,188

Figure 1: Net Over-Cost (Ex-Post Quantities) Across Bridge Projects

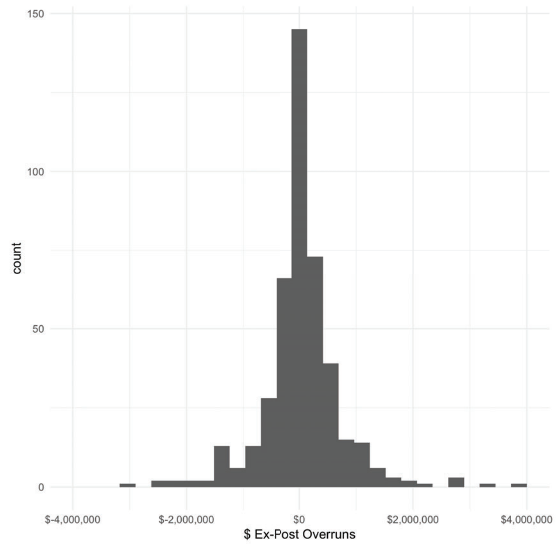


Table 2: Comparison of Firms Participating in <30 vs. 30+ Auctions

	Common Firm	Rare Firm
Number of Firms	24	92
Total Number of Bids Submitted	2,263	620
Mean Number of Bids Submitted Per Firm	94.29	6.74
Median Number of Bids Submitted Per Firm	63	2.5
Total Number of Wins	351	89
Mean Number of Wins Per Firm	14.62	0.97
Median Number of Wins Per Firm	10	0
Mean Bids Submitten	$2,774,941	$4,535,310
Mean Ex-Post Cost of Bid	$2,608,921	$4,159,949
Mean Ex-Post Overrun of Bid	9.70%	21.97%
Proportion of Bids on Projects in the Same District	28.19	15.95
Proportion of Bids by Revenue Dominant Firms	51.67	11.8
Mean Specialization	24.44	2.51
Mean Capacity	10.38	2.75
Mean Utilization Ratio	53.05	25.5

rare firms together for purposes of estimation. Table 2 presents summary statistics of the two firm groups. Common firms constitute 2,263 (78 percent) of total bids submitted, and 351 (80 percent) of auction victories.

The mean (median) common firm submitted bids to 94.29 (63) auctions and won 14.62 (10) of them. The mean total bid (e.g., the score) submitted is about $2.8 million, while the mean ex-post DOT cost implied by the firm's unit bids is $2.6 million. The mean ex-post cost overrun (the percent difference of the sum of unit bids multiplied by the ex-post quantities and the sum of blue book costs multiplied by the ex-post quantities) is 9.7 percent. By contrast, the mean (median) rare firm submitted bids to 6.74 (2.5) auctions and won 0.97 (0) of them. The mean total bid and ex-post scores are quite a bit larger than for the common firms — $4.5 million and $4.2 million, respectively. These firms also have substantially larger ex-post cost overruns: 21.97 percent on average.

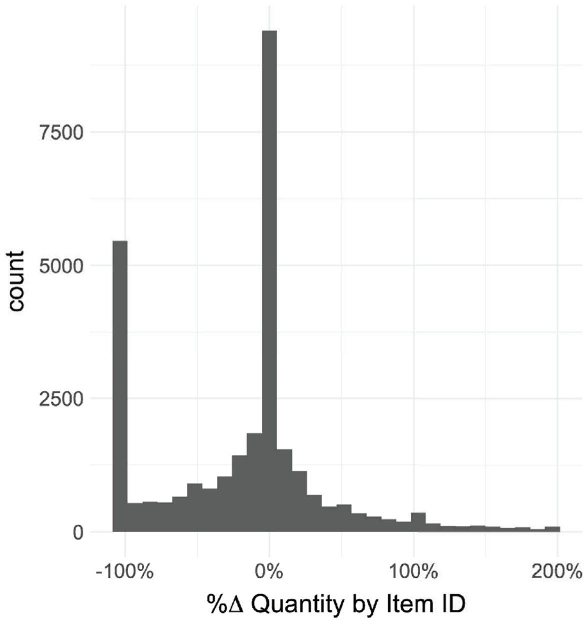
In addition to the firm's identity, there are a number of factors which may influence its competitiveness in a given auction (see Table 2). One such factor is the firm's distance from the project. Among common firms, 28.19 percent of bids were on projects that were located in the same district as the bidding firm's headquarters. By contrast, only 15.95 percent of bids among rare firms were in matching districts. Another measure of competitiveness is specialization — firms with extensive experience bidding on and implementing a certain type of project may find it cheaper to implement an additional project of the same sort. Our data involve three distinct project types, according to MassDOT taxonomy: Bridge Reconstruction/ Rehabilitation projects, Bridge Replacement projects, and Structures Maintenance projects. We calculate the specialization of a project bidder pair as the share of auctions of the same project type that the bidding firm has placed a bid on within our dataset. The mean specialization of a common firm is 24.44 percent, while the mean specialization of a rare firm is 2.51 percent.

As projects have varying sizes, we compute a measure of specialization in terms of project revenue as well. We define a revenue-dominant firm (within a project-type) as a firm that has been awarded more than 1 percent of the total money spent by the DOT across projects of that project type. Among common firms, 51.67 percent of bids submitted were by firms that were revenue dominant in the relevant project type. Among rare firms, the proportion of bids by revenue dominant firms is 11.8 percent. A third factor of competitiveness is each firm's capacity — the maximum number of DOT projects that the firm has ever had open while bidding on another project — and its utilization — the share of the firm's capacity that is filled when it is bidding on any given project. The mean capacity is 10.38 projects among common firms and 2.75 projects among rare firms. This suggests that rare firms generally have less business with the DOT (either because they are smaller in size or because the DOT constitutes a smaller portion of their operations). The mean utilization ratio, however, is 53.05 percent for common firms and 25.5 percent for rare firms. This suggests that firms in our data are likely to have ongoing business with the DOT at the time of bidding, and are likely to have spare capacity during adjacent auctions that they do not participate in.

Quantity Estimates and Uncertainty

As discussed above, scaling auctions enable risk averse bidders to insure themselves against uncertainty about the item quantities that will ultimately be used for each project. Bidders in a scaling auction can greatly reduce the risk that they face by placing minimal bids on the highly uncertain items (and higher bids on more predictable items). Our data set includes records of 2,985 unique items, as per the DOT's internal taxonomy. For each item, in every auction, we observe the quantity with which the DOT predicted it would be used at the time of the auction, the quantity with which the item was ultimately used, and a blue book DOT estimate of the market rate for the unit cost of the item. DOT-predicted quantities are typically inaccurate: 76.7 percent of item observations in our data had ex-post quantities that deviated from DOT estimates. Figure 2 presents a histogram of the percent quantity overrun across item observations. The percent quantity overrun is defined as the difference of the ex-post quantity of an item observation and its DOT quantity estimates provided to the bidders.

Figure 2: Histogram of the Percent Quantity Overrun Across Item-Project Pairs (ex-post quantity of an item vs. DOT quantity estimates)



A MODEL FOR BIDDING WITH RISK AVERSION

We construct an econometric model to estimate the level of risk in each project and the degree of risk aversion. We employ a two-stage procedure in which we first estimate a model of bidder uncertainty using the history of predicted and actual item quantities for each of the projects in our data. Then, we use the information about the bids in our data to estimate the risk aversion and cost faced by the bidders. These calculations of uncertainty, bidder cost, and risk aversion allow us to estimate the overpayment costs that the DOT incurs.

COUNTERFACTUALS

Perfectly Predicted DOT Quantities

In order to draw conclusions from our results, we must determine how much money the DOT would save if it were able to perfectly predict the actual quantities that will be required for each project. To answer this question, we estimate a counterfactual setting in which the DOT perfectly predicts the actual quantities. We assume that the DOT's accuracy is common knowledge and so the bidders believe that the actual quantities will be equal to the DOT's projections. We calculate the DOT's cost from uncertainty by taking the difference in the expected amount paid to the winning bidder in the baseline auction (the auction used in the status quo) and in the counterfactual setting with all uncertainty removed. We find that the DOT's cost in the baseline auction is only $2,145 — or 0.70 percent — higher, on average, than in the counterfactual auction with no uncertainty.

It is important to note that this estimate reflects the sum of two opposing forces that are shifted by the counterfactual: prediction and risk. First, eliminating uncertainty drives bidder risk down, thereby increasing the value of the project to all of the bidders and causing them to bid more aggressively. Second, in the baseline, bidders optimize unit bids with regards to quantity predictions that may be inaccurate (and so, the bids may not be optimal with respect to the realized quantities, which the winner is ultimately paid for). In the counterfactual with no uncertainty, the bidders always optimize unit bids with respect to the actual quantities that will be used. As a result, in the auctions where bidders "mis-optimized" under the baseline, the DOT bears a higher cost under the counterfactual, where bidders always optimize.

In order to isolate the effect of risk alone, we repeat the counterfactual exercise under the assumption that, in the baseline, bidders' quantity projections are equal to the ex-post quantities but bidders are not sure that the projections are accurate (even though they are). In this new version of the baseline, bidders always optimize correctly with respect to ex-post quantities, and so the second channel, by which eliminating risk can hurt DOT savings because of the lack of "mis-optimization", is shut down. Absent bidder mis-optimization due to inaccuracies in their quantity projections in the baseline, the mean expected savings to the DOT under the counterfactual is $172,513 or 13.7 percent of the (adjusted) baseline expected cost.

Lump-sum Auctions

Next, we use our counterfactual results to assess the extent and direction to which DOT costs would change if the DOT switched from a scaling auction to an alternative in which part or all of the amount paid to the winning bidder is fixed at the time of bidding. A mechanism of this sort curbs bidders' ability to skew their bids: In a lump-sum auction, bidders are paid the amount they bid and so, there is no advantage to spreading unit bids across items in any particular way. It may also offer benefits to the DOT by reducing its burden in project specification and budgeting flexibility. However, lump-sum auctions shift risk from the DOT to the bidders, who become less competitive as a result. As such, bidders lower the expected value of winning each auction because of this risk and, because the auction is less attractive, submit higher, less aggressive bids. We estimate that switching to a lump-sum auction would increase DOT costs by 128 percent on average (85 percent on median).

More Competition

While the reduction in risk from perfectly-known item quantities will result in savings to the DOT, the lack of mis-optimization by the bidders will likely dampen such savings. By increasing the risk borne by bidders, lump-sum auctions are likely to increase costs and therefore exacerbate the already-high costs of bridge construction and maintenance.

One alternative solution, would be a policy that aims to increase competition in infrastructure procurement auctions.

One alternative solution, however, would be a policy that aims to increase competition in infrastructure procurement auctions. We measure the benefits of such a policy in our setting by taking the difference between the expected amount paid by the DOT to the winning bidder in the baseline and in the counterfactual with an additional participating bidder. The mean upper bound on entry costs in the MassDOT setting is $2,583, while the mean MassDOT savings from an additional bidder is $88,562. Thus, there is substantial potential value to encouraging entry. A relatively modest guaranteed bonus payment to the winning bidder could do the trick, as could reductions in administrative barriers to entry for prospective bidders.

CONCLUSION

Our examination of data from the Massachusetts Department of Transportation reveals that the construction firms that participate in scaling procurement auctions strategically skew their bids, placing high bids on items they predict will overrun the DOT's quantity estimates and low bids on items they predict will underrun. For policymakers, bid skewing may raise concerns of increased project costs and higher bills for taxpayers. However, we find that in a competitive environment, such as the one in MassDOT's bridge auctions, skewing generates substantial savings to the DOT, especially over lump-sum actions. Though we find that the DOT would benefit by increasing the accuracy of its quantity estimates and decreasing the risk faced by contractors, we acknowledge that this may prove challenging in practice. Efforts to increase competition may offer an additional channel to improve DOT cost efficiency. It is well known that an increase in competition benefits the auctioneer. We estimate that adding one more bidder to an average auction results in DOT savings of $88,562. The cost of bringing in an additional bidder, meanwhile, could be as little as $2,583 and could be achieved with a guaranteed bonus payment.

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