On the Number and Heterogeneity of Bidders in Livestock Auctions

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We show in the context of livestock auctions that a seller's revenue may increase or decrease as the number of buyers increases, whether the additional bidder wins or not an object. Additional bidders who fill part of their demand from an outside source may have an even more adverse effect on prices. We use data from the Quebec daily hog auction to measure the effect of new bidders on auction prices. Variations in the number of bidders come from the entry and exit of Quebec packers and sporadic invitations extended to Ontario packers. We find that entry by Quebec packers had a significant positive impact on hog auction prices but that sporadic participation by Ontario packers did not have a significant impact on hog prices.

Nous démontrons que le revenu généré par une enchère d'animaux peut augmenter ou diminuer avec le nombre d'enchérisseurs et ce, que le nouvel enchérisseur gagne ou pas un objet. Des enchérisseurs additionnels qui s'approvisionnent principalement d'autres sources peuvent avoir un effet encore plus négatif sur les prix. Nous exploitons des données de l'enchère journalière du porc au Québec pour analyser l'addition d'enchérisseurs sur les prix. Les variations dans le nombre d'enchérisseurs sont le résultat d'entrées et sorties de transformateurs québécois et d'invitations sporadiques à des transformateurs ontariens. Nos résultats empiriques indiquent que l'entrée de transformateurs québécois a eu une influence positive sur les prix mais que la participation de transformateurs ontariens n'a pas eu d'effets significatifs.

INTRODUCTION

Auctions are common in the procurement of agricultural commodities, in particular in cattle and hog markets (Crespi and Sexton 2004; Larue et al 2004). One of the reasons behind the popularity of auctions in these markets is that they are perceived as offering an open market setting that promotes competition among buyers. This is especially important in agriculture because of increased concentration and concerns of market power by buyers. In these concentrated markets, repeated auctions do not assure competitive pricing. This failure does not necessarily indicate collusion among buyers, but may reflect, as Crespi and Sexton (2004) observe, tacit arrangements like respect for incumbency or the inability of bidders to precisely evaluate the value of all lots offered. It is also true that complete

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information about the value of lots among competitive buyers gives them a tremendous advantage over a poorly informed seller when objects are sold sequentially. This insight goes back to the 2-bidder 2-object example in Krishna (1993, p. 150) in which bidders *A* and *B* have valuations $a_1 = a_2 = 10$ and $b_1 = 9$, $b_2 = 1$ and equilibrium prices are $p_1 = 2 > 1 = p_2$. The seller's revenue for the two objects, 3, is small relative to the bidders' total valuations for the two objects (20 and 10). The knowledge that each bidder has about his valuations and his rival's valuation allows both bidders to exploit bidder *B*'s much lower valuation for the second object without colluding. Bidder *A* allows bidder *B* to win the first object, anticipating that bidder *B* will bid his low second object valuation for the second object. As such, bidder *A* can be thought as a residual monopsonist (Menicucci 2009).

The traditional wisdom is that increasing the number of bidders in an auction should increase competitiveness, because a bidder's perceived probability of winning is lower and prompts more aggressive bidding. However, we show that this is not always true in the context of a multi-unit demand sequential auction under complete information. The introduction of a new bidder generally increases competition in late auctions rounds, but may negatively affect bidding in the early rounds and cause the seller's revenue to decline. The intuition is that bidders with high valuations may find it profitable to exploit the decline in their rivals' valuations by "giving up" objects in early rounds to secure cheaper prices in later rounds. We demonstrate that the incidence of an additional bidder on the performance of an auction is very sensitive to the heterogeneity among bidders.

Data about hog auctions in Quebec offer a unique opportunity to investigate how increases in the number of bidders affects auction prices. This is particularly so because of the large degree of heterogeneity among bidders. We exploit entry and exit of Quebec packers to identify the effect of increases in the number of bidders on the average auction price. On rare occasions, the *Fédération des Producteurs de Porc du Québec* (i.e., Quebec's hog marketing board known as FPPQ) invited bidders from the neighboring province of Ontario. The effect of these invitations on auction prices may be estimated in different ways depending on the plausibility that the invitations were extended randomly. The alternative hypothesis is that the timing of invitations was endogenous, possibly when hog prices were relatively low. We account for this possibility by using the difference between hog prices in Quebec and the United States as an instrument. The motivation for this instrumentation strategy is that a narrow price spread might have been interpreted by the FPPQ as a sign of weakening competition, which might have justified extending invitations to Ontario bidders. The null hypothesis of random invitations could not be rejected and we found that the addition of a Quebec packer had a significant positive impact on auction prices while sporadic invitations to Ontario packers did not affect auction prices. This result indicates low marginal valuations on the part of Ontario packers, which could be explained by limited marginal slaughtering capacities when asked to bid on the Quebec auction, high transport costs, or just simply lower productivity.

The next section reviews the literature on the relationship between the number of bidders and the performance of auctions. In the section "Adding a Bidder in Sequential Multi-Unit Demand Auctions under Complete Information," we present examples of sequential auctions involving bidders with multi-unit demands under complete information to show that adding bidders may increase or decrease average prices generated by a sequential multi-unit demand auction. In the section "Background: Hog Marketing Mechanisms in Quebec," we provide background information about Quebec hog auctions, the subject of our empirical investigation in the section "Empirical Evidence from the Quebec Daily Hog Auction." Finally, the last section concludes with a summary and a discussion on the institutional implications of our results.

AUCTION PERFORMANCE AND THE NUMBER OF BIDDERS: A REVIEW

Many microeconomics textbooks discuss single-object first-price and second-price auctions when bidders have independent private valuations.[1] In those auctions, increasing the number of bidders increases the seller's expected revenue. In a single-object first-price auction, a participant's bid maximizes expected payoff, which is the product of the probability of winning and the difference between the bidder's valuation for the object and the bid. Adding bidders induces more aggressive bidding to compensate for the adverse effect on each bidder's probability of winning. A key assumption behind this result is that from a bidder's perspective, all other bidders are stochastically symmetric, in the sense that the competing independent private valuations of new bidders are drawn from the same distribution. Perhaps because this result has been widely disseminated, there is a perception that it generally applies, even to sequential auctions bringing together bidder with multi-unit demands.

Matthews (1984) challenges the wisdom that auction prices increase with the number of bidders. In first-price auctions with common values, Matthews (1984) shows that increasing the number of bidders can induce individual bidders to lower their bids because adding bidders can magnify the winner's curse problem. A similar intuition is offered in Bulow and Klemperer (2002) who also dwell on the role of asymmetries among bidders. In first-price auctions with symmetric and affiliated private valuations,[2] Pinkse and Tan (2005) show that some bidders may decrease their bids because they fear after winning that competition is weaker than expected. Because of affiliation, this effect grows with the number of bidders. Menicucci (2009) produces an example in which the affiliation effect dominates and confirms that the seller is justified in some circumstances to reduce the number of bidders.

Mishra et al (2005) show that prices increase with the number of bidders in sequential auctions when there are synergies between asymmetric bidders. Kittsteiner et al (2004) find the same result in auctions where bidders have unit-demands derived from independent private valuations that decrease over sequential rounds. In quasi multi-unit demand auctions, Elmaghraby (2005) analyzes two successive second-price procurement auctions in the presence of bidders with asymmetric production capacity and economies of scale. Elmaghraby (2005) shows that adding bidders does not necessarily translate into lower procurement costs. In two successive second-price procurement auctions involving bidders with asymmetric capacities (i.e., small bidders are only able to bid for the sale of the second object), Rong and Zhi-xue (2007) show that inviting small bidders can

[1] Under the independent private valuation paradigm, the bidder knows his valuation of the object but not the valuations of other bidders—except that these valuations are drawn from a commonly known distribution. Under the common valuation paradigm, all bidders' valuations are drawn from a common distribution as they do not know *ex ante* the exact valuation of the object (e.g., mining rights). Finally, under complete information, bidders know their valuation and the valuations of other bidders precisely while the seller is clueless.

[2] Affiliation entails that signals influencing bidders' valuations are positively correlated.

increase the average expected procurement cost. The result hinges on the effect of asymmetric capacities and its inflationary effect on the bids of large bidders. Finally, under complete information, the seller's revenue may decrease, and even be zero, in Vickrey-Clarke-Groves (VCG) auctions when the number of bidders is increased (e.g., Ausubel and Milgrom 2002; Milgrom 2004).[3]

Sequential auctions in which individual bidders demand more than one object are complex to model, except under complete information as shown in the pioneering works of Bernheim and Whinston (1986), Krishna (1993, 1999), and Katzman (1999). In this paradigm, the seller is assumed to be poorly informed, as he cannot observe buyers' valuations for the item(s). In contrast, bidders are completely informed, not only about the item(s) auctioned, but also about all bidders' valuation for the item(s). Bernheim and Whinston (1986) argue that the assumption of complete information is appropriate when the same few firms, relying on a common technology, frequently bid against one another.

The literature on sequential auctions under complete information has generated several insightful results. For example, Katzman (1999) shows for the 2-bidder 2-object case that the outcome of a second-price auction may be inefficient in the sense that the objects need not all be won by the bidders with the highest valuations. Gale and Stegeman (2001) show that the equilibrium for the 2-bidder n-object sequential equilibrium under complete information is unique. Jeddy et al (2010) show that when bidders have identical declining valuations, equilibria with asymmetric allocations and declining price trends are more likely than symmetric allocations with constant price trends. Jeddy and Larue (2012) show that the uniqueness of the equilibrium may not hold when there are several bidders.

ADDING A BIDDER IN SEQUENTIAL MULTI-UNIT DEMAND AUCTIONS

Under Complete Information

The objective of the section is to show the possibility that the addition of bidders can decrease seller's revenue and gain intuition about the working of sequential auctions in a setting that is consistent with the working of livestock auctions. Sufficiency is enough for the case at end. The necessary conditions are unmanageable even for a small number of bidders.[4] To keep the examples tractable, we will begin our theoretical analysis by assuming that the two incumbent bidders are identical and allow the third bidder to differ. We will derive formal results showing that the incidence of a third bidder on the seller's revenue can be positive or negative, depending on the third bidder's valuations. Examples showcasing highly asymmetric bidders are then briefly presented to show that the ambiguous effect of an additional bidder is robust. These numerical examples are briefly discussed in the text, but figures illustrating how these sequential auction games are solved are in provided in the Supporting Information.

[3] VCG auctions are combinatorial auctions where each bidder submits sealed bids for all of the objects and payments are determined so as to allow each bidder a payoff equal to his opportunity cost for the units won.

[4] For example, in an auction with two bidders and three objects, assuming that each bidder has a demand for the three objects, we must consider six valuations. Given that valuations may take different values depending on the number of objects obtained, there are a total of $\frac{6!}{3!3!} = 20$ permutations. With three bidders and three objects, there are a total of $\frac{9!}{3!3!3!} = 1{,}680$ permutations.

Using Bernheim and Whinston (1986)'s argument, we model livestock sequential multi-unit demand auctions assuming complete information. Typically, multiple lots are sold one after the other during the course of frequently occurring auctions (daily or weekly), bringing together the same small number of bidders. Even though livestock units are not identical, quality differences are easily measured and dealt with. In some cases bidders visit the stockyard before the beginning of the auctions, see pictures or videos of the animals, or receive a quality score for a lot. Another method to deal with quality variations after purchase is by using a grid of price discounts and premiums.

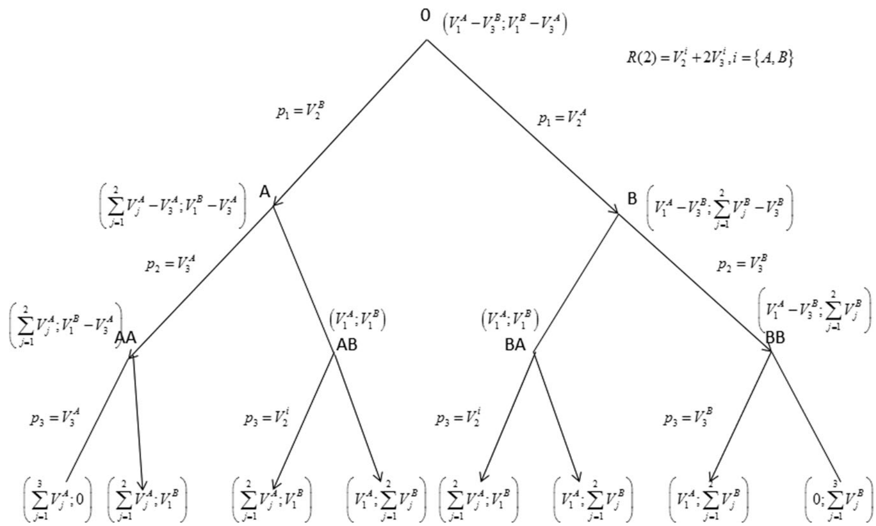
Livestock auctions do not all use the same bidding system. Early on, Quebec's hog auction featured a Dutch first-price approach, which saw the quoted price decreased until a bidder signaled his intention to buy. Later on, an English second-price component was added by allowing other bidders to raise the price once a bidder had signaled his intention to buy. However, under complete information, first-price and second-price auctioning methods are equivalent (e.g., Krishna and Tranaes 2002).

We assume that bidders have decreasing valuations (profit margin) for the objects.[5] In the context of the Quebec hog industry, decreasing valuations for lots of hogs is consistent with increasing transportation costs and high profit markets being served before low profit markets. The Quebec hog auction allocated hogs to minimize transportation costs. Hence, it naturally follows that the more lots a packer purchased, the higher its transportation costs were. Quebec hog packers sell hogs domestically and export to several countries, maximizing profits by prioritizing markets that give the highest return. Asymmetries in bidders' valuations reflect differences across processing plants, which greatly vary in size in the hog processing industry.

We consider a sequential auction involving bidders A, B, and C. We solve for the outcome of the auction by backward induction assuming that each bidder follows the weakly dominant strategy of sincere bidding in the third and last round as in Krishna (1993) and Katzman (1999). A weakly dominant strategy is to place a bid that makes a bidder indifferent between winning and losing the object auctioned, with payoffs accounting for the outcomes of subsequent rounds. We rely extensively on the outcome tree to solve for the equilibrium allocation and prices, a most useful tool developed by Krishna (1993), which, unlike the typical extensive-form game tree, features gross payoffs at every node that are obtained through subgame replacements.

We begin with two symmetric bidders, called A and B, competing for three objects, with decreasing valuations $V_1^i > V_2^i > V_3^i,\ \ i = \{A, B\}$. Under complete information, bidders know their own valuations as well as the valuations of their rival(s). Because the two bidders have identical decreasing valuations, each bidder wins at least one object. At equilibrium, the payoffs for winning a second object are such that the bidders are indifferent between winning one or two objects. This implies that the bidder winning two objects must pay a higher average price because the total payoff of that bidder is spread over two objects while the payoff of the other bidder is on a single object. For the indifference between winning one or two objects to hold, the 2-object winner must win the first two objects so that the other bidder knows that the 2-object winner cannot bid more than his lowest valuation in the last round. Thus, payoff symmetry entails that

[5] Declining valuations is a common assumption (e.g., Krishna 1993; Gale and Stegeman 2001; Rodriguez 2009).



Note: The payoffs for winning one or two objects must be identical. There are two equilibria because bidders must be indifferent between winning one or two objects.

Figure 1. A 2-symmetric-bidder auction competing for three objects

$V_1^i + V_2^i - p_1 - p_2 = V_1^{-i} - p_3$. Because bidders bid their marginal valuation in the last round, $p_3 = V_3^i$, and since $V_k^i = V_k^{-i}$, $V_2^i + V_3^i = p_1 + p_2$, for bidder i to take only the last object, it must be that $p_1 \geq p_2 \geq p_3$. In addition, when the first object is auctioned, bidders must be indifferent between winning the first two objects and winning only the third. These conditions are met when $p_2 = p_3 = V_3^i$ and $p_1 = V_2^i$. As a result, the seller's revenue is $R(2) = V_2^i + 2V_3^i$ and each bidder earns $V_1^i - V_3^i$, $i = \{A, B\}$.

Figure 1 illustrates the outcome tree for this equilibrium. Since the equilibrium is determined through backward induction, the payoffs at the very bottom indicate the gross payoffs for all potential allocations. At this stage, the gross payoffs are the sum of the valuations associated with objects won by the bidders. At node AA, the first two objects are allocated to bidder A. Bidder B must bid in a way to be indifferent between losing and winning the third object. He wins the third object because his valuation for a first object, V_1^B, exceeds the gross gain that bidder A could obtain by winning a third object, V_3^A. Because the auction is played under complete information, bidder B will not bid more than V_3^A, which ends up being the price for the third object, conditional on the game reaching these nodes.

The gross payoff vector at node AA is an update of the gross payoff at the bottom for the allocation that has bidder A winning the first two objects and bidder B winning the last one with the gains for bidder B calculated as the difference between his valuation and the price of the third object. The same rationale applies at node BB, which shows the third object going to bidder A, conditional on bidder B having won the first two objects. This explains the arrow from node AA (BB) pointing toward the gross payoff vector with bidder A (B) winning two objects and bidder B (A) winning one. At nodes AB (and

BA), the first object is conditionally allocated to bidder A (B) while the second object goes to bidder B (A). Bidders value equally the third object and both bid their valuation V_2^i, $i = \{A, B\}$ and thus two arrows emanate from nodes AB and BA and the price for the third object, conditional on the game reaching these nodes, is V_2^i, $i = \{A, B\}$.

Comparing the payoffs at nodes AA and AB, we can ascertain that bidder A is willing to bid V_2^A for the second object and ensure that the game reaches node AA. The willingness to pay of bidder B for the second object is given by his payoff differential at nodes AA and AB, V_3^A. Thus, if the first object is won by bidder A, bidder A will win the second object and pay $p_2 = V_3^A$. The gross payoff vector at node A is the same as that at node AA except that the gains for bidder A have been reduced by the price of the second object. Since the game is symmetric, the same arguments can be made to explain why, conditional on bidder B winning the first object, the equilibrium path goes through nodes BB and B. Comparing the gross payoffs at nodes A and B, we can determine that bidders A and B value equally the first object and are willing to bid V_2^i, $i = \{A, B\}$. The first object can be allocated to either bidder and the price for the first object will be $p_1 = V_2^i$, $i = \{A, B\}$. This confirms that both bidders get the same payoff, $V_1^i - V_3^i$, whether they win one or two objects and that $p_1 = V_2^i$, $p_2 = p_3 = V_3^i$ with the revenue of the seller given by $R(2) = V_2^i + 2V_3^i$.

Now that we have described the basic method to solve a sequential auction game, we can study the impact of the addition of an additional buyer. Starting from our benchmark with two identical bidders, there are four cases to consider for the addition of a third bidder.

1. If $V_1^C > V_2^i$, the seller's revenue increases as the third bidder wins at least one object. When $V_1^C > V_2^i > V_2^C$, bidder C wins one object and all three objects are sold at the same price V_2^i and $R(3) = 3V_2^i > R(2)$. When $V_2^C > V_1^i$, there are two possible allocations, one with bidder C winning all three objects and one in which he wins only one that would also generate $R(3) = 3V_2^i$. When $V_2^i + V_2^C + V_3^i > 3V_1^i$, bidder C earns a larger payoffs by winning all three objects at price V_1^i than by winning only one. Then $R(3) = 3V_1^i$.
2. When bidder C's valuations are identical to the other bidders' valuations, the price is constant $p_1 = p_2 = p_3 = V_2^i$, $i = \{A, B, C\}$ and $R(3) = 3V_2^i > R(2)$.
3. If $V_1^C < V_3^i$, A and B get all three objects and the addition of bidder C has no impact relative to the 2-symmetric-bidder benchmark: $R(3) = V_2^i + 2V_3^i = R(2)$.
4. If $V_2^i > V_1^C > V_3^i$, bidders A and B have the four highest valuations. In a candidate equilibrium where A and B together get the three objects, the allocation would be asymmetric, but the payoffs would have to be symmetric, implying same payoffs $V_1^i - V_1^C$ to the bidder getting only one object and to the bidder getting two objects. However, this cannot be an equilibrium because bidders A and B would earn a larger payoff by letting bidder C win an object. Under this allocation, the price would be constant with $p_1 = p_2 = p_3 = V_2^C$ and payoffs for bidder A and B would be $V_1^i - V_2^C$ while bidder C would earn $V_1^C - V_2^C$. Thus, with $V_2^i > V_1^C > V_3^i > V_2^C$, the revenue of the seller would be $R(3) = 3V_2^C < V_2^i + 2V_3^i = R(2)$.

The implication is that in a sequential auction for three objects under complete information with two identical bidders A and B, the addition of a third bidder C weakly increases the seller's revenue except when $V_2^i > V_1^C > V_3^i > V_2^C$. The anticompetitive effect of an extra bidder is due to bidder *C*'s low valuation for a second object, which makes incumbent bidders *A* and *B* most accommodating toward bidder *C*. Rather than bid aggressively to get the first object, they let bidder *C* win the first round knowing that bidder *C* will bid his second evaluation when the second and third objects are auctioned. It follows that if adding a bidder is to have an adverse effect on the seller's revenue, there must be asymmetries among bidders.

To further dwell on this insight, consider a 2-bidder game with highly asymmetric bidders such that $V_1^A > V_2^A > V_3^A > V_1^B > V_2^B > V_3^B$. Bidder *A* is a dominant firm who can possibly win all of the objects auctioned.[6] Assuming the conditions are satisfied for bidder *A* to win all three objects when competing against bidder *B* and that bidder *C*'s valuations are all between bidder *A*'s valuations and bidder *B*'s valuations, then the participation of bidder *C* in the auction would increase the seller's revenue. But this is not always true.

The Supporting Information develops numerical examples to complement our findings mentioned above. As mentioned at the outset, the number of potential cases to consider is overwhelming. These numerical examples allow us to gain further insights as under which conditions can the revenue of a seller decline when the number of bidders increases. Table 1 shows the results of the numerical examples and the Supporting Information provides a detailed description of the solutions.

We begin in case 1 with a 2-bidder benchmark where bidder *A* has the three highest valuations and bidder *B*'s valuation for a third object is very low. The equilibrium is efficient as all three objects end up with bidder *A*. This auction earns the seller a revenue of R(2) = 38.85. Case 2 allows the entry of bidder *C* who has a valuation for the first object that is larger than bidder *B*. However, the seller's revenue declines (R(3) = 38.1) compared to case 1.

Since bidder *C*'s valuations are not that different from bidder *B*'s valuations and that the 3-bidder auction, like the 2-bidder auction, is efficient, the worsening of the auction performance when a third bidder is introduced is puzzling. In the 3-bidder auction, equilibrium prices are constant and equal to bidder *C*'s highest valuation, 12.7. The key to understand why the 3-bidder auction underperforms relative to its 2-bidder benchmark is actually in the off-equilibrium path of the 2-bidder game. In this game, if bidder *B* had won the first round, he would have won the second round. This is so because bidder *A* would have found it more profitable to exploit bidder *B*'s low valuation for a third object and win only one object rather than bid up the price to win two objects. In this off-equilibrium path, the gains of bidder *B* in the second round makes him bid more aggressively in the first round, which in turn forces bidder *A* to pay more to win the first round. The game conditional on bidder *A* not winning the first object plays out in a very different manner when bidder *C* is added. The outcomes of these alternative paths are such that neither bidder *B* nor bidder *C* can win in the second or third round. Because winning the first object would not allow them to win more, their bids for the first object is less aggressive and as a result bidder *A* pays a lower average price than when competing only with bidder *B*.

[6] This would be an efficient allocation because the objects would go to the bidder with the highest valuations. However, this would happen only if bidder *A* finds it more profitable to snatch all three objects than to exploit his rivals' lower valuations by letting them win one or two objects.

Table 1. Summary of numerical examples results

Valuations					
Bidder *A*	Bidder *B*	Bidder *C*	Winners of each round	Prices for each round	Seller's revenue
(1) 2-bidder benchmark with bidders A *and* B *when the 3-bidder auction is efficient*					
{20, 20, 15}	{12.6, 12.5, 3.95}		*A, A, A*	13.65, 12.6, 12.6	38.85
(2) 3-bidder auction with bidders A,B *and* C *when the 3-bidder auction is efficient*					
{20, 20, 15}	{12.6, 12.5, 3.95}	{12.7, 10, 5}	*A, A, A*	12.7, 12.7, 12.7	38.1
(3) Alternative 2-bidder benchmark with bidders A *and* C *when the 3-bidder auction is efficient*					
{20, 20, 15}		{12.7, 10, 5}	*B, A, A*	10, 10, 10	30
(4) A 2-bidder benchmark with bidders A *and* B *when the 3-bidder auction is inefficient*					
{20, 17, 16.5}	{14.3, 13.5, 9.9}		*A, A, A*	14.4, 14.3, 14.3	43
{20, 17, 16.5}	{14.3, 13.5, 9.9}	{15.5, 14.2, 14.1}	*C, A, A*	14.3, 14.3, 14.3	42.9
(5) The incidence of a weak third bidder on the seller's revenue					
{20, 20, 15}	{12.6, 12.5, 3.95}	{5, 0, 0}	*A, A, A*	12.6, 12.6, 12.6	37.8

Case 3 shows an alternative 2-bidder benchmark where bidder C replaces bidder B. Compared to case 1, case 3 does not produce as high a revenue for the seller, $R(2) = 30$ and the 3-bidder auction, as indicated before, yields a higher revenue for the seller of $R(3) = 38.1$. The key again is in the 2-bidder auction between bidders A and C. The equilibrium path is inefficient as bidder C whose valuation for a first object is below bidder A's valuation for a third object wins the first object. The addition of a third bidder in this case increases the seller's revenue and makes the allocation of objects efficient.

The examples in case 4 show that the 3-bidder auction need not be efficient for the effect of an additional bidder on the seller's revenue to decrease. In the auction involving only bidders A and B, bidder A wins all three objects, $R(2) = 43$ and the price path is $P(2) = (14.4, 14.3, 14.3)$. Bidder B is very aggressive in the first round, willing to pay more than his valuation for a first object because had he won the first object, he would have also won the second object. The addition of bidder C produces an inefficient allocation because bidder C wins the first object. Prices are constant at 14.3, bidder B's valuation for a first object, and $R(3) = 42.9$. The addition of bidder C has an adverse effect on the seller's revenue and the implication of this result is that it cannot be inferred from observing an additional bidder win an object that this bidder has a competitive effect. Note that the tendency for the extra bidder to induce higher equilibrium prices in late rounds is not observed here because the competitive effects occur off the equilibrium path. This is because bidder A maximizes its payoff by forgoing the first object, which removes the competitive effect associated with the extra bidder in later rounds of the auction.[7]

In our analysis so far, the additional bidder could be regarded as a new entrant that uses the auction as its main source of procurement. In the context of the Quebec hog auction, these cases provide insights about the entry of a new Quebec processing firm. However, the case with out-of-province processors being sporadically invited to bid on the Quebec auction significantly differs because these firms sourced most of their hogs outside of Quebec and have fixed capacities. In our simple auction models, this means that the additional bidder has a nonzero valuation only for one object. Put differently, in the context of our examples, the highest valuations of the outside bidder are "used up" on two objects bought from a nearby source and only the third valuation remains. If that third valuation is sufficiently high, the addition of a capacity-constrained bidder may still have a positive effect on the seller's revenue. Case 5 shows that a weak bidder C may have an adverse effect by considering that bidder C in case 2 had used up his first two valuations. The outcome of this 3-bidder auction is that bidder A still wins all three objects, but at lower prices than in case 2. Recall that prices are higher in case 1 when only bidders A and B compete. Thus, when bidder C is interested in only one object, its presence is even more detrimental to the seller than when it wants three objects.

[7] This counterintuitive result is not specific to the complete information paradigm. Bulow and Klemperer (2002, p. 1) argue that excluding buyers in auction markets is "perfectly reasonable" in auction markets in which each bidder's valuation has a private component and a common value one. The intuition is that in such markets, the risk of paying too much, also known as the winner's curse, increases with the number of bidders and the more conservative bidding that ensue may end up lowering the expected price. In their paper, the result hinges on the relationship between the number of bidders and the valuations of bidders. In our case, the valuations are fixed and known by all bidders and this rules out the winner's curse problem.

To sum up, an additional bidder may increase, have no effect, or decrease the average price received by a seller. The capacity/demand of an additional bidder plays an important role on whether an additional bidder will have a positive or negative effect on average prices. For the empirical investigation we conduct below on Quebec's electronic hog auction, the implication is to differentiate the effect of additional bidders based in Quebec with large demands for hogs from infrequent participants from Ontario with possibly smaller demands for Quebec hogs. Before presenting the empirical results, we describe the circumstances that motivated the creation of the electronic auction, its changing importance in the marketing of hogs in Quebec, and its eventual demise.

BACKGROUND: HOG MARKETING MECHANISMS IN QUEBEC

A provincial marketing board coordinates the marketing of hogs in Quebec. A common objective of marketing boards in Canada is to offset the market power of downstream firms.[8] This is particularly true for Quebec's hog industry, whose 756 producers in 2011 (Statistics Canada 2012), down from 3,322 in 1981, sell their hogs to a few processors (historically seven or eight).

Quebec's hog marketing board, FPPQ, was established in 1981. It has control over the marketing of all of the hogs produced in Quebec. Every four years or so, it negotiates with Quebec hog processors the terms of a marketing agreement. A daily electronic auction was introduced under the first agreement. It began its operations in 1989. All of the hogs produced in Quebec at the time, including those owned by Quebec processors, had to be marketed through the auction.[9] Every day of the week, but not on weekends, processors competed for fixed size lots (except the last one) of virtual hogs scoring 100 on a quality index. Price adjustments were made upon delivery for live hogs scoring below or above 100. Processors also involved in hog productions had to market their hogs through the daily auction and were not guaranteed to receive their hogs back. The FPPQ ran an algorithm to minimize transport costs between the farms and the slaughtering plants. Processors with hog farms located near their processing plants were getting their own hogs as long as they won enough lots on the auction, but had no incentive to contract for specialty hogs. Lower-than-expected prices led to various rule changes early on.

In 1994, FPPQ added a second marketing mechanism to work concurrently with the daily hog auction. In that second mechanism, hogs were formula-priced and supplies were allocated based on the volume slaughtered in the previous year by each processor. The base price was the U.S. reference price adjusted for the exchange rate, a carcass weight differential, and a discount factor. The share of the provincial hog supply marketed through the hog auction was reduced from 100% to 28%. Each processor had a more

[8] The empirical evidence reported in Fulton and Tang (1999) and Gervais and Devadoss (2006) suggests that producers are still at a disadvantage vis-à-vis downstream firms. Recent results about Canada's chicken supply chain in Pouliot and Larue (2012) indicate that retailers carry more weight than processors, who in turn carry more weight than producers.

[9] A contract between the FPPQ and the hog processors listed the responsibilities of the FPPQ and the processors as well as the rules of the auction. The processors agreed to buy all of the hogs marketed by the FPPQ and in exchange the FPPQ agreed to sell only to Quebec processors. As a result, Quebec remained a large exporter of pork meat while other provinces like Ontario and Manitoba exported more piglets and live hogs.

stable supply. The matching between farms and plants for preattributed hogs was also done to minimize transport costs. Quebec processors exported large volumes to the United States and their profits and the profits of their U.S. rivals were conditioned by common factors, which influenced U.S. hog prices, including the one used to price preattributed hogs. However, the reference U.S. hog price did not capture all of the factors impacting on the profitability of Quebec processors and this is why daily auction prices sometime differed by a sizable margin in relation to the U.S. price. Figure 1 in Larue et al (2004) shows that the monthly average auction price was consistently in excess of the monthly average U.S. price between 1994 and 2000.

The improved performance of the daily auction led to the introduction in 2000 of a third marketing mechanism, an auction of monthly supplies which marketed 15% of Quebec's hog supply in 2000 and 25% in 2004, while the share of hogs marketed through the daily auction was set at 25%. In the 2000s, the daily auction generated prices in excess of the U.S. hog reference price when market conditions were favorable to processors, but there were spells of relatively low daily auction prices that were considered as unreasonably low by the FPPQ. At different times, the FPPQ invited processing firms from Ontario to participate in the auction, possibly to induce more aggressive bidding. Ontario bidders still purchased most of their hogs in Ontario when invited to bid on the Quebec auction. Thus, their valuations for Quebec hogs must have been relatively low, or at least lower than if they had been consistently invited to bid on the Quebec auction. Typically, invitations to Ontario bidders were for one to three days.

The merger of Quebec's two largest hog processors in 2005, combined with declining prices in North America, pressured auction prices down. The daily auction was temporarily shut down in October of 2006, but it resumed its activities in April of 2007, only to be permanently closed in April of 2009 when a new agreement between the FPPQ and processors took effect.[10]

In the last 10 years of existence of the auction, Quebec meat processing firms competed in the domestic output market, dominated by three large distributors/retailers, and in export markets, with the United States and Japan as the main destinations at the time. In addition, processors competed in a daily auction for the purchase of "virtual" hogs scoring 100 on a quality index.[11] The processing technology is well known and so were the processing firms' plant sizes and costs for other inputs like labor, energy, and materials. These conditions are very similar to the ones described by Bernheim and Whinston (1986) to justify the modeling of auctions under complete information.

[10] This agreement was a major departure not only because it terminated the daily and monthly auctions, but also because it defined three hog categories: processors owned hogs, specialty hogs, and commodity hogs. This was important for processors who wanted to contract for specialty hogs. The FPPQ was reluctant to move in this direction because it anticipated that greater integration would diminish its influence on the industry. However, the fact that the U.S. reference price is a floor price was seen as a gain for producers because the average price received by producers between 2007 and 2009 was below that benchmark and because it reduced downside risk. Gervais and Lambert (2010) analyze the consequences of this price commitment for processors and producers.

[11] Delivered hogs were graded and deviations from the 100-score entailed a premium or a discount that was agreed upon between producers and processors. Hence, uncertainty over quality did not play a role.

Table 2. Summary data

Variable	Mean	Standard deviation	Minimum	Maximum
AUCprice	172.27	31.21	101.14	254.33
USprice	161.68	28.15	96.55	223.13
AUCquantity ('000)	5.891	1.802	0.895	9.362
AUCshare	24.21	0.05	0.10	0.35
Qcpackers	7.32	0.46	7	8
Dinvited	0.034	0.181	0	1

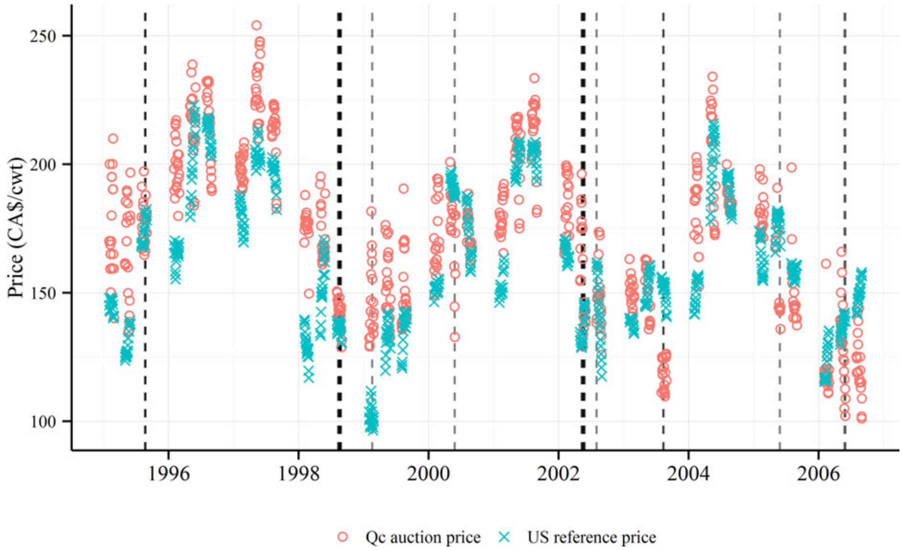
EMPIRICAL EVIDENCE FROM THE QUEBEC DAILY HOG AUCTION

FPPQ graciously provided us with the full data about daily auctions held in February, May, and August from 1995 to 2006, for a total of 760 observations. We requested the full data but FPPQ was not willing to share more than three months per year. As the same three months are provided for every year of the data set, we do not believe that the data suffer from a selection problem.

The data detail the outcome of every auction round and include the identification number of the winner at each round, prices for each lot, lot size, total number of hogs sold that day, and the U.S. reference price. Over the period covered by our data, there were on average 45 lots auctioned per day. We aggregate the data to calculate the weighted average daily auction price (*AUCprice*), the reference U.S. daily hog price converted to Canadian dollars and adjusted for carcass size (*USprice*), and the daily quantity of hogs sold on the auction (*AUCquantity*). From the total daily quantity of hogs marketed, we calculate the share of daily quantity of hogs marketed that goes to auction (*AUCshare*). We add to the data set the number of Quebec hog packing plants that participate in the auction (*Qcpackers*) and a dummy for the presence or absence of additional bidders from Ontario (*Dinvited*).

Table 2 shows summary statistics of our data and Figure 2 plots the daily weighted average auction price and the U.S. reference price. Bidders from Ontario were invited 26 times to participate in the daily auction, consisting of 3.4% of the daily auctions for which we have data. Figure 1 shows when these invitations were extended. Summary statistics and the graph confirm that hog prices were quite volatile over the period covered by our sample.

Because we are interested in the seller's revenue, our dependent variable is the average daily price. We estimate the effect of adding bidders through the entry and exit of Quebec hog packing plants and invitations extended to Ontario packers. In our data, the number of hog packers in Quebec changed on six occasions by increasing from seven to eight, or declining from eight to seven. We were able to identify entry and exit of firms by observing winners and the first bidder on each lot. Our inference from the data on the entry and exit of firms was corroborated by other sources of information, including McEwan's (2010). As a significant share of Quebec hog production was preattributed to hog packers based on their historical production, a packer that entered the market had to source its hogs through the auction system. This means that a new packer had to bid aggressively and thus we expect that increases in the number of Quebec hog packers had a positive effect on the average daily auction price.



Note: Vertical dashed lines indicate when invitations were extended to Ontario bidders.

Figure 2. Quebec auction price and U.S. reference price

In contrast to our static theoretical model, dynamics might play an important role in the daily Quebec auction. In particular, given the short amount of time between auctions and that a substantial share of Quebec's hog supply was marketed through other marketing mechanisms, one could argue that a buyer's share on the auction could vary from one day to the next as a smaller number of lots won on a given day could be compensated by a larger number of lots won the next day. We believe that the scope for this kind of dynamic adjustment was limited. Processing facilities operate daily and small variations in hog procurements can disrupt operations and significantly increase average processing costs.[12] Processors prefer a stable procurement of hogs on a daily basis and this is why they were supportive of the preattribution system based on historical shares to work alongside the daily auction, even though this caused higher hog procurement costs for them (Larue et al 2004).

Ordinary Least Squares Estimates

We begin investigating the impact of changes in the number of bidders in Quebec hog auctions with an ordinary least squares (OLS) model. We account for endogeneity in the timing of invitations using two-stage least squares (2SLS) and Heckman selection models in the next subsection.

We regress the average quantity-weighted daily price generated on Quebec's hog auction on the reference U.S. daily hog price, the daily quantity of hogs sold on the auction, the share of daily quantity of hogs marketed that goes to auction, the number

[12] Workers in Quebec hog processing facilities are unionized. Thus, given contracts with unions, processors have little flexibility in adjusting their labor force in the short run.

of Quebec hog packing plants that participate in the auction, and a dummy for the presence or absence of additional bidders. The model also includes a lagged dependent variable that accounts for the dynamic properties of the data and to control for serially correlated unobservables. The U.S. price was used by the FPPQ in the implementation of its preattribution mechanism, which ran alongside the daily auction in the period covered by our data set. The U.S. price is considered exogenous as changes in the volume marketed through the Quebec daily auction are not important enough to impact the U.S. market. Along with the variable for the U.S. price, the lagged dependent variable captures market conditions such as the demand for pork and processing costs. As the pricing system in Quebec for hogs sold outside of the auction used the U.S. price as a reference, the U.S. hog price also controls for seasonality. The quantity is exogenous as supplies of hogs are determined by decisions made months before slaughter. As hogs reach maturity, feedlots do not have other options than to send them for slaughter, regardless of prices, hence justifying the exogeneity of the quantity variable.

The regression equation for the model is

$$\begin{aligned} AUCprice_t = \beta_1 + \delta AUCprice_{t-1} + \beta_2 USprice_t + \beta_3 AUCquantity_t \\ + \beta_4 AUCshare_t + \beta_5 Qcpackers_t + \gamma Dinvited_t + \varepsilon_t \end{aligned}$$

where ε_t is a well-behaved error term.

The first column of Table 3 summarizes the OLS regression results. We calculate the long-run effect implied by the presence of a lagged dependent variable only for the number of Quebec packers and calculate the standard error for the long-run coefficient using the delta method. Entry of a new packer indicated that investment had been made in production capacity thus signaling that the additional bidder had plans to gain market share at the expense of the regular Quebec bidders. We do not calculate the long-run effect associated with invitations to Ontario bidders because these invitations were extended sporadically for short periods of time. The fact that the FPPQ invited Ontario bidders more than once suggests that a single episode did not have a lasting effect on the behavior of regular bidders. Thus, our interest is in the immediate effect of these invitations.

The coefficients on the lagged auction price and U.S. price are positive and smaller than one. The coefficient of the quantity of hogs auctioned is negative as expected and the coefficient for the share of hogs auctioned is not statistically significant. The coefficients for the number of Quebec hog processors, both for the short run and long run, are positive and statistically significant. The coefficient on the indicator variable for the presence of invited bidders from Ontario is negative and not statistically significant.

The data show that Ontario processors did make some purchases when invited to bid on the auction, but their share averaged only 5.8% of the volume sold on the auction on the days they bid. We do not know which plants among all Ontario plants were asked to bid. From McEwan's (2010) description of Canada's hog processing industry, the Ontario hog industry is dominated by two large plants located in Burlington and Toronto. These plants have large weekly capacities by Canadian standards, but the small volumes purchased by Ontario processors suggest that their highest valuations were tied to hogs sourced in Ontario.[13]

[13] The capacity utilization statistics reported in McEwan (2010) for 2005–09 show that Ontario

Table 3. Regressions outcomes for hog auction prices

		2SLS		Heckman: Two-step		Heckman: MLE	
	OLS	*One lag*	*Five lags*	*One lag*	*Five lags*	*One lag*	*Five lags*
Intercept	0.543	−0.145	−3.117	−0.361	−3.204	−0.481	−3.174
	(6.693)	(6.884)	(7.996)	(6.030)	(6.941)	(6.025)	(6.927)
L.AUCprice	0.864***	0.866***	0.865***	0.867***	0.865***	0.867***	0.865***
	(0.019)	(0.019)	(0.020)	(0.018)	(0.020)	(0.018)	(0.020)
USprice	0.090***	0.090***	0.092***	0.090***	0.092***	0.090***	0.092***
	(0.020)	(0.020)	(0.023)	(0.018)	(0.020)	(0.018)	(0.020)
Quantity	−1.774***	−1.740***	−1.834***	−1.730***	−1.830***	−1.724***	−1.831***
	(0.313)	(0.322)	(0.372)	(0.307)	(0.349)	(0.307)	(0.349)
AUCshare	0.189	0.176	0.193	0.171	0.191	0.169	0.192
	(0.127)	(0.130)	(0.144)	(0.112)	(0.126)	(0.112)	(0.126)
Qcpacker	1.882**	1.932**	2.307***	1.948**	2.313**	1.957**	2.311**
	(0.764)	(0.773)	(0.884)	(0.797)	(0.911)	(0.797)	(0.910)
Dinvited	−2.281	−0.236	1.031	0.405	1.238	0.760	1.167
	(1.908)	(3.313)	(3.490)	(4.173)	(4.358)	(4.076)	(4.231)
Qcpacker (LR)	13.797**	14.400**	17.092**	14.59**	17.17**	14.70**	17.14**
	(6.564)	(6.736)	(7.767)	6.73	(7.77)	(6.75)	(7.77)
N. obs.	724	724	580	724	580	724	580
R^2	0.91	0.91	0.91				
Hansen *J*		1.09	0.61				
Cragg–Donald		66.74	56.20				
Hausman		0.44	0.55				
Lamba				−1.61	−1.99	−1.83	−1.94
(*p*-Value)				(0.47)	(0.40)	(0.39)	(0.39)

Notes: Standard errors are in parentheses and statistical significance is denoted by $*p < 0.10$, $**p < 0.05$, $***p < 0.01$. The Hansen *J* is the test for overidentification restriction with the null hypothesis that the instruments are uncorrelated with the error term. Lambda is the coefficient for the inverse Mills ratio in the Heckman selection model.

Transport costs are larger for out-of-province bidders, but McEwan (2010, p. 9) reports important volumes of interprovincial trade in hogs. For instance, in 2007, 445,000 Ontario hogs were slaughtered in Quebec, 200,000 Quebec hogs were slaughtered in Ontario, while 616,000 and 144,000 hogs from Alberta and Saskatchewan were slaughtered in Manitoba.[14] Anecdotal evidence suggests that interprovincial exchanges typically involve specific contractual terms about pricing and the volume and timing of deliveries, and that deliveries are integrated in the planned production schedule of the plants. The small

plants were jointly operating at 86–94% of their annual capacity. We can infer that the two largest plants could have slaughtered more hogs on certain days. However, we can also suppose that they were operating close to or at full capacity on some days. Thus, despite their large size, the timing of the invitations might not have matched their "slack."

[14] To validate or check for others years, see http://aimis-simia.agr.gc.ca/rp/index-fra.cfm?menupos=1.01.01&r=593&action=pR&pdctc=&LANG=FR.

volumes purchased by Ontario bidders on the daily auction make the anticompetitive effect of new bidders a plausible, but possibly not the only, explanation for the statistical nonsignificance of the coefficient for invitation. However, the coefficient may embody an endogeneity bias that, if sufficiently large, could mask a positive relationship from invited Ontario bidders to the average auction price. A bias would be present if invitations had been extended only when prices were low. If invitations were made at random dates, there is no need to correct for the endogeneity of the invitations.

Estimates from 2SLS and Heckman Selection Models

The first method that we employ to control for the endogeneity of invitations is a 2SLS approach. This method does not account for the invitation variable being binary but this is inconsequential as consistency of the 2SLS does not require continuity of the instrumented variable.

2SLS require that one or more instruments be correlated with the decision to extend an invitation to Ontario bidders while being uncorrelated with the error term of the equation for the auction price. The alternative hypothesis of interest is that the FPPQ sent an invitation to Ontario buyers when it perceived a lack of competitiveness in the Quebec daily hog auction as revealed by the size of the premium for Quebec hogs over U.S. hogs. This rationalizes instrumenting the invitation decision using lagged differences between the auction price and the U.S. benchmark price. These lagged variables are excluded from the auction price equation because it is current prices in levels that determine the demand of Quebec hog packers.[15] As such, lags of the difference in prices are expected to have strong explanatory power about the decision to invite Ontario buyers while being uncorrelated with the error term of the auction price equation. Thus they constitute appropriate instruments to address the endogeneity of the invitations. This hypothesis is tested against the null of random invitations.

We first use a one-day lagged difference between the auction price and the U.S. price to instrument the decision to invite buyers from Ontario. If in fact it takes more than one day to organize participation by Ontario bidders, then a one-day lagged price differential is not an appropriate instrument. Hence, in an alternative specification, we use instead a five-working-day lag of the difference between the auction price and the U.S. price. In addition to the lagged price differential, we use a momentum variable, defined by a dummy variable that equals 1 when Ontario bidders were allowed to bid the previous day, to internalize the possibility of invitations for more than one day.

Columns 2 and 3 of Table 3 show 2SLS estimates. Regression outcomes for the first stage are provided in the Appendix. Small values for the Hansen *J*-statistic indicate nonrejection of the null hypothesis that the instruments are uncorrelated with the error term. Large values of the Cragg–Donald *F*-statistic indicate rejection of the null hypothesis that our instruments are only weakly correlated with the endogenous regressor. Small values for the Hausman test for endogeneity support that invitations were extended

[15] The contract between the FPPQ and Quebec hog processors essentially prevented the FPPQ to directly contract with outside buyers and Quebec hog processors from sourcing hogs outside Quebec as both parties agreed on the principle that all of Quebec hogs were to be processed in Quebec and marketed through the agreed upon marketing mechanisms. This is why the FPPQ did not contract directly with Ontario packers and why they rarely participated in the daily auction.

exogenously. Overall, these tests show evidence that our instruments are appropriate, but that endogeneity is not a significant issue. Thus, our OLS estimates are consistent.

Overall, 2SLS estimates are similar to the OLS estimates. The addition of a packer in Quebec has a positive and statistically significant effect on the auction price. The effect of the participation of Ontario bidders is again negative and not statistically significant.

As an additional robustness check, we estimate Heckman models to explicitly account for the binary nature of the variable for the invitations. We use both a two-step approach and a maximum likelihood estimator (MLE). The MLE approach has the advantage of jointly estimating the equations, but at the cost of imposing more structure on the residuals, which are assumed to be distributed according to a bivariate normal. The two-step approach yields estimates that are consistent, but less efficient than the MLE.[16]

The last four columns of Table 3 report the results of the Heckman (1979) model. The parameter *Lambda* is associated with the inverse Mills ratio, which corrects for the bias from the endogeneity of invitations. In the four models, its value is not statistically significant indicating that the timing of invitations to Ontario bidders was exogenous. Estimates from the Heckman selection models are similar to the OLS and the 2SLS estimates. The coefficient for the number of Quebec packers is positive and significant and the coefficients for invitations to Ontario bidders are negative, but not statistically significant. Our empirical results show that adding bidders from Ontario did not have a statistically significant impact on Quebec auction prices.

SUMMARY AND CONCLUSION

This paper investigates the effect of increasing the number of bidders in livestock auctions. We show that in sequential multi-unit auctions under complete information, a setting consistent with the working of livestock auctions, a seller's revenue may increase or decrease when additional bidders are allowed to participate. The existence of an anticompetitive effect from adding bidders to an auction hinges on new bidders affecting the ranking of the highest valuations for an object. In some cases, even if valuations for an object are higher with the addition of bidders, the average price in sequential multi-unit auctions may decline as the bidders change their bidding strategies. We show that an additional bidder can exert a negative effect on the seller's revenue even if he does not win a single object. Furthermore, observing that the additional bidder wins one object is neither necessary nor sufficient for a positive effect on the seller's revenue. Such adverse effects have been documented by others under different theoretical assumptions (e.g., Matthews 1984; Bulow and Klemperer 2002; Menicucci 2009), but not under complete information.

[16] Identification of the parameters in the two-step approach does not require restrictions on the parameters that appear in the first and the second equation. However, for the MLE, formal identification of the parameters requires exclusion of parameters that appear in the selection equation from the price equation. We report in Table 2 regression outcomes when exclusion restrictions are not included in equation for the auction price. When including the exclusion restrictions in the models with one lag on the price difference, identification of coefficients becomes difficult because of correlation between the price difference, the lag of the auction price, and the U.S. price. In models with five lags on the price difference, including the exclusion restrictions has a small impact on regression outcomes.

Our findings shed new light on competition in livestock markets. In particular, we show that auction prices are not a monotonic and increasing function of the number of bidders. The number of bidders is not the only variable that matters in determining equilibrium auction prices. The ranking and differences between the valuations of the bidders is also crucial. An implication is that in markets with great heterogeneity among a few buyers, which is common in agriculture given the increasing levels of concentration, auctions may not be the best marketing mechanisms in terms of maximizing the sellers' revenues.

The empirical analysis focuses on Quebec's daily hog auction that involved only a few bidders/meat processors from Quebec, except under special circumstances when bidders from Ontario were invited. We do find evidence across econometric models that the addition of Quebec packers had a statistically significant effect on auction prices but that the occasional participation of Ontario bidders did not impact auction prices. These results are consistent with our theoretical argument that takes into account the sequential nature of the auction and the ability of bidders to exploit each other's declining valuations under complete information. New entrants in the Quebec hog packing business had no other source of procurement for hogs than auctions and thus their entry introduced more competitive bids. The positive coefficient on the number of Quebec bidders suggests that the reduction in the number of bidders from the merger of Olymel and Brochu in 2005 adversely impacted auction prices by impacting the highest valuations for Quebec auctioned hogs. However, Ontario bidders had to source hogs mainly in Ontario and could not purchase Quebec hogs on a regular basis. As a result, they had low marginal valuations, possibly because of low remaining slaughtering capacity and/or higher transport costs, when invited to bid on the Quebec auction. In this light, the fact that Ontario bidders did not have a positive effect on the average daily auction price is not surprising as their valuations did not impact the highest valuations for Quebec auctioned hogs.

We do not find evidence that invitations to Ontario bidders were extended when Quebec auction prices were low. In fact, the lack of evidence that invitations were endogenous to the auction price suggests that these invitations were extended at random, maybe to remind Quebec packers that noncompetitive bidding would not be tolerated.

Our results have important implications for the marketing of livestock and agricultural markets generally. In particular, the informational advantage of buyers and their small numbers (due to significant economies of scale) makes it particularly challenging to design efficient marketing mechanisms, including auctions. As evidence, in Quebec the provincial hog marketing board gave up entirely on auctions in 2009, after 20 years of experimentation with different fixes. Similarly, the Quebec egg, chicken, and turkey industries have been experimenting with various types of double auctions. From the start, the auctions of egg and turkey quotas were either canceled or suffered from a small number of participants. The *Fédération des producteurs d'oeufs de consummation du Québec* decided in 2013 to replace the quota auction by an administered price system. Our theoretical results suggest that the addition of marginal buyers might induce a decline in a sellers' revenue. Similarly, our empirical results show that sporadic temporary invitations to Ontario buyers (marginal buyers) had no impact on Quebec hog prices but that the addition of a single buyer, local buyer, had a positive and significant impact on hog prices. Together, these results suggest that a permanent, rather than a temporary, expansion of the pool of buyers could improve the performance of livestock auctions in Quebec. This could be achieved, for example, by the pooling of provincial marketing boards into larger regional boards. For instance, the pooling of Quebec and Ontario hogs in auctions would create more competitive auctions in which buyers would have more incentives to bid their valuations. The number of farms and processing firms within each Canadian province has fallen rapidly in the last 40 years and the "thin market" problem could be solved by a lesser clustering of markets in Canada.

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APPENDIX

Regression outcomes for first-stage regressions

	2SLS		Heckman: Two-step		Heckman: MLE	
	One lag	*Five lags*	*One lag*	*Five lags*	*One lag*	*Five lags*
Intercept	0.205***	0.262***	4.114	4.340	4.252	4.463
	(0.079)	(0.101)	(2.727)	(2.784)	(2.736)	(2.798)
L.diff.price	0.005***		0.094		0.091	
	(0.002)		(0.058)		(0.057)	
5L.diff.price		0.001		0.009		0.009
		(0.001)		(0.007)		(0.007)
Momentum	0.397***	0.406***	1.757***	1.685***	1.753***	1.677***
	(0.099)	(0.103)	(0.296)	(0.296)	(0.296)	(0.296)
L.AUCprice	−0.006***	−0.001**	−0.108*	−0.019***	−0.105*	−0.019***
	(0.002)	(0.001)	(0.058)	(0.007)	(0.058)	(0.007)
USprice	0.005***	0.000	0.093	0.004	0.089	0.003
	(0.002)	(0.001)	(0.058)	(0.008)	(0.057)	(0.008)
Quantity	−0.016***	−0.016***	−0.279***	−0.259**	−0.284***	−0.259**
	(0.005)	(0.006)	(0.096)	(0.102)	(0.097)	(0.104)
AUCshare	0.006**	0.006**	0.089***	0.081**	0.088***	0.081**
	(0.002)	(0.003)	(0.033)	(0.035)	(0.033)	(0.034)
Qcpacker	−0.015	−0.021	−0.591	−0.605	−0.591	−0.613*
	(0.010)	(0.014)	(0.360)	(0.369)	(0.361)	(0.371)

Notes: Statistical significance are denoted by $^{*}p < 0.10$, $^{**}p < 0.05$, $^{***}p < 0.01$.

SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article:

Figure B1: Outcome tree for the 2-bidder numerical example involving bidders *A* and *B*.
Figure B2: Outcome tree for the 3-bidder efficient auction.
Figure B3: Outcome tree for the 2-bidder numerical example involving bidders *A* and *C*.
Figure B4: Outcome tree for the 2-bidder numerical example involving bidders *A* and *B*.
Figure B5: Outcome tree for 3-bidder auction in example 3.
Figure B6: Outcome tree for a 3-bidder auction where the valuations of bidder *C* for a second and a third object equal to zero.