Empirical Documentation of Bid Shading in the Discriminatory Auction

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Abstract

This manuscript provides an empirical documentation of the existence and magnitude of heterogeneous bid shading in the discriminatory auction. Unlike existing empirical work that uses aggregate data, this manuscript makes use of a unique data set collected at the individual bidder-level containing bidding behaviour and detailed cost information covering a natural experiment in which the format of the auction switches from uniform to discriminatory pricing. Preliminary regression results indicate that bid prices in the discriminatory auction are $1,813 lower than bid prices in the uniform auction. In other words, the magnitude of bid shading in the discriminatory price auction is on average 6.3% of bidders' willingness to pay. Capacity utilization, housing type and milking system are bidder-specific characteristics identified as being determinants in explaining heterogeneity in the magnitude of bid shading across bidders. In terms of allocative efficiency, the uniform auction achieves a higher average efficiency of 91% compared to an average efficiency of 74% reached by the discriminatory auction. The majority of the inefficiency of the discriminatory auction is attributed to the use of bid-spreading strategies while the remaining portion of inefficiency is due to heterogeneous bid shading across bidders. All auction inefficiency identified in the uniform auction is attributed to the use of bid-spreading strategies.

Keywords: Uniform auction; discriminatory auction; efficiency, bid shading

1 Introduction

Multi-unit auctions are becoming increasingly important in the marketplace as tools to allocate resources and assets. Examples include: personal communication services (Cramton 1997); sulphur dioxide permits (Joskow et al. 1998); treasury bills; (Nyborg et al 2002; Hortascu and McAdams 2010) and agricultural goods. A recent survey of security trading practices of numerous countries report an overwhelming majority use the discriminatory auction formats relative to the uniform price auction format (Bartolini and Cottarelli 1997). Despite this overwhelming empirical popularity of the discriminatory auction, theoretical results of the superiority of these two auction formats is ambiguous. The bulk of the existing empirical multi-unit auction literature examines bidding behaviour collected from treasury auction settings in which the presence of a when-issued and liquid resale market are commonly exploited to obtain estimates of bidder's underlying true valuation for the financial asset. For example see, Nyborg and Sundaresan (1996) for an examination of U.S. Treasury auctions for treasury bonds; and Umlauf (1993) for Mexican Treasury bill auctions. In the absence of when-issued markets, as is the case in the auction setting examined in this manuscript, traditional methodologies do not apply. This manuscript addresses the issue of the relative performance of these two auction formats with a novel empirical approach that recovers bidders' underlying WTP without the use of secondary markets or strict assumptions necessary for structural estimation techniques.

The objectives of this manuscript are twofold. Primarily, this manuscript sets out to document individual bidding behaviour in both the discriminatory and uniform price auction. Heterogeneity in bid shading across bidders is identified and variations in the magnitude of bid shading are explained by observable bidder-specific characteristics. Secondly, this manuscript provides an empirical ranking of the allocative efficiency of the uniform and discriminatory auction formats. Unlike existing literature offering empirical rankings of these two auction formats, this manuscript identifies and separates two sources of inefficiency in the discriminatory auction and one source of inefficiency in the uniform auction. Interestingly, a proportion of inefficiency in the discriminatory auction is attributed to heterogeneity in bid shading; previously undocumented in the existing literature

A unique data set of individual bidding histories collected from the Ontario dairy quota auction; a monthly auction transferring dairy production quota between registered Ontario dairy producers is studied in this manuscript. Production quota, under the Canadian system of supply management, gives producers the "right" to market their milk specified by individual quota holdings.[1] Ontario's dairy quota auction makes for an interesting setting to analyze as it is a simplified auction setting, absent of regulations and restrictions. For example, bidders are not restricted in terms of number of price-quantity bid pairs one can submit in addition to the total quantity an individual bidder can win in a given auction; both of which are often regulated by the auctioneer in treasury auctions. In addition, speculation and arbitrage are likely to play a small and innocuous roles in the strategic manipulation of individual bidding strategies due to the nature quota's ownership rules. For these reasons, in addition to the recent change in auction format from uniform to discriminatory pricing, the Ontario dairy quota auction offers a unique setting to document bid shading and compare the relative performance of these two widely used multi-unit auction formats.

The balance of the paper is divided into five sections. The next section provides an overview of the Ontario dairy industry including recent polices changes taking place in the dairy quota auction. Section three reviews relevant literature follows by an description of the existing theoretical auction models. Section five describes the data and section six describes out empirical approach. Section 7 wraps up with a discussion and concluding thoughts on the implications of these findings

[1] Dairy production quota is measured in kilograms of butterfat per day; one kilogram is roughly equivalent to the milk one dairy cow will produce in one year.

2 Ontario Dairy Industry

The Ontario dairy industry is a part of the federal Canadian supply management system and is characterized by three important components: 1) import barriers; 2) administered milk prices based on a cost of production formula; and 3) production quota to restrict domestic production with domestic demand.[2] Each provincial milk marketing board administers a provincial quota auction that facilitates the transfer of production quota among willing buyers and sellers (i.e., registered dairy producers within a given province) in a competitive bid-and-offer double auction setting on a monthly basis. The Ontario dairy quota auction, introduced in 1980, is administered on a monthly basis by the Ontario Milk Marketing Board (i.e., The Dairy Farmers of Ontario (DFO)).

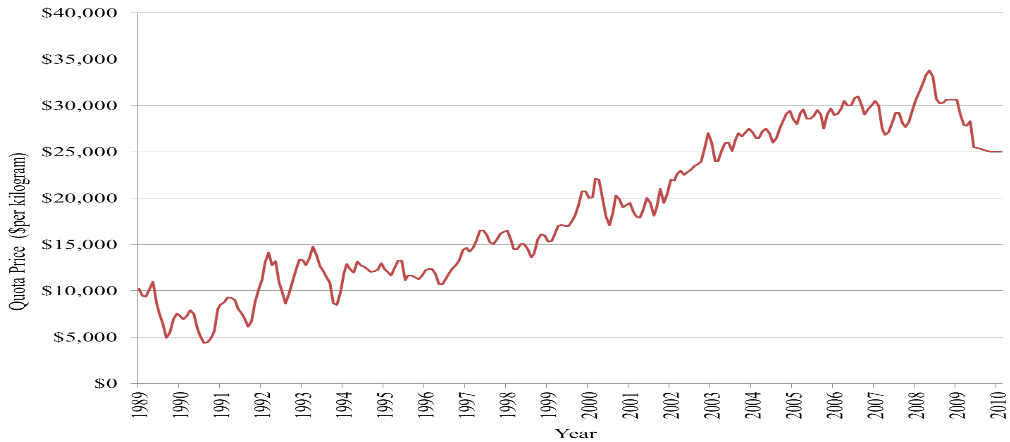

Figure 1: Ontario Real Monthly Quota Price 1989- 2010
Source: Dairy Farmers of Ontario Statistical Handbook (1989-2010)

Figure 1 illustrates the steady rise in Ontario dairy quota value from approximately $10,000 per kilogram in 1990 to $35,0000 per kilogram in 2009. The upward trend in quota value was seen by the DFO as an impediment to the viability of the industry as high prices likely created significant entry and expansion barriers due to the substantial debt producers would have to incur. Consequently, the DFO intervened in the quota market on multiple occasions beginning in 2006. The DFO first implemented a progressive transfer tax (PTA) on quota sales in conjunction with a change in auction format from uniform to discriminatory pricing in November 2006. The PTA imposed a variable in-kind tax on all producers selling quota through the quota auction. This tax mechanism effectively placed a ceiling on the price producers selling their quota received at $25,500/unit of quota while producers purchasing quota remained unrestricted. Aggregate annual data from Table 1 suggests that following the PTA, a significant reduction in the quantity of quota offered for sale occurred, as producers' returns from quota sales dropped substantially over night. For example, producers that sold in October 2006 prior to the introduction in the PTA earned $30,995 per kg of quota, compared to the cap of re-sale price of$25,500 in the December 2006 auction.[3] Paralleling the implementation of the progressive transfer assessment was a change in auction format from uniform to discriminatory pricing. As a result of this change, successful bidders now had to pay their bid on units awarded, whereas in the prior uniform price auction format, all successful bidders paid the market clearing price. Table 1 reveals very little change in quantity of bids demanded between the years of 2006 and 2007 suggesting that the change in auction format and the PTA had minimal effect on adjusting producer's quantity demanded.

Despite the implementation of the PTA and discriminatory format, quota values continued to rise, promoting

[2]One kilogram of quota allows a dairy producer to deliver one kilogram of butterfat per day to provincially licensed milk processors. This is roughly equivalent to the annual milk (butterfat) production of an average dairy cow.

[3]The DFO cancelled the November 2006 auction following the announcement of the policy changes.

Table 1: Annual Quota Transfers through Ontario Quota Auction (2003-2010)

Year	Policy	Kg Bid For	Kg Sold	Kg Purchased
2003	Unregulated	19,649.90	12,946.30	12,887.30
2004	Unregulated	17,556.40	12,003.80	12,108.10
2005	Unregulated	16,894.60	11,407.70	11,308.00
2006	PTA introduced November	19,036.20	11,756.93	11,575.03
2007	PTA	15,426.39	6,893.64	6,898.79
2008	PTA	14,655.34	5,563.22	5,565.04
2009	Price Cap announced March	21,739.24	5,414.21	5,380.04
2010	Price Cap	97,106.73	2,588.14	2,589.92

a second intervention by the DFO in August 2009 with a ceiling price on quota of $25,500, with scheduled monthly reductions to $25,000/unit by January 2010. Under this price cap policy, buyers will pay and sellers will receive $25,000 per unit of quota and less if the price cap is not binding. In conjunction with the price cap, two additional restrictions on producers' bidding behaviour were implemented: total quantity demanded per auction could not exceed 10% of their existing quota holdings and producers could submit only one price-quantity bid pair per auction. Referring back to Table 1, it is apparent that the introduction of the price cap had a significant effect on increasing the quantity of quota bid for. In particular, the aggregate quantity of quota bids increased by 346% from 21,739 kilograms in 2009 to 97,106 kilograms in 2010, paralleled with a 52% reduction in annual offers from 5,414 kilograms in 2009 to 2,588 kilograms in 2010. In total, these two policies created a divergence in supply and demand for quota that has resulted in a 40% overall reduction in quota transferred through the quota auction from 2006 to 2010. The substantial increase in quota demanded for quota has effectively revealed that the vast majority of producers value production quota much more than the value of the cap; making quota purchases at this price of $25,000 a bargain. Consequently, the majority of producers are flooding the monthly quota auction with bids specifying the maximum allowable quantity at the maximum price (i.e., $25,000).[4]

It should be noted that producers were given *no* notification of this first change in policy that occurred in November 2006. This is in contrast to the next major policy changes that occurred in August 2009, in which all producers were made aware of the policy changes well in advance. An announcement was issued in March 2009 outlining the quota policy changes that would become effective August 1, 2009. Reflecting the fact that the release of this memo likely influences bidding behaviour, the sample is restricted to auctions occurring prior to March 2009.

3 Literature Review

There are two streams of previous literature relevant to this manuscript . The first stream of existing literature examines bidding data collected from natural experiments of auction design involving switches in auction formats from uniform to discriminatory or visa-versa. This stream of literature focuses exclusively on treasury auctions and is primarily motivated to find an empirical ex post ranking of these two auction formats in terms of revenue and efficiency. In this stream, aggregate bidding data is often analyzed to determine an empirical ranking of the uniform and discriminatory price auction in terms of revenue and efficiency. Methods differ in terms of recovering bidder's underlying demand curve, but often a when-issued market or resale market is used to proxy

[4]When demand for quota exceeds the supply of quota on the quota auction, the first 50% of the kilograms up for sale is allotted equally to each individual producer with a successful bid in 0.1 kilogram increments. The remaining 50% of quota is then proportionally allotted to those producers whose bids were not completely filled; according to bid size (Dairy Farmers of Ontario: Corporate News 2009)

for the true valuation of the auctioned financial asset.

For example, in an examination of the Mexican T-bill auction that switched from discriminatory to uniform pricing, Umlauf (1993) analyzes bidders' profits in a regression analysis. Individual bidders' profits are calculated using a weighted average of Wednesday resale prices to model true valuations less the bid price. The resale market is described as being relatively competitive and Wednesday resale activity is exceptionally high with large participation, ensuring that theses resale prices accurately represent common values of issues treasury debt. Controlling for variables such as: variance of overnight lending rates, number of competitive bidders,and quantity-weighted variance of winning bids, Umlauf (1993) finds that individual bidders profits significantly decreased when the uniform auction format was implemented. Interestingly, multiple regression models are run separately for: the entire sample; the members of a well-know cartel consisting of 6 firms that make up 72% of aggregate demand; and non cartel bidders. Comparing across models indicated that reductions in the profits of cartel firms were larger relative to non cartel firms.

Tenorio (1993) examines aggregate bidding behaviour collected from the Zambian government foreign exchange auctions containing 42 and 26 uniform and discriminatory auctions. Using multiple time series models, Tenorio (1993) tests whether the clearing price, maximum auction bid and minimum auction bid are effected by the auction format change. Controlling for other variables that likely affect bidding behaviour such as: supply, demand, expectations, number of bids, results indicate that the uniform format earned more revenue relative to the discriminatory format due to the higher bidder participation in the former auction format; likely reflecting the fact that bidding strategies in the uniform auction are more straightforward to calculate than in the discriminatory auction.

Nyborg and Sundaresan (1996) examine US treasury auctions for two and five-year treasury notes during the time period in which the US treasury began experimenting with uniform auctions. In particular, transactions from one large broker: Garban, in the when-issued market are analyzed for both discriminatory and uniform auction formats. The difference between the when-issued rates and auction rates (i.e, markups) at varying times are used as metrics to compare the two and five-year treasury notes in the two auction formats. In a test of mean markup across uniform and discriminatory actions for two-year notes, the uniform auction had lower mean markup when calculated at 1pm, while a higher mean markup was found for the uniform auction at release time of auction results. Alternatively, for five-year notes, consistent results were found across different time periods indicating that mean markup were lower in the uniform relative to discriminatory auction. Overall, findings suggest that the uniform auction released more information, thereby decreasing the winner's curse and resulting in lower markup and higher expected selling prices.

This common approach employed by Umlauf (1993) and Nyborg and Sundaresan (1996) using reference points to model true value such as average when issued price in Nyborg and Sundaresan (1996) or weighted average resale price as in Umlauf (1993) is limited to auctions in which a secondary market is available. Even more limiting is the implicit assumption that bidders' true valuations are accurately captured in the resale market. For example, due to the re-sale (when-issued) market occurring after (before) the actual auction, changes in information regarding market fundamentals may have changed from the end (beginning) of the auction to the start of the resale market (end of the when-issued market) and are likely affecting bidder's valuations ; potentially introducing bias as these are likley unobservable.

For these reason, a separate, but related stream of auction literature uses structural econometric modeling to recover bidders' underlying marginal valuations. Commonly found in this second stream of auction literature is detailed data from either a uniform or discriminatory price auction and a counter factual analysis is preformed to examine "what if" scenarios to examine whether gains in efficiency or revenue "could" have been achieved if an alternative auction format replaced the existing one. Structural estimation imposes equilibrium behavioural assumptions such that bidders bid accordingly to Bayesian-Nash equilibrium strategies in order to estimate the underlying probability law of valuations using bid data. See Hendricks and Paarsch (1995) for a survey on recent structural estimation auction techniques.

For example, Kastl (2011) analyzed 28 uniform Czech government treasury bills auction to examine the uniform auction's performance relative to a counter-factual Vickrey auction. Kastl (2011) incorporates step rather than continuous bidding functions and finds that the uniform auction mechanism performs relatively well, having failed to extract at most three basis points of buyers surplus. In a similar vein of structural analysis, Hortacsu and McAdams (2010) examine a discriminatory auction and applies a nonparametric structural procedure to recover bounds on marginal valuations given observed bidding behaviour. Estimates of marginal valuations are used in a counter factual analysis to determine whether gains in revenue and allocative efficiency could have been achieved 'if' a uniform or Vickrey auction had been implemented. The hypothesis that the hypothetical uniform auction generated the same revenue of the discriminatory auction could not be rejected, indicate the auctioneers would not have been better off if a uniform auction was rather used to sell Turkish Treasury T-Bills. Efficiency of the discriminatory auction's allocation is then measured using upper and lower bounds of bidders' estimated marginal valuations: inefficiency if the lower bound on the marginal valuation of a unit that was won is less than the upper bound on the marginal valuation of a unit was lost. These results suggested that on average, the discriminatory auction had little allocational efficiency loss as the average auction was 98% efficient.

Fevrier et al (2004) employs a parametric structural approach to estimate bidding in a discriminatory auction under the assumption of a common value framework in which a single and perfectly divisible good is auctioned. The estimated model is then applied to bidder level data collected from French Treasury securities auctions to conduct a counter factual analysis to examine the hypothetical revenue collected if a uniform auction had replaced the discriminatory pricing format. Results indicate that the discriminatory auction was revenue superior and revenues collected were on average 5% higher relative to the hypothetical uniform format.

Finally, Kang and Puller (2008) use a unique data set containing bidding behaviour from both uniform and discriminatory auction format used for trading government securities in Korea. Kang and Puller (2008) extend the methodology of Hortacsu and McAdams (2010) to recover bidder's marginal calculations from observed bidding behaviour in both the uniform and discriminatory auction formats to conduct a counter factual revenue comparison of the two auction formats. Results suggest that the discriminatory auction yielded significantly more revenue and a more efficient allocation relative to the uniform format. However the economic differences of the revenue and efficiency differences are quite small; less than 1% difference.

An apparent gap in the methodologies of the existing multi-unit auction literature is an empirical approach to recover bidder's WTP without imposing strong assumptions required for structural econometric methods, or reliance on the presence of a highly liquid resale or when-issued market to model true valuation of financial assets. In addition, these previous studies have been unable to differentiate the sources of inefficiency in the discriminatory and uniform auctions, nor identify and explain the presence of heterogeneity in individual bidders bidding strategies in the discriminatory auction. The next section describes appropriate assumptions to model the dairy quota auction and how these relate to the existing theoretical multi-unit auction models.

4 Multi-Unit Auction Theory

This section describes the existing multi-unit auction literature and discusses equilibrium predicted equilibrium behaviour in both the uniform and discriminatory auction. The assumptions underlying the Ontario dairy quota auction setting necessary to select appropriate conceptual framework are first discussed. Existing streams of multi-unit auction literature can be differentiated by the underlying assumptions of the valuation structure of the auctioned good. For example, a common distinction that separates auctions into two main categories - the particular type of valuation held by bidders: either common or private. Additional assumptions that are placed on the valuation structure of bidders in an auction setting in order to derived appropriate predictions for equilibrium bidding behaviour are the slope of underlying demand curve and presence of market power in the auction. This section discusses each assumption regarding the valuation structure of registered dairy producers bidding in the Ontario dairy quota auction, followed by the predictions for equilibrium bidding behaviour in both the uniform and discriminatory auction given these assumptions.

4.1 Independent Private Valuations

Financial assets have been modeled in the previous literature as a common value good, for example: treasury bills: Nyoborg et al (2001); Bikhchandani and Huang (1993). In a common value model characterizes a good in which bidders have the same value for the good, but bidders are unaware of this valuation at the time of bidding. In contrast, a private value model, each individual bidder is aware of his/her own valuation and this valuation is not affected by learning information regarding competitor's individual valuation. The intuition provided by the authors in the case of treasury bills is that there exists a liquid secondary market in which these treasury bills can be resold; presenting a common value component because all owners of the asset will receive the same resale price. An additional characteristic of treasury auctions motivating the common value framework is the existence of either a when issued market or a resale market. Bidders can begin trading treasury securities as soon as the details of an issue have been announced until the actual issuance of the securities. This prior trading takes place on a "when issued" basis, whereas resale market take place soon after the treasury auction. Haile (1999) indicate that the opportunity for bidders to resell their securities on a resale market is likely to affect bidding behaviour during the auction.

The Ontario quota auction environment differs substantially from the treasury auction setting as it contains no sequential components in terms of the existence of a when issued market or a secondary resale market. Secondly, the nature of quota does not illicit a quick resale of the good in a secondary market, making the opportunity for arbitrage extremely limited in the quota auction. For example, consider a bidder that submits a bid on March 31st will observe on April 1st if the bid was successful but will not be granted or receive possession of the quota bid for until May 1st. Therefore, if the bidder were engaging in arbitrage activities they would have to take possession of the quota for one month (i.e., May) until they could submit an offer to sell for the June auction. Furthermore, The DFO has the ability to remove quota holdings from producers due to underproduction; therefore removing any incentives bidders may have to purchase quota for purely speculative reasons. Reflecting upon these difference, production quota is modelled as an independently privately valued good.

4.2 Constant Marginal Valuations

Conceptually, a constant marginal valuation framework is motivated by considering a producer who would like to purchase additional kilograms of quota. Adjustment costs associated with increasing production are likely to include the price of the cow, additional feed costs, additional labour costs. It is argued that these costs are constant for each additional cow added to production due to the ease of accessibility and presence of well-developed competitive markets for these inputs.

An additional factor confirming the appropriateness of the constant marginal valuation assumption is the recent change in lending practices concerning production quota in Canada. In 1996, Farm Credit Canada (FCC) a crown corporation that operates at arms lengths to the Government of Canada supplying financial credit to farmers, relaxed policies on the issuance of loans for the purpose of quota purchasing to farmers. In particular, the availability of credit was increased to producers and dairy quota was recognized as an asset that could be assigned as collateral for additional loans. These changes in lending practices highlights the fact that financial institutions place a value on the each unit of quota a producer owns that will be constant across all units owned. For these reason, the assumption of constant marginal valuations seems appropriate for the dairy quota setting.

4.3 Market Power

Market power is important in constructing multi-unit auction models and is particularly critical for the the uniform auction model, as bidders pay the clearing price for all units they are awarded, rather than their actual bids. This characteristics of the uniform auction highlights the importance market power pays in determining whether a given bidder has a positive probability of setting the clearing price, and therefore can manipulate the price that they (and all other bidders) pay for all units awarded.

Unlike treasury auctions which often have restrictions in place to limit the quantity an individual bidder can submit bids for in a given auction (i.e., 35-percent rule in the US treasury auction (Malvey et al 1997); 50-percent rule in the Czech treasury auction (Kastl 2011)), the Ontario quota auction has no such restrictions. The absence of this restriction suggest that at first glance, there is no concern for the market power in the Ontario dairy quota market. To examine market power more directly, the range of bidders participating in a given monthly auctions are analyzed. The average number of bidders per auction is 291 and the minimum and maximum are 214 and 432 respectively. The average proportion of total quantity an individual bidder bid for in a given auction was 0.31% of total quantity demanded. The minimum and maximum was 0.004% and 8.3% of total quantity demanded. These figures suggests that no one bidder submitted a significantly large amount of quota in one auction such that they achieved market power; rather the Ontario quota auction appears to highly competitive.

Furthermore, I consider a counter factual thought experiment in which I examine the profitable deviation of the bidder that submitted the bid that set the market clearing price in a given auction. In particular, I ask the question: by holding all other bids fixed, by how many dollars could this bidder have adjusted his/her bid downward to affect the clearing price and pay a lower price on all units awarded? Focusing on the uniform auction, in four of the six auctions, the next closest bid to the bid that set the clearing price was one dollar below. This suggests. In the other two auctions, the next closest bid was 28 and 48 dollars below. This suggest that the distribution of bids around the clearing price is extremely dense and that each bidder has little to no opportunity to influence the clearing price in a material way.

4.4 Theoretical Predictions in Uniform and Discriminatory Auctions

Given the above assumptions, the theoretical predictions derived by Ausubel et al (2014) for both of the uniform and discriminatory auctions are now described. The framework constructed by Ausubel et al (2014) is general enough to encompass our assumptions outlined in the previous section of: independent private valuations, constant marginal valuations and absence of market power. In both the uniform and discriminatory auction formats, bidders submit multiple price-quantity bids pairs that are aggregated to form individual bid schedules. The auctioneer then allocates units to successful bidders whom submitted bids that were above the market clearing price: the price that equates supply with demand. The fundamental difference in these two auction formats lie in the price successful bidders pay. In the uniform auction, all successful bidders pay the clearing price for all units allocated, whereas in the discriminatory auction bidders pay their full bid price for all units allocated to them. This difference in pricing rules creates a divergence in the equilibrium bidding strategies of these two auction formats. In order for theoretical models to predict equilibrium bidding strategies, assumptions need to be made on bidder's valuation structures.

Ausubel et al (2014) predict that in the uniform auction, it is optimal for bidders to submit a flat bid function that is equal to their true WTP. The intuition is as follows: due to the absence of market power in the uniform auction, bidders have no incentive to utilize demand reduction strategies that are commonly present in the uniform auction when bidders demand multiple units. In other words, because bidders cannot influence the clearing price, submitting a bid below their WTP only reduces the bidder's probability of winning the bid (i.e., probability the bid is higher than the clearing price), and as a result truthful bidding is the optimal bidding strategy. Alternatively, for bidders with flat demand and no market power in the discriminatory auction, Ausubel et al (2014) predict that it is optimal for bidders to submit a flat bid function that is shaded below their true WTP. The amount of shading is predicted to be constant across all units, however there exists no prediction in term of potential heterogeneity in bid shading across bidders; a point expanded upon in Section 6.2.

Given these theoretical predictions, Table 2 examines the breakdown of the number of price-quantity bid pairs individual bidders submitted in a given auction to test whether observed bidding behaviour is consistent with the predicted bidding behaviour described above (i.e., submit a flat bid function consisting of one price-quantity bid pair in both the uniform and discriminatory auction). In line with predictions an overwhelming majority of bidders (over 87%) in the uniform auction submit a flat bid function that consists of one price-quantity bid pair. Similarly, the majority of bidders (66%) of bidders in the discriminatory auction submit a flat bid function made up of one price-quantity bid pair, in line with predictions. A smaller proportion of bidders appear to follow equilibrium predictions in the discriminatory auction relative to the uniform auction. I address the implications of this divergence in observed bidding behaviour from equilibrium predicted behaviour on the allocative efficiency of both auction formats in Section 6.3.

Table 2: Breakdown of Individual Bid Functions

	Uniform Auction		Discriminatory Auction	
	Number of Bidders	Proportion	Number of Bidders	Proportion
Number of Bids==1	1,313	0.872	3,582	0.660
Number of Bids==2	158	0.105	1,153	0.213
Number of Bids==3	24	0.016	439	0.081
Number of Bids==4	10	0.007	134	0.025
Number of Bids==5	0	0	75	0.014
Number of Bids==6	1	0.001	21	0.004
Number of Bids==7	0	0	9	0.002
Number of Bids==8	0	0	4	0.001
Number of Bids==9	0	0	1	0.0002
Number of Bids==10	0	0	5	0.001
Total	1506		5423	

5 Data

The data set used in this manuscript spans from May 2006 to February 2009; covering 6 uniform price auctions and 26 discriminatory price auctions. See table 3 for summary statistics of the 32 auctions contained the data set. The data set is comprised of two seperate components: 1.) individual bidding behaviour consisting of submitted price-quantity bid pairs; and 2.) individual annual cost of production (COP) information. The individual bidding behaviour is collected from the DFO; the provincial board that facilities, monitors and regulates the Ontario dairy quota auction. The COP data set is sourced from the Ontario Dairy Farm Accounting Project (ODFAP), a joint undertaking of the DFO, Agriculture Canada, the Canadian Dairy Commission, and the University of Guelph. Initiated in 1976, the ODFAP project has developed and maintaining: "a sample of farms which represents typical Ontario dairy farm situations and which reflects different levels of technology, regional differences and other significant factors," (ODFAP Annual Report 2006, pg.5). The panel of farms surveyed in the ODFAP data set are systematically changed annually. Each farm remains in the sample for a maximum of five years; however some of the farms enter the sample for a shorter period. The unbalanced panel of farms is regionally stratified to closely represent the industry. Producers within a region are randomly chosen to avoid biasedness of farms voluntarily entering into the sample. Figure 2 graphically illustrates and compares industry level averages with COP sample averages between 2001 and 2009 for herd size and milk production to demonstrate that the COP sample is representative of the entire industry. For example, average herd size in the COP sample is highly correlated with average herd size of all Ontario dairy farmers, as both statistics are steadily rising over the time period.

Table 3: Summary Statistics of Auctions

	Format	Num.Bidders	Num. Bids	Clearing Price	Total Q.Demanded	Avg Num.Bids/Bidder	Avg Q. Demanded/Bidder
May 06	UA	371	432	29700	1988.2	1.16	5.36
Jun 06	UA	340	389	30500	1850	1.15	5.44
Jul 06	UA	217	248	30001	1100	1.17	5.07
Aug 06	UA	189	218	30010	1106.7	1.18	5.86
Sep 06	UA	205	246	30800	1253.8	1.2	6.12
Oct 06	UA	184	214	30995	1100.5	1.19	5.98
Dec 06	DA	354	619	29000	2286.2	1.72	6.46
Jan 07	DA	267	419	29600	1605.9	1.63	6.01
Feb 07	DA	346	478	30015	1945.1	1.39	5.62
Mar 07	DA	271	364	30501	1993.3	1.37	7.36
Apr 07	DA	151	207	29995	1032.2	1.4	6.84
May 07	DA	109	167	27502	400.5	1.45	3.67
Jun 07	DA	240	435	26837	1488.4	1.68	6.2
Jul 07	DA	249	455	27120	1797.1	1.69	7.22
Aug 07	DA	233	387	28102	1685.4	1.58	7.23
Sep 07	DA	188	317	29200	1446.5	1.62	7.69
Oct 07	DA	140	193	29210	952.9	1.5	6.81
Nov 07	DA	76	110	28101	373.4	1.53	4.91
Dec 07	DA	138	228	27670	787.2	1.61	5.7
Jan 08	DA	237	383	28213	1325.9	1.56	5.59
Feb 08	DA	341	527	29501	1864.5	1.54	5.47
Mar 08	DA	341	482	30666	1944.9	1.42	5.7
Apr 08	DA	291	426	31505	1732.7	1.47	5.95
May 08	DA	238	339	32405	1527.2	1.47	6.42
Jun 08	DA	201	285	33235	1241.2	1.47	6.18
Jul 08	DA	119	158	33805	682	1.44	5.73
Aug 08	DA	75	109	33115	495	1.46	6.6
Sep 08	DA	72	118	30651	426.2	1.5	5.92
Oct 08	DA	191	339	30205	1465.9	1.64	7.67
Nov 08	DA	143	233	30310	860.7	1.6	6.02
Dec 08	DA	147	224	30610	865.2	1.56	5.89
Jan 09	DA	125	191	30610	710	1.6	5.68
Feb 09	DA	140	208	30601	645.4	1.56	4.61

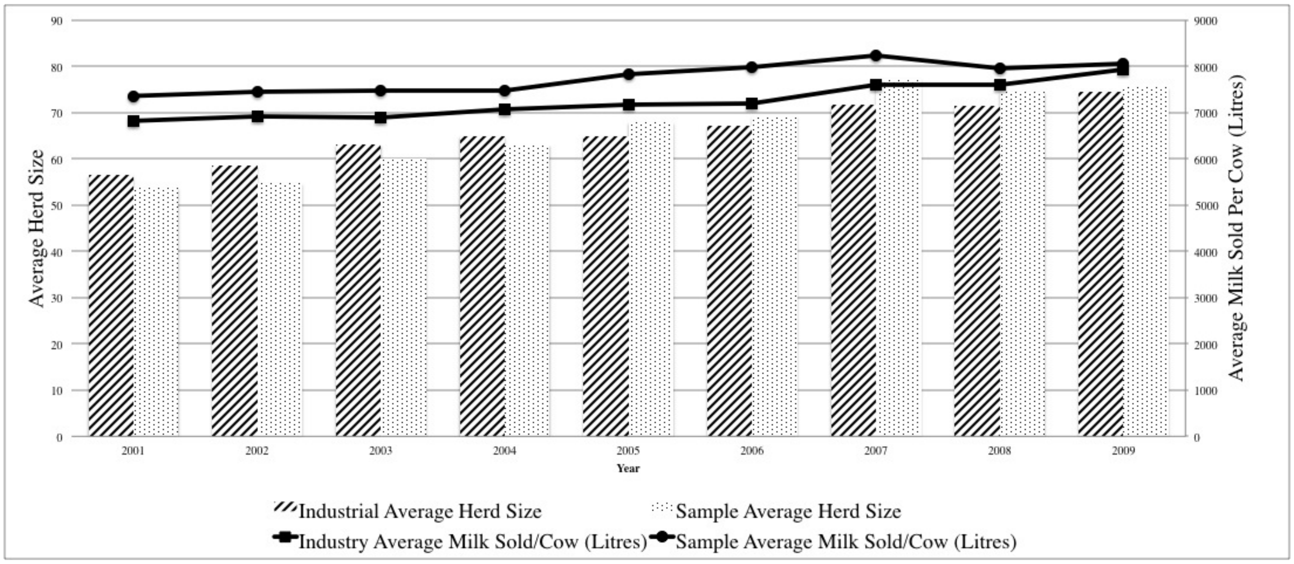

Figure 2: Comparing ODFAP Sample with Industry Level Statistics
Source: Dairy Farmers of Ontario Statistical Handbook (1989-2010)

The COP component of the data set contains over 1,500 variables broken down into three groups: 1.) personal characteristics of the primary operator such as: age, education, off-farm income; 2.) physical structure of dairy farm operation such as: milking system, dairy barn capacity ; and 3.) dairy farm operation expenses such as: veterinarian costs, protein supplements, labour, etc. The presence of this COP data set accompanying the individual bidding behaviour data set provides the setting to develop novel methodologies to empirically recover bidders' underlying WTP as well as identify important determinants to explain variations in the magnitude of bid shading across bidders.

6 Empirical Approach

This section is broken down into three parts to document bid shading. Section 6.1 utilizes a unique subset of the bidders that first participated and lost all of their bids in a uniform auction and then participated shortly thereafter in a discriminatory auction to estimate the degree of bid shading. Section 6.2 examines a different subset of bidders that participated in the COP study as well as bid in either the uniform and discriminatory action. Using this larger sub sample, a novel approach to recover bidder's underlying WTP exploits the fact that it is optimal for bidders to submit truthful bids in the uniform auction is presented. In addition section 6.2 explains heterogeneity in bid shading across bidders using observed bidder-specific characteristics from the the COP data set. Section 6.3 applies the results from Section 6.2 to the entire sample of bidders to estimate the allocative efficiency of each auction format. Table 4 provides a description of the different sub samples used in the empirical section of this approach to provide clarity to the reader.

Table 4: Breakdown of Sub Samples Used in Three Different Sections of the Empirical Approach

Section of Analysis	Characterization of Bidders in Sub Sample	Number of Bidders
6.1	Repeat Losers	115
6.2	Overlap of Uniform Auction and COP	116
6.2	Overlap of Discriminatory Auction and COP	213
6.3	Uniform Auction	1506
6.3	Discriminatory Auction	5423

Table 5: Break Down of the Repeat Loser Sample

	Number of bidders
Number of Auctions Between Observations==1	29
Number of Auctions Between Observations==2	22
Number of Auctions Between Observations==3	8
Number of Auctions Between Observations==4	6
Number of Auctions Between Observations==5	8
Number of Auctions Between Observations==6	7
Number of Auctions Between Observations==7	7
Number of Auctions Between Observations==8	5
Number of Auctions Between Observations==9	7
Number of Auctions Between Observations>=10	14
Total	115

6.1 Document Changes in Individual Bidding Behaviour Across the Uniform and Discriminatory Auctions

In this section of the empirical approach, the sample of bidders is restricted to include only the bidders that bid in both the uniform and discriminatory auction. In addition to having bid at least once in each of the auction formats, these bidders also have in common that they lost all of their bids in the uniform auction they bid in. Therefore, these bidders are " losers" in the sense that they lost all of their bids in the uniform auction, and then are "repeaters" as they participated again in the next consecutive auction which we restrict to be the discriminatory auction. By examining only "repeat losers", bidders' underlying demand curve are controlled. In other words, because this subset of bidders lost all of their bids in the first auction, each bidders' underlying demand for quota is held constant and any observable change in bidding behaviour across these two auctions can be attributed to the change in auction format from uniform to discriminatory pricing. This "repeat loser" methodology hinges on the assumption that all unobservable bidder-specific variables that likely effect bidding behaviour such as risk aversion, are held constant during the time period between these two auction formats. Table 5 provides a breakdown of the composition of "repeat losers" to show that the majority of bidders (73%) bid within six auctions of their bid loss in the uniform auction. These findings indicate that the assumption that unobservable bidder specific characteristics effecting bidding behaviour are held constant between the time the bidder bid in the uniform and discriminatory auction is valid and not too restrictive.

Table 6 reports the results of four separate paired t-tests to test whether components of bidding strategies for a given bidder depend upon whether the bidder was bidding within a uniform or discriminatory auction.[5] Results are broken down into four main findings:

Result 1: The hypothesis that total quantity demanded under the uniform auction is equal to total quantity demanded in the discriminatory auction for a a given bidder is rejected with a p-value < 0. Rather, results indicate that quantity demanded by an individual bidder is 2.027 units of quota more on average in the discriminatory auction relative to the uniform auction. This result is consistent with Tenorio (1997) whose empirical study of Zambian treasury auctions indicate the presence of strategic quantity reduction in the uniform auction such that bidders submitted bids of zero in order to influence the clearing price down.

Result 2: Interestingly, the number of bids submitted per bidder in the uniform auction is statistically smaller relative to the number of bids submitted by the same bidder in the discriminatory auction. This suggest

[5] We re-run our empirical t-test with a sub-sample of the 115 bidders and remove those bidders than have more than 10 auctions between their uniform and discriminatory auction bidding observations. Results are qualitatively consistent with those reported in Table 6 and are omitted to save space.

that bidders are submitting bid functions with more steps in the discriminatory auction.

Result 3: The null hypothesis that quantity placed on the maximum price in a bid function is equal across the uniform and discriminatory auction formats cannot be rejected at conventional levels. This suggests that bidders placed equal amounts of quantity on the first step of their bid function. Taking this results in conjunction with Result 2 suggests that although bidders in the discriminatory auction submit more than one price-quantity bid pair but that likely a very small amount of quantity demanded is placed on the latter price-quantity bid pair.

Result 4: Finally, maximum bid prices are statistically larger in the uniform auction relative to the discriminatory auction, indicating the presence of bid shading in the discriminatory auction. On average, for bidders that participated in both UA and DA, bids in the uniform auction were $1,302 higher relative to the discriminatory auction.

Table 6: Results of Paired T-Test for Repeat Losers

Variables	Format	Mean	Hypothesis	Diff	T-Statistics	P-value
Total Quantity Demanded	UA	3.703	mean(UA)≠mean(DA)	-2.027	-4.420	<.000
	DA	8.044				
Num. of Bids	UA	1.078	mean(UA)≠mean(DA)	-0.652	-5.564	<.000
	DA	1.617				
Quantity @ Max. Bid Price	UA	3.498	mean(UA)≠mean(DA)	0.205	0.69	0.48
	DA	5.341				
Max. Bid Price	UA	29567	mean(UA)≠mean(DA)	1302	7.130	<.000
	DA	27870				

Figure 3 provides an example of a representative individual bidder that lost all of their bids in October 2006 (uniform auction format) and repeated again in the December 2007 (discriminatory auction format). By controlling for changes in willingness to pay for quota with past auction outcomes, the difference in maximum bid price of **$3400** across these two auctions is attributed to the use bid shading strategies, consistent with equilibrium predictions.

6.2 Recovering Willingness to Pay in Uniform and Discriminatory Auctions

The purpose of this section is to further examine the degree of bid shading in the discriminatory auction. Using repeat losers in section 6.1, it was found that on average that bidders shaded their bids in the discriminatory auction by $1,302 below WTP. This section provides an alternative approach that makes use of a larger subset of bidders participating in the auction that also participated in the COP data set to check the robustness of the magnitude of bid shading.

To begin, bidders participating in either the uniform or discriminatory auction are matched with bidders participating in the annual COP study. In particular, the years for which producers are match in COP data set is restricted to be the most recent data points without going further than four years back from the time of bidding to ensure the COP data is still relevant at the time of bidding. Next, recall the equilibrium predictions presented in Section 3 indicating that bidders have no incentive to shade in the uniform auction and therefore the maximum bid price of a given bidder's bid schedule submitted is equal to their underlying true WTP. Alternatively, the maximum bid price of a given bidder's bid schedule submitted under the discriminatory auction is not demanded revealing, rather bids are shaded below bidders' underlying true WTP. In other words, bidder's true WTP in the uniform auction is observable via the maximum bid price submitted by a given

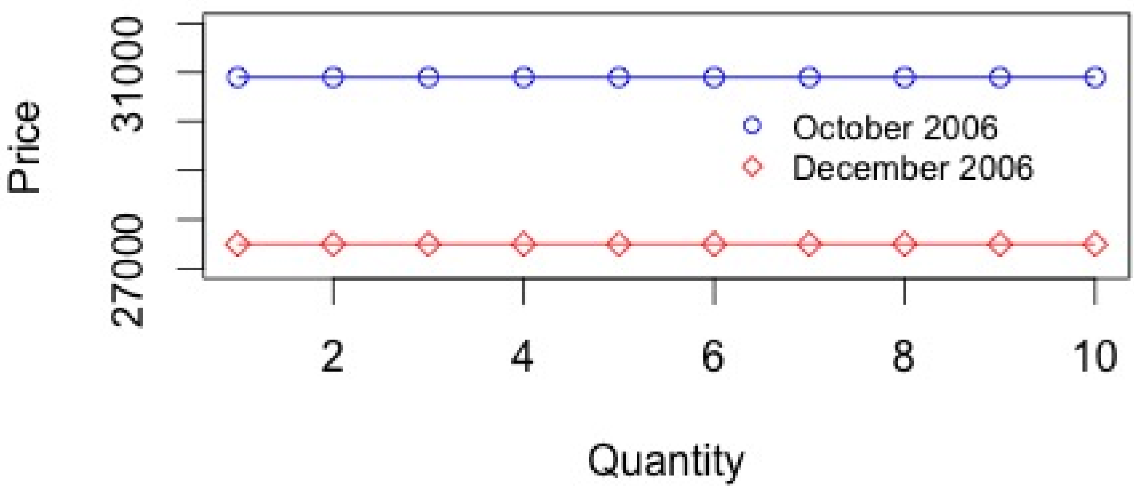

Figure 3: A representative bidder lost all bids in October 2006 (UA) and repeated again in the December 2007 (DA).

bidder, whereas bidder's true WTP is unobservable in the discriminatory auction and needs to be recovered. The approach to recover bidders' WTP in the discriminatory auction is unique as it makes use of the following stylized conditions resulting from the discussion of Ausubel et al (2014) predictions in Section 3 for bidder i in a given auction :

$$(Uniform\ Auction): \quad True\ WTP_i = Maximum\ Bid\ Price_i \tag{1}$$

$$(Discriminatory\ Auction): \quad True\ WTP_i = Maximum\ Bid\ Price_i + Bid\ Shading_i \tag{2}$$

In order to recover the latent WTP in the discriminatory auction, the magnitude of bid shading is estimated via a regression model and condition (2) is used to construct WTP. To this end, a regression model is constructed in which the maximum bid price in both the uniform and discriminatory is the dependent variable and a matrix of explanatory variables consists of various COP variables, producer specific characteristics and a dummy variable to capture the change in auction format. In particular, *Discriminatory Auction* is a dummy variable that takes on a value of one for bidding under a discriminatory auction format and zero for bids collected under the uniform auction format. Under the assumption that condition 1 and 2 hold, the coefficient on the dummy variable will capture the degree at which bids in the discriminatory auction are shaded below true WTP. Therefore, the predicted coefficient on this variable is negative with a magnitude similar to the average degree of bid shading we found in section 6.1 of $1,302. A second objective of the regression analysis is to identify observable bidder-level characteristics that explain heterogeneity in bid shading values across individual bidders.

Two regression models are presented below: the first of these models (Model 1) estimates the magnitude of bid shading whereas the second regression model (Model 2) offers a preliminary examination of factors that are likely to effect the degree of bid shading employed by a given bidder. Model 2 differs from Model 1 only in the explanatory variables included in the regression model. In particular, five observable bidder characteristics are selected that likely influence the choice of bid shading: bidder age, barn capacity, milking system, housing type and capacity utilization. Each of these five COP variable are then interacted with the dummy variable *Discriminatory Auction* in order to construct five new variables: 1.) *Producer Age∗DA*; 2.) *Barn Capacity∗DA*; 3.) *Milking System∗DA*; 4.) *Housing Type∗DA*; and 5.) *Capacity Utilization∗DA*. These five new interaction variables will capture the interaction effect of these variables on the magnitude of bid shading in the discriminatory auction. Table 7 provides summary statistics of the explanatory variables used in the regression Model 1 and Model 2.

Table 7: Explanatory variables used in the Regression Analyses

Statistic	N	Mean	St. Dev.	Min	Max
Discriminatory Format DV	329	0.647	0.479	0	1
Purchased Feed Additives	329	107,720.800	77,859.480	14,174.110	469,954.200
Wheat	329	197.566	846.797	0.000	10,645.360
Hay	329	1,835.880	3,459.942	0.000	29,762.500
Corn Silage	329	4,967.180	8,508.990	0.000	62,152.640
Total labour	329	81,846.800	32,277.700	29,433.600	176,469.300
Breeding	329	1,115.944	2,059.652	0.000	9,921.750
Veterinary	329	12,155.250	11,783.380	402.760	69,013.960
Fertilizer	329	9,234.791	9,888.283	0.000	45,162.840
Bedding	329	315,091.600	226,268.900	3,673.550	1,050,609.000
Herd Size (t-1)	329	78.416	63.838	20	284
First Year of Production	329	1,990.219	12.606	1,922	2,007
Average Milk per Cow	329	8,271.320	1,237.077	4,158.458	11,383.030
Milking System	329	3.371	0.673	1	5
Housing Type	329	1.447	0.588	1	3
Barn Capacity	329	78.021	64.787	24	275
Building Purchases	329	37,385.870	112,838.000	0.000	656,431.900
Quota Purchases (t-1)	329	129,011.800	243,611.600	−590,000.000	1,098,615.000
Quota Purchases (t-2)	329	274,637.800	395,858.200	−728,380.000	1,629,645.000
Capacity Utilization	329	0.450	0.498	0	1
Price of Milk	329	67.954	2.639	63.300	73.370
Contract Labour	329	5,762.739	8,369.238	0.000	45,990.480
Artificial Insemination	329	5,392.334	9,305.303	0.000	49,839.620
Feeding System	329	2.161	0.591	1	3
Producer Age	329	42.739	7.834	25	70
Calving Interval	329	13.501	1.326	1.000	15.100
Average Weight per Cow	329	2.924	0.417	2	4
Horsepower of Largest Tractor	329	63.553	70.242	0	280
Producer Education	329	3.131	1.246	1	5
Fat Content of Milk	329	3.912	0.140	3.465	4.376
Protein Content of Milk	329	3.303	0.099	3.069	3.584

Table 8 provides the regression results for the OLS regression models to explain variations in maximum bid prices in both the uniform and discriminatory auction with observable cost of production as well as bidder specific personal characteristics. The majority of variation in maximum bid prices has been explained as an R-squared of 0.997 is calculated for both Model 1 and Model 2.

Focusing on column 1 of Table 8 reports a negative and statistically significant coefficient of $1,813 on the dummy variable capturing the discriminatory auction format, suggesting that while controlling for all various

COP variables, bidders in the discriminatory auction submit bids that are statistically lower relative to bids submitted in the uniform auction. This indicates that bidders shade their bids on average by 6.3% of their true willingness to pay in the discriminatory auction, a result consistent with the difference in equilibrium bidding behaviour predicted by Ausubel et al (2014) and consistent with findings in Section 6.1.

Table 8

	Dependent variable:	
	Maximum Bid Price	
	(Model 1)	(Model 2)
Purchased Feed Additives	−0.004 (0.002)	−0.004 (0.003)
Wheat	0.074 (0.109)	0.109 (0.109)
Hay	0.032 (0.030)	0.036 (0.030)
Corn Silage	0.004 (0.012)	0.005 (0.012)
Total Labour	0.003 (0.004)	0.003 (0.004)
Breeding	0.088 (0.059)	0.104* (0.059)
Veterinary	0.027* (0.015)	0.025* (0.015)
Fertilizer	−0.002 (0.013)	−0.005 (0.013)
Bedding	−0.001 (0.001)	−0.001 (0.001)
Herd Size (t-1)	18.433** (8.055)	14.218** (6.827)
First Year of Production	7.450*** (2.684)	6.322** (2.623)
Average Milk Per Cow	0.020 (0.099)	0.053 (0.099)
Building Purchases	−0.004** (0.002)	−0.005** (0.002)
Quota Purchases (t-1)	0.001* (0.001)	0.001** (0.001)
Quota Purchases (t-2)	0.001 (0.0004)	0.001 (0.0005)
Price of Milk	140.214*** (44.265)	143.448*** (43.897)
Contract Labour	0.030 (0.019)	0.027 (0.019)
Insemination	−0.053** (0.023)	−0.057** (0.023)
Feeding System	10.662 (221.793)	86.320 (211.932)
Calving Interval	−95.191 (87.876)	−84.359 (83.423)
Average Weight per Cow	38.461 (292.868)	4.160 (279.565)
Horsepower of Largest Tractor	2.790 (2.008)	1.604 (2.027)
Producer Education	−296.756*** (108.787)	−262.392*** (99.960)
Fat Content of Milk	994.996 (780.733)	1,334.275* (764.351)
Protein Content of Milk	914.594 (1,099.473)	1,092.875 (1,084.410)
Producer Age	26.786** (13.436)	
Capacity Utilization	−408.977* (212.199)	
Milking System	−132.544 (290.253)	
Housing Type	235.739 (288.456)	
Barn Capacity	−11.730* (6.993)	
Discriminatory Auction	−1,813.183*** (280.850)	−539.333 (1,106.344)
Producer Age∗DA		26.025 (15.894)
Capacity Utilization∗DA		−863.878*** (318.233)
Housing Type∗DA		612.738* (333.846)
Milking System∗DA		−794.395** (361.246)
Barn Capacity∗DA		−4.923 (6.239)
Observations	329	329
R^2	0.998	0.998
Adjusted R^2	0.997	0.997
Residual Std. Error (df = 298)	1,529.049	1,514.921
F Statistic (df = 31; 298)	4,069.084***	4,145.516***
Note:		*p<0.1; **p<0.05; ***p<0.01

Next, focusing on the regression results of Model 2 reported in column 2 of Table 8 in which the dummy variable capturing the discriminatory auction is interacted with five observable bidder characteristics, three significant variables explaining variations in the degree of bid shading are identified. Interestingly, capacity utilization and type of milking system variables both have negative and statistically significant effects on the magnitude of bid shading. Capacity utilization is a dummy variable that takes on a value of one if the bidder has an underutilized milking facility (i.e., the current number of cows being milk is less than the capacity of the milking facilities) and zero otherwise. The negative coefficient suggest that bidders with underutilized milking facilities are shading their bids more so relative to bidders with capacities that are running at full capacity. Milking system is a discrete variable that takes on a value of 1 through 5 to capture the type of system used by the producer to milk cows (i.e., tie-stall, parlor style, robots, etc). The negative coefficient suggests that producers using relatively more modern milking technologies will utilize a higher degree of bid shading in their bidding strategy relative to bidders with less technology advanced milking systems. Finally, housing type is a discrete variable that takes on a value of 1 if a tie-stall is used, a value of 2 if a free-stall is used and value of 3 if loose housing is used. The positive and statistically significant coefficient on this variable suggests that producers using housing types that enable sufficient cow mobility will submit bids that are shaded less below true WTP. Further analysis will build on these preliminary findings by including additional variables to explain variations.

6.3 Efficiency Comparison

This next section provides preliminary analysis estimating the efficiency of both the uniform and discriminatory auction. In addition to providing an empirical ranking of these two auction formats, two sources of inefficiency in the discriminatory auction are identified and the proportion of inefficiency resulting from each sources are separated out. In the case of the uniform auction, only one source of inefficiency is identified.

Maximizing the efficiency of the Ontario dairy quota auction is an important objective of the DFO for a number of reasons. Mainly, given the fact that the WTP of a producer corresponds to the productive efficiency of the producer's operation, the DFO is motivated to facilitate the transfer of quota into the hands of the most efficient producers in the industry to improve the competitiveness and viability of the industry. Elskamp and Hailu (2015) found in a recent efficiency analysis that the Ontario dairy quota auction was facilitating the transfer of quota towards the most scale efficient producers on an aggregate annual level. However, what remains to be examined is whether the efficiency of the auction mechanism is achieved at the auction level and whether an empirical ranking of the uniform and discriminatory auction can be achieved to shed some light on the ongoing debate regarding the superiority of these two widely used multi-unit auctions.

An inefficient auction allocation occurs if a given bidder's WTP for a unit of quota that he/she won is less than a rival bidder's WTP for a unit of quota that was lost in the same auction. The first step to measure efficiency of each auction is to identify the underlying true WTP of each individual bidder in a given auction in order to determine whether the bidders with highest WTP were awarded the auctioned goods. As previously mentioned, for bidders participating in the uniform auction, individual WTP are directly observable from maximum bid prices. Alternatively, bidder's WTP is unobservable in the discriminatory auction as maximum bid prices do no coincide with true WTP due to the presence of bid shading. Section 6.2, outlined an empirical approach to recover WTP in the discriminatory through a regression analysis that estimated the magnitude of bid shading. Those results are utilized in this section to recover the underlying WTP of *all* bidders that participated in the discriminatory auctions covered in the data set.

To recover the unobservable WTP of individual bidders, a distribution using the estimated bid shading coefficient and standard error from Table 8 is constructed under the simplifying assumption that bid shading is

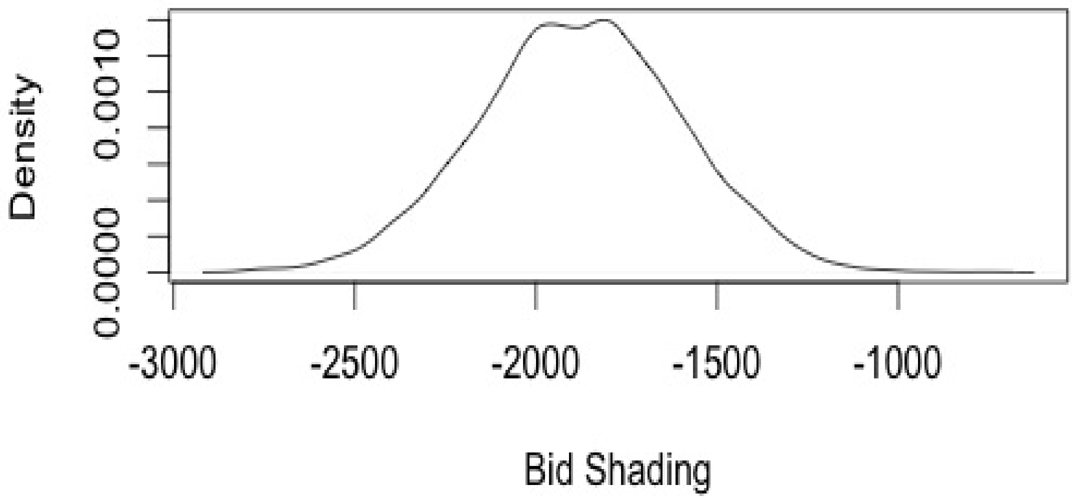

Figure 4: Density of Estimated Bid Shading in the Discriminatory Auction

normally distributed. Next random draws from this distribution illustrated in Figure 4 are simulated to obtain bid shading estimates for individual bidders. Bid shading estimates are applied to observed maximum bid prices to construct individual WTP following condition 2. In order to get a representative true WTP estimates for each individual bidder, 1000 random draws for each bidder within each auction are simulated. In order to calculate the efficiency of both the uniform and discriminatory auction, the procedure below is followed:

1. Simulate a random draw for each bidder
2. Construct WTP for each bidder following condition 2: $WTP = Bid + Bid\ \widehat{Shading}$
3. Rank all bidders within an auction in order of their WTP
4. Calculate auction efficiency
5. Repeat steps 1 through 4, 1000 times to get 1000 efficiency estimates for a given auction
6. Repeat steps 1 through 5, 25 times to get an average efficiency estimate for each auction

Column 1 in table 9 provides summary statistics of the 32 discriminatory actions that we analyze. On average, efficiency of the discriminatory action 73.9% compared to the average uniform auction efficiency of 90.6%. Sources of inefficiency in both the uniform and discriminatory auction are examined. An inefficient auction allocation may occur for two reason in the discriminatory auction. Firstly, as predicted by Ausubel et al (2014) bidders will shade their bids below their true WTP, however little is know regarding the heterogeneity of bid shading across bidders: if it exists and if it is economically significant. For example, if bid shading is constant across bidders, then efficiency is still preserved as higher bids necessarily correspond to higher WTP. Alternatively, if bid shading is heterogeneous among bidders, then higher bids may no longer correspond with higher WTP, likely introducing inefficient auction allocation. The second source of inefficiency is common to both the uniform and discriminatory auctions. Recall, table 4 outlined the number of price-quantity bid pairs bidder submitted in both the uniform and discriminatory and indicated that 87% and 66% of bidders submitted a flat bid consisting of one price-quantity bid pair that is consistent with equilibrium prediction of Ausubel et al (2014) in the uniform and discriminatory auction, respectively. The presence of bid spreading strategies in which the bidder spreads quantity demanded over more than one price point (i.e., bid spreading strategy) is likely to cause inefficient allocations for the units specified at the lower price point; as a reduction in bid price directly reduces the probability that these units are won.

Column 2 and 3 in Table 9 separate out two sources of inefficiency in the discriminatory and uniform auctions. All of the inefficiency in the uniform auction is attributed to the use of bid spreading strategies which on average cause 9.4% inefficiency. Interesting, the majority of the inefficiency in the discriminatory auction is due to the use of bid spreading strategies which makes up over two-thirds of the inefficiency. Heterogeneous bid shading makes up a substantially smaller portion of the inefficiency in the discriminatory auction, causing on average 6% of inefficiency identified in the discriminatory auction. This latter source of inefficiency in the discriminatory auction suggests that the relationship between bid shading and WTP may not be monotonic, a previously undocumented finding that is likely to have important theoretical and empirical implications for future and existing auction literature.

7 Discussion and Conclusion

This manuscript analyzes bidding behaviour in two widely used multi-unit auctions to estimate the magnitude of bid shading, explain heterogeneity in bid shading and provide relative efficiency rankings of these two multi-unit auction formats. Two approaches are employed to examine the magnitude of bid shading in the discriminatory auction. The first approach employs a unique sub sample of bidders that participated in the uniform auction, lost all their bids and then the next auction they repeated in was of a discriminatory pricing format. Thereby, controlling for bidder's underlying WTP, through this unique sub sampling technique, bids on average are shaded below WTP by $1,302 in the discriminatory auction. The second approach estimates the magnitude of bid shading using a regression analysis in which various COP variables are regressed on maximum bid prices submitted in both the uniform and discriminatory auction formats. Under the assumption that maximum bids are demand revealing in the uniform auction and while controlling for bidder-specific cost variables, the average amount a bid in the discriminatory auction is shaded by is estimated to be $1,876. Therefore, on average, bidders shade their true WTP by 6.3% in the discriminatory auction. Preliminary factors that were found to increase the amount of bid shading an individual bidder would utilize in their bidding strategy in the discriminatory action include: capacity utilization and milking system. Further analysis will provide a deeper examination into heterogeneity in bid shading across bidders.

In terms of allocative efficiency performance of the uniform and discriminatory auction formats, the uniform auction achieves a higher average efficiency relative to the discriminatory auction. Results indicate that the uniform auction is 91% efficient compared to the average discriminatory auction achieving 74% efficiency. An examination into individual bidding strategies across these two auction formats indicates that the vast majority of bidders submit a flat bid function consisting of one price-quantity bid pair, however a proportion of the inefficiency identified in both auction formats is attributed to this small minority of bidders that use bid spreading strategies (i.e., submit more than one bid pair). In the uniform auction, bid spreading is the only source of inefficiency and results in approximately 9% of inefficiency on average. In addition to bid spreading, a second identified source of inefficiency in the discriminatory auction is heterogeneous bid shading across bidders.

Table 9: Uniform and Discriminatory Auction Efficiency Summary Statistics

	Efficiency	Inefficiency From Bid Shading	Inefficiency From Bid Spreading
		Uniform Auctions	
May06	0.881	0	0.119
Jun06	0.835	0	0.165
Jul06	0.946	0	0.054
Aug06	0.877	0	0.123
Sep06	0.928	0	0.072
Oct06	0.970	0	0.030
Average	**0.906**		**0.094**
		Discriminatory Auctions	
Dec 06	0.754	0.0000	0.246
Jan 07	0.715	0.062	0.223
Feb 07	0.728	0.151	0.122
Mar 07	0.607	0.075	0.318
Apr 07	0.908	0.002	0.090
May 07	0.952	0.002	0.046
Jun 07	0.670	0.002	0.328
Jul 07	0.564	0.065	0.371
Aug 07	0.475	0.185	0.340
Sep 07	0.681	0.128	0.191
Oct 07	0.854	0.0005	0.146
Nov 07	0.930	0.001	0.069
Dec 07	0.840	0.010	0.150
Jan 08	0.679	0.161	0.160
Feb 08	0.662	0.173	0.166
Mar 08	0.799	0.071	0.130
Apr 08	0.819	0.080	0.101
May 08	0.777	0.145	0.078
Jun 08	0.801	0.042	0.157
Jul 08	0.791	0.068	0.140
Aug 08	0.877	0.010	0.114
Sep 08	0.844	0.000	0.156
Oct 08	0.759	0.020	0.220
Nov 08	0.821	0.075	0.105
Dec 08	0.763	0.065	0.172
Jan 09	0.877	0.005	0.118
Feb 09	0.833	0.009	0.158
Average	**0.739**	**0.059**	**0.165**

In other words, the varying degree of bid shading used by bidders has in some cases eliminated the link that bids correspond to higher WTP and points to a failure in a monotonic relationship between bids and true WTP. Although this latter source of inefficiency only contributes less than one third of total discriminatory inefficiency, it likely has implications for future theoretical and empirical multi-unit auction analysis.

The results of this manuscript has implications for multi-unit auction design. For example, these results shed light on to the impact of heterogeneous bid shading on the efficiency of the discriminatory auction and provides evidence to indicate the uniform auction is able to achieve higher allocative efficiency in the Ontario dairy quota auction. Further analysis will focus on additional performance ranking of these two auction formats including revenue extraction and a deeper examination into the presence of heterogeneous bid shading and the role it plays in the monotonicity of individual bid functions in the discriminatory auction.

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