Keep It Down: An Experimental Test of the Truncated *k*-Double Auction

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The introduction of a centralized institution for trading production rights in quota-regulated agricultural sectors can dramatically improve the flow of information among market participants and increase efficiency. On the other hand, prevailing conditions in these small markets can provide sellers with a market advantage, yielding high quota prices that impose important financial costs on quota holders and limit the entry of new producers into the industry. In this paper, we modify the normal allocation rule of the *k*-double auction (kDA) to counter thin market conditions and to favor buyers who bid low prices. In laboratory experiments, we test the "truncated" kDA (T-kDA) against a regular kDA for its ability to affect buyer and seller behavior and decrease equilibrium prices, and assess how it impacts efficiency. The results show that the T-kDA significantly lowers the equilibrium price and results in moderate efficiency losses. Most importantly, the T-kDA effectively counters the market power of oligopolists when demand far outstrips supply.

Key Words: *k*-double auction, experimental economics, truncated, efficiency, commodity market

This paper reports on the design and experimental test of a modification to the allocation rule of the uniform price *k*-double auction (kDA) that we call the truncated *k*-double auction (T-kDA). This rule was developed in response to a request by members of the Federation of Québec Egg Producers to develop a market-based trading mechanism that systematically put a downward pressure on the price of tradable egg production quotas.

Our objectives are to introduce the allocation rule, experimentally investigate its impact on the behavior of buyers and sellers, and study how it

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affects the market-clearing price, quantities traded, and the efficiency of the k-double auction.

In a nutshell, the T-kDA implements a two-step allocation rule. In the first step, the equilibrium quantity and the identification of which units are to be sold are determined by the usual intersection of the suppliers' offer curve and demanders' bid curve. In the second step, the allocation to buyers is determined. This is where the T-kDA differs from the regular kDA. In the kDA, the units transacted are allocated starting from the *highest* bidder, successively working *down* the bid curve until the last unit (at the equilibrium quantity) is reached. In the T-kDA, all demanders who made bids equal to or above the price asked by the seller of the equilibrium unit are eligible to receive units. In contrast to the kDA, the allocation is done starting with the *lowest* of those bids and working *up* the buyer's bid curve.

In effect, the T-kDA allocation rule is designed to provide strategic incentives for buyers to submit the lowest possible bids while remaining above or at the marginal offer price established at the intersection of the bid and offer curves. It is hypothesized that this competition among buyers will create downward pressure on buyers' bids and thus on equilibrium prices.

If effective, this rule may be particularly useful in situations characterized by oligopoly or where

there exists a substantial demand for a tightly constrained number of units offered for sale. This is precisely the type of conditions prevailing in several Canadian markets for tradable agricultural production quotas. Therefore, while this research is motivated by the design of a market mechanism for the trading of egg production permits in the province of Québec, the findings are equally applicable to milk or chicken quota systems in effect across Canada. The knowledge gained from our experiments also applies more generally to broader applications of the uniform price kDA and our understanding of this important family of auctions.

Our laboratory experiments show that, as hypothesized, the T-kDA produces equilibrium prices that are on average 25 percent lower than under the regular kDA. This outcome is primarily the result of significantly lower buyer bids.

For egg producers in Québec, the T-kDA would likely represent an important improvement over the unstructured quota market currently in place, and might also achieve the desired effect of providing improved access to young producers who do not have unfettered access to financial markets.

However, lower prices are generally accompanied by a reduction in the number of units traded and a significant increase in the misallocation of units to buyers who value them less than other excluded buyers. In our experiments, this results in an overall efficiency loss of approximately 15 percent of the available surplus. Such losses should not be disregarded since the sub-optimal allocation of production quota under the T-kDA could have significant long-term negative impacts on the competitiveness of the industry.

We present and discuss these results in the Data and Results section. Before this, we provide a brief contextual description of the Québec egg industry and its production quota market, describe the T-kDA rules of allocation, and provide a description of the experimental design and research protocol. We conclude the paper with a discussion and some final thoughts.

Context—The Québec Egg Industry

Numerous agricultural commodities are plagued by important upswings in prices, followed by periods of deeply depressed prices. In the egg production sector, the U.S. response to price vola-

tility (and processors' market power) was the development of a vertically integrated industry. In Canada a supply management regime was put in place, coupled with import restrictions. Accordingly, Canadian egg producers are required by law to hold a production permit (quota) for each laying hen they own. The quota system strictly controls the expansion of the industry and creates an oligopoly that maintains higher egg prices and reduces price volatility.

The presence of oligopoly rents confers value to the individual transferable quota required for production. In a well-functioning quota market, we would expect the price of a unit of quota to reflect the rents it generates by equating the annual rental cost (i.e., the financial cost or opportunity cost of holding permits) with the annualized economic rents from production. However, the small size of the industry and the illiquid nature of the physical infrastructure required to produce eggs (and other agricultural commodities where quotas are also required) likely make for a thin quota market, especially on the seller side. With few sellers and the demand for quota likely exceeding the supply available, it is believed that prevailing conditions in the egg industry (as well as in the milk and chicken sectors) provide sellers with a distinct advantage, yielding quota prices that are relatively high within the range of admissible equilibrium prices.

High quota prices are a concern for Québec's egg producers for two central reasons. First, large sums of money need to be capitalized into this non-productive asset (Boots, Lansink, and Peerling 1997, Alvarez, Arias, and Orea 2006). In the province of Québec, there are approximately 103 egg farms, each with an average of 36,000 laying hens. Hence, the capitalized value of the quota likely exceeds CA$800 million, or close to $8 million per farm.

Second, and perhaps more importantly, there is a perception among producers that high quota prices are detrimental to the industry's renewal. They make it difficult for young individuals to become producers, artificially favoring a concentration of the industry into the hands of a few large agri-food corporations who can more easily access financial capital. This is slowly reducing the geographical distribution of producers across the province. While these trends may be desirable from the perspective of increasing the efficiency

and long-term competitiveness of the industry, current producers and stakeholders view this issue quite differently.

Motivated by environmental and regional economic development concerns, current producers have clearly expressed that one of their objectives is to maintain a producer-owner structure over a large territory. One interpretation of the situation is that existing quota holders—i.e., those who stand to lose the most from lowering quota prices—view the continuation of the current industry structure as a public good. Furthermore, they are collectively willing to accept lower quota prices (when they eventually sell their quota) in exchange for its provision. Unfortunately, this willingness to provide a public good must inevitably confront the free-rider problem.

In Québec's egg industry, the current lack of organized institutions for quota trading likely means that this collective good is not provided. Perhaps even worse, the existing approach to quota trading might also greatly exacerbate the impact of other market imperfections. In the last decade, a small number of input suppliers have become *de facto* quota brokers. Their regular contact with a large fraction of egg producers puts them at a great advantage for identifying both potential buyers and sellers of quota among existing producers. They can also most easily identify potential new entrants who must necessarily plan their feed supply ahead of entering the industry. Feed suppliers have successfully capitalized on this informational advantage by purchasing much of the available quota and tying its resale to exclusive long-term input contracts. This situation likely results in the systematic capture of informational rents by feed suppliers. It has also made the real quota price unobservable and allowed input suppliers to select buyers as they wish. Cumulatively, it is believed that the current system leaves input suppliers with a large portion of the industry's rents and undue influence over its future.

It is within this context that the Federation of Québec Egg Producers decided to create a centralized market institution for quota trading. The Federation's wish is to implement a budget-balanced market mechanism that avoids the need for administrative allocations of quota and the risk of creating perceptions of manipulation or favoritism. The market mechanism would ideally foster efficient trading of a relatively low volume of units in a market characterized by a small number of sellers and demand that substantially outstrips supply. The Federation of Québec Egg Producers wishes to adopt a market rule that maintains downward pressure on the price as an indirect mechanism to favor the provision of its "industry structure public good."

The Auction Markets

Doyon and Rondeau (2006) explored various policies and market designs that could potentially meet the objectives of Québec's egg producers. Given that the market is expected to be populated by relatively few potential sellers at any given time, continuous trading was excluded for fear that situations would arise in which a single seller could exercise substantial market power and drive up the market price. This eliminates the continuous double auction (Smith 1962, 1964, 1965, 1976) and similar stock market trading mechanisms from the set of options. More desirable is a call market in which buyers and sellers submit bids and asks over a certain period of time (potentially weeks or even months) and until the market closes at a pre-announced time. At the market's closure, a pre-determined price and allocation rule are applied.

Many different rules have been studied theoretically or experimentally (e.g., Smith et al. 1982, Van Boening, Williams, and LaMaster 1993, Davis and Williams 1997, Cason and Friedman 1999, Denton, Rassenti, and Smith 2001, Dubey and Shubik 1980). Incentive-compatible call market mechanisms based on a two-sided multiple unit Vickrey auction (e.g., Yoon 2001) are not guaranteed to be budget balanced and thus require that the market regulator have the power (and will) to tax sales or subsidize purchases. This was not possible for the Québec egg industry.

Institutions based on an open book were also eliminated. The open book is a feature in which all bids and asks submitted prior to the closing of the market are made public. While the information from an open book might help equilibrate the market, it was rejected for the same thin market reason invoked earlier, a decision reinforced by experimental evidence showing that the open book rule leads to more strategic bidding and lower rates of efficiency (Cason and Friedman 1999, Denton, Rassenti, and Smith 2001).

One of the simplest mechanisms that could be modified to help deliver the Federation's objectives of an independent market that could keep in check the equilibrium price with a minimum loss of efficiency is called the "*k*-double auction."[1]

The *k*-double auction (sometimes referred to as the "single price double auction") is a simple uniform price call auction for a two-sided market. In this market, buyers submit sealed bids and sellers submit sealed asks that are then ordered to form the market's revealed demand and supply schedules respectively. The intersection of these schedules determines the quantity traded and the market price. If there is a difference between the asking price and the bid for the last unit traded (the prices at the intersection of the bid and ask schedules), the clearing price paid for all units traded is a weighted average (using a factor $k \in [0,1]$) of the two marginal prices. Following Friedman (1993), we implement a $k = 0.5$ auction where the clearing price for all transactions is the average of the highest asking price resulting in a transaction and of the lowest demand bid resulting in a trade.

Satterthwaite and Williams (2002) show that the kDA is both incentive-compatible (i.e., traders' incentives are to bid or ask their true reservation prices) and efficient (i.e., all potential gains from trade are realized) when the market is perfectly competitive and composed of an infinitely large number of small traders. This result relies only on the rationality of players and complete information about the distributions from which the reservation prices of buyers and sellers are drawn. Unfortunately, this is a limit result. In the absence of a very large number of players and competitive conditions, attempts at market manipulations and the exercise of market power cannot be excluded (Chatterjee and Jarrow 1998, Bower and Bunn 2001).

Satterthwaite and Williams (2002) do show, however, that the kDA is "worst-case asymptotic optimal," meaning that among all market mechanisms with rational players that can operate independently of taxes or subsidies, the uniform price

kDA converges most rapidly to full efficiency as the number of players increases. Hence, the uniform price double auction has properties that make it a desirable market mechanism for field applications. Yet, most field conditions do not provide for perfect competition, and neither incentive-compatibility nor efficiency can be predicted or expected.

In experimental studies, call markets are generally slightly less efficient than the continuous double auction in which traders can make bilateral contracts at any time during the trading period. Whereas the continuous double auction regularly achieves allocative efficiency of 95 percent or more, variants of the kDA are more likely to achieve efficiency levels in the 85 percent to 95 percent range (Friedman 1993, Cason and Friedman 1999). Yet in some cases the two mechanisms performed equally well (Davis and Williams 1997). It also appears that the gap between the two families of auctions becomes smaller with increased trader experience.

The experimental literature consistently reports how modifications to auction rules affect the behavior of market participants and equilibrium outcomes. Cason and Plott (1996) compare the rules of a market for SO_2 emission permits proposed by the U.S. Environmental Protection Agency (EPA) to a standard kDA. Under EPA rules, buyers' bids were ranked from highest to lowest, and sellers' asks from lowest to highest. The lowest ask was matched with the highest bid and the transaction price set at the bid price. Since a successful buyer paid the amount he bid (a discriminatory rather than uniform price kDA), the EPA auction rules created an incentive for buyers to misrepresent their true value. Cason and Plott found that the EPA rules significantly reduced the average price and decreased market efficiency by up to 6 percent.

It is worth pointing out that concerns over high prices in centralized auctions are not unique to Québec's agricultural sector. They are especially strong in the U.S. electricity market where a uniform price (here in single-sided supply auctions) leads consumers to pay peak prices based on high marginal producer costs, even for the electricity produced at the same time by cheap baseload suppliers (Cramton and Stoft 2007). For this situation, Vossler et al. (2009) explore whether modifying a single-sided uniform price auction can mitigate high prices. They consider the introduc-

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[1] Because allocation rules and procedures vary across papers and studies, care should be taken not to excessively generalize the meaning of these names. For instance, Cason and Friedman (1999) implement a *k*-double auction they name a "single price call market." This mechanism differs from their "uniform price double auction" only in that the second market mechanism makes use of an open book. Elsewhere, Friedman (1993) calls the call market the "clearinghouse" institution and implements three different book information treatments.

tion of a "soft cap" with a uniform pricing rule. They conclude from their experimental investigation that the soft cap is unable to lower prices.

In a study methodologically closer to ours, Doyon et al. (2008) evaluate the impact of modifying the kDA employed for the trading of dairy quota in Canada. Once again, the principal impetus for the modifications tested by Doyon et al. was to create downward pressure on prices. They test three different alternatives: (i) a tax on units offered but not sold, (ii) outright exclusion of the highest bids and offers from the bid and ask schedules, and (iii) a combination of the two rules. Experimental results show that a tax significantly reduces the number of units offered and the efficiency of the market without significantly reducing the market price. While the exclusion of highest-priced bids and asks slightly decreased the equilibrium price, it also significantly decreased the number of exchanges (and economic efficiency). The principal disadvantage of this rule is that, by construction, some tradable units are always necessarily excluded from the final allocation, making it impossible for the mechanism to achieve 100 percent efficiency. Combining the two rules did not improve results.

The truncation rule tested in this paper is an alternative price determination and quantity allocation procedure that modifies the normal rules of the uniform price kDA. While we have outlined the rule in the introduction, greater details and an example are now provided.

Under the T-kDA, both buyers and sellers are invited to submit bids and asks consisting of (i) the number of units they wish to buy or sell, and (ii) the price at which they are prepared to buy or sell. While multiple units are involved, a restriction is imposed that participants can only submit a single bid or ask (participants can freely choose the number of units but must select a single price). This restriction limits the ability of participants to directly influence the equilibrium price with a series of bids or asks each with small quantities at various prices, a possibility that could lead to extensive strategic behavior (Wilson 1979, Back and Zender 1993, Khrisna 2002).[2] Once the

bids and asks are ordered in the way of typical supply and demand curves, the intersection of the bid and ask curves determines the quantity supplied to the market. In a standard kDA, the units to be sold are those starting with the lowest asking price on the supply curve, moving sequentially up to the intersection of the bid and ask functions. This rule remains unchanged in the T-kDA.

The T-kDA modifies which buyers get to purchase those units (and at what price). Whereas a standard kDA simply allocates the units in decreasing order of bid price, the T-kDA favors bidders with low bids first. Bidders are declared eligible to purchase some of the traded units as long as their bid price is equal to or greater than the price asked by the seller of last transacted unit (the unit at the intersection of the bid and ask curves). In a reversal of normal rules, the units are then sold in priority to bidders who submitted the lowest (rather than the highest) price bids.[3]

Another way of looking at the allocation rule is that it implements a leftward shift of the bid curve whenever demanded units to the right of the supply-demand intersection have a bid price that exceeds the asking price at the equilibrium quantity.

Figure 1 illustrates the truncation rule and its potential impacts on the equilibrium allocation. The solid lines represent examples of ordered buyer bids and seller asks hypothetically submitted by market participants. Ignoring the dashed lines momentarily, the intersection of the supply and demand curves determines that 50 units will be traded. This is true whether the kDA or T-kDA rules were applied to these bid and ask curves. Under the standard kDA, all units to the left of the intersection are traded. Buyers A through D

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[2] Allowing multiple bids or asks creates low-cost incentives to attempt manipulations of the market. To see this, think of a large seller seeking to obtain the largest possible price on as many units as possible when multiple asks can be entered. One strategy might be to offer a large number of units at a relatively low price, and a series of single

unit offers each at $1 more than the previous one. Each of those higher price offers has some positive probability of being the marginal ask, and therefore of increasing the uniform clearing price of the auction. Such a strategy comes at a relatively small expected cost (higher priced single unit offers may not sell), but potentially very large benefits since the price of all units sold will then be higher.

[3] We have also implemented identical tie-breaking rules in the kDA and T-kDA. For given bid and ask schedules, these rules do not modify the equilibrium price and quantities, but determine which participant gets to sell (buy) units when two or more sellers (buyers) have submitted asks (bids) at the same price and it is not possible to meet all orders at that price. The tie-breaking rule that we apply universally to both buyers and sellers gives priority to the smallest quantity submitted. This simply increases the likelihood that at least one order in the tie will be fully traded. If the offers are identical with respect to both the price and quantity submitted, the order fulfilled first is chosen randomly.
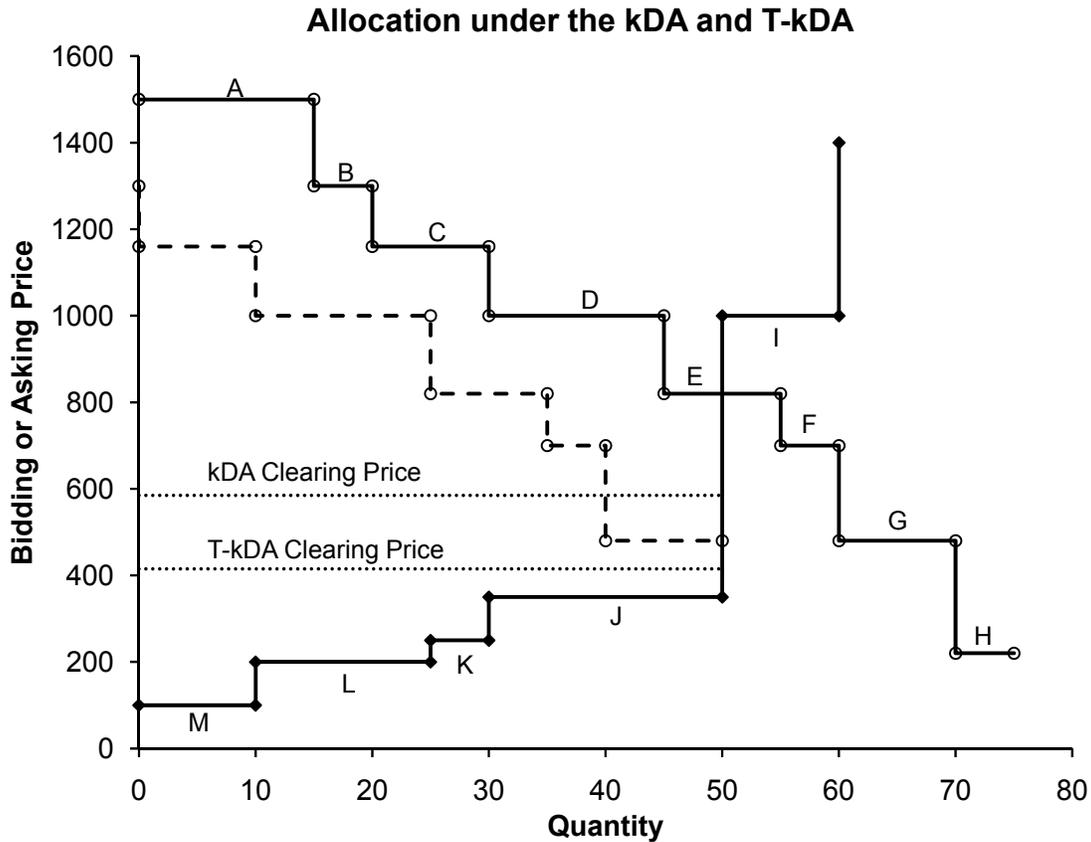
Figure 1. Truncation Rule—An Example

would see their entire orders fulfilled and buyer E would receive only a fraction of his order. The equilibrium price under the kDA would be set at the halfway point between the marginal de-manded and supplied units, yielding a transaction price of 585 Experimental Currency Units (ECU).

If the same bids and asks were submitted in the T-kDA, however, the outcome would be differ-ent. The asking price of the last unit to be sold is 350 ECU. Inspection of the bid curve reveals that all buyers from A to G inclusively made bids above 350 and are therefore qualified to purchase units. Only Buyer H is automatically excluded. The allocation to buyers is made starting with Buyer G (the lowest qualifying price) and moving sequentially to F, E, D, up to and ending with Buyer C, who, in this example, obtains his full order. Effectively, the allocation results from shifting the bid curve to the left (the downward-sloping dashed curve in Figure 1) up to the lowest

possible point of intersection that maintains a total of 50 units being traded. With k = 0.5, the uniform clearing price would be 415 ECU, half-way between the asking price and bidding price at the intersection of the supply and shifted demand schedules.

It is worth pointing out that for given bid and ask schedules, the T-kDA and standard kDA rules yield identical results whenever extra-marginal bids (units on the demand schedule to the right of the intersection) are below the asking price of the last unit sold. Thus, if the T-kDA rule did not modify the bids and asks made by market partici-pants (as we expect it should), it would either leave the equilibrium price unchanged, or it would lower it when the configuration of the bid and ask schedules triggered the shift in the revealed demand curve.

However, as with the exclusion rule tested in Doyon et al. (2008), the T-kDA rule is designed

to create strategic incentives for buyers to lower their bids by creating greater competition among them and favoring low-price bidders. While it is beyond the scope of this paper to develop a formal Bayesian game-theoretic prediction for the T-kDA, a description of the fundamental incentives, and a comparison of how those might play out in the basic and truncated auctions with thin markets, is useful.

From a particular starting point (a useful one might be one's true value for the good), consider the costs and benefits to a buyer of marginally decreasing his bidding price *ex ante*. In the normal kDA, decreasing the bidding price lowers the expected transaction price on all units since it either makes no difference to the transaction price if this trader's bid is not pivotal, or it lowers it if the bid is pivotal. Hence, there is a clear expected benefit for a buyer to decrease his bid. On the other hand, there is a cost. A buyer who lowers his bid increases the probability that he will find himself outside of the market and obtain no unit. Thus, the optimal bid must balance the positive incentives of a lower expected clearing price against the increased probability of being excluded from the market.

In contrast, consider the bidder's incentives under the truncation rule. As before, lowering one's price increases the probability that it will become the marginal price. But given that there are now more buyers who are in contention for the allocation, and that these additional buyers all have lower reservation prices than the initial group, decreasing one's bid has a smaller expected impact on the clearing price than in the regular kDA auction. From this perspective, there is therefore less of an incentive to lower one's bid than in the standard kDA. However, a lower bid no longer has the unambiguous effect of decreasing the probability of obtaining units. Those who bid highest now run a serious risk of being left out of the allocation. This comment generalizes to all players, since they do not know with certainty the actual distributions of reservation prices. Thus, while traders in the kDA need to worry only about bidding too low, those in the T-kDA may fail to obtain units if they bid either too low or too high. Thus, on this side of the equation, there is a greater incentive for bidders to lower their bid in the T-kDA than in the kDA.

Strictly speaking, whether the net effect of passing from the kDA to the T-kDA is to decrease or increase buyers' bids is therefore ambiguous. However, it is worth remembering that everything else constant, introducing the truncation rule increases the number of buyers who have a chance at obtaining units. As such, this increases the competition for the existing supply. Since the allocation rule gives priority to high price bids in the kDA and low price bids in the T-kDA, we hypothesize that the sum of incentives goes in the direction of lower buyer bids in the T-kDA.

It should be obvious that the T-kDA is not incentive-compatible regardless of the size of the market. A high-value buyer, for example, would never have a dominant strategy to bid his own value. But this is precisely the point of the truncation rule. Existing quota holders in Québec's egg industry wish to force the indirect provision of a public good through a decrease in the price of quota.

Unfortunately, the T-kDA rules could have negative effects on the efficiency of the market. Efficiency losses will occur whenever the allocation of traded units is incorrect in the sense that bidders who value the units the most are excluded from transacting while others with lower value of the units purchase them. Such risks are present in all forms of market institutions, but might be exacerbated by the T-kDA rules. High-value buyers with incentives to lower their bid might collectively demand units at prices too low and exclude themselves from the market. The overall number of units traded would then be lower than the welfare-maximizing number. By the same token, units could be allocated to bidders who value them less than others. For these reasons, we expect the T-kDA to be less efficient than the standard kDA auction. At a minimum, we hope that the T-kDA will generate greater efficiency than the tax and exclusion treatments tested by Doyon et al. (2008).

Experimental Design and Procedure

Two sets of experiments were conducted to compare the impact of the T-kDA against the standard uniform price kDA. The underlying market environments were identical across all experiments.

The market was made up of seven buyers and five sellers who kept the same role for a total of

thirty periods of play.[4] At the beginning of each period, sellers were given a number of units they could sell, and a uniform cost of producing each unit if it was successfully sold. Buyers were told that they could attempt to buy up to a specified number of units and that each unit they successfully purchased would yield a given amount of currency (i.e., a constant resale value).

Subjects could visually determine that there were twelve participants, but were not told how many were buyers or sellers. All information on quantities and reserve prices (induced values) was private and confidential.

In each period, a subject's task was to submit a bid or ask containing two pieces of information: (i) the number of units offered (seller) or sought (buyer), and (ii) the price at which he is prepared to transact (maximum willingness to pay for buyers and minimum willingness to accept for sellers). The information was aggregated and the outcome of the market computed. At the end of each period, each individual was privately given the number of units he or she transacted, the market-clearing price, and the resulting level of individual profit.

The first six periods of the experiment were unpaid practice rounds. Each of these periods implemented different vectors of market parameters (individual quantities and reserve prices), allowing participants to familiarize themselves with their task, the computer interface, and the impact of their decisions.

The experiment then proceeded with 24 paid trading periods, divided in three sets of eight. During each set, the same vector of market parameters were kept, but the quantity and induced value that a participant was given changed with each new period. This was done to prevent participants from settling into particular patterns of behavior premised on a simple repetition of previous rounds, yet it maintained the overall market structure to facilitate data analysis and comparisons over time and across treatments.

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[4] The number of buyers and sellers in our experiments was chosen primarily to reflect the egg industry's anticipated market conditions for the quota market. While the literature recognizes that as few as four traders on each side of the market can deliver what looks like competitive results, it is also noted that broad gaps between supply and demand can favor one side of the market (Smith 1962, Kagel and Roth 1995, Doyon 2001). It was most relevant for this study to create conditions favorable to the development of market power through supply and demand schedules rather than through group size.

We label the three different configurations of the market as Models A, B, and C, respectively. They are summarized by the three panels of Figure 2, and in Table 1.

The different models introduce variations in the relative position of the demand and supply functions. The models were created with stakeholders' input and were extensively pretested in the lab. Two main features strongly influenced the design as they were deemed very likely to be representative of the Québec egg quota market: (i) the number of buyers should exceed the number of sellers, and (ii) it was generally anticipated that the underlying demand for quota would exceed supply, potentially creating a large spread at the intersection of the demand and supply curves. These two conditions are favorable to sellers, who, even under an efficient equilibrium might be in a position to capture a large portion of the gains from trade by pushing the price closer to the upper boundary of the competitive equilibrium price interval [see Smith (1962) for results of this kind in the continuous double auction].

This led to the creation of Model B, with 5 buyers and 7 sellers. The large vertical distance between the demand and supply curves and the excess demand leaves a substantial amount of room for the T-kDA allocation rule to generate intense competition between all buyers and putting downward pressure on the equilibrium price. As such, Model B should provide insights into the ability of the T-kDA to contain seller power in a supply-constrained market. A failure of the T-kDA under these most favorable circumstances should raise serious doubt about the desirability of adopting such a mechanism. The addition of Models A and C was motivated by the uncertainty surrounding the extent of the spread between demand and supply. For this reason, but also to better gauge the effectiveness of the T-kDA, it was deemed necessary to test the mechanism in tighter markets as well. Model A was constructed to represent a fairly tight market, while Model C represents an intermediate case. In these market conditions, it should be more difficult for both the kDA and T-kDA to achieve high efficiency levels.

The experiments were implemented using z-tree (Fischbacher 2007) and conducted at the CIRANO laboratory for experimental economics in Montréal, Canada. Subjects were university students from all disciplines recruited via email invi-
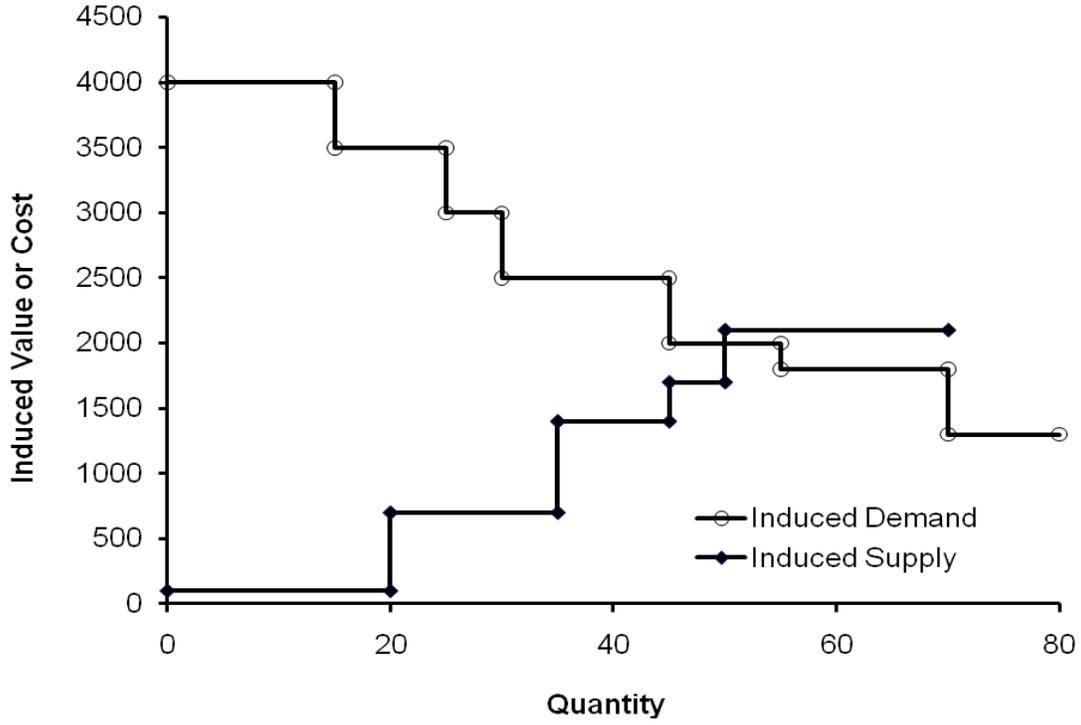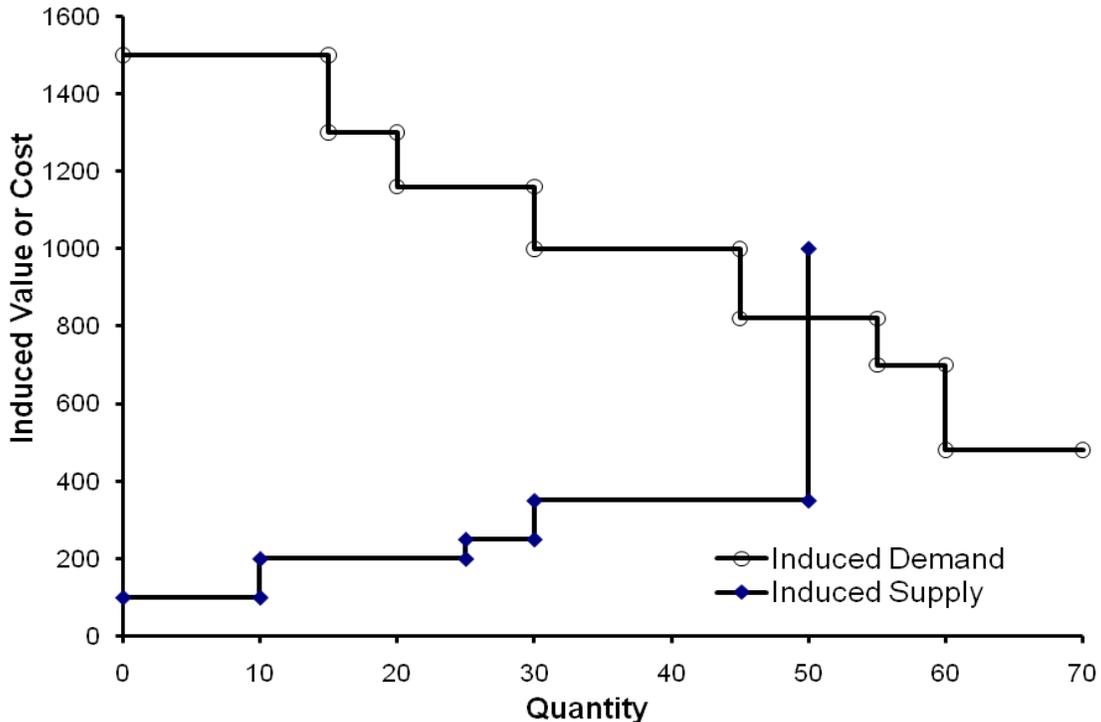
Model A
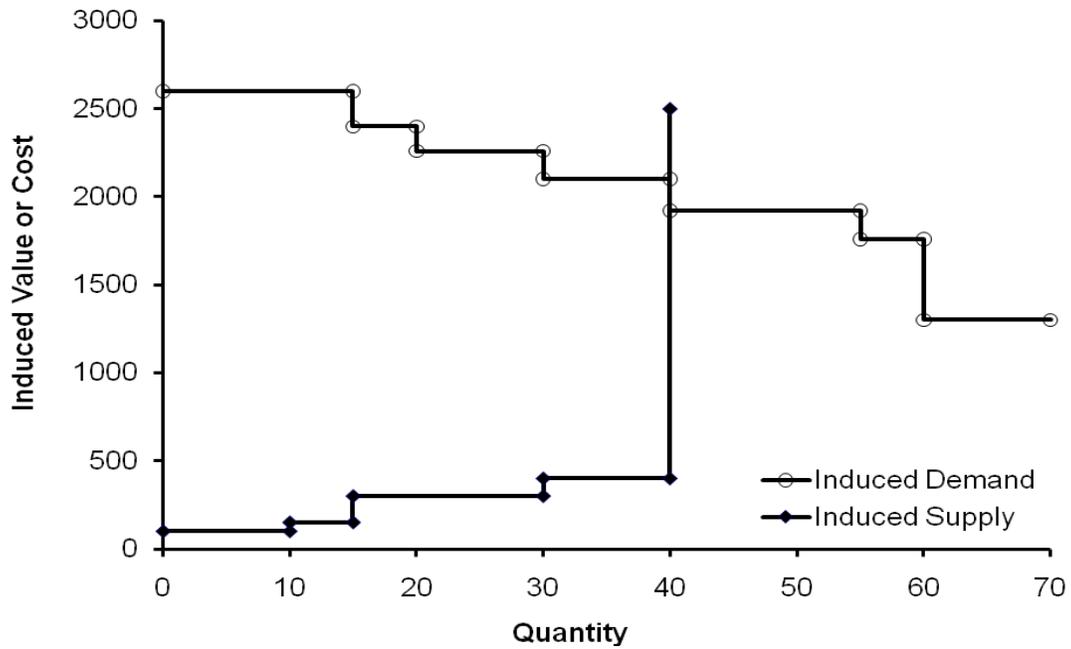
Model B

cont'd.

Figure 2. Induced Demand and Supply Models

Model C

Figure 2. Induced Demand and Supply Models (cont'd.)

tations using the laboratory's standing list of student volunteers. Though some subjects had likely participated in economic experiments in the past, none were allowed to attend more than one of our own sessions.

Individuals arrived at the laboratory and were randomly seated at a station protected by privacy screens (hence randomly assigned to their role of buyer or seller), before reading and signing consent forms. They then received oral explanations and instructions. They were given the opportunity to ask questions in private, which were relayed to the entire group and answered publicly only if they concerned general understanding and clarifications (questions of strategy or revealing private information were neither shared nor answered). Participants' experimental earnings were paid at an exchange rate of CA$15 per 100,000 experimental currency units (ECU). They earned between $18 and $50 (including a $5 show-up fee) for a session that lasted approximately 90 minutes.

Data and Results

In total, we report the data from 10 sessions of the normal uniform price kDA and 11 sessions of the T-kDA. We analyze the data from Model A for all 21 sessions. In all sessions, Model A was the first one presented to participants. A minor programming error resulted in a small allocation error in about 20 percent of the periods of Models B and C. Thus, we restrict our analysis of behavior under these market conditions to three sessions for each of the two auction modes.[5] Table 2

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[5] The programming error resulted in one of the buyers (not always the same individual) purchasing one fewer unit than the auction rules actually called for, and only on some occasions. We have separately analyzed the data from the affected sessions and find no qualitative differences in the behavior of participants. However, the slight misallocation makes efficiency calculations inaccurate. Thus, while there is no evidence to suggest that the programming error was perceived by participants (consciously or not), we simply err on the side of caution and leave all of the affected data out of this paper.

Table 1. Experimental Parameters

MODEL A

Buyers							
Value	4,000	3,500	3,000	2,500	2,000	1,800	1,300
Quantity	15	10	5	15	10	15	10
Sellers							
Value	100	700	1,400	1,700	2,100		
Quantity	20	15	10	5	20		
Competitive equilibrium	Quantity: 50	Price: [1,700, 2,000]					

MODEL B

Buyers							
Value	2,600	2,400	2,260	2,100	1,920	1,760	1,300
Quantity	15	5	10	10	15	5	10
Sellers							
Value	100	150	300	300	400		
Quantity	10	5	5	10	10		
Competitive equilibrium	Quantity: 40	Price: [400, 2,100]					

MODEL C

Buyers							
Value	1,500	1,300	1,160	1,000	820	700	480
Quantity	15	5	10	15	10	5	10
Sellers							
Value	100	200	250	350	350		
Quantity	10	15	5	10	10		
Competitive equilibrium	Quantity: 50	Price: [350, 820]					

Table 2. Number of Participants and Number of Individual Observations (decisions) by Model

	Model A	Model B	Model C	Total
Unique buyers/sellers kDA	70/50	21/15	21/15	182/130
Unique buyers/sellers T-kDA	77/55	21/15	21/15	119/85
Total unique buyers/sellers	147/105	42/30	42/30	301/215
Number of bids/asks kDA	560/400	168/120	168/120	1,456/1,040
Number of bids/asks T-kDA	616/440	168/120	168/120	952/680
Total bids/asks	1,176/840	336/240	336/240	2,408/1,720

summarizes the number of observations underlying the analysis.

The analysis proceeds first by presenting overall market outcomes before delving into how the underlying behavior of buyers and sellers is affected by the T-kDA market rule. Our approach follows first and foremost Savage's "interocular trauma test." While we report test statistics, they, for the most part, only confirm what can be readily observed graphically. The reality is that the

data does not test as being drawn from normal distributions and, in many cases, neither are the distributions symmetrical. In addition, we pool the data from each model (across periods), almost certainly violating the usual assumption that observations are independent. For these reasons, most statistical tests are, in some way, potentially biased. Yet, the high degree to which most hypotheses of equality are rejected should leave little doubt as to the existence, direction, and statistical significance of the effects observed.

As a guide to the strength of the differences, we report in the text the p-value for Mood's χ^2 test on medians. This is a simple test to determine whether observations from two samples are equally likely to be below or above the median of the two samples combined. This non-parametric test requires no assumption about the underlying distributions. When we discuss means, we offer as a rough guide the least favorable of the test-statistics derived from standard tests (t-test, Welch test, F-test, Mann-Whitney). For the reasons mentioned above, we caution the reader to assume that parametric tests are likely biased.

Transaction Prices

RESULT 1. *The uniform transaction price under the T-kDA allocation rule is significantly lower than under the kDA rule.*

Result 1 confirms the central hypothesis of the paper: the T-kDA puts a significant downward pressure on transaction prices. The summary statistics by model are presented in Table 3, while Figure 3 presents the results visually for the mean transaction price per period for both treatments. In addition to the mean transaction price for each period, Figure 3 includes three horizontal lines for each model. As benchmarks, they indicate the minimum, maximum, and mid range of the interval of prices that are consistent with efficient market-clearing.

For each of the models, the average price in the truncated auctions is lower than in the kDA by a significant margin. In model A, the decrease in price is slightly less than 10 percent, whereas for Models B and C the decrease is respectively 51 percent and 36 percent. Statistical analysis of the data confirms these casual observations. The weakest of the Mood tests comparing the medians of the two auction modes is obtained from Model A,

with a p-value $p < 0.0006$. For the means, the weakest test is also for Model A, where the probability that the means are equal is $p < 0.0003$. The variance in the equilibrium price across treatment is significantly different for Model A and for Model B, but not so ($p = 0.69$) for Model C. This, we speculate, is the result of different factors, including learning over time and the large band of theoretically admissible equilibrium prices in Model B compared to Models A and C.

It is worthwhile to discuss the results of Model B in greater detail. Model B is the economy where the gap between demand values and supply costs is greatest, and where supply is most severely constrained relative to demand. Consistent with the early findings of Smith (1962) using box-designs and a continuous double auction, the kDA data under these conditions show clearly how such market conditions favor sellers. Indeed, for Model B (and C to a lesser extent), transaction prices are significantly greater than the mid-range of the theoretical market-clearing price. Moreover, the average clearing price of Model B (1,554) is much closer to the willingness to pay of the marginal buyer (1,920) than to the reserve price of the marginal seller (400). This conveys that in this stressful environment, sellers can command a disproportionate share of the surplus. The T-kDA, on the other hand, successfully restrains sellers' ability to capture those profits. The average equilibrium price falls to 758.

Overall, these results establish the ability of the T-kDA to lower equilibrium prices, and to do so effectively when market conditions otherwise strongly favor sellers.

Number of Units Traded

The formal testable hypothesis that we explore in this section is that the number of units traded under the two market rules are equal across treatments, irrespective of the underlying economic conditions. This is a necessary condition—though not a sufficient one—for achieving allocative efficiency. Unfortunately, it is not entirely borne out by the data.

RESULT 2. *The T-kDA allocation rule results in a weakly smaller number of trades than the kDA.*

Table 4 presents the descriptive statistics for the number of units traded, aggregated for each of

Table 3. Mean Equilibrium Transaction Price (aggregated by model)

	Model A		Model B		Model C	
	kDA	T-kDA	kDA	T-kDA	kDA	T-kDA
Mean	1,831.28	1,655.16	1,554.33	757.92	721.46	460.90
Median	1,800.25	1,700.25	1,562.50	704.75	702.50	472.75
Max.	2,375.00	2,300.00	1,725.00	1,149.50	900.00	676.00
Min.	1,200.50	700.00	1,350.00	512.50	575.00	337.50
Std. Dev.	214.44	369.71	108.07	206.52	89.18	80.92
Obs.	80	88	24	24	24	24

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).
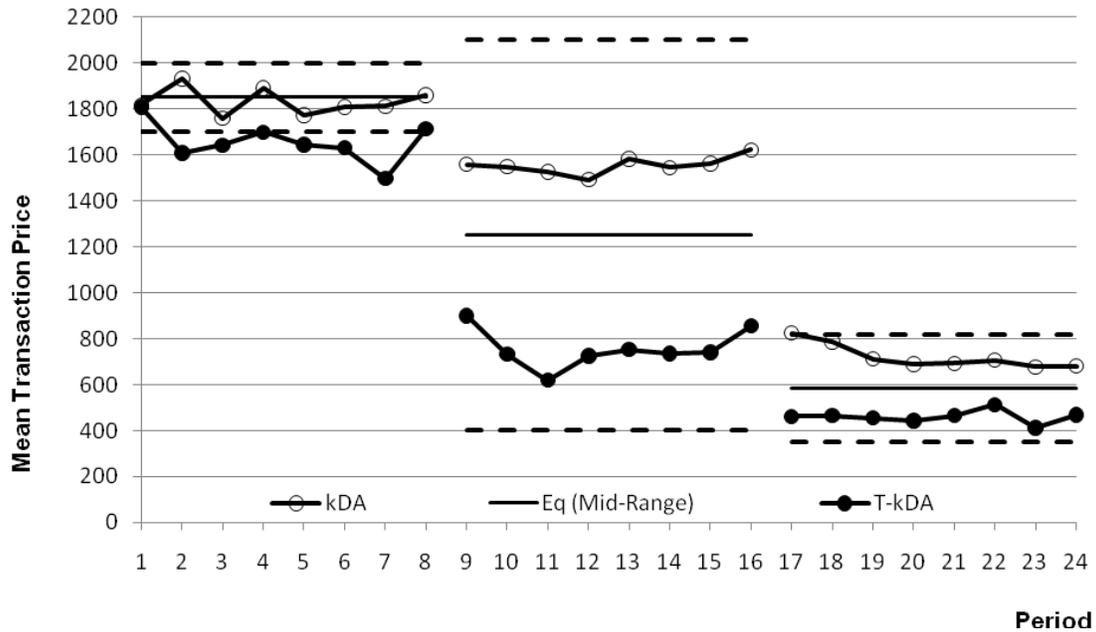

Figure 3. Mean Equilibrium Transaction Price (per period and per model)

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).

the model economies. Figure 4 shows the evolution of the mean number of trades for each period. As a benchmark, the number of units that would be traded in an efficient allocation is 50 for models A and C, and 40 for Model B.

While the actual number of trades is generally lower under the T-kDA than the kDA, the difference is not large in absolute terms and not always statistically significant. Overall, 4 percent fewer units are traded under the T-kDA. This difference

is not systematic and is statistically weak. The Mood tests on medians produce probabilities of equality $p < 0.13$, $p < 0.001$, and $p < 0.085$. Thus, the number of units traded is only significantly less in the economy of Model B. The (potentially biased) t-tests on the means yield p-values of 0.007, 0.003, and 0.079 for Models A, B, and C, respectively.

While it is encouraging to see that the difference in the number of units is small and not al-

Table 4. Mean Number of Units Traded (aggregated by model)

| | Model A | | Model B | | Model C | |
	kDA	T-kDA	kDA	T-kDA	kDA	T-kDA
Mean	43.30	41.00	39.40	37.90	45.80	42.80
Median	45.00	43.00	40.00	38.00	49.50	45.00
Max.	50.00	50.00	40.00	40.00	50.00	50.00
Min.	25.00	17.00	35.00	34.00	25.00	32.00
Std. Dev.	4.98	5.84	1.47	1.94	6.21	5.35
Obs.	80	88	24	24	24	24

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).
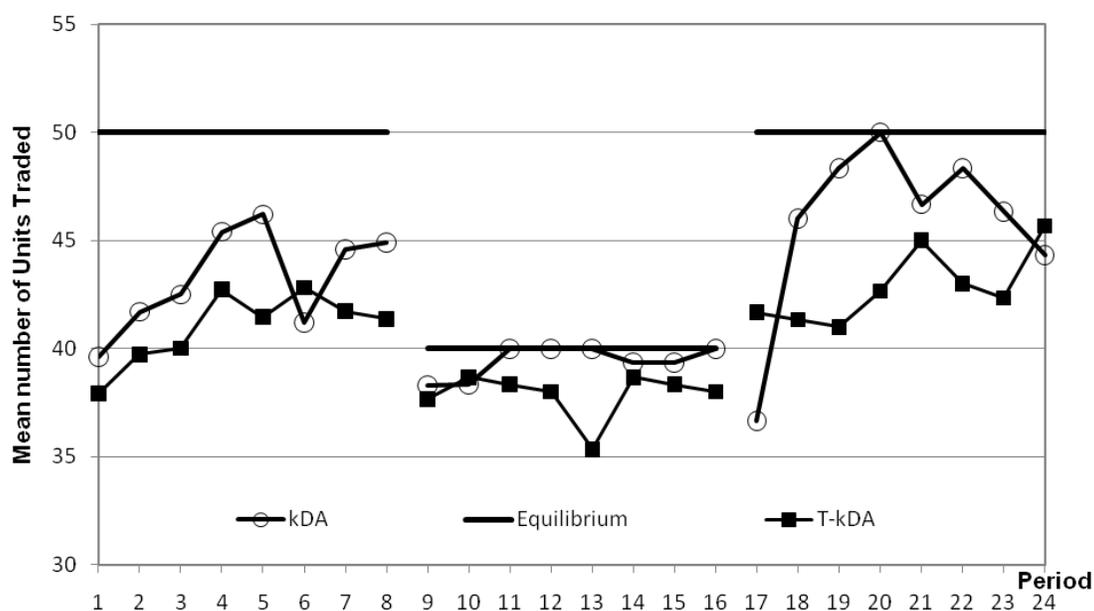
Figure 4. Mean Number of Units Traded (per period and per model)

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).

ways statistically significant, the largest p-value is 0.13, only barely outside the bounds of safe rejection of the equality hypothesis. Since the number of units traded is also almost always lower, it seems prudent to conclude that the T-kDA has a weak tendency to lower the number of trades in the market.

Note that neither the kDA nor the T-kDA is clearly successful at delivering all of the units that should ideally be traded if all the gains from trade were seized. Early in the experimental sessions (Model A), participants managed to trade fewer than 80 percent of units predicted to trade. This percentage increases over time, but a significant number of trades remain unexecuted even in the last periods. The exception is model B, where 98 percent of trades take place under the kDA and 95 percent under the T-kDA. Once again, much of this can probably be attributed to the large spread between the demand and supply functions.

The somewhat weakened ability of the T-kDA to deliver all the welfare-enhancing trades should raise concerns for the efficiency performance of the mechanism, a criterion we now turn to.

Market Efficiency

The results presented up to this point indicate that the T-kDA sufficiently alters the incentives of market participants to have a marked effect on the equilibrium (especially the price) of the traded commodity. To the extent that, collectively, lower prices are seen as a positive outcome to perpetuate the current structure of the Québec egg industry, this result can be viewed as a benefit by existing egg quota holders whose quota value would be lowered by the introduction of the T-kDA.

The potential to reduce the number of units traded, on the other hand, should be seen as a potential cost associated with this mechanism. Failing to trade units almost always implies that opportunities to reallocate quota from those who value it less to others who value it more are missed. This negative aspect of the T-kDA will have repercussions on the level of efficiency attained by the mechanism.

As is common in the experimental mechanism design literature, we measure efficiency as the proportion of the maximum possible gains from trade that are actually captured by market participants. The central result from our experiments is summarized by the following statement:

RESULT 3. *For the experimental conditions implemented in this study, the T-kDA captures significantly less of the potential gains from trade than the kDA.*

Table 5 provides a summary of the results.

If subjects in our experiments had been 100 percent efficient at capturing all of the possible gains from trade, they could have captured 12,963,200 ECUs in the kDA, and 13,943,200 ECUs in the truncated auctions (the difference is due exclusively to the different number of sessions run with the two mechanisms). In reality,

Table 5. Percentage of the Total Available Surplus Captured, Aggregated by Model

	kDA	T-kDA
Model A	88.8%	76.1%
Model B	97.1%	77.9%
Model C	93.3%	74.3%
Total	91.3%	76.1%

participants in the experiments managed to capture 90.6 percent of the possible gains from trade in the standard kDA, and 76.1 percent in the T-kDA. Thus, in our experiments, the kDA resulted in a loss of efficiency of approximately 15 percentage points. This varies somewhat across the three models of the economy. In the kDA, the efficiency varies from 89 percent to 97 percent, while it varies from 74 percent to 78 percent in the truncated auction.

Two factors contribute to the loss of efficiency. The first, already noted, is the loss associated with the sub-optimal number of units traded. Each unit that goes untraded necessarily implies a loss of efficiency. The second factor that might be particularly problematic for the T-kDA is the "misallocation" of units to extra-marginal buyers and sellers. When a unit that comes from the right side of the equilibrium crossing of the induced supply and demand curves is traded, it is misallocated in that a perfectly efficient allocation of the quota would not trade this unit. Therefore, a market mechanism that favors such exchanges runs a risk of being inefficient. The T-kDA is particularly vulnerable to this since, by construction, the allocation rule explicitly gives priority to holders of extra-marginal units (albeit in the vector of submitted bids and asks rather than induced values). This explicitly gives a chance to participants with extra marginal buyer values to displace higher-value demanders. This effect of the truncation rule can be attenuated only if high-value buyers systematically place the lowest of the admissible bids. The difficulty that arises, of course, is that with this strategic incentive to bid low comes the risk of being left out of the market entirely. Hence the hypothesis and result:

RESULT 4. *Units defined as extra-marginal based on the underlying distributions of reserve prices are more likely to be traded in the T-kDA auction and contribute significantly to lowering the efficiency of the market rule.*

In our dataset, we identified whether a unit is extra-marginal based on the induced demand and supply curves. It is then possible to identify the number and proportion of transactions that involve such units. For the regular kDA, and across all models, merely 1.05 percent of the 5,507 units exchanged in our experiments were extra-marginal on the demand side. In contrast, this pro-

portion climbs to 10.3 percent of the 5,542 units traded under the T-kDA. This tenfold increase in the transaction of extra-marginal units appears to be the principal weakness of the T-kDA. The rule provides significant opportunities for less efficient buyers to purchase units and contributes to the loss of efficiency associated with the T-kDA.

Individual Behavior

We conclude the analysis of results with a brief description of the impact of the allocation rule at the individual level. We look, in turn, at the bids of buyers and offers of sellers in an effort to understand the channels giving rise to the market outcomes we previously described.

Buyer Behavior

The central idea behind the truncation rule was to generate downward price competition among buyers. Since the equilibrium price is indeed lower under the T-kDA, it is worth verifying whether these incentives have in fact affected the price submitted by buyers.

> RESULT 5. *Buyers submit significantly lower bids under the T-kDA than under the kDA.*

We converted buyer bids to express them as a ratio of their induced value. The result is a normalized measure—ranging from 0 to 1.3 (measures above 1 must be bidding errors but there are only a small number of ratios above 1), which we present in Table 6 and Figure 5.

Table 6 clearly demonstrates a sharp and systematic difference between the bidding prices of participants across treatments. Buyers submit prices that are on average 88 percent of their true value in the kDA compared to 72 percent in the T-kDA. All means and medians from the T-kDA are substantially lower than the comparable measure in the kDA. These differences are universally highly significant in all parametric and non-parametric tests performed. In particular, the Mood test produces p values smaller than 0.0001 for all three models. With the exception of Model A, the variance of the T-kDA price is also significantly greater, making the overall distributions of prices both shifted down and much flatter under the T-kDA.

Figure 5 further illustrates the impact of the auction rule in different models. It presents the average of the bid to value ratio for each of the 24 periods. The patterns observed are consistent with the result that the T-kDA has the greatest impact when there exists excess demand (Models B and C) and when there is a wider interval of efficient equilibrium prices (Model B). Of the two conditions, it would appear that the excess demand is a more important factor since buyers continue to substantially shave their bids in Model C, where there continues to be excess demand, but where the gap in the reserve price is smaller than in Model B. These observations are necessarily speculative at this point. Greater variation in underlying parameters, and controlling for possible order effects, would seem necessary in order to parse out the importance of each component. One thing is very clear, however: buyers respond to the T-kDA by lowering their bid prices.

Seller Behavior

As we did for buyers, we employ the quotient of bid price to reserve price to explore the behavior of sellers. Here, the results are mixed. Table 7 and Figure 6 document the differences in mean markup by sellers. Statistical tests on the means indicate that the markup by sellers is significantly lower in the T-kDA only for Model B. However, Mood's median test reveals otherwise (p = 0.031). Qualitatively, it is notable that asking prices in the kDAs with Model B are the most volatile data from our experiments. This is undoubtedly attributable to the large gap between demand and supply prices at the theoretical equilibrium, and the opportunity for sellers to search for greater profits. In contrast, the T-kDA produced much less volatility in this imperfect market, a result that could be seen as an additional benefit in agricultural quota markets. The counterpart to this is Model C, in which visual inspection and tests on means do not reveal a difference, but where the median asking prices are statistically different across the two auctions.

It is notable that the T-kDA mechanism can lead sellers to lower their asking price (at least some of the time) since the only direct effect of modifying the auction's incentive is on buyers. This might reinforce the ability of the truncation rule to contain inflationary pressure.

Table 6. Average Price Submitted by Buyers as a Percentage of Their Induced Value (aggregated by model)

	Model A		Model B		Model C		All	
	kDA	T-kDA	kDA	T-kDA	kDA	T-kDA	kDA	T-kDA
Mean	85.3	76.6	92.0	66.0	93.1	64.8	88.0	72.6
Median	91.4	79.3	95.8	71.7	97.2	65.4	93.3	76.0
Max.	107.7	130.8	100.0	100.0	108.3	100.0	108.3	130.8
Min.	5.0	6.0	13.1	16.7	5.4	24.7	5.0	6.0
Std. Dev.	16.8	16.3	10.8	22.5	11.1	20.1	15.3	18.9
Obs.	560	616	168	168	168	168	896	952

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).
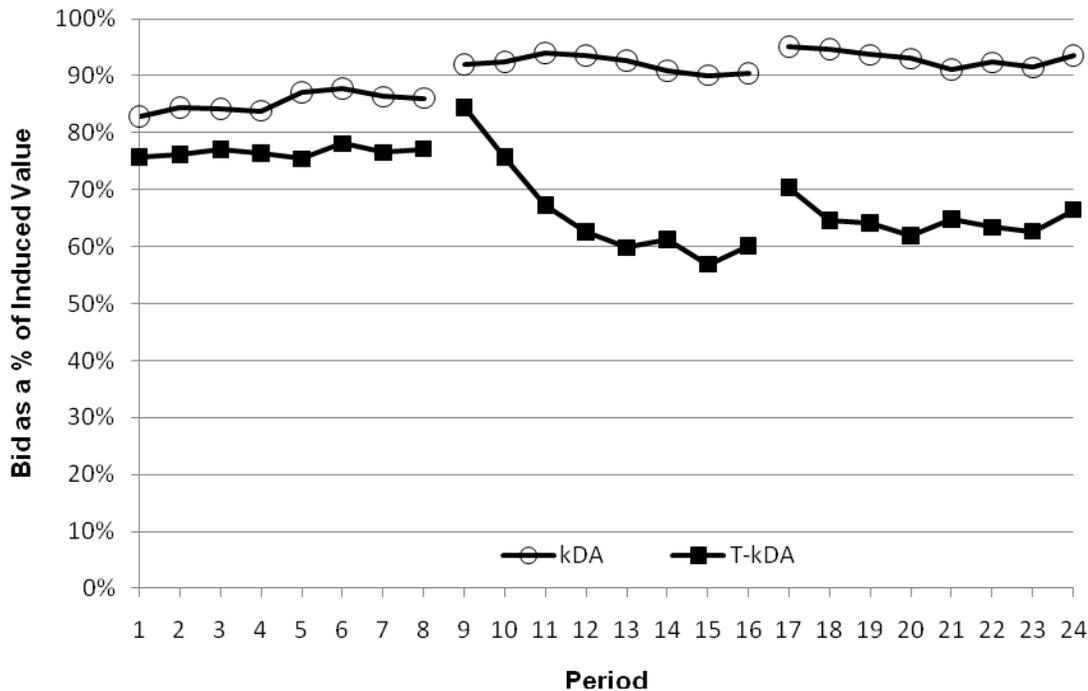

Figure 5. Average Price Submitted by Buyers as a Percentage of Their Induced Value (per period and per model)

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).

Closing Remarks

The truncated uniform price *k*-double auction has been shown to significantly reduce the market-clearing price when compared to the standard uniform kDA. The reduction is brought about by a combination of the pricing rule based on extra-marginal bids, and by significantly reducing buyers' bidding prices. It is particularly effective in extreme market conditions where sellers in a kDA normally have an advantage over buyers. The greatest effect of the truncated rule was felt under

Table 7. Average Price Submitted by Sellers as a Percentage of their Induced Cost (aggregated by models)

	kDA		T-kDA		P-value
	Mean	Median	Mean	Median	(Mood test comparing medians)
Model A	152%	106%	159%	106%	0.70
Model B	267%	106%	174%	138%	0.31
Model C	184%	107%	164%	128%	0.02

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).
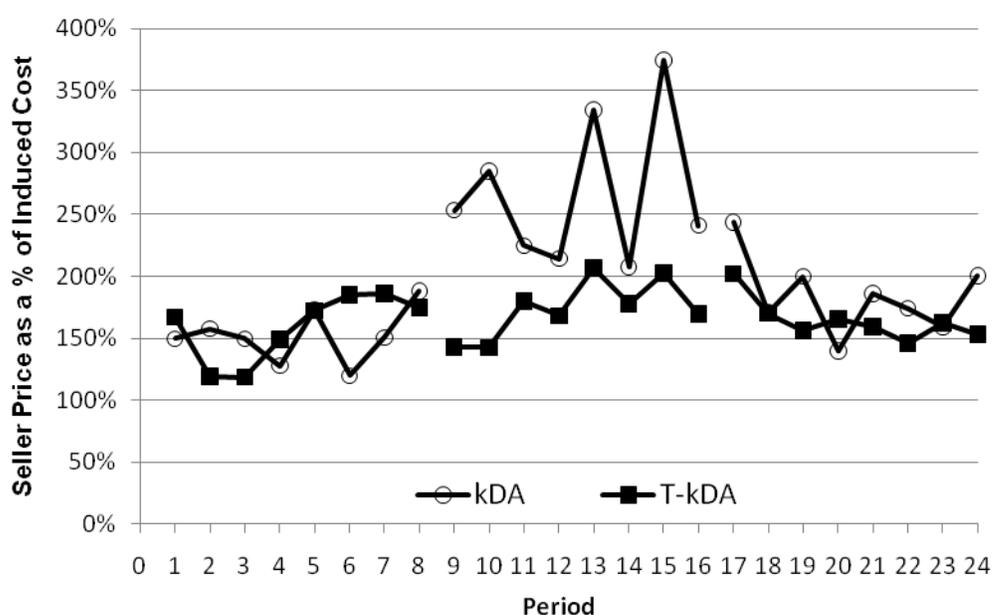
Figure 6. Average Price Submitted by Sellers as a Percentage of their Induced Cost (per period and per model)

Note: Periods 1 to 8 (Model A), periods 9 to 16 (Model B), and periods 17 to 24 (Model C).

conditions that ought to be considered the most favorable to sellers: large excess demand and wide difference between the reserve prices of the marginal buyer and seller (Model B). In these conditions, the truncated rule was able to dramatically reduce the ability of sellers to push the equilibrium price up. This is an important finding that could help devise better allocation rules in thin agricultural quota markets and in other sectors marked by excess demand and market power.

The reduction in market-clearing prices and the ability to mitigate market power among sellers come at a cost. This cost is a drop in the number of units transacted, and the sub-optimal allocation of some units to buyers who value them less than other excluded participants. These combined effects resulted in a loss of efficiency in the order of 15 percentage points in our experiment.

It might be possible to adopt other pricing rules to decrease the equilibrium price while avoiding significant efficiency losses by maintaining a normal allocation rule in which high-price buyers obtain units first. Alone, the uniform transaction price based on the lowest extra-marginal bid above the

normal crossing of demand and supply could still deliver downward pressure on the price. Similarly, a lower *k* parameter could be implemented (making the price closer to the marginal seller's ask).

Whether such measures can regularly deliver high efficiency and lower prices cannot be determined without additional experimentation since the pricing and allocation rules affect player behavior. However, two concerns deserve mention. First, a uniform price auction in which high bids obtain the first units should remain incentive-compatible. This suggests that bids would be similar to those observed in our control experiment and remove one source of downward pressure on prices. In addition, the lack of incentive to lower bids may provide enough room for sellers to increase their bids in situations like our Market B.

Since we can only speculate that providing incentives to lower bids plays a major role in our observed results, additional experimentation should be conducted in order to distinguish the role of the pricing rule from that of the order in which the units are allocated.

Our results compare advantageously with the modifications to the uniform price double auction market tested by Doyon et al. (2008). The best that Doyon et al. achieved was a 5 percent reduction in market-clearing price, with a reduction of 50 percent in the number of units traded and a 52 point reduction in efficiency. This contrasts sharply with our results in Model B, where a 51 percent reduction over the competitive market price is obtained in exchange for a reduction of roughly 4 percent in the number of units traded and an efficiency loss of 15 percentage points.

Although efficiency losses are not as important here as they were in Doyon et al. (2008), they are significant. It is difficult to measure the long-term impact of this phenomenon. One could argue that if buyers' bids are a reflection of their comparative advantage, then the efficiency loss caused by the introduction of a T-kDA would reduce the long-term competitiveness of Québec's egg production sector. From the producers' perspective, this might be acceptable. As a government-sanctioned agricultural policy, however, the merits of this approach are debatable. As Cramton and Stoft (2007) point out for the U.S. energy sector, standard (single-sided) uniform price auctions generally provide the correct incentives to participants,

and the resulting price acts as a strong signal of marginal value and costs. Moving to alternative institutions muddies this important signal and can jeopardize the long-term viability, stability, and efficiency of the industry. The T-kDA could have such effects. While a mechanism like the kDA rewards most efficient buyers, the truncation rule effectively rewards those buyers who are best able to predict the clearing price. Obviously, these need not be the same individuals, and it could follow that the resulting market prices will no longer reflect the fundamentals of the industry.

By construction, the T-kDA also has distributional consequences that favor buyers over sellers. In our experiments, sellers captured 50.3 percent of the realized gains from trade in kDAs, compared to 39.7 percent under the T-kDA. It might very well be that this kind of redistributive impact and the lower prices generated by the T-kDA are positive indicators of the ability of the T-kDA to favor small and new entrants, and to limit the geographical concentration of the industry. If so, the T-kDA might be effective at meeting the secondary objectives of Québec's egg producers.

So, while it is quite likely that the adoption of the truncated k-double auction in Québec's egg industry (or any other centralized market mechanism that evicts input suppliers from the quota trade) would represent a sizeable improvement over a system controlled by feed producers, few if any economists would enthusiastically recommend the broad adoption of such a mechanism.

Québec's egg producers have the legal power (through a democratic process) to choose and implement the quota allocation rules they wish to have. Current quota holders who stand to lose the most from the implementation of the T-kDA are in fact preparing for its deployment in Québec. Since they have received the information gathered in this research project, their decision to forge ahead with the mechanism must be taken as evidence that they are deeply committed to maintaining a low level of industry concentration despite the cost falling predominantly on them.

The actual implementation of the auction should provide exciting opportunities to analyze the behavior of actual buyers and sellers in the Québec egg quota market. Given that the egg industry (and many other such markets) is composed of a relatively small group of individuals potentially able to identify and communicate with other par-

ticipants, future research could explore the effect of manipulating group size and whether allowing more explicit means of manipulating the market or colluding with other participants might affect the auction's outcome.

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