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1. Introduction

Urban transport management has always been a high priority for Singapore, one of the most densely populated countries in the world and widely admired for its rapid industrialization and modern efficient economy. Even in the early stages of nation building, the government recognized the pressing need to meet the transportation demands of the growing economy and increasingly affluent citizens, against the constraints of scarce land space in this city-state.

Road traffic congestion was observed as early as late 1960s, and the government adopted proactive traffic management measures by the early 1970s. These include investments in public transportation and road infrastructure, and adoption of an integrated approach to transportation. In particular, draconian measures were adopted to curb automobile ownership and usage through consistently high import and road taxes, and registration fees. Despite the high costs, there were concerns by late 1980s that automobile ownership was increasing too rapidly. With rapid economic growth, increases in income were neutralizing the effects that fiscal instrument might have on automobile ownership (Phang and Chin, 1990).


Fig.1: Population, Population Density, Vehicle and Vehicle Population from 1960 to 2010. Vehicle population on right axis

In May 1990, the government implemented the Vehicle Quota System (VQS), a quantity rationing system of automobiles in Singapore: a car buyer who wishes to purchase a new car must first bid successfully for a Certificate of Entitlement (COE). The COEs are allocated through a public auction and the price that successful bidders pay is known as the COE premium.
Since the implementation of VQS, there had been many changes to the system and bidding format. After a review by a Parliamentary Committee in 1999, the bidding format was gradually changed from a sealed bid to open bid format in July 2001. It was argued that an open bid format will provide better access of information to auction bidders and result in smaller fluctuations of COE premiums and ultimately a better reflection of demand and supply. From the perspectives of policymakers, volatility in the COE premiums is seen as undesirable. Wild monthly fluctuations in COE premiums had been a constant source of frustration for car buyers and car dealers, as it created a lot of uncertainty for them. It is thus important for policy makers to understand and manage the volatility of COE premiums.

The objective of this paper is to apply auction theory to analyze the impact on COE premium volatility after the change from a sealed bid to open bid auction format, and empirically investigate if the change resulted in lower volatility of COE premiums.

The paper is structured as follows: Section two surveys the existing literature on the VQS and auction theory of multiunit uniform price auctions. Section three provides a brief overview of the VQS. Section four develops the theoretical framework to analyze the impact on volatility after the change in auction format. Section five describes the data and empirical model used in this study. Section six reports the empirical results. Lastly, section seven concludes with a discussion of theoretical analysis and empirical results.

2. Literature Review

VQS is a unique transportation management policy that has been studied by many economic researchers. A rich literature on auctions had also been developed since the 1980s. A survey of studies that are relevant to the topic can be divided broadly into two categories: First, studies related directly to the VQS. Second, studies on auction theory, especially those on simultaneous multiunit uniform price auctions.

Vehicle Quota System

Many studies on VQS have focused on effectiveness and impact on social equity. Chin and Smith (1997) looked at the economic motivations behind the implementation of VQS, specifically the market failure of vehicle ownership and usage. In addition, they did an empirical assessment of VQS and concluded that VQS is indeed effective in controlling vehicle population, though they caution that the ultimate target of policy should be to avoid the harmful externalities associated with excessive vehicle usage.

Koh and Lee (1994) applied auction theory to the VQS and discussed the optimal bidding strategies, for both transferable and non-transferable COEs. They also looked at the social equity and desirability of the uniform price format. In conclusion, they argued that COE auction should be made discriminatory, and that “a lowest successful percentage of vehicle value” pricing would be both more equitable and politically acceptable.

Koh (2003) took an industrial economics approach and studied the impact of the VQS on the market structure of car dealers in Singapore. He developed an economic model and hypothesized that VQS had
increased the concentration of the car dealership industry. He then confirmed the hypothesis with an empirical assessment analyzing the populations and new registrations of different brands of automobiles. In his conclusions, he also suggested that the switch to online open-bidding format may “facilitate coordination among car distributors, so that they may collectively bid more conservatively and prevent the occurrence of bidding wars”. This implies that there would be less volatility in quota premiums if car distributors were successful in their collusion strategy.

Chu, Koh and Tse (2004) hypothesized that car buyers use the public information available on past auctions to update their expectations on market demand. Their empirical analysis concludes that information on past bid distributions has good predictive power for the COE premiums.

Koh, Mariano and Tse (2003) tested for revenue equivalence when the VQS was changed from the sealed bid format to the open bid format. They developed a regression model to estimate what COE prices would have been under the original sealed bid format and concluded that revenue equivalence did not hold. Quota premium would be on average about US$1,000 lower under the open bidding format.

Chu (2010) conducted an empirical analysis of the impact on volatility of COE premiums since the change from sealed bid to open bid format. His study focused only on one category of COE premiums (CAT E) and concluded that the open bid format resulted in lower volatility for that category. I intend to build upon his work, by extending the empirical analysis to other categories. In addition, I will develop a separate regression model that will better estimate the volatility of COE premiums. Furthermore, I will apply auction theory to study the impact on volatility of COE premiums.

Auction Theory

Auction theory has traditionally focused on the case of single unit auctions. The literature on multiunit auctions is less developed, especially for cases where bidders demand more than a single unit each.

As detailed in Klempenerer (1999), homogenous units sold in multiunit auctions are allocated among bidders either simultaneously or sequentially. In the first case, all units are sold at the same time while in the latter case each unit is sold sequentially in repeated rounds of bidding. Under simultaneous allocation, there are two main pricing mechanisms: discriminatory and uniform price. Under discriminatory pricing, each bidder pays his own bid while under uniform price each bidder pays the same price, which is usually the lowest winning bid or highest losing bid. VQS is an example of a multiunit auction that has simultaneous allocation under a uniform price system, where bidders demand more than one unit each.

As studies on single unit auctions are more developed, the studies on multiunit auctions build upon the works on single unit auctions. The best single unit analogue of the sealed bid version of VQS is called the second-price sealed bid auction or Vickrey auction. It is named after Vickrey (1961) who designed the auction for a single object, in which bidders submit sealed bids and the highest bidder wins the object but pays the second highest bid amount. He was the first to prove the revenue equivalence theorem, which was subsequently generalized by Riley and Sameulson (1981). The theorem implies that all
standard auctions are equivalent in terms of expected revenue, assuming that bidders are risk-neutral and the objects are allocated to the bidders with the highest values. In addition, under the Vickrey auction for single units, it is a weakly dominant strategy to bid one’s true value and the auction is efficient.

One of the earliest studies on multiunit auctions is by Wilson (1979). He analyzed share auctions, where each bidder submits a bid similar to a demand schedule that states the bid for every possible quantity of the units in the auction. He showed that under uniform price auction, there are equilibrium strategies which support bid prices lower than that in the case where the units are sold individually.

Ausubel and Cramton (2002) showed that multiunit auctions differ from single unit auctions in important ways. When bidders demand more than one unit, both discriminatory and uniform price auction formats lead to inefficient outcomes and the revenue equivalence theorem fails. In particular, they showed that bidders have incentive to reduce their demands under multiunit uniform price auctions. By shading his bids, a bidder reduces the price paid on all the units won. The more units a bidder is bidding for, the greater is his incentive to shade. List and Lucking-Reiley (2000) reproduced the demand reduction results in controlled field experiments. Kagel and Levin (2001) achieved similar results in an experimental setting.

Krishna’s (2009) book on auction theory is thorough and comprehensive. He presents and discusses different types of single unit and multiunit auctions. In this paper, we will build upon his model on simultaneous multiunit uniform price auction to show the demand shading as shown by Ausubel and Cramton (2002), to analyze the volatility of the COE premiums under VQS.

3. Overview of VQS

The Vehicle Quota System (VQS) was first implemented by the Singapore government in May 1990, in response to concerns that existing fiscal tax measures to control vehicle population growth were not adequate. Since its implementation, there had been a number of modifications to the system, especially after a major review of the VQS in 1999. This section will describe the VQS and the subsequent changes.

Brief outline of VQS

Under VQS, every car buyer must first successfully bid for Certificate of Entitlements (COE), a vehicle quota license, before a vehicle can be purchased. A car buyer has 3 months after securing a COE to purchase a vehicle before it expires. Each quota license is assigned specifically to a vehicle and allows the vehicle to be driven for 10 years. At the end of 10 years, the owner may choose to either de-register the vehicle or renew the license for a further 5-year or 10-year period by paying the “Prevailing Quota License Premium” (PQP). PQP was calculated as a moving average of the 12 months quota premium. But from Nov 98 onwards, PQP is calculated as a moving 3 months average of the quota premium.

If the motor vehicle is sold before the expiry of the quota license, the quota license will be transferred to the new owner together with the vehicle. If a motor vehicle is deregistered before the expiry of the
quota license, the owner is entitled to a rebate based on the quota license premium that was paid, and pro-rated according to the remaining life span of the quota license.

VQS has been a substantial revenue source for the government. Since 1990 to 2010, it has generated an average of S$1,670mil for the government annually. This constitutes an average of about 4% of the annual government revenue from 1991 to 2010. The government invests this revenue in the transportation infrastructure and other transportation management policies.

![Annual COE Revenue (in SGD mil)](image)

Fig.2: Annual COE revenue from 1990 to 2010

**Quota Categories**

COEs are divided into separate categories. The rationale for this is to protect motorcyclists and small car buyers from being outbid by richer buyers of bigger cars (Phang, 1993). Initially, COEs were broken down into 7 categories: 4 categories of automobiles, goods vehicles/private buses, motorcycles and an “open” category that could be used for any of the other type of vehicles. The 4 different categories of automobiles varied in their engine sizes: Cat 1 – Cars 1000cc & below, Cat 2- Cars 1001-1600cc & Taxis, Cat 3 -1601-2000cc, Cat 4 – Cars above 2000cc. Following the review of VQS in 1999, the 4 categories of automobiles were collapsed into 2 from May 1999: Cat A – 1600cc and below and taxi, Cat B – above 1600cc.
Before VQS review: Aug 1990 to Apr 1999 | After VQS review: May 1999 to today
---|---
CAT 1 – Cars 1000cc & below | CAT A – Cars 1600cc and below & Taxis
CAT 2 – Cars 1001- 1600cc & Taxis | CAT B – Cars above 1600cc
CAT 3 – Cars 1601-2000cc | CAT C – Goods Vehicles & Buses
CAT 4 – Cars above 2000cc | CAT D – Motorcycles
CAT 5 – Goods Vehicles & Buses | CAT E – Open
CAT 6 – Motorcycles | |
CAT 7 – Open | |

Table 1: Changes to COE categories after the VQS review in 1999

The quota categories were merged due to their converging COE premiums and small quota size in Category 1. COE premiums for the smaller cars accounted for a larger proportion of the purchase price and attracted fewer buyers. Over the years, there had been a decrease in the number of quotas available for the smaller cars due to the calculation method for quotas available. The VQS review committee wrote in their 1999 report (Chay, 1999), “A small quota in any particular category is undesirable, as it is likely to lead to anomalies and fluctuations in COE prices, and such categories can also be manipulated more easily.”

**Transferability of COEs**

Before Oct 1991, all the categories of COEs were transferable once, i.e. the COE won can be sold to a third party. This quickly encouraged the growth of a speculative secondary market, where participants hoped to generate quick profits by reselling the COEs. The COE premiums thus showed marked fluctuations. In response, the government made COEs non-transferable from Oct 1991 onwards, to curb the speculative activity which was seen as disruptive to the market.

**Quota calculation**

The quota year begins in May, and the quota for new vehicles is determined based on the target growth rate in the car population and the number of de-registrations. The formula to calculate the quota number was tweaked twice after the inception of VQS in May 1990. The first time was after the VQS review in 1999 and the second time was more recently in 2010.

From May 1990 to Apr 2000, the formula is as follows:

\[ COE_t = Dereg_{t-1} + g \cdot VehPop_{t-1} \]

The COE quota is set as the number of vehicles de-registered the previous year plus additional COEs to allow for a g% growth in vehicle population. Vehicle population growth is fixed at 3% for May 1990 to Apr 2000. 25% of the COEs from de-registered vehicles are allocated to the Open Category, while the remaining 75% are returned to their respective vehicle quota categories. The additional g% growth in vehicle population is also distributed to the various categories according to the vehicle mix at the end of the previous calendar year in Dec. The quota number calculated for each category is then divided equally among the 12 months.
After the review in 1999, from May 2000 to Apr 2010, the formula is as follows:

$$\text{COE}_t = \text{ProjDereg}_t + g \times \text{VehPop}_{t-1} + (\text{ActDereg} - \text{ProjDereg})_{t-1}$$

ProjDereg$_t$ is the projected de-registrations for the current year. ActDereg – ProjDereg is the adjustment to correct errors in estimation of de-registration in the previous year.

This new formula will remove the 1-year lag in the recycling of COEs and should better reflect the demand arising from de-registration of vehicles. From May 2001 onwards, a mid-year quota review was introduced in November of each quota year to make adjustments to the original quota allocated for the remaining months, based on more updated numbers of deregistered cars. This was pushed forward to October in 2002 and finally to September in 2003.

From Apr 2010 onwards, the formula is as follows:

$$\text{COE}_{(Feb-Jul)}_t = \text{Dereg}_{(Jul-Dec)}_{t-1} + g \times \text{VehPop}_{t-1}$$

$$\text{COE}_{(Aug-Jan)}_t = \text{Dereg}_{(Jan-Jun)}_{t-1} + g \times \text{VehPop}_{t-1}$$

The quota year is shifted to start in February and reverts back to the original formula of not making projections of deregistration. Instead, the recycling period is shortened to 6 months. This eliminates the need to make any corrections due to any under or over estimation, and hopefully a more responsive VQS that is reflective of the vehicle de-registration patterns. It is hoped that in the future, the recycling period could be shortened further to make the system even more responsive. In addition, the growth rate of vehicle population was slowed to 1.5% for years 2009 to 2011.

**Auction bidding process**

Initially, VQS was intended as a quarterly auction, but it was changed to a monthly auction in Aug 1990 after public feedback that a long lag time would encourage speculation. From Aug 1990 to Jun 2001, VQS is a uniform price sealed bid auction, where all winners pay the lowest successful bid. Bidders are ranked according to their bid price and the winners are number of highest bidders that equal the number of quotas available. In the event of a tie at the cutoff, the bids that are tied are considered unsuccessful. Unallocated quota licenses are carried over to the next auction. The number of quotas available is public information and all bidders have access to this information before the auction.

The sealed bids are submitted through automated bank-teller machines or on forms from the Land Transport Authority of Singapore (LTA). Each bidder is allowed to submit only one bid and must place a deposit equal to half the bid amount. Each bidder will not know the number of bidders in each round of auction before its conclusion. Once a bid is submitted, it cannot be changed and bidders are encouraged to submit that maximum that they are willing to pay for their bids.

After the review of VQS in 1999, the auction format was switched to an online-open bid format but remained as a uniform price auction, where winners pay the lowest successful bid. In the open bidding
format, bidders see the current prevailing successful bid price and the number of bids submitted. In addition, auctions are conducted bi-weekly instead of monthly. Bidding is also conducted online at the website of the LTA, taking place over three days. The switch was carried out in several phases, beginning in Jun 2001 with a mix of open and closed bidding, and completely phased in from May 2002 onwards.

Another important change resulting from the VQS review is that bids can now be revised over the three days auction window. A bid cannot be withdrawn and the bid can only be revised upwards. It was hoped that with open bidding, bidders can revise their bids accordingly to new information. Bid deposits are also now fixed at $10,000 for cars and $200 for motorcycles, regardless of the bid amount.

**Role of car dealers**

Since the inception of VQS, car dealers have played a major role in the bidding process. Dealers bid on behalf of almost all car buyers, due to the convenience and attractive financial packages offered. As part of the package, car dealers will also take charge of submitting the COE bids and bid deposit.

If a car buyer goes to a car dealer, he usually chooses between a few car-with-COE packages: First, to buy a car immediately. This is usually the most expensive package where the car dealer uses one of the CAT E 'Open' COE that he is holding and immediately delivers the car to the buyer. Second, a guaranteed COE. The car dealer promises to obtain a COE and deliver the car within the next few auctions. Third, a non-guaranteed COE. The car dealer tries his best effort to get a COE within the next few auctions but does not promise that it will eventually get one and it will be cheaper than the guaranteed option. Both the second and third options might also come with a COE rebate. If the COE cost below the agreed rebate level, the buyer is refunded the difference between the actual cost of the COE and the rebate level.

A car buyer who has successfully won a COE on his own can also go to a car dealer, but it usually costs him more than if he has chosen one of the car-with-COE packages. The price packages offered by car dealers do not favor the self-bidding for COEs.

There are only a few main car dealers in the Singapore car market, which is dominated by 5 main brands: Toyota, Nissan, Mercedes Benz and Mitsubishi, and they each have their own sole distributors. Based on Koh’s (2003) study on the car market, the top 5 brands represents 64% of the total car population in 2001 and 95% of new car registrations in 2002. Since car dealers do the bidding for COEs on behalf of almost all car buyers, there is only a small number of bidders in the VQS and this has important implications for our analysis later.
Fig. 3: COE premiums by category from Aug 1990 to Apr 1999
Fig. 3: COE premiums by category from Aug 1990 to Apr 1999

Fig. 4: COE premiums by category from May 1999 to Dec 2010
4. Theoretical Argument

Wild monthly fluctuations in COE premiums have always been a problem for car buyers and dealers. The uncertainty in COE premiums makes it difficult for car buyers to choose the right time to purchase a car and adds to the business costs of car dealers, as funds have to be set aside for the auctions. To meet these concerns, VQS was gradually changed from a sealed bidding to an open bidding format. It was argued that this would result in less volatility of COE premiums and better reflect demand and supply. In this section, we apply auction theory to analyze the volatility of COE premium.

Krishna’s (2009) work on multiunit auctions will form the basis of our theoretical framework in evaluating the VQS and the volatility of COE premiums. VQS is an example of a multiunit uniform price simultaneous auction, where multiple units of the same object are sold simultaneously in each auction. We first examine the case of the sealed bid format before discussing the implications of an open bid format.

The main participants in the auctions are car dealers, who are bidding on behalf of car buyers to secure the COEs. Given their profit maximization objective and financing costs of the COE deposits, they will want to secure the COEs with the lowest bids possible. We also assume that there is declining marginal value — the value of each additional COE secured by the car dealer decreases with the number of COEs already obtained. This makes sense because each COE secured translates into a successful car sale and the car dealers will use the COEs secured for cars in decreasing profit margins. In addition, we assume that each car dealer has independent private values for the COEs.

We assume that there are N bidders (or car dealers) in each auction. Let K be the quota of COEs available in each auction. This is public information decided by a formula prior to the auction. In each auction, each bidder submits K bids $b_{i}^{1}, b_{i}^{2}, \ldots, b_{i}^{K}$, indicating his bid for each unit, such that $b_{i}^{1} \geq b_{i}^{2} \geq \cdots \geq b_{i}^{K}$. $b_{i}^{1}$ is the amount bidder $i$ is willing to bid for the first unit, $b_{i}^{2}$ is the amount bidder $i$ is willing to bid for the second unit and so on. Similarly, let $x_{i}^{1}$ be the marginal value of obtaining the $k^{th}$ object, such that $x_{i}^{1} \geq x_{i}^{2} \geq \cdots \geq x_{i}^{K}$. Then $b^{i} = (b_{i}^{1}, b_{i}^{2}, \ldots, b_{i}^{K})$ is the bid vector and $x^{i} = (x_{i}^{1}, x_{i}^{2}, \ldots, x_{i}^{K})$ is the value vector for bidder $i$.

The total number of competing bids facing bidder $i = (N\cdot K)$. By arranging the bids in decreasing order and select the first K of these, we get $c^{i}$ the K-vector of competing bids for bidder $i$. Under the VQS, the lowest winning bid is the “market-clearing” price, the price which all successful bidders pay. This is analogous to using the price of the highest losing bid, which is what we will use in the model. The number of units bidder $i$ wins is the number of K highest competing bids he defeats. Bidder $i$ wins exactly $k^{i} > 0$ units if and only if:

$$b_{k^{i}}^{i} > c_{K-k^{i}+1}^{-i} \quad \text{and} \quad b_{k^{i}+1}^{i} < c_{K-k^{i}}^{-i}$$

In other words, the lowest bid of bidder defeats the $k^{i}$ lowest competing bids and the second lowest bid of bidder $i$ is less than the $k^{i} + 1$ lowest competing bids. Then the lowest successful bid or the price that all bidders pay will be
In other words, the minimum of bidder $i$’s bid and the competing bidders’ bid.

Without explicitly solving for the equilibrium strategy, we can make some observations about it as shown by Krishna (2009).

First, bids cannot exceed marginal values, $b_k^i \leq x_k^i$. We will examine all situations and show that $b_k^i > x_k^i$ is weakly dominated by a strategy of bidding $b_k^i = x_k^i$.

If $b_k^i = \text{price} = \text{lowest winning bid}$, bidder $i$ wins exactly $k$ units. And if $b_k^i > x_k^i > c_{K-k+1}$, then bidder $i$ can reduce his bid to $x_k^i$ which will decrease the price (of the bid) and increase his profits. Alternatively, if $b_k^i > c_{K-k+1} > x_k^i$, bidder $i$ is over-paying for at least one unit and reducing his bid to $x_k^i$ will reduce his loss, as he will no longer win units at a price that exceed the marginal private value.

If $b_k^i < \text{price} = \text{lowest winning bid}$, there is no difference if bidder $i$ reduces his bid to $x_k^i$.

Second, the bid on the first unit must equal its marginal value, $b_1^i = x_1^i$. We will examine all situations and show that $b_1^i < x_1^i$ is weakly dominated by a strategy of bidding $b_1^i = x_1^i$.

If $x_1^i > b_1^i$, bidder $i$ does not win any units, and there is no difference if he increases his $b_1^i$ to $x_1^i$.

If $x_1^i > p > b_1^i$, bidder $i$ does not win any units but if he increases $b_1^i$ to $x_1^i$, he increases the chance to win a unit at a price that would be equal or less than $x_1^i$.

If $x_1^i > b_1^i > p$, bidder $i$ wins the first unit and there is no difference if he increases his $b_1^i$ to $x_1^i$.

Third, bidders have the incentive to shade their bids for $b_2^i, b_3^i, ..., b_k^i$ lower.

We start with the case of two units, where $K = 2$.

Let $x = (x_1, x_2)$ be the marginal values of bidder 1 and $b = (b_1, b_2)$ be his bid vector. All other bidders adopt a symmetric strategy of $B = (B_1, B_2)$. Let $c = (c_1, c_2)$ be the highest competing bids facing bidder 1 and have the random density given by $h(\cdot)$. Bidder 1’s expected payoff is then

$$
\pi(b, x) = \int_{c : c_1 < b_2} (x_1 + x_2 - 2b_1) h(c) dc + \int_{c : c_2 < b_1 \text{ and } c_1 > b_2} x_1 - \min(b_1, c_1) h(c) dc
$$
In other words, the first term represents the payoff when he wins both units and the second term represents the payoff when he wins one unit.

Let $H_1$ denote the distribution of the higher competing bed $C_1$ and $H_2$ the distribution of the lower competing bid $C_2$ with densities $h_1$ and $h_2$ respectively. Then,

$$H_1(b_2) = \text{Prob}[C_1 < b_2] = \text{bidder wins two units}$$

$$H_2(b_1) = \text{Prob}[C_2 < b_1] = \text{bidder wins at least one unit}$$

This simplifies the expected payoff to:

$$\pi(b, x) = H_1(b_2)(x_1 + x_2) - 2 \int_0^{b_2} c_1 h_1(c_1) dc_1 + [H_2(b_1) - H_1(b_2)] x_1 - [H_2(b_2) - H_1(b_2)] b_2 - b_2 b_1 c_2 h_2 c_2 dc_2$$

Differentiating with reference to $b_2$:

$$\frac{\delta \pi}{\delta b_2} = h_1(b_2)(x_2 - b_2) - [H_2(b_2) - H_1(b_2)]$$

And at $b_2 = x_2$:

$$\frac{\delta \pi}{\delta b_2} \bigg|_{b_2 = x_2} = -[H_2(b_2) - H_1(b_2)] < 0 , \text{since } H_1 \text{ stochastically dominates } H_2$$

Therefore, in equilibrium the bidder should bid $b_2 < x_2$. The shading of bids downwards after the first unit is because every bid other than the first unit determines the price paid on all the units he wins, and this argument extends for $K > 2$ as well. More specifically, increasing $b_2$ raises the probability of winning the second unit represented by $h_1(b_2)$. But it also reduces the gain from the second unit represented by $(x_2 - b_2)$. Furthermore, increasing $b_2$ also increases the expected payment on the first unit. Ausubel and Cramton (2002) provide a more detailed discussion on the bid shading strategy.

Even though we did not explicitly solve for the equilibrium strategy, the shading of bids is illuminating. Relating back to the VQS, the shading of bids will lead to increased volatility and fluctuations in the COE premiums. As $K$ increases or if bidder $i$ is in need of more units, it is easy to see that he is more likely to shade the bids downwards for the latter units with smaller marginal value. The latter units are not worth as much to him, while he stands to profit from a lower price for the units he had put it a higher bid for. There is only a small number of car dealers representing car buyers in the Singapore car market. As the demand for car fluctuates, the number and proportion of bids submitted by the small number of bidders is constantly changing; the uncertainty in the bid shading strategies of each bidder will lead to greater fluctuations in the COE premiums that is not directly related to supply and demand changes.

We now consider the case of open bids. There are two main differences between the open bidding format. First, bidders can now observe the market clearing price in real time. Second, bidders can revise their bids upwards according to the new information. Unfortunately, current auction literature is limited
on an open bid format like the VQS, and it is not clear what the bidding strategy or the extent of demand shading would be.

Under both the sealed bid and open bid auction formats, it is not easy to solve directly for the equilibrium strategy. However, we have shown that demand shading occurs in the sealed bid system, which affects the COE volatility. In short, current auction literature is inconclusive on the impact on volatility due to the auction format change.

5. Data and Empirical Model

Data

The Land Transport Authority of Singapore (LTA) maintains and publishes two decades worth of VQS auction data from Aug 1990 to Dec 2010 on its website. There is a total of 361 auctions that took place during this period, resulting in the allocation of 1,775,120 COEs. Of these, 141 were sealed bids and 220 were open bids. The information available on each auction includes: the winning COE premium, the number of bids submitted, the quota of COEs available, the number of successful bids and the prevailing quota premium.

The data can be divided into 3 main periods: the sealed bid format, the learning period and the open bid format. The sealed bid format lasted from Aug 1990 to Jun 2001. The learning period for the transition to open bidding, where a mixed of sealed and open bidding were carried out, lasted from Jul 2001 to Apr 2002. The open bid format began in May 2002 and lasted till today.

The study period in this paper starts from Oct 1991 and ends in Dec 2010. Oct 1991 is chosen as the start date because COEs are made non-transferable since then. This removes the initial wild fluctuations in the premiums resulting from the transferability of COEs. The learning period from Jul 2001 to Apr 2002 is also removed, as it is assumed participants are still adjusting to the new auction format and the fluctuations will not be meaningful.

We focus our study only on the COE for cars: CAT A, CAT B and CAT E. We study Cat E even though it can be used for any vehicle type, because almost all of it is used for private cars under Cat A and B. As noted in earlier sections, Cat 1 and 2 were merged in May 1999 to form Cat A while Cat 3 and 4 were merged to form Cat B, and Cat 7 was renamed Cat E. For purposes of data continuity, we calculated for the period Oct 1991 to April 1999 an index of the COE premiums for Cat 1 and 2, weighted by the number of quota licenses in each category. A similar index is constructed for Cat 3 and 4 over the same period. We use the same data for Cat 7 and Cat E because they are essentially the same.

Furthermore, we remove 2 data points from Cat A that consisted of extraordinary auction results. In Jun 01, COE premium for Cat A fell from $32,100 to $101. This happened because there were almost an equal number of bids to quota available and a lucky bidder succeeded to win a bid at $101. A similar result happened in Nov 08, where the COE premium for Cat A fell from $10,455 to $2. These are very rare events and we consider these as outlier data points and remove them from the study.
This yields 116 sealed bid auctions and 209 open bid auctions for a total of 325 auctions for category A, and 117 sealed bid auctions and 210 open bid auctions for a total of 327 auctions for categories B and E each.

**Empirical Model**

Regression models are used to study the change in volatility of COE premiums after the switch from a sealed bid to an open bid format. We use both an ordinary-least-squares (OLS) model and a fixed effects (FE) model, which controls for the unobserved fixed effects in each COE category. The framework of our empirical approach to study COE volatility is as follows:

For OLS, we setup a regression model with the COE premiums as the independent variable and relevant demand factors as dependent variables. We then run separate regressions for each category of COE, under both the sealed bid and open bid format. *Our measure of COE volatility is the standard deviations of the residuals, or the deviation of the data points from the predicted values.*

The regression models used are built upon the experiences of previous empirical studies on COE premiums. Past studies have included different economic variables to proxy demand for COEs, with varying successes. Hon and Yong (2004) used the Straits Times stock index in their model of pricing COE and concluded that it is not a significant variable. Similarly, Phang etc. (1996) used the stock index in their model to analyze policy effects and concluded that it is significant for only two out of five categories of COEs tested. Koh etc. (2007) tested for revenue equivalence between sealed bid and open bid format and used the following macroeconomic variables: interest rate differential of the 3-month bank commercial paper over the 3-month Treasury bill, interest rate differential of the 5-year government bond over 3-month Treasury bill, non-oil exports and industrial production. Only the first variable was significant in 2 car categories.

Another approach by Chu etc. (2004) in their study of COE pricing, is to proxy demand by using the “supply and demand” ratio, or the number of bids divided by quota available, and they find it to be statistically significant. Chu (2007) also found the same variable to be statistically significant in a study to look at the change in volatility of COE premiums after the switch from sealed bid to open bid format.

The models developed in this paper combine the approaches of using economic variables and the “supply and demand” ratio to proxy demand. In particular, we used economic variables that we believe directly affects the demand for cars and COE.

\( \text{COE}_{it} \) is the dependant variable in the regression and is the resulting COE premium from each auction. Subscript \( i \) denotes the COE category and subscript \( t \) denotes the time of auction.

\( \text{COE}_{it-1} \) is the lagged variable of \( \text{COE}_{it} \) and is the resulting COE premium from each the previous auction. We expect a positive relationship due to price momentum and bidders updating their expectations based on most recent market conditions. In Chu’s (2002) study of bid distribution in VQS almost 86% of all bids were between \( \pm 40\% \) of previous month COE premium.
Bidratio\textsubscript{t,i} is the number of bids submitted divided by the number of CAT i COEs available for the auction in period t. We expect a positive relationship, i.e. for COE premium to increase as the number of bidders relative to quota available increases.

Quota\textsubscript{t,i} is the number of CAT i COEs available for the auction in period t. We expect a negative relationship, i.e. for COE premium to decrease as the number of quota increases.

Intrate\textsubscript{t} is the average interest rate for 3-year car loan for new car purchases from the major financial institutions in Singapore in period t. The data is obtained from the Singapore Department of Statistics. We expect a negative relationship as an increase in car loan interest rates adds to the financing cost of the new car and reduces demand.

For FE, we use a panel data by combining the data for CAT A, B and E into one dataset and run separate regressions for sealed bid and open bid format. This will control for the unobserved fixed effects in each category. Because Intrate\textsubscript{t} is common to all categories, we carry out the estimation in two steps: First, to account for the fixed effects we run a ‘dummy variable regression’, that is to have a dummy variable for each category and each time period (or auction). Second, we regress the coefficients associated with each time dummy variables with the Intrate\textsubscript{t}, to control for its effects. Our measure of COE volatility is the standard deviations of the residuals of the second regression.

The regression models used in the study are as follows:

**OLS:**

\[ COE_{i,t} = \beta_0 + \beta_1 COE_{i,t-1} + \beta_2 Bidratio_{i,t} + \beta_3 Quota_{i,t} + \beta_4 Intrate_{t} + \varepsilon_t \]

**FE:**

\[ COE_{i,t} = \beta_1 COE_{i,t-1} + \beta_2 Bidratio_{i,t} + \beta_3 Quota_{i,t} + \beta_4 \alpha_A + \beta_5 \alpha_B + \beta_6 \alpha_E + \beta_t t + \varepsilon_t \]

\[ \hat{\beta_t} = b_0 + \beta_1 Intrate_{t} + \varepsilon_t \]
### 6. Regression Results

#### OLS Regression Model

**Dependent variable:** $\text{COE}_{i,t}$

<table>
<thead>
<tr>
<th>Variable</th>
<th>CAT A - Sealed</th>
<th>CAT A - Open</th>
<th>CAT B - Sealed</th>
<th>CAT B - Open</th>
<th>CAT E - Sealed</th>
<th>CAT E - Open</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\text{COE}_{i,t-1}$</td>
<td>0.8944497***</td>
<td>0.8614331***</td>
<td>0.8682844***</td>
<td>0.88782***</td>
<td>0.8928751***</td>
<td>0.9804145***</td>
</tr>
<tr>
<td></td>
<td>(28.46)</td>
<td>(36.97)</td>
<td>(20.00)</td>
<td>(36.41)</td>
<td>(23.54)</td>
<td>(54.62)</td>
</tr>
<tr>
<td>$\text{Bidratio}_{i,t}$</td>
<td>2636.63***</td>
<td>5151.37***</td>
<td>3195.855***</td>
<td>8913.448***</td>
<td>2304.805***</td>
<td>5947.326***</td>
</tr>
<tr>
<td></td>
<td>(5.17)</td>
<td>(9.21)</td>
<td>(5.11)</td>
<td>(10.58)</td>
<td>(2.57)</td>
<td>(7.61)</td>
</tr>
<tr>
<td>$\text{Quota}_{i,t}$</td>
<td>-1.09523</td>
<td>-1.270547***</td>
<td>-13.01728***</td>
<td>-1.429266</td>
<td>-3.728455***</td>
<td>0.39262</td>
</tr>
<tr>
<td></td>
<td>(-1.26)</td>
<td>(-4.37)</td>
<td>(-3.56)</td>
<td>(-1.57)</td>
<td>(-2.04)</td>
<td>(0.59)</td>
</tr>
<tr>
<td>$\text{Intrate}_t$</td>
<td>-1335.284***</td>
<td>-875.3168***</td>
<td>-3552.437***</td>
<td>-1049.145***</td>
<td>-1820.59***</td>
<td>-1140.729***</td>
</tr>
<tr>
<td></td>
<td>(-4.63)</td>
<td>(-2.18)</td>
<td>(-4.68)</td>
<td>(-3.35)</td>
<td>(-3.20)</td>
<td>(-3.74)</td>
</tr>
<tr>
<td>Constant</td>
<td>9401.626***</td>
<td>2573.817</td>
<td>28103.03***</td>
<td>-2810.497</td>
<td>14929.31***</td>
<td>-3364.854</td>
</tr>
<tr>
<td></td>
<td>(2.41)</td>
<td>(1.24)</td>
<td>(4.17)</td>
<td>(-1.12)</td>
<td>(2.44)</td>
<td>(-1.55)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Obs.</th>
<th>116</th>
<th>209</th>
<th>117</th>
<th>210</th>
<th>117</th>
<th>210</th>
</tr>
</thead>
<tbody>
<tr>
<td>$R^2$</td>
<td>0.9152</td>
<td>0.9524</td>
<td>0.8165</td>
<td>0.9611</td>
<td>0.8798</td>
<td>0.9671</td>
</tr>
<tr>
<td>Adj. $R^2$</td>
<td>0.9122</td>
<td>0.9515</td>
<td>0.8100</td>
<td>0.9604</td>
<td>0.8755</td>
<td>0.9665</td>
</tr>
<tr>
<td>F-stat</td>
<td>299.55</td>
<td>1020.34</td>
<td>124.61</td>
<td>1267.65</td>
<td>204.96</td>
<td>1507.95</td>
</tr>
<tr>
<td>Prob(F-stat)</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
</tr>
<tr>
<td><strong>Std. deviation of residuals</strong></td>
<td><strong>3173.262</strong></td>
<td><strong>1922.215</strong></td>
<td><strong>7976.257</strong></td>
<td><strong>2146.951</strong></td>
<td><strong>6533.168</strong></td>
<td><strong>1994.243</strong></td>
</tr>
</tbody>
</table>

T-statistics are reported in parentheses.

*, **, *** indicates significance at the 90%, 95%, and 99% level, respectively.
## FE Regression Model

<table>
<thead>
<tr>
<th>Variable</th>
<th>Seal bidding</th>
<th></th>
<th></th>
<th>Open bidding</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dependent variable: COE\textsubscript{t}</td>
<td>Dependent variable: ( \hat{\beta} )</td>
<td>Dependent variable: COE\textsubscript{t}</td>
<td>Dependent variable: ( \hat{\beta} )</td>
<td></td>
</tr>
<tr>
<td>COE\textsubscript{t+1}</td>
<td>0.7275231***</td>
<td>Not used</td>
<td>0.8477898***</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(15.69)</td>
<td></td>
<td>(24.77)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bidratio\textsubscript{t}</td>
<td>2760.939***</td>
<td>Not used</td>
<td>2094.871***</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(5.17)</td>
<td></td>
<td>(5.33)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Quota\textsubscript{t}</td>
<td>-2.775325</td>
<td>Not used</td>
<td>0.8468419***</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-1.42)</td>
<td></td>
<td>(2.85)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time Dummies</td>
<td>117 dummy variables, 1 dropped</td>
<td>Not used</td>
<td>210 dummy variables, 1 dropped</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>Category Dummies</td>
<td>3 dummy variables</td>
<td>Not used</td>
<td>3 dummy variables</td>
<td>Not used</td>
<td></td>
</tr>
<tr>
<td>Intrate\textsubscript{t}</td>
<td>Not used</td>
<td>-2540.465***</td>
<td>Not used</td>
<td>-1741.748***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(-6.14)</td>
<td></td>
<td>(-5.57)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Constant</td>
<td>Not used</td>
<td>24228.75***</td>
<td>Not used</td>
<td>8740.494***</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(8.38)</td>
<td></td>
<td>(5.60)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Obs.</td>
<td>350</td>
<td>116</td>
<td>629</td>
<td>209</td>
<td></td>
</tr>
<tr>
<td>( R^2 )</td>
<td>0.9920</td>
<td>0.2486</td>
<td>0.998</td>
<td>0.1305</td>
<td></td>
</tr>
<tr>
<td>Adj. ( R^2 )</td>
<td>0.9877</td>
<td>0.2421</td>
<td>0.997</td>
<td>0.1263</td>
<td></td>
</tr>
<tr>
<td>F-stat</td>
<td>231.58</td>
<td>37.73</td>
<td>980.90</td>
<td>31.08</td>
<td></td>
</tr>
<tr>
<td>Prob(F-stat)</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td>0.0000</td>
<td></td>
</tr>
<tr>
<td>Std. deviation of residuals</td>
<td>5915.382</td>
<td></td>
<td>2527.487</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* T-statistics are reported in parentheses.
** * indicates significance at the 90%, 95%, and 99% level, respectively
7. Discussion and Conclusions

Based on the econometric results, most of the explanatory variables are statically significant for the three COE categories. In particular, the coefficients for \( \text{Bidratio}_{i,t} \) are positive, while the coefficients for \( \text{Quota}_{i,t} \) and \( \text{Intra}_{t} \) are negative as predicted. In addition, we also achieved a high R\(^2\) of about 80-95%

Interestingly, the coefficients for \( \text{Bidratio} \) are consistently bigger in open bidding compared to the sealed bidding. This suggests that \( \text{Bidratio} \) became a more important factor in determining COE premiums under the open bidding system.

Based on our econometric analysis, the results show a decline in volatility since the implementation of the open bidding auction format. The result is consistent in all COE categories and in both regression models: Based on the OLS model, there is a 39.42% drop in volatility in CAT A, 73.08% drop in volatility in CAT B and 69.48% drop in volatility in CAT E. Similarly, based on the FE model, there is a 57.27% drop in volatility based on the aggregate panel data. For a graphical representation of the results, figures showing the distribution of the residuals and the fitted lines can be found in the appendix.

Although the current auction literature is limited in explaining the decline in volatility after the change in bidding format, there are a few possible explanations:

An open bidding format allows car dealers to monitor the bids in real time and may facilitate coordination or collusion among them. This was suggested by Koh (2003) in the conclusion of his industrial economics study of the VQS and car dealers in Singapore. As cheating is easier to detect, it makes a collusive strategy among car dealers more feasible. They may collude to bid lower for the COE premiums and reduce the volatility in COE premiums if a collusion strategy is successfully coordinated. Collusion among car dealers is not considered in our theoretical analysis and could be an area for further research.

One difficulty in constructing a well-specified regression model is the lack of a monthly variable that is a good indicator of general macroeconomic conditions in Singapore. Almost all macroeconomic indicators available are compiled either quarterly or annually. Based on our study, the bid-ratio (number of bids submitted divided by the number of COEs available) and the financing costs of the car (average interest rates of car loans) are statistically significant variables in the demand for cars and COEs. Future studies should build on these indicators and find a way to include other macroeconomic indicators.
More information on the bid distribution would shed light on the bidding strategies of car dealers. LTA used to release the bidding distributions of auctions under the sealed bid system from September 1994 to June 2000, but has since stopped (Chu 2002). Currently, no information on the bid distribution is available for the open bidding system. If and when it becomes available, further research could be done on the bidding strategies which would affect volatility of COE premiums.

In conclusion, the objective of this paper is to apply auction theory to study the impact on COE premium volatility after the change from a sealed bid to open bid format in the VQS and to investigate it empirically. Current auction literature is inconclusive in predicting the impact on COE premium volatility. Econometric analysis shows a decline in volatility since the implementation of the open bid auction format. The empirical results should contribute to the auction theory literature and hopefully suggest new ways of studying similar simultaneous multiunit uniform price auctions. We also discussed some caveats and areas for further research, which includes the possible collusive behavior among bidders under the open bidding system.
References

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Chin, Anthony and Smith, Peter (1997), “Automobile ownership and government policy: the economics of Singapore’s Vehicle Quota Scheme” Transportation Research, 31A, pp. 129-140


CAT B - Sealed Bid