1-2004

Congestion Control and Vehicle Ownership Restriction: The Choice of an Optimal Quota Policy

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SMU ECONOMICS & STATISTICS
WORKING PAPER SERIES

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January 2004

Paper No. 03-2004

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Final Revision: 31 December 2003

Forthcoming in *Journal of Transport Economics and Policy*

Abstract

Singapore introduced a vehicle quota system (VQS) in 1990 as part of its overall policy to control urban congestion. While the VQS has reduced the annual growth rate of the vehicle population to about 3%, it has created uncertainty in the cost of vehicle ownership due to the fluctuations in license prices. The paper discusses three issues relating to the optimal design of a VQS: license transferability, sub-categorization and the choice of an auction format. Our analysis shows that license transferability is not unambiguously desirable, sub-categorization is highly regressive, and an open auction format results in less aggressive bidding and lower license prices.

JEL Classification number: D44, D45, R48

Keywords: congestion control, vehicle ownership, optimal quota, transport policy

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* I would like to thank Steve Morrison, the Managing Editor, and an anonymous referee for perceptive comments and suggestions in the revision of the paper; and Sock Yong Phang for discussions on the subject. Research support from the Wharton-SMU Research Centre, Singapore Management University is gratefully acknowledged. The usual disclaimer applies here.

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1. Introduction

Urban congestion is a problem faced by countries all over the world. Governments have tackled the problem in different ways, ranging from road taxes levied on car usage, toll charges for cars entering city business districts (e.g., most recently in London) and other high-traffic areas during the day, as well as controlling the growth of the vehicle population through ownership taxes. Singapore has implemented the Area Licensing Scheme (ALS), the Vehicle Quota System (VQS) and the Electronic Road Pricing Scheme (ERP) to control urban congestion. The ERP (and its antecedent, the ALS) represents a sophisticated form of marginal cost pricing of road usage, while the VQS remains the only scheme in the world to directly control the growth rate of the vehicle population to manage urban congestion.

Before the VQS was introduced, the expansion of the vehicle population in Singapore was controlled through a range of ownership taxes, including a road tax (based on engine capacity), an import duty, a fixed registration fee, and an *ad-valorem* additional registration fee (ARF).[1] A key motivation behind the introduction of the VQS is the concern that, with rising affluence, existing ownership taxes were not effective in controlling the growth in the vehicle population. Periodic increases in the ARF were politically unpopular. Moreover, announcements of impending increases in ARF had the effect of bringing forward car purchases.

Under the VQS, a car buyer must first obtain a license, referred to officially as a Certificate of Entitlement (COE). Each license allows the vehicle to be on the roads for ten years, after which the vehicle must be deregistered, or the license renewed for a further 5-year or 10-year period, by paying a "prevailing quota license premium", which is the three-month moving average of the license premium.

While the principles behind marginal cost pricing of road usage to control urban congestion are well established in the urban economics literature (see for instance, Small

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1 For a review of different aspects of Singapore's transport policies, see McCarthy and Tay (1993), Chin and Smith (1993), Phang and Asher (1997), Toh and Phang (1997) and Willoughby (2001).

(1992), Liu and MacDonald (1998), Verhoef, Nijkamp and Rietveld (1996), Small and Gomez-Ibanez, (1998), Small and Yan (2001), Small (2003), among others), there is relatively little study on the optimal design of a quota system to control the growth of the vehicle population. This provides the motivation for this paper, which examines some issues relating to the choice of an optimal quota policy and its implementation. Specifically, we shall examine the following questions: (a) is license transferability desirable for the maximization of social welfare; (b) should a vehicle quota be sub-categorized, as is the case with Singapore's VQS; (c) should the allocation of the vehicle licenses be conducted as a sealed-bid auction or as open-online auction, and what are the implications on auction revenue? We shall use Singapore's VQS as the context of our study.

In principle, usage taxes can fully internalize congestion externalities, as these taxes directly affect the cost of urban travel. The main justification for a quota system is that they allow for tighter control over the size of the vehicle population, which in turn affects the magnitude of potential urban congestion. The optimality of the VQS should not be judged by its effectiveness in tackling congestion per se, but by its success in attaining the targeted growth of the vehicle population and its impact on social welfare.

As of June 2003, the VQS has generated auction revenues totaling of S$20.22 billion (US$11.55 billion) from 156 license auctions. Although the auction revenues are not channeled into a specific account to finance the development of transport infrastructure – such as the expansion of the mass rapid transit (MRT) rail system – or to increase the capacity of the road networks, these revenues had made it possible to fund the construction of the recently North-East MRT Line and the Circle Line (to be ready around 2008). The development and continual expansion of the MRT system has cut travel time, improved the quality of urban travel, as well as reduced urban congestion, as more commuters switched from traveling by bus to the MRT system and fewer cars are driven into the central business district.

Although Singapore's VQS has met its objective to limit the growth of vehicle population to about 3% a year, and in the process generated substantial revenues to finance the development of transport infrastructure, the scheme has also led to substantial price uncertainty concerning the cost of car ownership. Car buyers complained about the presence of speculation and the consequent volatile movements in license prices. Car dealers complained that the vehicle quota system has added costs to their business operations. Pointing to the exit of smaller car distributorships, some industry observers have argued that the VQS favored those distributors with larger market shares, as smaller companies lacked the resources to compete for licenses. Available data from 1998 onwards shows that industry concentration in the car distributorship industry has indeed increased over the period 1998 to 2002 (Koh, 2003).

When the VQS was first introduced in 1990, speculation drove the price of vehicle licenses to levels as high as S$100,000 (US$70,000) in 1994 – about the price of a luxury car in Singapore. This led to calls to abolish the license transferability. The licenses were soon made non-transferable, but although this eliminated the speculative trade, some commentators in the local press have argued that this made the quota system less efficient, as the presence of a secondary market trading facilitates the optimal allocation of the quota licenses when market conditions change (The Straits Time, 6 June 1992).

Besides the removal of license transferability, there were also calls to do away with sub-categorization, so that there is only one category of licenses. The rationale behind sub-categorization is to ensure that buyers of smaller cars do not compete with and pay the same license premiums as the buyers of large cars; however, the actual experience proved otherwise. The prices for licenses of smaller cars were often as high, if not higher, than those for larger cars. Since the vehicle license premium is fundamentally another ownership tax, it has been argued that it would be more socially equitable to have a system whereby car buyers bid a percentage of the car value that they are willing to pay as additional road tax.

Another issue that was widely discussed is whether the license auction should remain as a sealed-bid auction, rather than an open-online auction, as it is currently being conducted. In fact, the government argued that that since the valuations of the vehicle licenses reflect the private valuations of car buyers, the choice of the bidding format is non-consequential from an efficiency point, as all the different systems will lead to the same optimal allocation of quota licenses, with the same level of revenue generated for the government on average (The Straits Times, 9 April, 1994). The choice of the specific auction system reflects the administrative ease of managing the system. As we shall show, revenue equivalence does not hold for the VQS, and the switch to an open auction format has improved the transparency of the auction process, and in the process lowered the license prices.

The issues we highlighted above are broadly concerned with the optimal design of a vehicle quota policy and its impact on market structure and social welfare. The chief benefit of a vehicle quota system is direct control over the vehicle population which is the key factor in urban congestion. For Singapore, congestion-free roads and its urban infrastructure form part of its competitive advantages to attract investments and businesses to the country. However, the adverse impact of fluctuations in license premiums and the consequent uncertainty over cost of car ownership that the population is subject to has prompted some observers to question if the vehicle quota system could be better designed to maximize social welfare.

The rest of the paper addresses this issue, and is structured as follows. In Section 2, we briefly review key features of the VQS. Section 3 discusses the issue of license transferability and the case for and against it. Existing empirical studies (Phang, Wong and Chia, 1996; Tan, 2001) show that there is inconclusive evidence that non-transferability of vehicle licenses lead to lower license prices. To provide new insights into the issue, we adopt a theoretical approach to examine the impact of license transferability on social welfare. We construct a mathematical model to show that transferable and non-transferable licenses have different effects on market competition, industry concentration, aggregate industry profitability and net social welfare. The theoretical model helps to delineate circumstances under which license transferability may improve social welfare.

Next, in Section 4, we examine the issue of sub-categorization and its failure to achieve equity, contrary to its aim to do so. The simplest and most effective way to show that sub-categorization has favored buyers of more expensive cars (in Categories 3 and 4 till April 1999;

and Category B, from May 1999 onwards) is through an analysis of a set of descriptive statistics derived from the data made available by the Land Transport Authority of Singapore (LTA, http//:www.lta.gov.sg). We also discuss an alternative *ad-valorem* scheme, where there is only one category of licenses and bids are percentages of the car value to be paid as license premiums, as a potential method to achieve the equity objective.

In Section 5, we study the recent switch from a sealed-bid auction to an open online license auction and the impact on bidding behavior. We first review the relevant theory in the literature on auctions and then discuss the findings in Koh, Mariano and Tse (2003), in which an econometric model is constructed to test if the change in auction format has led to a change in bidding behavior. The econometric analysis, using auction data from 1994 to 2003, allows us to reject the hypothesis that the switch in auction format has not changed bidding behavior. By improving informational transparency, the open-online auction format produces less aggressive bidding and results in lower quota premiums. Section 6 concludes the paper.

2. Singapore's Vehicle Quota System

In this section, we briefly review the major features of the VQS and its developments over the past thirteen years. In a world of certainty, ownership taxes and a quota system are clearly equivalent means to control the vehicle population. However, when the demand for vehicles varies over time and cannot be forecast accurately, controlling the growth rate of motor vehicle population requires periodic adjustments of the various taxes to check the increase in the vehicle population. On the other hand, a vehicle quota system provides almost complete control over the growth of the vehicle population, but leads to fluctuations in license prices and uncertainty in the cost of vehicle ownership.

The VQS came into effect in May 1990. Except for the first license auction, which covered the period from May 1990 to July 1990, license auctions were held monthly. Under the VQS, motor vehicles are classified into several categories, with a separate license quota for each category. When first introduced in 1990, there were seven quota license categories, namely: Category 1 for cars of 1000 cc and below; Category 2 for cars of 1001-1600 cc and below, and taxis; Category 3 for cars of 1601-2000 cc and below; Category 4 for cars of above 2000 cc; Category 5 for goods vehicles and buses; Category 6 for motorcycles; Category 7, an "Open" category for registration of all types of vehicles. Following a review of the VQS, Categories 1 and 2 were merged in May 1999 into one category to form Category A for cars of 1600cc and below, and taxis. Similarly, Categories 3 and 4 were merged to form Category B for cars of 1601 cc and above. Under the revamped classification, Categories 5, 6 and 7 were renamed as Categories C, D and E, respectively.

In May 1991, a "weekend" car quota license category was also introduced, but later abolished in 1994. The weekend car was originally conceived as a measure to broaden the ownership of vehicles among Singaporeans who wanted the convenience of private transport but only outside of office hours and weekends. Besides Saturday (after 1 p.m.) and Sunday, the weekend car can be used during public holidays, and at specific times during weekdays (before 7 am and after 9 pm). Outside of these permitted times, weekend car owners may use the cars during weekdays by purchasing a S$10 daily license for half-day usage, or a S$20 daily license to full-day usage. The option to purchase daily-usage licenses led to situations where the estimated total license cost of a weekend car for normal usage (every day, over 10 years) was substantially lower than the price of a vehicle license of a non-weekend car.

As of June 2003, a total of 905,281 licenses were auctioned in 156 auctions. In total, these auctions generated total revenue of S$20.22 billion (US$11.55 billion) for the Singapore government. Thus, each auction yielded revenue averaging S$129.05 million (US$74.06 million), and each quota license issued since May 1990 had cost an average of S$22,334 (US$12,762).[2] These revenues are channeled into a consolidated government fund that is used to fund infrastructural development, and other government projects.

Every quota year beginning in May (following the first auction in May 1990), the available quota for new motor vehicles is determined in accordance with a targeted rate of

[2] All figures are in current prices. The calculations were based on an exchange rate of US$1 to S$1.75 as at July 2003.

growth in the vehicle population, and taking into account the forecast de-registration of vehicles in the coming year. The Land Transport Authority of Singapore (LTA) releases on its website (http://www.lta.gov.sg) the exact calculations for the target vehicle population and the number of vehicle licenses available for auction each month. To allow changes in tastes to influence the composition of the vehicle population over time, 25% of the licenses created from the deregistered vehicles in each category are allotted to the "Open" category, where the quota licenses can be used to register motor vehicles belonging to any of the quota categories. The other 75% of the new quota licenses are allocated back to the original category.

From May 1990 to June 2001, the vehicle licenses were allocated on monthly basis via a sealed-bid auction, where successful bidders pay the lowest successful bid. Car dealers typically bid for the licenses on behalf of car buyers, since car deals are often bundled with a guaranteed license[3]. In fact, it is rare that car firms would entertain a deal whereby the car buyer attempts to bid for a license himself. Thus, the VQS is effectively a quota on industry sales, as car firms must obtain vehicle licenses before they can sell cars.

Following a government review in 1999-2000, the bidding format for the vehicle quota license auctions switched to an online open-bid format in several phases, beginning in July 2001. At present, two auctions are held each month, each taking place over three days at the beginning and middle of each calendar month. Bidders can see, in real time, the market clearing bids at each point in time before the auction closes. Bidders can update their valuations, decide to enter or drop out of the auction, or revise their bids on-line.

3. The Value of License Transferability

The VQS has succeeded in controlling the growth of the vehicle population. From 1990-2001, the average annual vehicle growth rate was 2.9%, with a standard deviation of 2.1%. By comparison, the average annual growth in the vehicle population during the 1975-1989 period (before the VQS was introduced) was 4.4%, with a standard deviation of 4.3%.

[3] The guarantee is usually for three consecutive attempts at obtaining a vehicle license in the license auctions.

Vehicles licenses were initially transferable when the VQS was first introduced. However, car dealers began hoarding vehicle licenses by paying people to bid on their behalf. Toh and Phang (1997) reported anecdotal evidence that the car distributors collectively controlled more than two-thirds of the bidding for quota licenses in each auction then. This led to sharp rises in the vehicle license prices, and vehicle licenses became short-term speculative investments. Amidst public outcry to curb speculation in vehicle licenses, license transferability was removed in 1994 after a government review (except for Category 7 licenses). However, the non-transferability of quota licenses did not completely eliminate the hoarding of vehicle licenses by car firms. In a practice that came to be known as "double-transfer", car firms would register cars (without confirmed buyers) with successfully tendered quota licenses; these so-called 'pre-registered' cars were later sold accompanied with letters certifying that they were in effect 'first-hand' cars, with a slight discount for the depreciation in value.

The issue of license transferability was a hotly debated topic. Proponents of license transferability argue that like all tradable assets, transferable licenses are bound to attract speculation, but they also facilitate a more efficient allocation of licenses as secondary market trading helps to smooth out demands between auctions and ensure that the licenses go to those individuals with the highest valuations. Furthermore, it is argued that unsuccessful bidders and some car buyers welcome a secondary market as they may decide not to participate in future auctions but purchase licenses in the secondary market instead. There were also a number of smaller car distributors, with less financial resources, who my not wish to tie up their funds in deposits (equal to half the value of each submitted bid). Thus, while car buyers may pay a higher price for transferable licenses, the resultant social welfare could be higher compared with the case of non-transferable licenses.

A number of studies have examined the impact of non-transferability on the vehicle license premiums. The first study to do so was Koh and Lee (1993), who regressed the vehicle license premium on a dummy variable for transferability, and other variables such as the ratio of bids received to the number of successful bids and the range of bids, for the period of May

1990 to February 1992. Koh and Lee found that non-transferability introduced from October 1991 onwards appears to have little effect in dampening vehicle license prices. The hypothesis that transferability and speculative activities resulted in higher quota license premiums was supported only in Category 1, which was dominated at that time by three major car distributors. The study found that vehicle license premiums were higher in Categories 3 and 4 after the switch to non-transferable licenses. There was no discernible effect on the quota license premiums in Category 2. Koh and Lee (1993) also found that the elimination of license transferability intensified competition among car distributors, as the absence of the secondary market makes it important to be successful in the license auctions. Failure to secure vehicle licenses in a monthly auction not only meant a loss of sales order, but also the incurrence of further storage cost for the imported but unsold cars.

In a later study, Phang, Wong and Chia (1996) also analyzed the issue and found that the ban of immediate double transfers had some dampening effect on speculation, but the results were not conclusive. More recently, Tan (2001) studied the same issue using data from 1990 to 1999. Tan used as her regression variables the quota license premiums in Categories 1 to 4, relative to those in Category 7 (which has always been transferable), and found that while non-transferability appeared to have some effect in dampening quota premiums over the longer term, the effect was overwhelmed by other market developments pushing license premiums upwards. Based on existing empirical studies, there is no conclusive evidence that the non-transferability of vehicle licenses lead to lower license prices.

To shed new insights on the issue, we present a theoretical model of vehicle market competition with sales restrictions. This model builds on the framework presented in Koh (2003), and is set up to capture the main features of the competition in the car distributorship in Singapore. We solve for the market equilibrium under both transferable and non-transferable licenses. Our analysis shows that license transferability is not unambiguously desirable, as industry profitability, which affects social welfare, may be lower under transferable licenses.

3.1 A Model of Vehicle Quota and Market Competition

Suppose a quota, denoted *Q*, is imposed on the sale of new vehicles. A vehicle license is required for each new car sale. For simplicity, suppose there is only one category of licenses. There are *M* car distributors, each selling a different brand of car. Let the demand for a car brand be given by

$$q_i(p_i, \bar{p}_{-i}) = \alpha_i - \beta p_i + \theta \bar{p}_{-i} \qquad i = 1, 2, \ldots, M \tag{1}$$

where p_i is sale price of brand i, $\bar{p}_{-i} \equiv \frac{1}{M-1}\sum_{j=1, j\neq i}^{M} p_j$ is the average price charged by the other (M–1) brands. Here, α_i is the demand shift parameter for firm *i*, while β and θ represent the symmetric price sensitivity of firm *i*'s demand to p_i and $\bar{p}_{-i}$, respectively. We shall assume that $\beta > \theta > 0$, so that each firm's sales are more sensitive to its own price than to the average price of the competition. Suppose firm *i's* cost structure is given by $C_i(q_i) = c_i q_i$, where c_i is a constant marginal cost. Each firm chooses p_i, given p_{-i}, to maximize its profits, which is given as follows:

$$\Pi_i(p_i, \bar{p}_{-i}) = (p_i - c_i)(\alpha_i - \beta p_i + \theta \bar{p}_{-i}) \tag{2}$$

Firms differ in both costs and demands, c_i and α_i, which are drawn from continuous distributions with supports of $[c^-, c^+]$ and $[\alpha^-, \alpha^+]$, respectively. A firm's demand and its cost structure may be related in several ways. For instance, a better-quality brand may face more favorable demand conditions in the form of a larger α_i, but may incur also higher costs of operation (i.e. higher c_i) compared with a lower-quality rival brand. In this case, α_i and c_i are positively correlated. In general, α_i and c_i may be uncorrelated or even negatively correlated. As we shall show, the degree of correlation between a firm's demand and cost in the industry is plays an important role in determining the market concentration, industry profitability and social welfare in the post-quota market equilibrium.

To keep our analysis tractable, we shall make the simplifying assumption that for firms *i* and *j*, α_i is uncorrelated with α_j and c_i is uncorrelated with c_j, or with α_j. In general, α_i

and α_j are likely to be positively correlated; for instance, it is reasonable that rising income levels will lead to higher demands for all car brands. Similarly, c_i is likely to be positively correlated with c_j, so that firms' business costs move in line with one another. However, the qualitative aspects of our results on the value of license transferability carry over to the more general case when demands and costs are correlated across firms. The crucial aspect of our model is the nature of the correlation between a firm's demand and its cost structure.

Under the VQS, firms compete in a two-stage game. The timing of events is as follows. The license auction takes place in the first-stage, and each car firm submits bids based on their beliefs regarding the bidding strategies that rival firms will adopt as well the pricing strategies that will be used in the second stage game (after licenses are allocated). Although firms can observe the distribution of cost structures in the industry, they cannot observe the distribution of demands. In the second-stage, firms learn the demand conditions in the industry and set prices independently to maximize profits. If licenses are transferable, they may also buy licenses if the secondary market price for a license is lower than the profit that they can make from the sale of an additional vehicle.

We are interested in the welfare implications of license transferability and its impact on market structure. Our focus is therefore on a representative firm in the *ex-ante* market equilibrium (i.e. before costs and demands are drawn) for both the cases where licenses are transferable and when they are non-transferable. The detailed model and the steps to deriving the market equilibrium are presented in Appendix A. We state the main results in Propositions 1 and 2. The following notation will be used:

$$\bar{\alpha} = \frac{1}{N}\sum_{i=1}^{N}\alpha_i \text{ and } \bar{c} = \frac{1}{N}\sum_{i=1}^{N}c_i\ ;$$

$$\mu \equiv E[\alpha_i]\ ;\ \phi \equiv E[c_i]\ ;$$

$$Var(\alpha) \equiv E\left[\alpha_i - \mu\right]^2 ;\ Var(c) \equiv E\left[c_i - \phi\right]^2 \text{ and } Cov(\alpha, c) \equiv E\left[\alpha_i - \mu\right]\left[c_i - \phi\right].$$

The market-clearing bid in a license auction is denoted by *b*. Lastly, the superscript *N* refers to the non-transferable case, while the superscript *T* refers to the transferable case.

Proposition 1: The *ex-ante* market equilibrium under non-transferable licenses.

Market price $\tilde{p}^N = \frac{1}{\beta-\theta}\left[\mu - \frac{Q}{M}\right]$

Sales $\tilde{q}^N = \frac{Q}{M}$

License price $\tilde{b}^N = \frac{\mu}{\beta-\theta} - \phi - \frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}$

Profits $\tilde{\Pi}^N = \frac{1}{\beta}\left[\frac{Q}{M}\right]^2 - \frac{(M-1)^2}{M\left[2(M-1)\beta+\theta\right]}\beta Cov(\alpha,c) + \left[\frac{M-1}{M}\right]\left\{\frac{(M-1)\beta+\theta}{2(M-1)\beta+\theta}\right\}^2 \beta Var(c)$

Proposition 2: The *ex-ante* market equilibrium under transferable licenses.

Market price $\tilde{p}^T = \frac{1}{\beta-\theta}\left[\mu - \frac{Q}{M}\right]$

Sales $\tilde{q}^T = \frac{Q}{M}$

License price $\tilde{b}^T = \frac{\mu}{\beta-\theta} - \phi - \frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}$

Profits
$$\tilde{\Pi}^T = \frac{1}{\beta}\left[\frac{Q}{M}\right]^2 - \frac{2(M-1)^2\left[(M-1)\beta+\theta\right]}{M\left[2(M-1)\beta+\theta\right]^2}\beta Cov(\alpha,c)$$
$$+\left[\frac{M-1}{M}\right]\left[\left\{\frac{M-1}{2(M-1)\beta+\theta}\right\}^2 \beta Var(\alpha) + \left\{\frac{(M-1)\beta+\theta}{2(M-1)\beta+\theta}\right\}^2 \beta Var(c)\right]$$

3.2 Industry Profitability and Market Concentration

Propositions 1 and 2 indicate that the expected price, sales and license price of a representative firm in the *ex-ante* equilibrium are the same under both license transferability and non-transferability. However, expected firm profits are different. This is due to the fact that license transferability allows firms to trade licenses after learning their demands, so that the final distribution of the vehicle licenses will be reflective of both cost and demand conditions.

We first compare the expected profitability of a car firm with non-transferable licenses and the expected profitability under license transferability. The comparison simplifies to:

$$\tilde{\Pi}^N > (<)\ \tilde{\Pi}^T \iff \frac{Cov(\alpha,c)}{Var(\alpha)} < (>)\ \frac{M-1}{\theta} \tag{3}$$

The condition in (3) indicates that license transferability is unambiguously attractive to car distributors only when the correlation between a firm's cost and demand, $Cov(\alpha,c)$, is either zero or negative. However, when the correlation is positive, as in the case when higher-quality brands incur higher costs of operation, license transferability results in higher expected firm profits only if there is a sufficiently large number of competing firms and/or a sufficiently low degree of substitutability (as measured by θ). Otherwise, firms can expect to earn a higher level of profits when licenses are non-transferable.

License transferability also has a differential impact on the industry structure. A commonly-used measure of industry concentration is the Herfindahl index, which is simply the sum of squares of market shares. At present, there are about 50 brands of cars sold in Singapore, but the industry is dominated by the distributors for five main brands: Toyota, Nissan, Honda, Mercedes Benz and Mitsubishi (in the order of their market share of new car sales in 2001). Based on data provided by the Land Transport Authority, the collective share of these five brands in the car population has steadily risen from 57% in 1998 to 64% in 2001 and 65.6% in 2002. The statistics for the registration of new cars also indicate that the combined market share of the top five brands has steadily risen from 1998 to 2002. In fact, our calculation of the Herfindahl Index of industry concentration shows that, even though licenses are non-transferable, the car market in Singapore has become increasingly more concentrated. The results are reported in Table 1 below.

Table 1: Cumulative Market Share of New Vehicles Registered by Ranking of Brand

%	1998	1999	2000	2001	2002
Top 5	88.31	91.25	90.25	91.82	94.66
Top 8	96.20	96.85	96.86	97.80	98.02
Top 10	97.85	98.46	98.13	98.95	99.31
Herfindahl Index	935	1113	1078	1229	1427

Source: Land Transport Authority of Singapore

It has been argued that the increase in industry concentration is due to the non-transferability of licenses, and restoring license transferability would help to lower industry concentration. To examine this issue, let $H^N \equiv \sum_{i=1}^{M} \left\{ \frac{q_i^N}{Q} \right\}^2$ and $H^T \equiv \sum_{i=1}^{M} \left\{ \frac{q_i^T}{Q} \right\}^2$ denote the Herfindahl indices for the two post-quota industry equilibria, with q_i^N and q_i^T being the sales of firm *i* under non-transferable licenses and transferable licenses, respectively. As derived in Appendix A, we have

$$q_i^N = \frac{Q}{M} - \frac{[(M-1)\beta + \theta]\beta(c_i - \overline{c})}{2(M-1)\beta + \theta}$$

$$q_i^T = \frac{Q}{M} + \frac{(M-1)\beta(\alpha_i - \overline{\alpha}) - \left[(M-1)\beta + \theta\right]\beta(c_i - \overline{c})}{2(M-1)\beta + \theta}$$

so that

$$H^T - H^N = \left\{ \frac{(M-1)\beta}{\left[2(M-1)\beta + \theta\right]Q} \right\}^2 \sum_{i=1}^{M} (\alpha_i - \overline{\alpha})^2 > 0 \qquad (4)$$

Hence, industry concentration is higher when licenses are transferable. The differential impacts on market concentration and aggregate profitability can be explained as follows.

When firms bid for licenses in the first-stage auction, they only observe costs but not demand conditions. Hence, each firm bids for licenses conditional on an expected demand of μ (since individual demands are not drawn yet). As such, the initial allocation of licenses resulting from the auction reflects only the distribution of costs, and not the distribution of demands. When licenses are non-transferable, this is the final allocation of licenses.

However, when licenses are transferable, trading in licenses will take place after firms learn their demands. Firms who draw demands higher than the expected level of μ will attempt to obtain more licenses to increase sales, while those who draw demands lower than μ will sell their licenses in the secondary market. The final allocation of vehicle licenses will be a function of both cost and demand distributions. With transferable licenses, firms with higher demands will obtain more licenses and sell more cars than firms facing lower demands. As a result, for a given set of demand distributions, the final allocation of transferable licenses, and market shares, will be more *dispersed* compared with the allocation of non-transferable licenses. This in turn leads to a higher market concentration under transferable licenses.

The effect of license transferability on market concentration is seen most clearly in the case when firms face the same cost structures. In this case, the allocation of non-transferable licenses would be the same for each firm, since each firm bases its bids on a common cost c and the same expected demand μ. Each firm has 1/M share of the market. With transferable licenses, the final allocation would reflect the demand distribution, so that some firms would have greater than 1/M share, while others have smaller shares. It is straightforward to verify that market concentration is higher with license transferability.

3.3 Social Welfare Comparison

In general, it is ambiguous whether social welfare is higher or lower with license transferability. Let $W^N(Q)$ and $W^T(Q)$ denote, respectively, the *ex-ante* social welfare under non-transferable and transferable licenses for a quota of Q. Consider a social welfare function comprising a weighted sum of consumer surpluses, firm profits, license auction revenue and net externalities. For simplicity, suppose the negative externalities of congestion are represented by a quadratic function ηQ^2. Let δ_1, δ_2, δ_3 and δ_4 represent the weights attached to the consumer surpluses, firm profits, license auction revenue and externalities, respectively.

The steps in the derivation of $W^N(Q)$ and $W^T(Q)$ are contained in Appendix B. We are interested in the difference in the social welfare of the *ex-ante* market equilibria.

$$W^N(Q) - W^T(Q) = -\frac{1}{2}(\delta_1 + 2\delta_2)(M-1)\left\{\frac{M-1}{2(M-1)\beta + \theta}\right\}^2 \beta Var(\alpha) \qquad (5)$$

$$+ \frac{(M-1)^2\left[\delta_1(M-1)\beta + (\delta_1 + \delta_2)\theta\right]}{\left[2(M-1)\beta + \theta\right]^2}\beta Cov(\alpha, c)$$

Note that in equation (5), δ_3 and δ_4 are not present. This is not surprising since license auction revenue and net externalities are functions of the size of the quota Q, and not the distribution of the quota among firms. The first term on the right-hand side of (5) is negative, while the sign of the second term on the right-hand side of (5) is dependent on the correlation of firm cost and demand, $Cov(\alpha, c)$. If $Cov(\alpha, c)$ is either zero or negative, then the right-hand side of (5) is unambiguously negative. In this case, social welfare is always higher when licenses are transferable. However, if $Cov(\alpha, c) > 0$, the social welfare comparison is as follows:

$$W^N(Q) > (<)\ W^T(Q) \ \Leftrightarrow\ \frac{Cov(\alpha,c)}{Var(\alpha)} < (>)\ \frac{(\delta_1 + 2\delta_2)(M-1)}{2\left[\delta_1(M-1)\beta + (\delta_1+\delta_2)\theta\right]} \tag{6}$$

Hence, license transferability does not unambiguously lead to higher social welfare. The critical factor in choosing between transferable and non-transferable licenses to maximize expected social welfare is the direction and magnitude of the correlation between costs and demands. Consider two special cases when $Cov(\alpha, c) > 0$,

$$\delta_1 = 0,\ W^N(Q) > (<)\ W^T(Q) \ \Leftrightarrow\ \frac{Cov(\alpha,c)}{Var(\alpha)} < (>) \frac{M-1}{\theta} \tag{7}$$

$$\delta_2 = 0,\ W^N(Q) > (<)\ W^T(Q) \ \Leftrightarrow\ \frac{Cov(\alpha,c)}{Var(\alpha)} < (>) \frac{M-1}{2\left[(M-1)\beta + \theta\right]} \tag{8}$$

$$\delta_1 = \delta_2,\ W^N(Q) > (<)\ W^T(Q) \ \Leftrightarrow\ \frac{Cov(\alpha,c)}{Var(\alpha)} < (>) \frac{3(M-1)}{2\left[(M-1)\beta + 2\theta\right]} \tag{9}$$

When $\delta_1 = 0$, then profitability is the deciding factor in choosing between transferable and non-transferable licenses. The condition in (7) is the same as the one in (3). On the other hand, if $\delta_2 = 0$, then for a given set of $Cov(\alpha, c)$ and $Var(\alpha)$, condition (8) implies a weaker requirement for license transferability to yield greater social welfare, since

$$\frac{M-1}{\theta} > \frac{3(M-1)}{2\left[(M-1)\beta + 2\theta\right]} > \frac{M-1}{2\left[(M-1)\beta + \theta\right]}$$

Finally, when $\delta_1 = \delta_2$, condition (9) implies an intermediate requirement for license transferability to be desirable.

To summarize, our theoretical analysis has shown that, a-priori, it is not always the case that license transferability will lead to higher social welfare, when one takes into account the impact of the sales quota on market competition and the allocation of licenses. In our model, license transferability has a value insofar as it allows firms that draw higher demands to obtain more licenses from the secondary market. However, depending on the specific relationship between costs and demands, the net impact on social welfare may be smaller with transferable licenses than with non-transferable licenses.

4. Sub-Categorization and Social Equity

In this section, we examine the issue of sub-categorization, which is another aspect of the VQS that has caused a great deal of frustration among car buyers. As mentioned earlier, there were seven quota categories when the VQS was initially implemented. The rationale to have separate categories of vehicle licenses was to separate buyers of small cars so that do not face competition from wealthier car buyers and end up paying the same license premium as buyers of expensive luxury cars. However, in practice, the VQS sub-categorization had led to highly regressive outcomes instead, with buyers of small cars (those in Categories 1) paying more in relative – and, in some cases, absolute – terms compared with buyers of more expensive cars (those in Categories 2 to 4).

The empirical evidence supports the claim that sub-categorization had failed to achieve its stated equity objective. Using data from May 1990 to April 1999 (106 auctions), we found that Category 4 license premiums ranked the highest among four quota categories for 53% of the time; Category 3 ranked second highest for 49% of the auctions, Category 2 ranked second-lowest for only 59% of the auctions; and Category 1 ranked the lowest for 81% of the auctions. The desired equitable outcome, i.e. where Category 4 ranked the highest, Category 3 ranked second highest, followed by Category 2 and Category 1, was only observed in only 53% of the auctions. Hence, approximately half the time, the license for a larger passenger car (by engine capacity) actually cost less than that for a smaller car. Moreover, we found that in 13% of the license auctions, Category 1 license premiums were in fact higher than those in Category 4.

As noted earlier, the purpose of the Open category (Category 7) license is to provide flexibility in the composition of the vehicle population, as consumer preferences change over time. However, the objective of using sub-categorization to achieve social equity is in conflict with the existence of the Open category to bring about allocative flexibility. To recapitulate, 25% of the new vehicle licenses created from de-registered vehicles are channeled into the Open category. Although the intention is that Open category licenses can be used to purchase vehicles belonging to any category, in practice, they are used mainly for the purchase of larger cars (in Categories 3 and 4 before April 1999, and Category B, from May 1999 onwards). Therefore, the effective quota constraint for smaller cars (in Categories 1 and 2 before May 1999, and Category A from May 1999 onwards) is more restrictive compared with the constraint for larger cars. As a result, license prices in Category 1 and 2 are often close to those in Categories 3 and 4, and sometimes higher.

Using data from May 1990 to April 1999, we found that the strongest correlations with the Category 7 (Open) license prices were for Categories 3 and 4, as shown in Table 2 below.

Table 2: Correlation Coefficient of License Premiums with Category 7 License Premiums

	Cat 1	Cat 2	Cate 3	Cate 4	Cat 5	Cat 6
1990	0.888	0.713	0.750	0.762	0.798	0.012
1991	0.944	0.961	0.970	0.983	0.711	0.176
1992	0.705	0.745	0.506	0.449	0.617	0.000
1993	0.873	0.992	0.992	0.971	0.887	0.000
1994	0.307	0.936	0.981	0.965	0.939	0.337
1995	0.595	0.717	0.570	0.691	0.569	0.217
1996	0.445	0.322	-0.159	0.480	-0.342	0.415
1997	0.864	0.836	0.874	0.921	0.752	0.233
1998	0.741	0.951	0.345	0.896	0.603	0.781
1999	0.023	0.374	0.810	0.970	0.853	-0.653
1990-1999	0.735	0.910	0.963	0.981	0.906	0.646

Note: For 1990: May to December; for 1999: January to April. From May 1999, Categories 1 and 2 were merged to form Category A, while Categories 3 and 4 were merged to form Category B.

Source: Land Transport Authority of Singapore

The strong correlation between Open category license premiums and those of Categories 3 and 4 reflects the fact that the small quota of the open category had been used mostly to purchase larger cars in Categories 3 and 4, which later merged to form Category B in May 1999. This is evidenced by the data on vehicle registrations. As shown in Table 3, from 1992 to 2002, the ratios of new car registrations to the quota levels were substantially higher than one for Category B, compared with the other categories.[4] On average, the ratio for Category B is about 2, while the ratios for Categories A and C were about one.

[4] The LTA did not provide disaggregated data from Categories 1, 2, 3 and 4 before 1999.

Note that for Category D (the motorcycle category), license quotas were significantly higher than the actual demands from 1992 to 1994, resulting in a ratio of new registrations to quota that was substantially less than one. This oversupply of licenses also led to Category D license premiums falling to a minimum level of S$1 from December 1991 to February 1994.

Table 3: Ratio of New Car Registrations to License Quotas

	Cat A	Cat B	Cat C	Cat D
1992	1.093	2.410	0.997	0.352
1993	1.147	2.601	0.944	0.103
1994	0.999	2.435	0.938	0.498
1995	1.134	2.351	1.042	1.023
1996	1.176	2.282	1.035	1.059
1997	1.176	1.874	0.976	0.937
1998	1.277	1.664	0.995	0.932
1999	1.168	2.173	0.964	0.970
2000	1.260	1.994	0.976	0.948
2001	1.300	1.826	1.023	0.984
2002	1.279	1.891	0.824	1.443
Average	1.193	2.049	0.970	0.562

Note: There was no breakdown of the number of registrations according to the original classification (Categories 1 to 6) before 1999.

Source: Land Transport Authority of Singapore

Since the VQS was implemented, there had been calls to abandon the sub-categorization practice, and to address the issue of equity more directly. Since the license premium is a form of ownership tax, it would be more equitable to have car buyers bid a percentage of the car value that they are willing to pay as license premium. In this way, although the buyers of large cars pay the same percentage of ownership tax as buyers of smaller cars, they would pay more in absolute amounts.

The *ad-valorem* bidding scheme was first suggested by Koh and Lee (1994) and discussed in Tan (2001). The scheme was, however, considered too administratively complex by the authorities, although a similar scheme had been used in Australia's auction quotas for import licenses in the 1980s. An *ad-valorem* bidding scheme eliminates with the need for separate categories of vehicle licenses, and avoid the perverse effects of shifting the demand and composition of the vehicles in favor of the more expensive brands. As shown in Falvey (1979) and Rodriguez (1979), *ad-valorem* tariffs do not result in a shift in the composition of imports in favor of more expensive items, unlike the case for quotas.

Although the *ad-valorem* scheme may encourage car dealers to under-invoice the transaction in order to lower the applicable car price for the computation of the license tax, this potential loophole can be addressed easily by setting a minimum set of requirements for accessories and safety features to be installed before the cars are imported.

Under the current sub-categorized VQS, the license premiums of large cars constituted a smaller percentage of the car price. An analysis of license premiums versus car prices, reported in Table 4 below, shows that license prices as a percentage of the car price was sharply lower for Category B from 1999 to 2002. The substitution effects that were created led car buyers to favor the more expensive brands in each license category. In fact, Phang, Wong and Chia (1996) reported that by 1995, Mercedes Benz had overtaken Toyota as the most popular make of car registered in Singapore. By 1998, *The Straits Times* (Singapore) further reported, on 3 February, that Mercedes Benz ranked third in its share of the car population.

Table 4: License Premium as a Percentage of Car Price for Top-Ten Selling Brands

		1999		2000		2001		2002	
		Cat A	Cat B	Cat A	Cat B	Cat A	Cat B	Cat A	Cat B
1	Nissan	88	42	81	45	77	33	72	43
2	Toyota	78	37	78	36	61	27	71	26
3	Honda	72	45	64	43	63	35	64	38
4	Hyundai	102	64	101	58	77	42	91	56
5	Mitsubishi	83	46	78	43	65	31	69	41
6	Mercedes Benz	52	21	60	23	45	16	42	18
7	Mazda	85	52	89	54	69	44	81	55
8	B.M.W.		23		26		19		16
9	Kia	129	72	115	68	85	48	101	44
10	Ford	87	54	81	68	186	44	72	44
	Average	86	46	83	46	81	34	74	38
	Standard deviation	21	16	17	16	41	11	17	14

Source: Land Transport Authority of Singapore

Since 25% of the vehicle de-registration created new licenses for the Open Category, the shifting consumer preference towards larger cars and the prevalent use of the Open category licenses to buy Category B cars led to a steady increase in the share of license quotas for Category B over time. Table 5 confirms this trend. While the shares for Categories A and B in the aggregate vehicle quota increased over the years, the ratio of Category B license quota to Category A license quota has increased from 19% in 1990 to 48% in 2002.

Table 5: License Quota of Each Category as a Percentage of Aggregate License Quota

	Cat A	Cat B	Cat C	Cat D	Cat E
1992	27.26	5.30	10.48	44.81	12.15
1993	19.25	3.75	6.56	61.84	8.60
1994	45.07	10.69	14.29	15.21	14.75
1995	41.77	10.06	17.34	16.78	14.06
1996	40.10	11.02	18.91	17.42	12.55
1997	34.79	12.52	21.47	20.19	11.03
1998	33.74	11.47	19.53	20.77	14.49
1999	37.62	9.71	20.03	15.19	17.46
2000	28.78	12.72	26.20	11.88	20.42
2001	35.92	14.34	15.11	15.02	19.62
2002	35.20	17.09	15.54	13.97	18.20

Note: The quotas for 1990 to 1999 were aggregated as follows: Category A = Categories 1 and 2; Category B = Category 3 and 4. The aggregation is carried out in order to facilitate comparison with the statistics for 2000, 2001 and 2002.

Source: Land Transport Authority of Singapore

Not surprisingly, the share of larger cars in the vehicle population also increased steadily over the years. Table 6 shows the share of Category B cars in the vehicle population rose steadily from about 10% in 1990 to about 19% to 2001, while the share for Category A cars has remained roughly the same over the years. Of course, besides the dynamics of the subcategorized vehicle quota system, increasing affluence on the back of Singapore's strong economic growth throughout most of the 1990s, as well as the availability of low interest-rate car loans, are other factors that could have contributed to the increase in preference for larger cars.

Table 6: Composition of Vehicle Population by Category (percentage)

	Cat A	Cat B	Cat C	Cat D	Total
1991	42.52	9.97	22.42	21.68	559,304
1992	41.86	10.80	22.81	20.75	557,584
1993	41.23	11.80	22.42	20.38	584,322
1994	40.62	12.85	21.67	20.49	611,611
1995	40.92	13.92	21.09	20.04	642,129
1996	41.29	14.67	20.59	19.67	668,304
1997	41.39	15.39	20.42	19.29	683,204
1998	41.02	15.80	20.14	19.44	681,081
1999	40.94	16.43	19.70	19.38	688,811
2000	40.75	17.88	18.95	18.92	692,807
2001	41.06	18.30	18.90	18.49	708,370

Note: The car population for 1990 to 1999 were aggregated as follows: Category A = Categories 1 and 2; Category B = Category 3 and 4.

Source: Land Transport Authority of Singapore

5. Choice of Auction Format and Revenue Implications

Until June 2001, vehicle licenses were allocated through a sealed-bid uniform price auction held monthly. This system was replaced with an open online bidding format, implemented in phases from July 2001. From July 2001 to March 2002, two auctions were conducted each month, one using the sealed-bid format and the other using the open-bid format. From April 2002, the fortnightly vehicle licenses auctions were conducted using the open bidding format (during the first and third weeks of each month).

An important result in auction theory is the *revenue equivalence theorem*, which states that if identical objects are auctioned in a simultaneous auction where the set of winners are those who submit the highest bids, and where valuations are independent and participants are risk-neutral, then it does not matter whether the auction is conducted in a sealed-bid format or in an open format. The revenue equivalence theorem – first proven in Vickery (1961), and subsequently generalized in Myerson (1981) and Riley and Samuelson (1981) – states that all standard auctions, such as the first-price sealed-bid auction (where each winner pays his own bid), the second price sealed-bid auction (where the winners pay the highest rejected bid), the open outcry ascending (English) auction, or the open outcry descending (Dutch) auction are equivalent in terms of the expected revenue generated for each object auctioned.

However, if the assumptions of independent valuations or risk neutrality do not hold, then different auction formats will rank differently in terms of the expected revenue generated. Specifically, as shown in Maskin and Riley (1984) if participants are risk-averse (as is likely to be the case for car buyers) but valuations are independent, a first-price sealed-bid auction generates higher revenue than an open uniform-price auction. The intuition here is that if individuals are risk-averse, they would bid more aggressively in a sealed-bid auction to increase the probability of winning.[5] On the other hand, if bidders are risk-neutral and valuations are not independent, the second-price open (i.e. ascending English outcry) auctions will generate higher expected revenue than the second-price sealed-bid auction, which in turn, dominates the first-price sealed-bid auction. The underlying principle at work here is the greater informational linkage among bidders in the open auction format that allows bidders to revise their valuations as the auction progresses (see Milgrom and Weber, 1982).

In the context of the vehicle license auctions in Singapore, car buyers' valuations of vehicle license are not independent, since the bids they are willing to submit, through the car dealers, are influenced by the expected vehicle demand in each auction, the available quota in future auctions, as well as the outlook on the economy, etc. Since car buyers are risk averse, the switch of the quota license auctions from a sealed-bid to an open online format should result in less aggressive bidding, and consequently, lower auction revenues.

An open online-bidding format clearly improves the transparency of the bidding process. Under the sealed-bid auction format, bidders submitted bids independently and did not have the opportunity to revise their bids before the auction closed. By contrast, under the open online format, car buyers can monitor the progress of the auction in real time, and then decide if

[5] The second-price sealed-bid auction is strategically equivalent to the uniform-price open auction, bidding one's valuation is the dominant strategy in both cases. Hence, even if participants are risk averse, the revenue equivalence principle continues to hold for the second-price auctions when bidders' valuations are private values.

they should participate in the auction, revise their bids or drop out of the auction (by not revising their bids, for instance). Since the bids posted online provide information about other bidders' valuations, the greater transparency of the online auction improves decision-making.

A potential problem with the sealed-bid auction format is that it can sometimes lead to inefficient outcomes. An example is the January 1998 license auction for Category 3. In that auction, there were only 315 bids for 336 available licenses. The resulting quota license premium was S$50 (the lowest ever for Categories 1 to 5), and this was the only time that the license auction was ever undersubscribed. All the other categories were over-subscribed in the January 1998 auction. At that time, participants had no way of finding out that the January 1998 Category 3 license auction was going to be undersubscribed. If they had known, more bids would have been submitted, or lower bids (say, at the minimum of S$1) would have been submitted. Bidders in the other categories might have also switched to bid in Category 3. Such a situation would not have occurred under the current open online format.

Besides making the auction more transparent, thereby easing the uncertainty for car buyers, the switch to an open online format also has important implications on the auction revenue generated. Koh, Mariano and Tse (2003) examined this issue in an econometric study focusing on the period from January 1996 to June 2001 (66 monthly auctions) for the sealed-bid format, and the period April 2002 to March 2003 (24 fortnightly auctions) for the open online format. In the study, a regression model of the license premium was constructed for the sealed-bid auction, using a number of economic variables (such as monthly changes in industrial production, non-oil exports and interest rate differentials) that influenced the demand for vehicle ownership. The regression model is used to forecast the premiums under the open online auction format. If revenue equivalence hypothesis holds, there should be no statistical difference in the forecast license premiums and the actual license premiums.

Koh, Mariano and Tse (2003) found that the revenue equivalence hypothesis does not hold for Singapore's vehicle license auctions and the switch from the sealed-bid format to the open format had produced a dampening impact on license prices. This finding is consistent with our earlier discussion that the open auction format, by allowing bidders to observe the auction in real time, improves the transparency of the process Consequently, bidders bid less aggressively compared with the case of the sealed-bid license auction.

6. Conclusion

The objective of this paper is to examine a number of issues relating to the optimal design of a vehicle quota system, as part of a policy to control urban congestion. The context of our study is Singapore's VQS, introduced in 1990. While the VQS has slowed the growth rate of the vehicle population to about 3% a year, it has also created new uncertainties in the cost of vehicle ownership. Our analysis focuses on three aspects of the VQS: license transferability, sub-categorization and the switch to an open auction format. Singapore's experience with the VQS indicates that the choices made regarding these aspects of the vehicle quota policy have significant impacts on both the efficiency and equity of the system, and therefore, should not be made on the basis of ease of administration alone.

Our analysis shows that the case for or against license transferability is not clear-cut. Although license transferability has led to speculation in vehicle licenses, empirical studies did not find a significant dampening effect on license prices after vehicle licenses were made non-transferable. This does not mean that license transferability should be restored, as the public has argued, to facilitate a more efficient allocation of licenses.   In a theoretical model, we also show that license transferability leads to higher market concentration and has ambiguous effects on industry profitability and social welfare.

On the sub-categorization of the VQS, we found that while it was intended to make the VQS an equitable system, so that buyers of smaller cars do not have to compete with the buyers of larger cars, the sub-categorization policy actually produced highly regressive outcomes. Open category licenses were used mainly for the purchase of larger cars, so that the constraint on their quotas was less restrictive. Moreover, the license prices for larger cars constituted a smaller percentage of car values, compared with the license prices for smaller cars. In principle, a simple *ad-valorem* bidding scheme where bids are percentages of the car values that bidders are willing to pay in license premiums can achieve the equity objective more effectively, and without the distortionary effect of making larger cars more attractive purchases.

Finally, the recent switch to the open online format appears to have the desired effects of improving the transparency of the license auction process. The study by Koh, Mariano and Tse (2003) found that car buyers appeared to bid less aggressively than before and pay a lower price for the vehicle licenses. While the auction revenue collected may be lower under the new open online auction format, the government has likely gained political capital judging by the favorable response to the open online format. Since the reduction in uncertainty over cost of car ownership is an important consideration, it is likely that net social welfare has improved as a result.

Appendix A

Industry Equilibrium with Non-transferable Licenses

To compute the market equilibrium when a quota is imposed, we begin, as is usual in multi-stage games, by considering the second-stage game when licenses have been allocated. Suppose firm *i* successfully obtains k licenses at a cost of *b* per license. Firm *i*'s profit is

$$\Pi_i(p_i,\overline{p}_{-i},b,k)=(p_i-c_i)(\alpha_i-\beta p_i+\theta\overline{p}_{-i})-bk$$

Let $p_i(\overline{p}_{-i})$ solve $\left.\dfrac{\partial\Pi_i(p_i,\overline{p}_{-i},b,k)}{\partial p_i}\right|_{p_i(\overline{p}_{-i})}=0$, so that $p_i(\overline{p}_{-i})=\dfrac{1}{2\beta}\left[\alpha_i+\theta\overline{p}_{-i}+\beta c_i\right]$ and $q_i(p_i(\overline{p}_{-i}),\overline{p}_{-i})=\dfrac{1}{2}\left[\alpha_i+\theta\overline{p}_{-i}-\beta c_i\right]$. If $q_i(p_i(\overline{p}_{-i}),\overline{p}_{-i})\le k$, firm *i* has excess quota licenses and earns a profit of $\Pi_i(p_i(\overline{p}_{-i}),\overline{p}_{-i},b,k)=\dfrac{1}{4\beta}\left[\alpha_i+\theta\overline{p}_{-i}-\beta c_i\right]^2-bk$. However, if $q_i(p_i(\overline{p}_{-i}),\overline{p}_{-i})>k$, firm *i* sets $p_i=\hat{p}_i(\overline{p}_{-i},k)$, where $q_i(\hat{p}_i(\overline{p}_{-i},k),\overline{p}_{-i})=k$, where

$$\hat{p}_i(\overline{p}_{-i},k)=\frac{1}{\beta}\left[\alpha_i-k+\theta\overline{p}_{-i}\right]$$

$$\Pi_i(\hat{p}_i(\overline{p}_{-i},k),\overline{p}_{-i},b,k)=\frac{k}{\beta}\left[\alpha_i+\theta\overline{p}_{-i}-k-\beta(b+c_i)\right]$$

In the first-stage license auction, each firm submits bids before observing $(\alpha_1,...,\alpha_M)$. Each firm's expected profit, with expectation taken over $(\alpha_1,...,\alpha_M)$, is given by

$$\Pi_i^e(\hat{p}_i(\overline{p}_{-i},k),\overline{p}_{-i},b,k)=\frac{k}{\beta}\left[\mu+\theta\overline{p}_{-i}-k-\beta(b+c_i)\right]$$

Let $\varphi_i(\hat{p}_i(\overline{p}_{-i},k),\overline{p}_{-i},b,k)$ denote the marginal profit of acquiring another license:

$$\varphi_i(\hat{p}_i(\overline{p}_{-i},k),\overline{p}_{-i},b,k)\equiv\frac{\partial\Pi_i(\hat{p}_i(\overline{p}_{-i},k),\overline{p}_{-i},b,k)}{\partial k}=\frac{1}{\beta}\left[\mu+\theta\overline{p}_{-i}-2k-\beta(b+c_i)\right]$$

Let p_i^e and $\overline{p}_{-i}^e$ denote, respectively, firm *i*'s conjectures about p_i about $\overline{p}_{-i}$ in the second-stage game. Next, firm *i*'s valuation of the *k*th license is

$$v_i(k,\overline{p}_{-i}^e)=\frac{1}{\beta}\left[\mu+\theta\overline{p}_{-i}^e-2k-\beta c_i\right]\text{ if }k<q_i(p_i(\overline{p}_{-i}^e),\overline{p}_{-i}^e)$$

and zero otherwise. $v_i(k,\overline{p}_{-i}^e)$ solves $\varphi_i(\hat{p}_i(\overline{p}_{-i}^e,k),\overline{p}_{-i}^e,v_i(k,\overline{p}_{-i}^e),k)=0$. Since the license auction is a second-price auction, firm *i*'s optimal bid for the *k*th license is the valuation $v_i(k,\overline{p}_{-i}^e)$. Hence, we can write firm *i*'s demand function for licenses as follows:

$$x_i(b,\overline{p}_{-i}^e)=\begin{cases}\dfrac{1}{2}\left[\mu+\theta\overline{p}_{-i}^e-\beta(b+c_i)\right] & \text{if}\quad b>0\\ q_i(p_i(\overline{p}_{-i}^e),\overline{p}_{-i}^e) & \text{if}\quad b=0\end{cases}$$

where $v_i(x_i(b,\overline{p}_{-i}^e),\overline{p}_{-i}^e)=b$. The aggregate demand function for the quota licenses is given by

$$X(b,\mathbf{\overline{p}}^e)\equiv\sum_{i=1}^{M}x_i(b,\overline{p}_{-i}^e)=\frac{M}{2}\left[\mu+\theta\overline{p}^e-\beta(b+\overline{c})\right]$$

where $\mathbf{\overline{p}}^e=\{\overline{p}_{-1}^e,...,\overline{p}_{-M}^e\}$ and $\overline{p}^e\equiv\frac{1}{M}\sum_{i=1}^{M}\overline{p}_{-i}^e$. Hence, the auction price of a license is given by

$$b(\mathbf{\overline{p}}^e,Q)=\frac{1}{\beta}\left[\mu+\theta\overline{p}^e-\frac{2}{M}Q-\beta\overline{c}\right]$$

where $X(b(\mathbf{\overline{p}}^e,Q),\mathbf{\overline{p}}^e)=Q$. Inserting the auction license price into $x_i(b,\overline{p}_{-i}^e)$, the number of quota licenses obtained by firm *i* can be shown to be

$$x_i(b(\mathbf{\overline{p}}^e,Q),\overline{p}_{-i}^e)=\frac{1}{2}\left[\theta\left(\overline{p}_{-i}^e-\overline{p}^e\right)-\beta(c_i-\overline{c})\right]+\frac{Q}{M}$$

Let p_i^N denote the equilibrium price of firm *i* after licenses have been allocated. Utilizing (1) ,

$$p_i^N=\frac{1}{\beta}\left[\alpha_i+\theta\overline{p}_{-i}^{+}-\frac{1}{2}\left[\theta\left(\overline{p}_{-i}^e-\overline{p}^e\right)-\beta(c_i-\overline{c})\right]-\frac{Q}{M}\right]$$

where $\overline{p}_{-i}^N=\frac{1}{M-1}\sum_{j=1,j\neq i}^{M}p_j^{+}$. We focus on the consistent conjectures market equilibrium, i.e. we require that firm *i*'s conjectures, p_i^e and $\overline{p}_{-i}^e$, are the same as the set of equilibrium market prices. The conjectures that are consistent with the market equilibrium can be shown to be

$$p_i^e=\frac{1}{\beta-\theta}\left[\mu-\frac{Q}{M}\right]+\frac{(M-1)\beta(c_i-\overline{c})}{2(M-1)\beta+\theta}\quad;\quad\overline{p}_{-i}^e=\frac{1}{\beta-\theta}\left[\mu-\frac{Q}{M}\right]-\frac{\beta(c_i-\overline{c})}{2(M-1)\beta+\theta}$$

To ease notation, we denote $x_i(b(\mathbf{\overline{p}}^e,Q),\overline{p}_{-i}^e)$ by q_i^N and $b(\mathbf{\overline{p}}^e,Q)$ by b^N. Similarly, let $\Pi_i^N\equiv\Pi_i(p_i^N,\overline{p}_{-i}^N,b^N,q_i^N)$ denote the profit of firm *i*. Utilizing the consistent conjectures given in p_i^e and $\overline{p}_{-i}^e$ above, we obtain the following results for the *ex-post* industry equilibrium:

$$b^N=\frac{\mu}{\beta-\theta}-\overline{c}-\frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}$$

$$p_i^N=\frac{1}{\beta-\theta}\left[\overline{\alpha}-\frac{Q}{M}\right]+(M-1)\left[\frac{\alpha_i-\overline{\alpha}}{(M-1)\beta+\theta}+\frac{\beta(c_i-\overline{c})}{2(M-1)\beta+\theta}\right]$$

$$q_i^N=\frac{Q}{M}-\frac{[(M-1)\beta+\theta]\beta(c_i-\overline{c})}{2(M-1)\beta+\theta}$$

$$\Pi_i^N=\frac{1}{\beta}\left(q_i^N\right)^2+q_i^N\left[\frac{(M-1)(\alpha_i-\overline{\alpha})}{(M-1)\beta+\theta}\right]$$

Taking expectations over $(\alpha_1,...,\alpha_M)$ and $(c_1,...,c_M)$, we obtain the results in Proposition 1.

Industry Equilibrium with Transferable Licenses

When licenses are transferable, firms must still bid for the transferable licenses before they observe $(\alpha_1,...,\alpha_M)$. The auction price of a license in the first-stage auction game therefore will still be b^N, as given in Proposition 1, so that each firm receives an initial allocation of licenses, as given in q_i^N above. However, the secondary market price, which we shall denote b^T, will be a function of $\bar{\alpha}$, instead of μ, since secondary market trading takes place when $\bar{\alpha}$ is known. Firm *i* will buy more quota licenses if $(p_i - c_i)$ exceeds b^T. Conversely, it would sell a license if $(p_i - c_i) < b^T$. Firm *i*'s profit is

$$\Pi_i(p_i, \bar{p}_{-i}, b^T, k) = (p_i - c_i - b^T)(\alpha_i - \beta p_i + \theta \bar{p}_{-i}) + (b^T - b^N)q_i^N$$

Let $p_i(\bar{p}_{-i}, b^T)$ and $q_i(p_i(\bar{p}_{-i}, b^T), \bar{p}_{-i}, b^T)$ denote the optimal price and sales, respectively, for firm *i*, where $p_i(\bar{p}_{-i}, b^T) = \frac{1}{2\beta}\left[\alpha_i + \theta\bar{p}_{-i} + \beta(b^T + c_i)\right]$ and

$$q_i(p_i(\bar{p}_{-i}, b^T), \bar{p}_{-i}, b^T) = \frac{1}{2}\left[\alpha_i + \theta\bar{p}_{-i} - \beta(b^T + c_i)\right].$$

Since $\sum_{i=1}^{M} q_i(p_i(\bar{p}_{-i}, b^T), \bar{p}_{-i}, b^T) = Q,$ this allows us to solve b^T. Firm *i's* profits is

$$\Pi_i(p_i(\bar{p}_{-i}), \bar{p}_{-i}, b^T, k) = \frac{1}{4\beta}\left[\alpha_i + \theta\bar{p}_{-i} - \beta(b^T + c_i)\right]^2 + (b^T - b^N)q_i^N$$

Let p_i^T, q_i^N and Π_i^T denote, respectively, the equilibrium price, final allocation and profits of firm *i.* It is then straightforward to derive the market equilibrium with transferable licenses

$$b^T = \frac{2\beta - \theta}{M\beta(\beta - \theta)}\left[\sum_{i=1}^{M} q_i^* - Q\right]$$

$$p_i^T = \frac{1}{\beta - \theta}\left[\bar{\alpha} - \frac{Q}{M}\right] + \frac{(M-1)\left[\alpha_i - \bar{\alpha} + \beta(c_i - \bar{c})\right]}{2(M-1)\beta + \theta}$$

$$q_i^T = \frac{Q}{M} + \frac{(M-1)\beta(\alpha_i - \bar{\alpha}) - \left[(M-1)\beta + \theta\right]\beta(c_i - \bar{c})}{2(M-1)\beta + \theta}$$

$$\Pi_i^T = \frac{1}{\beta}\left(q_i^T\right)^2 + \left[\frac{\bar{\alpha} - \mu}{\beta - \theta}\right]\left\{q_i^T - \frac{(M-1)\beta(\alpha_i - \bar{\alpha})}{\left[2(M-1)\beta + \theta\right]}\right\}$$

Again, taking expectations over $(\alpha_1,...,\alpha_M)$ and $(c_1,...,c_M)$, we obtain the ex-ante equilibrium given in Proposition 2.

Appendix B

Social Welfare Functions

For aggregate industry sales of Q and a given set of cost and demand realizations, let $V(Q)$ denote the social welfare function, which comprises a weighted sum of consumer surpluses, firm profits and license auction revenue. Since demand curves are linear, it is routine to verify that the consumer surplus associated with the purchase (and ownership) of car brand i under non-transferable and transferable licenses are, respectively, $S_i^N = \frac{1}{2\beta}\left(q_i^N\right)^2$ and $S_i^T = \frac{1}{2\beta}\left(q_i^T\right)^2$. With δ_1, δ_2 and δ_3 being the weights attached to the consumer surpluses, firm profits and license auction revenue, we can derive the following results:

Non-transferable license:

$$\begin{aligned} V^N(Q) &= \delta_1 \sum_{i=1}^{M} S_i^N + \delta_2 \sum_{i=1}^{M} \Pi_i^N + \delta_3 b^N Q \\ &= \frac{1}{2\beta}(\delta_1 + 2\delta_2)\sum_{i=1}^{M}\left(x_i^N\right)^2 - \frac{(M-1)\beta}{2(M-1)\beta+\theta}\delta_2 \sum_{i=1}^{M}(\alpha_i - \bar{\alpha})(c_i - \bar{c}) \\ &\quad + \delta_3\left[\frac{\mu}{\beta-\theta} - \bar{c} - \frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}\right]Q \end{aligned}$$

Transferable license:

$$\begin{aligned} V^T(Q) &= \delta_1 \sum_{i=1}^{M} S_i^T + \delta_2 \sum_{i=1}^{M} \Pi_i^T + \delta_3 b^N Q \\ &= \frac{1}{2\beta}(\delta_1 + 2\delta_2)\sum_{i=1}^{M}\left(x_i^T\right)^2 + \delta_3\left[\frac{\bar{\alpha}}{\beta-\theta} - \bar{c} - \frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}\right]Q \end{aligned}$$

Taking expectations across $(c_1,...,c_M)$ and $(\alpha_1,...,\alpha_M)$, the *ex-ante* social welfare functions, are:

$$\begin{aligned} W^N(Q) = {} & \frac{1}{2}(\delta_1 + 2\delta_2)\left[\left\{\frac{(M-1)\beta+\theta}{2(M-1)\beta+\theta}\right\}^2 \beta(M-1)Var(c) + \frac{Q^2}{\beta M}\right] \\ & - \frac{(M-1)^2\delta_2}{2(M-1)\beta+\theta}\beta Cov(\alpha,c) + \delta_3\left[\frac{\mu}{\beta-\theta} - \phi - \frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}\right]Q + \delta_4\eta Q^2 \end{aligned}$$

$$\begin{aligned} W^T(Q) = {} & \frac{1}{2}(\delta_1 + 2\delta_2)(M-1)\beta\left[\left\{\frac{M-1}{2(M-1)\beta+\theta}\right\}^2 Var(\alpha) + \left\{\frac{(M-1)\beta+\theta}{2(M-1)\beta+\theta}\right\}^2 Var(c)\right] \\ & + (\delta_1 + 2\delta_2)\frac{Q^2}{2\beta M} - (\delta_1 + 2\delta_2)\left\{\frac{M-1}{2(M-1)\beta+\theta}\right\}^2\left[(M-1)\beta+\theta\right]\beta Cov(\alpha,c) \\ & + \delta_3\left[\frac{\mu}{\beta-\theta} - \phi - \frac{(2\beta-\theta)Q}{M\beta(\beta-\theta)}\right]Q + \delta_4\eta Q^2 \end{aligned}$$

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