# Individual tradable permit market and traffic congestion: An experimental study

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**Abstract**

This paper investigates the potential of an individual tradable permit system in an experimental two-sided repeated double auction market to overcome over-consumption through road demand management. The evaluation of this system shows that traders exhibit strong dependence on reservation price and there are significant transfers of permit from low value users to high value users. During peak hours, the permit price increases owing to high demand, so the cost of using the road is high during congestion. This creates incentive for low value drivers to postpone their trips and resell permits in the peak hours to gain profit. The results show the delayer pays principle, in which drivers who value highly have to pay drivers who are willing to stay off the road during peak hours.

*JEL Classification*: C91, D61, R41

*Keywords*: Individual tradable permit, Congestion, High value and low value drivers, Allocative efficiency

# 1. Introduction

Increasing social and environmental stress caused by ever-growing levels of road usage has created the urgent need for efficient and effective transportation policy. The many policies employed in different countries take a variety of forms and have different implications. Verhoef et al. (1996) categorized these policies as (1) direct demand management aimed at directly reducing the demand for road transport through pricing, (2) indirect demand management aimed at shifting the demand curve inwards by affecting the factors underlying the derived demand and (3) supply side-oriented policies. For direct demand management, the main targets are the road users themselves but supply side-oriented policies target automobile manufacturers and fuel industries. Indirect demand management refers to wider application in areas such as urban planning and public transport policies. This paper is chiefly interested in direct demand management through permit trading; the implementation and implications of the policies in the first category will be briefly discussed and evaluated. [1]

Direct demand management policy aims to reduce road demand in two different ways; vehicle ownership and road usage. Examples of vehicle ownership are the Singapore vehicle quota system (VQS) and car ownership taxation in Hong Kong. Such schemes affect car ownership more than actual car usage and therefore charges on car ownership can only affect congestion minimally except for the positive environmental impact of new vehicle production and the rate of disposal of worn out vehicles (Verhoef et al. (1997) ; May (1992)).

In directly policing the road usage, Goddard (1997) suggests that drivers should be allowed to drive only on certain days. Drivers should be allowed to choose for themselves their actual driving days, and use other transportation modes for the rest of the week. The impact of this policy on total usage, however, may be very small as drivers have an incentive to save trips for future usage. As a consequence, total reduction in

[1] Interested readers should refer to the article by Verhoef et al. (1996) for more information about indirect demand management and supply side-oriented policies.

congestion may exceed the targeted level during the driving days and direct demand management through pricing, such as Malaysia's earmarked tax or road toll collection, leaves the total road usage unaffected.

A tax policy fixes the price of the usage and leaves the quantity to be determined by the market. Since road users pay a fixed price, the external cost is underrepresented by the price, especially during peak hours when everyone wants to reach a destination at the same time. Another form of direct demand management is gasoline or carbon tax. For the tax to reflect the true individual marginal cost is not possible and it has to be done through trial and error (Wadud (2010)). The mechanism has been proven to be ineffective in reducing car usage because road users do not base their consumption on fuel tax saving (Graham and Glaister (2002)), its effectiveness is diminished when the price of fuel decreases (Raux (2004)) and the price elasticity of fuel demand is inelastic in the short to medium run (Raux and Marlot (2005)).

The policies mentioned above do not provide direct incentive to road users to reduce road consumption. A decentralized market by means of a personal tradable permit system could, however, insure quantitative achievement of congestion level at minimum cost. The system is effective particularly when one does not possess full information on individual cost of not using the road (Raux (2008)) (such cost refers to the value drivers place on using the road; cost and value are used interchangeably in the paper). The regulator can decide on a road usage level and allow the market to trade on the permit price. Since the price of the permit depends on the number of permits available in the market and the overall demand, any road users whose cost of not using the road is more than the permit price would buy it but would sell the permit if their cost of not using the road was lower than the permit price. Therefore, this possibility of reselling permits in the market provides incentive for road users to adjust driving behavior. Permits would be sold by those whose value from using the road is very low to others who place a high value on using the road.

Many applications of the individual tradable permit system in road transport combine it with other tools or treat congestion as a by-product of the main target. For example, in Raux and Marlot (2005) fuel consumption is allocated according to the number of permits given to road users. The permit corresponds to the right to emit $CO_2$ equivalent to a liter of fuel. The permit can be transacted in the open market and its cost is additional to the price of fuel. This encourages change to more fuel-efficient and environmentally friendly vehicles but does not reduce total road usage. The attempt to phase down lead in gasoline is a classic example of successful application of tradable permits (Hahn and Hester (1989)). In car ownership, the trading of permits to own a car involves auctions of certificates of entitlement. The number of permits is determined by annual traffic condition and road capacity (Koh and Lee (1994)). In controlling road usage, Verhoef et al. (1997) propose the use of tradable permits of vehicle miles. Under this scheme, each individual receives a certain number of miles of travel which can be traded in the open market. The disadvantages of the system, however, are the costly implementation and monitoring of consumption.

In this paper, we consider a simple double auction market for trading driving rights to mitigate the problem of over-consumption in road usage directly. Our aim is to investigate the potential of tradable permit systems in allocating scarce resources. We conduct this investigation in an experimental set-up.

In controlling road usage, the level of consumption reduction is guaranteed by the number of permits allocated in the market. In our experiment, the permits are given free to the drivers. This inefficiency is corrected when drivers can trade the permit in an auction market. Drivers will not drive (sell permit) as long as the permit price is higher than the cost of not driving. Drivers will drive (buy permit) when the cost is higher than the price of the permit. This self-determining of costs helps to allocate the permit according to the cost or willingness to pay of the drivers. In the main result in section 3, we observe a significant number of transactions from low cost sellers to high cost buyers. The system proves to be an effective allocative mechanism in the peak hours when those with high willingness to pay (those with high costs of not using the road) have to pay a higher price to use the road than those who are more willing to postpone trips. Our result is similar to the delayer pays principle, in which drivers who value consumption most pay other drivers who are willing to postpone their trips (Rafferty and Levinson (2009)).

This paper is divided into five sections. The next section explains the experimental designs and set-ups, section 3 discusses the theoretical predictions of the experiment, section 4 discusses the results of the experiment and section 5 concludes.

## 2. Experimental designs and procedures

We conducted a two-sided repeated double auction market with two-way traders. There were total of twelve periods in the double auction market; the first two periods were trials and are not reported. Each auction period lasted for 180 seconds. Thirty-three graduate students from different faculties at the Universiti Sains Malaysia participated in the experiment. Each period of the experiment consisted of three stages: (1) permit allocation, (2) auction market and (3) decision to use the permit. The auction market was introduced to correct for any initial misallocation of permits in the first stage. Banking of permits was not allowed in the experiment.

In each period in the allocation stage, the "government" issued permits randomly to the drivers for free. Each driver was initially endowed with a one-off $20 at the beginning of the experiment and was told the "value" of using a road, which was drawn independently for each period from a discrete uniform distribution over the range of [1,30]. The value was a private value and traders did not know the values of other traders.

In the second stage, if the driver decided to make a trip, s/he needed a permit which s/he had to buy from the auction market if s/he was not allocated a permit in the first stage.

If the driver decided to sell the permit to other drivers in the auction market, the price had to cover the cost of not using the road. The introduction of the auction market corrected the misallocation in the first stage by allowing transactions between high value buyers and low value sellers. If these transactions occurred, the exchange surplus, i.e. *V- cost*, which consisted of buyers' surplus *V - P* and sellers' surplus *P - cost*, could be maximized. If a buyer decided to resell the permit, the price had to cover both the cost of not using the road (i.e. the value) and the cost of purchase of the permit. Any surplus or deficit was added to the subject's income and paid at the end of the experiment.

Trading occurred in the auction market when buyers (sellers) could submit bids (ask). The system only allowed quotes which improved the current proposed trade, i.e. higher bids or lower asks. Every trade was based on the current bid and ask price, and every buyer (seller) could accept an ask (bid) and the transaction was executed immediately. A transaction immediately removed both the standing market bid and the ask. Subjects had full access to the traded prices for that period but not to the previous periods. Any surplus or deficit incurred was announced at the end of each period.

In the final stage, the drivers had to decide whether to drive or not to drive. If the decision was not to drive, the driver earned zero profit at this stage. If s/he decided to drive, s/he was paid according to his/her valuation of using the road.

The experiment was conducted in the experimental lab in the School of Social Science, Universiti Sains Malaysia. Upon entering the lab, the subjects were provided with the instructions and rules of the experiment. The experimenter then explained and gave exercises to the subjects. The experiment started after all the exercises were answered correctly by the subjects. The experiment was programmed and conducted with z-Tree experimental software (Fischbacher (2007)).

## 3. Theoretical predictions

The theoretical model used to predict the results of the experiment was Bayesian Game Against Nature (BGAN), which derives from the Bertrand Perspective from Friedman (1984). The experimental predictions are based on three observables as follows:

*Allocative Efficiency*

Traders' action is based on a reservation price to maximize final period expected utility, given the auction rules and information. The reservation price derives from the valuation of an asset. The actions that can increase trader utility are: (1) sell at market bid if it exceeds one's valuation plus the price at which s/he bought the permit, (2) buy at market ask if it is below the buyer's valuation of the permit, (3) raise the market bid if a trader does not own it and it is below the valuation of the permit and (4) reduce the market ask if a trader does not sell it and it is above the cost of the permit.

Exchange occurs as long as the buyer's valuation exceeds the seller's cost and stops when the seller's cost is higher than the buyer's valuation of the permit. To illustrate the trading behavior, Figure 1 shows the exchange whenever valuation exceeds cost.[2] Intra-marginal trade or mutual profitable exchange occurs between buyers 1, 2, 3, 4 and 5 and sellers 12, 13, 14, 15 and 16. If buyer 2 buys from seller 14, buyer 2 can resell the permit at least at the valuation level. The arrow in the Figure shows buyer 2 reselling the permit at a price at least equivalent to the valuation level. Seller 14 can buy again in the market and bid the most at the valuation level. For example, if the equilibrium price interval is [15, 16], if buyer 2 buys at price 15 from seller number 14 and his/her own valuation is 25, buyer 2 would resell the permit at least at the price of 25. Seller 14 whose valuation is 10, would then buy another permit from the market costing no more than the price of 10. This same process of buying/selling based on reservation price or valuation continues as long as cost of selling remains below the valuation of the buyers. This mechanism insures that high value traders purchase from low value traders and that permits are allocated from low cost sellers to high value buyers.

[2] The demand curve depicts the valuation and the supply curve represents the cost of sellers.

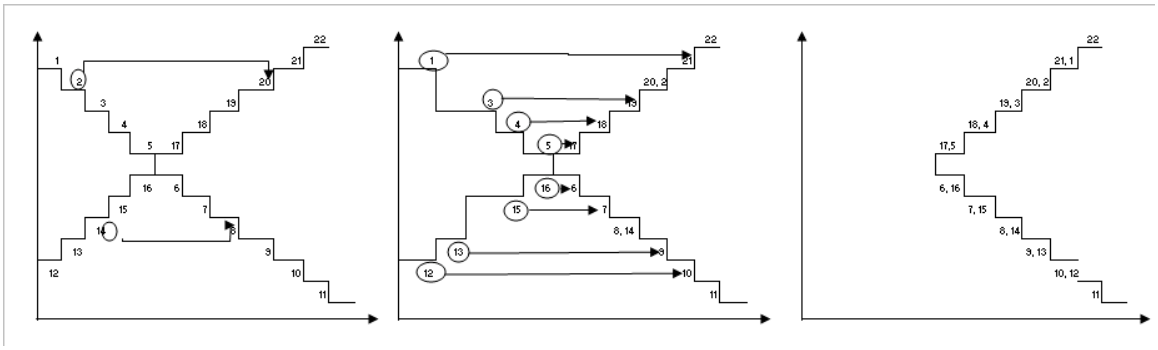

Figure 1: Theoretical demand and supply of permits

*Sources of inefficiency*

Allocative efficiency can fall short of 100% when (1) transactions are executed by extra-marginal traders and (2) mutually profitable trades are not executed. For example, in Figure 2, allocative efficiency predicts that trades occurred between the six highest value buyers, namely B10, B13, B15, B27, B20 and B6, and the six lowest cost sellers, namely S30, S2, S10, S13, S15 and S21.[3] Extra-marginal trade occurs if lowest value buyers manage to trade and mutually profitable trade is not executed if the six highest value buyers do not buy from low cost sellers.

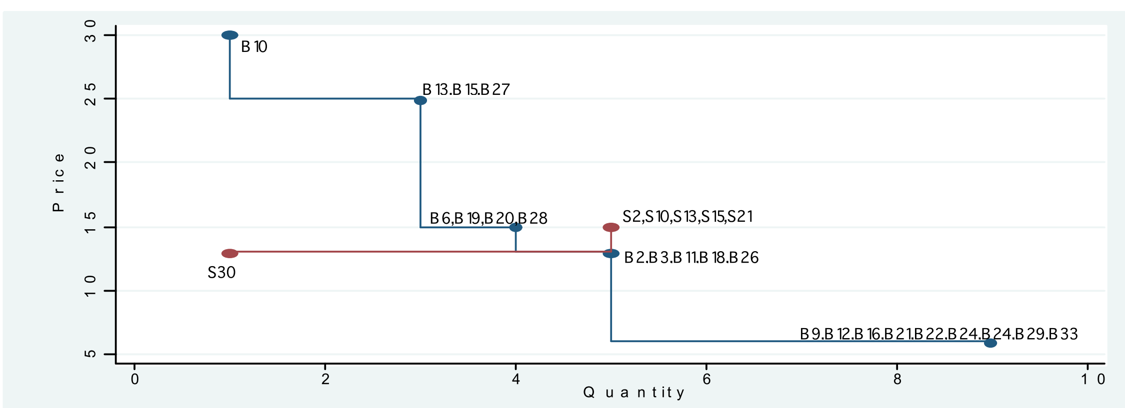


Figure 2: The demand (Value) and supply (Cost) in period 1

[3] Allocative efficiency is 45 when buyers B10, B13, B15, B27, B20 and B6 bought from sellers S30, S2, S10, S13, S15 and S21.

*Price change autocorrelation*

When traders base their reservation on market bid and ask prices, their beliefs about the market price will change according to the new bids and asks in the market. This leads to positive autocorrelated transaction price changes. According to Kagel (1996) and Friedman (1984), the serial correlation in price change is enhanced when traders gain experience.

# 4. Results

*Allocative efficiency*

Following Smith (1962) and Cason and Friedman (1996), allocative efficiency is defined as total profits earned divided by the maximum total profit that could have been earned by all the traders, or the sum of producer and consumer surplus. The surplus is maximized when permits are allocated to highest value traders from lowest cost traders. (Weitzman, 1974).

In the allocation market, as the government did not know the value of each trader, the permits were given randomly to the drivers. This did not only allow high value traders to own permit but also the low value traders. This misallocation was corrected in the auction market when high value traders offered a price higher than the cost of the permit owner.

The reallocation of permit in the auction market works as follows. A trader will demand a permit if the price is lower than his/her value. If the price offered by the trader is higher than the cost of the permit owner, the owner of the permit is willing to sell the permit. Efficiency is achieved when both buyer and seller earn positive surplus.

Figure 3 shows the difference in ownership of permits before and after the auction market. In the first allocation stage, drivers in value categories 1 to 15 owned a total of 42 permits compared with 47 permits in categories 16 to 30. This is corrected after the auction when the former category of traders owns only 26 permits and the latter owns 63 permits.

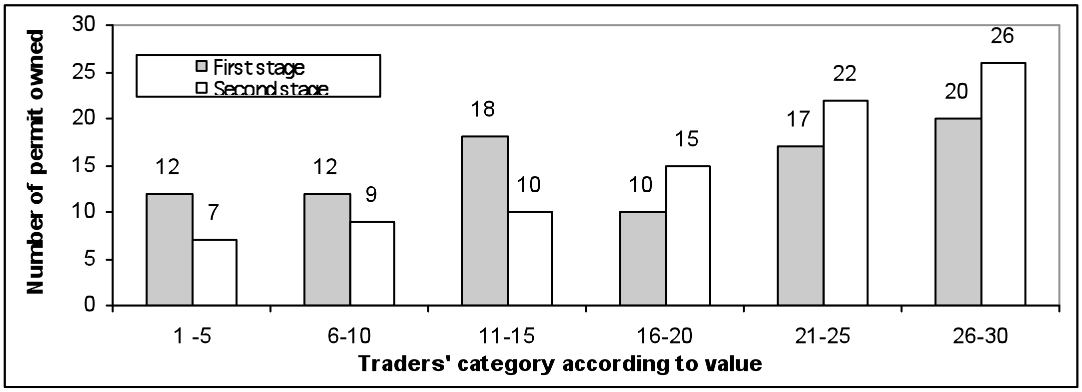


Figure 3: Overall ownership of permits in allocation stage (first stage) and auction (second stage)

The total trading volume meant 71 permits exchanged hands. Sixteen permits were sold from high value category traders to low value category traders, 40 permits from low value to high value traders and fifteen permits were in the same category. The average market price of the permit for the whole period was 16.01 ECU.

*Sources of inefficiency*

Table 1 breaks down the efficiency losses in each period owing to (1) extra-marginal trades and (2) non-execution of mutually profitable trades. The non-trade inefficiency is more common than inefficiency owing to extra-marginal trade. The table also highlights that neither type of inefficiency decreases with traders' experience.

Table 1 : Decomposition of efficiency loss

| Period | Average Efficiency | Percent loss due to extra-marginal trades | Percent loss due to profitable trades not executed |
|---|---|---|---|
| 1 | 0.27 | 0.33 | 0.67 |
| 2 | 0.45 | 0.19 | 0.81 |
| 3 | 0.41 | 0.05 | 0.95 |
| 4 | 0.71 | 0.1 | 0.9 |
| 5 | 0.55 | 0.4 | 0.6 |
| 6 | 0.79 | 0.12 | 0.88 |
| 7 | 0.42 | 0.37 | 0.63 |
| 8 | 0.49 | 0.21 | 0.79 |
| 9 | 0.56 | 0.19 | 0.81 |
| 10 | 0.79 | 0.16 | 0.84 |

*Autocorrelation of price*

Figure 4 summarizes the market outcomes in each trading period. The endpoints of each vertical line indicate maximum and minimum transaction prices, and the bar ‘ - ’ on the right of each vertical line represents the final transaction. Autocorrelation between current price and previous price within each period and market efficiency are shown below the horizontal x-axis. The estimated autocorrelation of prices is significantly negative in the early periods and becomes positive when traders gain experience in the later periods. The autocorrelation of price dies out after period 6, however. This is because traders gain more observations and change their beliefs less in response to new bids and asks. It can also be owed to the heterogeneity of traders (Cason and Friedman (1996)).

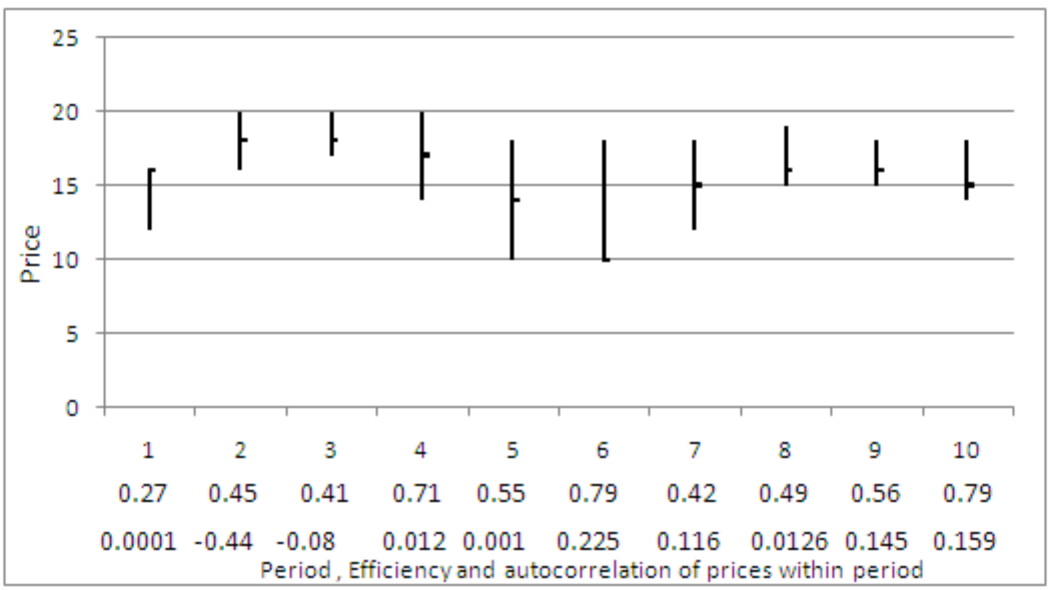


Figure 4: Formation of prices and efficiency levels across periods

# 5. Conclusion

This paper explores the potential of individual permit trading in traffic congestion during peak hours. Regulators can determine congestion targets through deciding the number of permits available in the market. The price of the permit is determined by the demand and supply in the auction market. The price is allowed to fluctuate according to over-demand at a particular time; higher demand in peak hours causes the permit price and the cost of using the road to increase. During off-peak hours, however, the cost is low and drivers pay a lower price.

From the equity perspective, trading in the auction market allows revenues to be returned to drivers who decide to car pool or use other alternative routes. The main weakness in the marginal cost pricing is its regressivity when the revenues are not returned, as it benefits those with high value of travel time (Evan (1992) and Arnott et al. (1994)). This redistribution concern is to some extent overcome by the revenue earned through buying and reselling the permits in the auction market.

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