

The Design of Transportation Service Auction under Time-cost Environment

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Abstract: Motivated by the taxi refusal problems, this paper presents an experimental study of demand-supply matching for taxi services through double auction system, which is against the existing service of a fixed surcharge. Due to a typical design of double auction is not suitable for taxi services, we examined particularly the information content for user interaction, taxi driver and passenger, and conducted laboratory experiments to investigate the effect of different levels of information content exposed to the users. The results have shown that the fixed surcharge policy is outperformed by the variable surcharge policy through double auction system. In addition, there is a significant effect of time-cost constraint, and providing the informative content to users lead to a better market efficiency.

Keywords: Transportation service, double auction, time-cost, information content, laboratory experiment

1. INTRODUCTION

Taxis are among the efficient transport modes in Bangkok and many big cities. However, a statistics revealed that taxi is the most complained among all public transport services in Thailand. In particular, taxi refusal complaint has risen from 16.5% in 2010 to 47.4% in 2012 (Department of Land Transport, Thailand, 2012). Promprechawut (2006) reported that 83.5 percent of interviewed taxi passengers in Bangkok indicate the need for taxi service improvement and the major problem encountered is taxi refusal, particularly when the trip destination is in a congested area. Taxi refusal problem is also a major concern in New York (Sonny, 2006) and in Australia (Latitude insights 2012). Two possible explanations to taxi refusal are due to 1) the problem of taxi demand and supply matching, the taxi fare is only regulated by the government (Sonny, 2006) and 2) financial motivation (disincentive) of providing a service: upon dropping off passenger, taxi drivers do not want to get stuck in traffic or return with an empty cab (Schaller Consulting, 2006). Both result in taxi drivers getting revenue that may not be sufficient compared to the service cost. Bruce and Jessop (2003) reported a difficulty of getting taxi services in Australia. About half of the failures to get the services are those attempted to get a taxi by calling a taxi company. A common problem is that passengers are told either taxi is not available or the taxi is on its way, and then for it not to show up. Based on the results of these studies, the situation is expected to be even worse when the above two mentioned situations are met: trip destination is in a congested area (or remote area with low demand) and when the passenger has limited access to get taxi services, but only possible by means of calling to the taxi company. The latter situation is quite common in Bangkok as many people live far away from the main streets, which is difficult for them to get a taxi by means of hailing. In this case, passengers have to

call the taxi company and pay a fixed surcharge (20 Baht) in addition to the normal metered fare. Even though the drivers can earn more from the additional surcharge, often passengers still could not get the taxi.

Instead of using a fixed surcharge, we assume that a variable surcharge policy through online double auction system is applied to such problems for those passengers who have limited access to taxi services and when taxi drivers are reluctant to provide services. As shown in Figure 1, the passengers can offer a high surcharge if they are in need of taxi services, while taxi drivers can ask for a desired surcharge to balance their disincentive. This is motivated by the past research showing that double auction is highly efficient and the market tends to reach its demand-supply equilibrium (Hagel and Roth, 1997; Soberg 2002). Moreover, there has been an increasing attention on the application of online auction to transportation and logistics services. To name a few, Rodrigo (2007), Sangwareetip and Indra-Payoong (2008) examined the potential benefit of double auction for reducing backhaul transport costs. Song and Regan (2003) investigated the benefits for shippers and carriers when a combinatorial auction for transportation service procurement is introduced. In an attempt to tackle a congestion problem, Raux (2007), Yang and Wang (2011), Ch'ng and Tang (2012) considered double auction of driving rights (or quotas) as an alternative approach to congestion pricing. Results from these studies have shown potential benefits of using auction in transportation and logistics sectors.

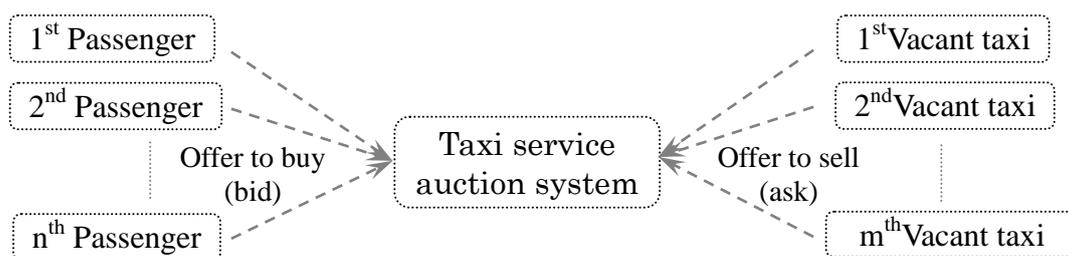


Figure 1. The proposed double auction scheme for taxi service

In this study, we investigate whether or not the variable surcharge policy based on double auction system is more efficient than the fixed surcharge policy, and the institutional design of double auction for taxi services is also examined. We refer to institutional design of auction as the design of which auction format to use as well as what information content to show on the user interface. Unlike commodity auction in which buyers and sellers can delay their offers in expectation of higher payoff in the future, for a service auction, delaying the trip, not getting taxi, or not getting passengers may incur some associated costs. Throughout this paper, we term these costs as a time-cost. With different nature, the same design of the information content for commodity auction may not be suitable when applied to taxi service auction under time-cost environment. Therefore, several research questions arise: 1) whether or not individual bidding strategies under time-cost constraint is similar to those without time-cost, 2) whether or not the efficiency of the market is the same with and without time-cost, and 3) what institutional design will provide more desirable properties under time-cost environment.

To clarify these questions, we conducted a double auction experiment to investigate the effect of different levels of information content on individual bidding strategies as well as on the aggregate market efficiency under time-cost environment. In addition, the efficiency of the variable surcharge policy is evaluated in comparison to that of the fixed surcharge. In section

2, related literatures are reviewed. Section 3 describes in details about the experimental design. Section 4 describes hypotheses of the research. Section 5 compares the market efficiency between the variable surcharge and the fixed surcharge policies. Section 6 describes descriptive statistics of the results, and investigates the effect of time-cost and information levels on individual transaction price as well as some aggregate indicators that measure market efficiency. Finally, conclusions and discussions are given.

2. RELATED LITERATURE

We refer to the problem of auction institutional design as the design of which auction format to use as well as what information content to show. Examples of different types of auction formats are the buyer bid auction, posted offer auction, Dutch or descending auction, English or ascending auction, first-price auction, second-price auction, continuous double auction, clearing house double auction, etc. Among several auction formats, Hagel and Roth (1997) reported that double auction performs better than other auctions. Soberg (2002) compared three formats of auction: bid auction, offer auction, and double auction. It was found that double auction prices tend to be higher than offer and bid auction prices. Noted that our focus is not on the auction format but rather on the information content, considering about what information to show to the passengers and taxi drivers at the time of bidding.

The effect of information on bidding strategies, price discovery, as well as on the market efficiency is also a focus in past research, mostly in the field of finance and stock exchange. Most of them focus on the effect of information contained in limit order book, defined as a database that records all outstanding quotes (bids and asks) as well as their corresponding volumes, sorted so that the best quotes are on the top for both the bid and the ask sides. It is only recently that this information is offered to the public in many stock and currency trade markets. Cao *et al.* (2009) considered the information content of a limit order book using data from the Australian Stock Exchange. They found that the information on the best bid, best offer, and the last transaction prices contribute to about 78% to price discovery while the rest comes from the information contained in all other parts of the book. Harris and Panchapagesan (2005) also found that information on limit order book is informative for future price movements. Li and Zhang (2009) compared the information content before and after the top price levels shown to public are increased from three to five levels in Chinese stock market. They found that the fourth and the fifth price levels are also informative to price discovery process. Anufriev *et al.* (2011) investigated the effect of information on market efficiency. Under full information of the action of others, they found that bidders tend to submit order at the price similar to the previously observed trading price. Under no information, however, bidders tend to submit their valuations/costs and this results in higher price volatility, and market efficiency was comparable in both cases. Cao *et al.* (2008) studied the effect of information on bidding strategies using data from the Australian Stock Exchange. They found that the best bid and best offer always affect order submissions, cancellations, and amendments while the rest of the book mostly affects cancellations and amendments. From these results, it is observed that the more the information, the more contribution to price discovery. Moreover, bidders act differently according to types of information they obtained. This also results in different price patterns, but there is no evidence in discrepancy in the market efficiency.

Economic laboratory experiment is a useful tool to evaluate policy proposal as well as a testing ground for institutional design (Smith, 1962, 1994; Friedman and Cassar, 2004). Apart from economics, it has also been applied in a broad range of fields, including food policy

(Hellyer *et al.* 2012), emission control and trading (Cason and Gangadharan, 2011; Cong and Weic, 2012), fishery (Higahsida and Managi, 2010; Moxnes, 2012) irrigation (Cummings *et al.* 2004). However, to our best knowledge, auction with time-cost constraint is not a major concern in the past research, perhaps due to the nature of typical commodity market. Katok and Kwasnica (2008) investigated the effect of timing on revenue in descending auction and later, Kwasnica and Katok (2009) studied the effect of timing on jump bidding in ascending auction. Both were conducted under the premise that time is a valuable resource, and time-cost was treated only implicitly in their experiments, one is by clock speed and another is whether the number of experimental period in one session is fixed or not. In the descending auction, they found that clock speed can have a significant effect on price. In the ascending auction, it was found that bidders respond by bidding larger increments when time is more valuable. However, they reported that time-cost does not have an effect on economic performance. Similar result in jump bidding was also found by Peng *et al.* (2009), when time-cost is high, jump bidding would be preferred. Note that all of these results were obtained under some types of one-sided auction, but not under double auction market.

3. EXPERIMENTAL SETUP

We conduct laboratory experiment of double auction of taxi service and investigate the effect of the information content. A single zone-to-zone pair is considered for the taxi service auction. Based on their private valuation, passengers can bid through an online marketplace a higher surcharge if they are in need of taxi services, while drivers can also ask through an online marketplace a desired surcharge to cover their operation costs.

The experiment is programmed with the z-Tree software (Fischbacher, 2007). It is conducted at Suranaree University of Technology, Thailand. Subjects are undergraduate and master students from different faculties and they have never participated in economics experiment before. Each session conducted with 12 subjects randomly assigned into a group of 6 passengers (hereafter called "buyers") and a group of 6 taxi drivers (sellers) upon arrival at the laboratory, and also assigned only a single role as either a buyer or a seller. In one session, there are 15 consecutive auction periods and each lasts 210 seconds. However, actual time spent in each period can be shorter if all offers are matched earlier.

At the beginning of each session, participants are first given the experimental instructions to read. To make sure the participants understand the trading rules, the experimenter repeats orally, and provides exercise to check the subject understanding. Afterwards, one training period is conducted separately before start running any experimental session and results of the training period are not reported.

3.1 Experimental Design

Our objective is to investigate the effect of two main treatment variables: 1) the level of information content and 2) the time-cost constraint. This experiment consists of six sessions, using 3x2 experimental design as shown in Table 1.

Basically, the computer screen of each subject shows the information of subject's private value (or cost), the remaining time in seconds, the input box where subject can submit the offer, the status of offer (either offer is already matched or not), and some additional information depending on which session is under conduction. Buyers and sellers can submit their offer for the surcharge and the system replies in real-time to them whether their offer can be matched or not. If the offer is not yet matched, subject is free to improve his/her offer by

re-submitting the order, as long as there is still time remain. Each subject can buy or sell the service at most once in each period.

Table 1. Summary of experimental design

Information content	Time-cost	
	No Time-cost	With Time-cost
No Info	Session 1	Session 2
Best Offer	Session 3	Session 4
Best Offer + Price	Session 5	Session 6

In the experimental design, we consider three levels of information content. “No information” represents the case where all participants do not receive any additional information apart from the basic information. The level “Best Offer” represents the case that all participants could see what the current best bid and the current best ask are in real-time, in addition to the basic information. The case of “Best Offer + Price” shows the current best bid and the current best ask as well as the last transaction price. Two levels of time-cost are “No Time-cost” and “With Time-cost”, in which all participants in the same session are supposed either not to have time-cost or to have time-cost. For sessions with time-cost, computer screen also shows two more information: the amount of total time-cost value in case the subject ends the period without getting a taxi (called “TCperiod”) and the amount of time-cost that accrued linearly as the time elapsed (called “TCelapsed”). The latter is the amount of time-cost that has already incurred to the subject in real-time and it will be equal to TCperiod if the subject ends the period without getting a service. The screen shows the updated value of TCelapsed every second. Note that different functional forms between the TCelapsed and time are possible; however, in this study we assume that this function is linear. A sample of computer screen in case of “Best Offer + Price” is shown in Figure 2.

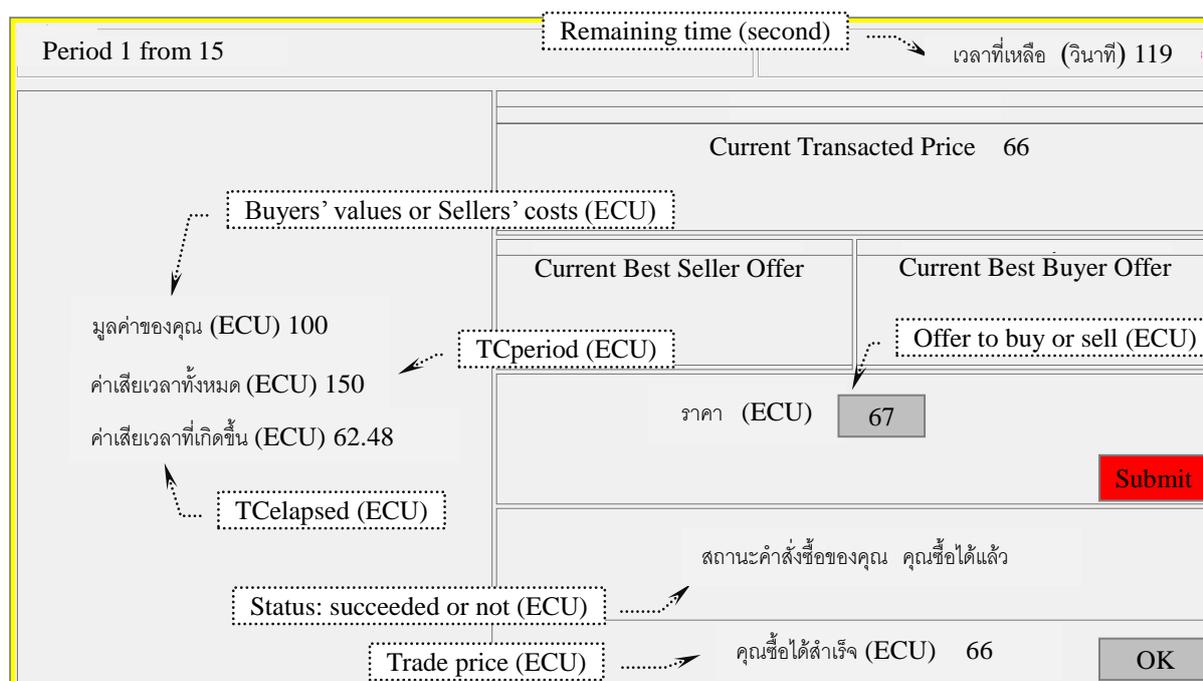


Figure 2. A computer screen used in session 6 (Best Offer + Price, With Time-cost)

3.2 Individual Private Values (Costs) and Time-cost

We follow the general guidelines for setting up the experiment in Friedman and Cassar (2004). Each experimental session used exactly the same set of buyer's values and seller's costs which are drawn independently for each period from a uniform distribution between 20 – 200 experimental currency unit (ECU) but these values and costs differ throughout a sequence of auction period. The value is a private value and subjects do not know the values of other subjects. We set the lowest value as 20 ECU to make it in line with the current surcharge for calling taxi in Bangkok (20 Baht). The maximum surcharge rate, 200 ECU, is arbitrary set so that it is not too high compared to the average taxi fare (Semchuchot, 2007). The selection of this range does not affect the general conclusions as the same range is used in all sessions. Nevertheless, this range can be replaced if any feasible range can be identified in the future.

To make it possible to explicitly evaluate the effect of time cost on bidding strategies in a thin market of 6 players in each side, we consider only the two extreme values of TCperiod: low and high. For the high time-cost, TCperiod is set as 150 ECU and for the low time-cost, TCperiod is 50 ECU. To determine which TCperiod is for each subject, a random value between 0 and 1 is drawn from the uniform distribution. If the random value is less than 0.5, the low TCperiod is used, and those that are greater or equal to 0.5, the high TCperiod is used. In one session, the values of TCperiod differ throughout a sequence of auction period. However, the same set is used for all the sessions with time-cost (sessions 2, 4, and 6).

Different from other studies, we allow buyers/sellers to bid/ask higher/less than their private value if they need to do so. This setting is intended to capture the subjects' tradeoff behavior between the loss from trading and the loss from time-cost.

3.3 Individual Incentive

During the laboratory experiment, getting or making a service has no intrinsic value of their own to the subjects, so preferences for them are induced. The concept here lies within the induced value theory (Smith, 1976) which is described in Friedman and Cassar (2004) as "*Induced value theory, ... is based on the idea that the proper use of a reward medium allows an experimenter to induce pre-specified characteristics in the subjects so that their innate characteristics become irrelevant*". Cash is used as a reward medium in this study. The amount paid to each subject is a function of the sum of his/her profit earned during the experiment. The profits for buyer and seller in each period for the case of no time-cost are defined as shown in Equation 1 and 2, and for the case of with time-cost as shown in Equation 3 and 4, respectively.

$$\Pr ofit_{buyer}^{NoTC} = \begin{cases} V_b - P & , \text{if auction succeeded} \\ 0 & , \text{otherwise} \end{cases} \quad (1)$$

$$\Pr ofit_{seller}^{NoTC} = \begin{cases} P - V_s & , \text{if auction succeeded} \\ 0 & , \text{otherwise} \end{cases} \quad (2)$$

$$\Pr ofit_{buyer}^{WithTC} = \begin{cases} V_b - P - c_b(t) & , \text{If auction succeeded} \\ -c_b(t) & , \text{otherwise} \end{cases} \quad (3)$$

$$\Pr ofit_{seller}^{WithTC} = \begin{cases} P - V_s - c_s(t) & , \text{If auction succeeded} \\ -c_s(t) & , \text{otherwise} \end{cases} \quad (4)$$

where V_b denotes buyers' valuations, V_s sellers' costs, P transaction price, and $c_b(t)$ and $c_s(t)$ denotes TC elapsed as a function of time t for buyer and seller, respectively. Profits from all period are added and any loss incurred is subtracted. The higher the total profit the subject earns, the more the subject is rewarded. The total profit in ECU is then converted to Thai Baht currency. To encourage volunteers, participants are also given a 100 Baht as a show up fee. The show up fee and the sum of her/his period profits are paid altogether at the conclusion of each experimental session. The participants receive a payment ranging from 180 to 610 Baht, with the average of 350 Baht. (US\$1 is about 30 Baht).

4. HYPOTHESES

We first present some hypotheses that will be used as an outline for our investigation. The first hypothesis is whether the variable surcharge policy is better than the fixed policy. The remaining hypotheses can be classified based on whether the individual subject or the aggregate market is considered. Moreover, in case of aggregate market, several aspects can be investigated, which include early trading behavior, average transaction price, and the market efficiency. The motivation and hypotheses are discussed below.

4.1 Variable Surcharge Policy vs. Fixed Surcharge Policy

As double auction is highly efficient and the market tends to reach its equilibrium, we hypothesize that the variable surcharge policy is better than the fixed policy. Laboratory results of double auction will be compared with the theoretical results of the fixed policy.

4.2 Individual Transaction Price

When individual is subject to time-cost constraint, it can be hypothesized that the transaction price may be different from that in the case of no time-cost. Moreover, the level of time-cost will also have an important role. In this case it is expected that the individual will tradeoff between the gain from trading and the loss from time-cost in order to maximize his/her profit. Thus, private value and time-cost would determine the transaction price of the subject. Moreover, it can be hypothesized that additional information will play an important role on the subjects' identification of possible transaction price. This will reduce price volatility compared to the case of no information.

Hypothesis 1, H_0 : Time-cost does not have an impact on the individual transaction price as compared to that observed under no time-cost situation

Hypothesis 2, H_0 : Additional information does not have an impact on the individual transaction price as compared to that observed under no information

4.3 Early Trade Volume

It is expected that under time-cost constraint, subjects will try to minimize their loss due to time-cost and thus an increase in the volume of trade early in the period. Moreover, additional information will ease the subjects to match the offer with their counterparts thus increase trade volume in the early of the period, compared to that of no information.

Hypothesis 3, H_0 : Time-cost does not have an impact on the volume of trade early in a given period as compared to that observed under no time-cost situation

Hypothesis 4, H_0 : Additional information does not have an impact on the volume of trade

early in a given period as compared to that observed under no information

4.4 Average Transaction Price

As a consequence of expected changes in individual transaction price, it is expected that the average transaction price in each period under time-cost environment will be different from that of no time-cost sessions. Similarly, expected difference in individual transaction price will also result in difference in average transaction price in each period under different information level.

Hypothesis 5, H₀: Time-cost does not have an impact on the average transaction price in a given period as compared to that observed under no time-cost situation

Hypothesis 6, H₀: Additional information does not have an impact on the average transaction price in a given period as compared to that observed under no information

4.5 Market Efficiency

Under no time-cost environment, past studies have used allocative efficiency as a measure of market efficiency. This is defined as the ratio of realized gain over all potential gain based on competitive equilibrium of demand-supply, multiplied by 100 to make a unit in percentage. However, under ‘With time-cost’, subjects are allowed to make a negative trading profit to prevent a big loss from time-cost. As a result, allocative efficiency may not be a suitable measure in this case. To measure a benefit in time-cost save, we define the measure of time-cost saving (%TCsave) as

$$\%TCsave_i = \frac{\sum_{j=1}^{n_i} (TCperiod_{i,j} - TCelapsd_{i,j})}{\sum_{j=1}^{n_i} (TCperiod_{i,j})} \times 100 \quad (5)$$

where: i denotes the index of period, j the index of subject, and n_i the number of subjects who succeeded in auction in period i . Note that %TCsave cannot be determined in case of ‘No time-cost’ sessions.

Another measure, called overall efficiency, is proposed in this study by combining the two dimensions of profit from trading and time-cost save altogether. this can be written as:

$$OverallEff_i = \frac{\sum_{j=1}^{n_i} (RealizedGain_{i,j}) + \sum_{j=1}^{n_i} (TCperiod_{i,j} - TCelapsd_{i,j})}{\sum_{j=1}^{N_i} (TheoreticalGain_{i,j}) + \sum_{j=1}^{n_i} (TCperiod_{i,j})} \times 100 \quad (6)$$

where: N_i denotes the number of subjects who would succeed in auction according to the theory of competitive equilibrium.

When the subjects receive more information, it is expected that the subjects will have a better idea about at what price they should submit to maximize the profit, thus improve the overall efficiency under with time-cost environment.

Hypothesis 7, H₀: Additional information does not have an impact on the overall efficiency in a given period as compared to that observed under no information

5. COMPARISON BETWEEN DIFFERENT SURCHARGE POLICIES

In this section, the performance of the variable surcharge policy is compared with the fixed policy. Allocative efficiency and trading volume per period are used as the indicators for comparison. For the variable policy, the values of these indicators are manipulated from the laboratory results. We take the average value of allocative efficiency and trading volume from all 45 periods of the three sessions without time-cost, and obtained 95.42% and 3.31 trade, respectively (see Table 2 for more details). For the fixed policy, the same set of private values as those in the laboratory experiment are used to construct the demand and supply curves and the performance indicators are then calculated from these curves. Figure 3 shows the results of these indicators averaged over all 15 demand-supply curves for all possible values of the fixed surcharge ranging from 20 to 200 ECU. The calculation for the fixed policy is done under the assumption that only the sellers whose private value is lower than the surcharge and the buyers whose private value is higher than the surcharge will certainly complete the trading. Even under such a favor assumption for fixed policy, it is still mostly outperformed by the variable surcharge policy. Note that the efficiency of the fixed policy is maximized when the surcharge is taken at the equilibrium price (about 110 ECU). However, a unique equilibrium point in reality is very difficult to determine as the demand-supply curve can change spatially and temporally thus fixing an arbitrary value of surcharge would mostly result in lower performance compared with the variable surcharge policy. Note that this comparison is made for the case of no time-cost only. Comparison under time-cost environment requires another laboratory experiments which will be a subject for our future research.

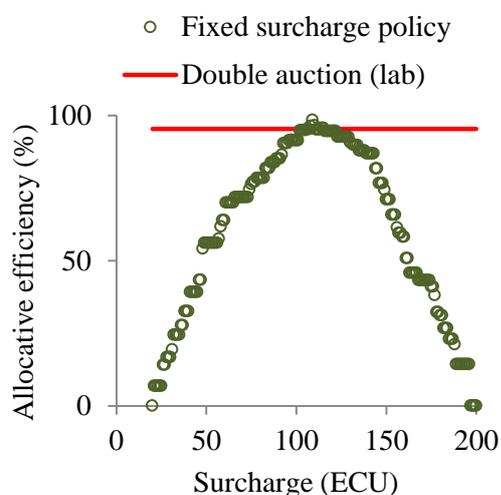


Figure 3(a). Comparison of allocative efficiency between fixed surcharge policy and double auction laboratory

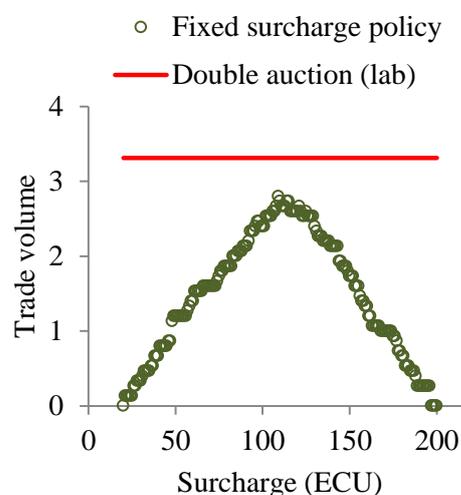


Figure 3(b). Comparison of trade volume between fixed surcharge policy and double auction laboratory

6. RESULTS AND ANALYSIS

We start with some general tendencies of the results using graphical illustrations and descriptive statistics as well as a simple t-test. Later on we provide a formal analysis based on linear regression to test the above hypotheses.

6.1 Some General Tendencies

6.1.1 Individual transaction price

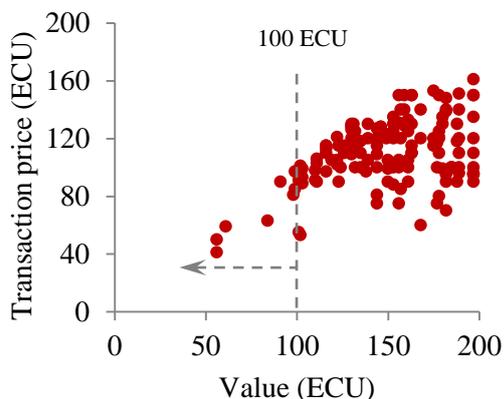


Figure 4(a). Individual buyer's transaction price, *No time-cost*

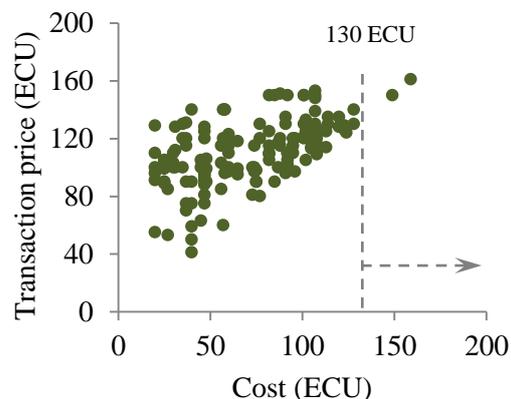


Figure 4(b). Individual seller's transaction price, *No time-cost*

First of all, a benchmark result under no time-cost environment is shown. Figures 4(a) and 4(b) show a scatter plot of subjects' valuation versus transaction price of buyers and sellers. The plots used data from sessions 1, 3, and 5 only. It can be observed that the relationships are similar to what have been found in the literature. The plots are all below the diagonal line in case of buyers and above the diagonal line in case of sellers. This implies that under no time-cost situation, subjects do not want to make a loss in trading, so buyers always bid less than their valuations and sellers always ask higher than their costs. The transaction prices scatter between 40 ECU and 160 ECU. It is noted that buyers whose valuation is lower than 100 ECU are less success in getting a service. On the other hand, sellers whose cost above 130 ECU are also less success in getting a customer.

Similar plots can also be made for the case of 'with time-cost' environment (sessions 2, 4, and 6). However, we separate the plot according to the level of time-cost of the subjects. Figures 5(a) and 5(b) present the plots of transaction prices versus buyers' values under low and high time-cost environment. Similar plots are made in Figure 6(a) and 6(b), but now for seller side.

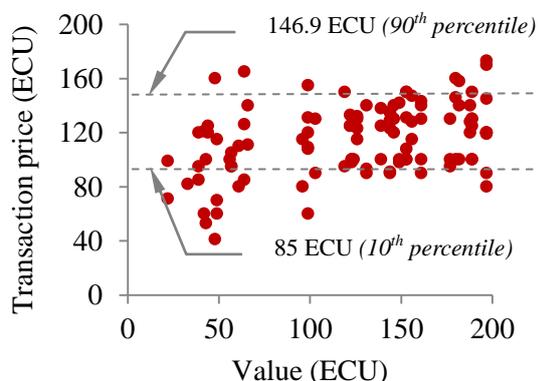


Figure 5(a). Individual buyer's transaction price, *Low time-cost*

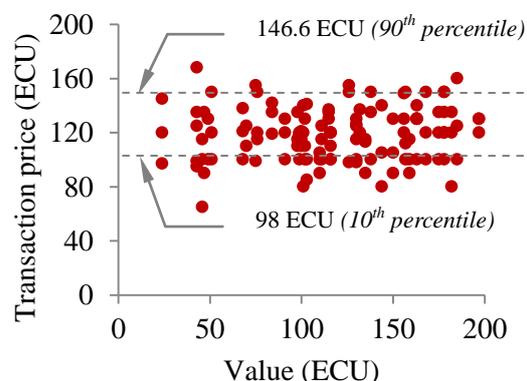


Figure 5(b). Individual buyer's transaction price, *High time-cost*

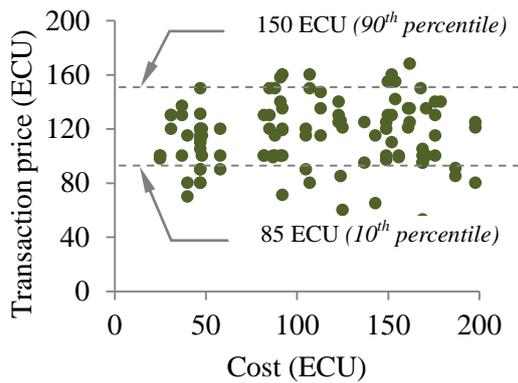


Figure 6(a). Individual seller's transaction price, *Low time-cost*

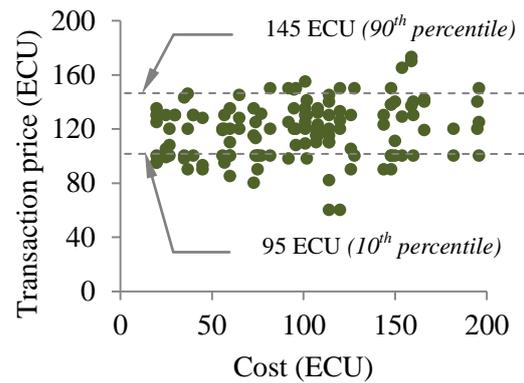


Figure 6(b). Individual seller's transaction price, *High time-cost*

It is observed that under 'with time-cost' environment, the plots scatter on a wider range on the x-axis compared to the case of no time-cost, implying that buyers with low values and sellers with high costs could also get/make a service. Trade-off behavior is found here. In terms of the transaction prices, it is found that the range of the transaction price (y-axis) under high time-cost is narrower than that under low time-cost, as can be observed by the range between the 10th and 90th percentiles.

6.1.2 Transaction time

A scatter plot between subjects' valuations and their corresponding transaction times is also made separately for buyers and sellers. They are shown in Figures 7(a) and 7(b), respectively. The scatter plots also differentiate between time-cost levels. In general, subjects with no time-cost have larger transaction time than those with time-cost. In case of buyer's plot, the data are densely scattered on the lower-right part of the plot, implying that buyers with higher valuation could finish their auction earlier. For seller's plot, the figure seems to be a mirror image of the buyer's plot and imply that sellers with lower cost also finished earlier. Nevertheless, it is more appropriate to characterize early trading behavior using another measure. This is because the number of successful trading is not the same, particularly for the sessions with-time-cost and no-time-cost and thus averaging will be biased.

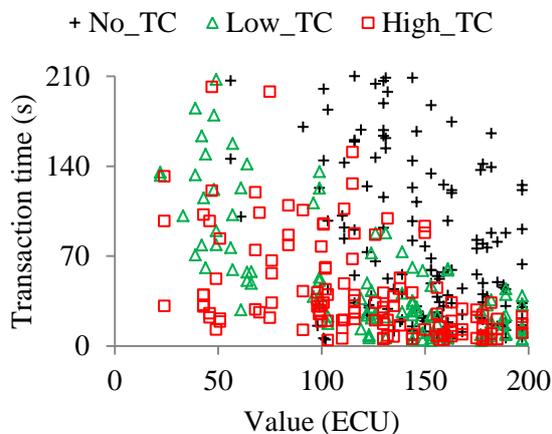


Figure 7(a). Individual buyer's transaction time, all sessions

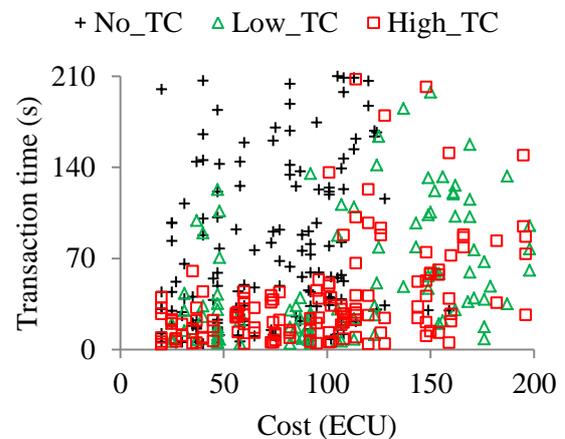


Figure 7(b). Individual seller's transaction time, all sessions

6.1.3 Aggregate measures

We now present the mean and standard deviation of some measures that characterize the efficiency of the whole market, determined over all 15 periods of each session, as shown in Table 2. Following the idea of Duxbury (2005), we use the total volume of trades in the period (Vol) and the volume of trades occurred within the first 45, 90, and 120 seconds of the period (Vol45, Vol90, and Vol120) as measures to investigate early trading behavior. Other measures including average transaction price, allocative efficiency, percent time-cost saving, and overall efficiency are described in more details later.

6.1.3.1 Early trade volume

Vol, Vol45, Vol90, and Vol120 are used to determine how fast the trade is made under different situations. These measures are more appropriate compared to the average transaction time. Comparisons of the values of these measures between the case of 'No time-cost' and 'With time-cost' under the same information level reveal significant difference between the two environments as also evidenced by the p-value from t-test. This implies that participants are more willing to conclude the trade earlier under time-cost environment.

Another interesting question is about the difference in early trade volume between different institutions. Surprisingly, sessions with no additional information (sessions 1 and 2) appeared to have largest number of early trade volume among the three institutions. Additional information on the current best offers as well as the last matched price tends to decrease the number of total trade as well as the number of early trade.

6.1.3.2 Average transaction price

In general, there is a significant difference between average transaction prices of 'No time-cost' and 'With time-cost' sessions and the prices under 'With time-cost' are higher. Exception is found under 'Best Offer + Price' information level as evidenced by the p-value (0.375). Moreover, under 'Best Offer + Price' information level, the average value and standard deviation of transaction prices are smaller compared to other information levels. This result is in line with the result of Anufriev *et al.* (2011) who stated that additional information decrease price volatility.

6.1.3.3 Market efficiency

Results from Table 2 reveal that, no matter of what information content, double auction is still highly efficient in terms of allocative efficiency. Considering only the sessions with time-cost (2, 4, and 6), it is shown that 'No Info' is the best in terms of %TCsave and 'Best Offer + Price' is the best in terms of overall efficiency.

6.2 Hypothesis Testing

In this section, we explore in more details about our hypotheses discussed so far. A more precise determination of the marginal (linear) effect of each treatment variable can be obtained by means of regression analysis (Friedman and Cassar, 2004; Duxbury, 2005). We present the models used for this purpose followed by results.

Table 2. Aggregate measure

Mean (STD)	No Info			Best Offer			Best Offer + Price		
	Session 1	Session 2	p-value	Session 3	Session 4	p-value	Session 5	Session 6	p-value
	No TC	With TC		No TC	With TC		No TC	With TC	
<i>Vol</i>	3.27 (0.88)	5.67 (0.62)	0.000	3.40 (0.83)	5.20 (1.01)	0.000	3.27 (0.70)	5.07 (0.80)	0.000
<i>Vol45</i>	1.87 (0.52)	3.93 (0.59)	0.000	1.80 (0.77)	3.00 (1.00)	0.000	0.73 (0.80)	3.87 (0.83)	0.000
<i>Vol90</i>	2.53 (0.74)	5.07 (0.59)	0.000	2.13 (0.92)	4.13 (1.06)	0.000	1.67 (0.98)	4.27 (0.80)	0.000
<i>Vol120</i>	2.87 (0.92)	5.33 (0.62)	0.000	2.40 (0.74)	4.60 (0.99)	0.000	1.87 (0.99)	4.60 (0.91)	0.000
<i>Trans. Price</i>	112.37 (23.76)	123.05 (22.53)	0.011	111.41 (23.48)	123.23 (23.28)	0.006	107.32 (20.77)	102.99 (15.04)	0.375
<i>Alloc. Eff.</i>	95.96 (7.73)	- -	- -	95.84 (7.82)	- -	- -	94.45 (9.21)	- -	- -
<i>%TC save</i>	- -	85.11 (4.30)	- -	- -	76.06 (7.61)	- -	- -	82.60 (7.39)	- -
<i>Overall Eff.</i>	- -	74.13 (8.59)	- -	- -	69.23 (10.30)	- -	- -	74.62 (8.66)	- -

- Not relevant; *TC* denotes Time-cost; *Trans. Price* denotes transaction price; *Alloc. Eff.* denotes allocative efficiency; *%TC save* denotes percentage of time-cost saving, calculated from equation 5; *Overall Eff.* denotes overall efficiency calculated from equation 6.

6.2.1 Empirical models

Basically, the models are developed separately for each performance measure, and as a consequent, separately for each hypothesis. Each of the performance measures is defined as the dependent variable, and the treatment variables as well as some other important variables are used as the independent variables in the model. The model for individual transaction price as the dependent variable is first presented, followed by a group of similar models for aggregate measures.

6.2.1.1 Models for individual level

According to our first hypothesis, effects of time-cost and information content on individual transaction prices are examined. At individual level, there are three levels of time-cost: ‘No TC’, ‘Low TC’, and ‘High TC’. There are also three levels of information. Each of the three-level-treatment variables is modeled using two dummy variables. However, when only data from ‘with time-cost’ sessions are used, there are two levels of time-cost and only one dummy variable (high time-cost) is used for the time-cost treatment. Using subject’s transaction price as dependent variable, the model is presented in Equation (7) and the results are presented in Table 3.

$$y_i = \beta_0 + \beta_1 V_i + \beta_2 Best_i + \beta_3 BPrice_i + \beta_4 TCLow_i + \beta_5 TCHigh_i + \varepsilon_i \quad (7)$$

where for subject i ($i \in \{1, 2, \dots, N_B, N_B + 1, N_B + 2, \dots, N_B + N_S\}$), N_B the number of buyers who succeeded in auction, N_S the number of sellers who succeeded in auction,

$$y_i = \begin{cases} \text{buyer } i \text{'s transaction price (data from all 6 sessions)} \\ \text{seller } i \text{'s transaction price (data from all 6 sessions)} \\ \text{buyer } i \text{'s transaction price (data from 'with time - cost' sessions)} \\ \text{seller } i \text{'s transaction price (data from 'with time - cost' sessions)} \end{cases}$$

$$V_i = \text{valuation or cost of subject } i, \quad Best_i = \begin{cases} 1, \text{ if } i \text{ receives 'Best Offer' information} \\ 0, \text{ otherwise} \end{cases}$$

$$BPrice_i = \begin{cases} 1, \text{ if } i \text{ receives 'Best Offer + Price' information} \\ 0, \text{ otherwise} \end{cases}$$

$$TCLow_i = \begin{cases} 1, \text{ if } i \text{ has low time - cost} \\ 0, \text{ otherwise} \end{cases}, \quad TCHigh_i = \begin{cases} 1, \text{ if } i \text{ has high time - cost} \\ 0, \text{ otherwise.} \end{cases}$$

6.2.1.2 Models for period level

The models for aggregate measures are described here. The dependent variables are those aggregate measures discussed in section 6.1.3. The structure of the models is similar so it is shown in a generic form as in Equation (8). Similar to the model for individual level, we use two dummy variables to represent three levels of information type. However, in case of time-cost treatment within a single observation period, there are only two levels, i.e. ‘with TC’ and ‘No TC’, and hence only one dummy variable with respect to ‘with TC’ is used. Tables 4 and 5 summarize the results in case of the use of the data from all six sessions and the data from ‘with TC’ sessions only, respectively.

$$y_{it} = \alpha_0 + \alpha_1 Best_{it} + \alpha_2 BPrice_{it} + \alpha_3 TC_{it} + \varepsilon_{it} \quad (8)$$

where observation is indexed relative to session i ($i \in \{1, 2, \dots, 6\}$) and trading period t ($t \in \{1, 2, \dots, 15\}$),

$$y_{it} = \begin{cases} Vol_{it} : \text{Total volume in period } t \text{ session } i \\ Vol45_{it} : \text{Trade volume within 45 sec in period } t \text{ session } i \\ Vol90_{it} : \text{Trade volume within 90 sec in period } t \text{ session } i \\ Vol120_{it} : \text{Trade volume within 120 sec in period } t \text{ session } i \\ OverallEff_{it} : \text{Overall Efficiency in period } t \text{ session } i \\ TransPrice_{it} : \text{Average transaction price in period } t \text{ session } i \end{cases},$$

$$Best_{it} = \begin{cases} 1, \text{ if information is 'Best Offer'} \\ 0, \text{ otherwise} \end{cases},$$

$$BPrice_{it} = \begin{cases} 1, \text{ if information is 'Best Offer + Price'} \\ 0, \text{ otherwise} \end{cases},$$

$$TC_{it} = \begin{cases} 1, & \text{if the period is with time - cost} \\ 0, & \text{otherwise.} \end{cases}$$

6.2.2 Individual transaction price

The results of regression analysis based on the model in 6.2.1.1 are shown in Table 3. As expected, private valuation (cost) is significant and affect positively to transaction price across all regressions. Although the R² is relatively low, its magnitude is comparable to many of the results in experimental economics literature (see for example in Ketcham *et al.* (1984)).

According to hypothesis 1, the estimated time-cost effects reveal that transaction prices when participants have high time-cost are greater than the prices when having low time-cost which again greater than the prices under no time-cost. Note that time-cost effects are significant for buyers' prices but are not statistically significant for sellers' prices, albeit weakly so in the high time-cost cases (p = 0.076 and 0.164).

According to hypothesis 2, the estimated information type effects reveal that transaction prices under 'No Information' tend to be greater than prices under 'Best Offer' which again are greater than prices under 'Best Offer + Price'. For example, when data from the three sessions with time-cost and only buyers are considered, the point estimate of the transaction prices under 'Best Offer' ('Best Offer + Price') relative to 'No Information' is -0.55 (-19.90) ECU. However, sellers' prices under 'Best Offer' tend to be greater than prices under 'No Information' for about 0.34 ECU. Nevertheless, this reflects tendencies only as only the effect of 'Best Offer + Price' information type is significant across all regressions. This supports the results found in Table 2.

Table 3. Regression analysis of individual transaction prices

	y = Individual Transaction Price							
	All 6 sessions				Only 3 sessions with Time-cost			
	Buyer		Seller		Buyer		Seller	
	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value	Coefficient	P-value
Constant	90.41	0.000	105.53	0.000	104.76	0.000	114.63	0.000
Value/Cost	0.17	0.000	0.13	0.000	0.13	0.000	0.06	0.030
Best Offer dummy	-0.78	0.760	-0.16	0.951	-0.55	0.861	0.34	0.918
Best Offer + Price dummy	-14.10	0.000	-13.14	0.000	-19.90	0.000	-18.65	0.000
TC_Low	8.38	0.002	0.03	0.991	-	-	-	-
TC_High	13.69	0.000	4.64	0.076	5.30	0.044	3.82	0.164
R ²	0.18		0.15		0.22		0.16	

6.2.3 Early trade volume

Results from Table 4 shows that there is a significant effect of time-cost on early trade volume. The estimated information type effects reveal that early trade volumes under 'No Information'

are significantly larger than volumes under ‘Best Offer’ which again are larger than volumes under ‘Best Offer + Price’. This implies that the auctions under ‘No Information’ could be matched earlier and thus could result in a significant time saving.

However, when considering only those sessions under time-cost as shown in Table 5, the rank is not the same. ‘Best Offer + Price’ tends to have larger early trade volumes than the ‘Best Offer’ case, while ‘No Information’ still has larger early trade volume. One important point to note from Table 5 is about trade volume within the first 45 seconds. Under this measure, it is observed that there is no statistically significant difference between the Vol45 in case of ‘Best Offer + Price’ and the Vol45 in ‘No Information’.

6.2.4 Average transaction price

Result from Table 4 reveals that time-cost has a significant effect on average transaction price. When participants are subject to time-cost, the average transaction price is about 7.12 ECU higher than when no time-cost. A significant reduction in average transaction price is found for the information type ‘Best Offer + Price’ relative to ‘No Information’ case (12 ECU lower). The average transaction price in case of ‘Best Offer’ is comparable and does not show any significant difference from that of the ‘No Information’. This finding supports the general tendencies observed from Table 2.

When only the sessions with time-cost are considered (Table 5), a much more reduction in average transaction price is found for the information type ‘Best Offer + Price’ relative to ‘No Information’ case (18.61 ECU lower). The average transaction price under ‘Best Offer’ tends to be higher than that of ‘No Information’ despite the fact that the t-test does not show any significant difference.

Table 4. Regression analysis of Trade volume, and Transaction price (all sessions)

Variables	Coefficient (P-value)				
	Vol	Vol45	Vol90	Vol120	Trans. Price
Constant	3.47 (0.000)	1.83 (0.000)	2.61 (0.000)	2.87 (0.000)	113.80 (0.000)
Best Off dummy	-0.17 (0.434)	-0.50 (0.027)	-0.67 (0.004)	-0.60 (0.009)	-0.05 (0.990)
Best Off + Price dummy	-0.30 (0.160)	-0.60 (0.008)	-0.83 (0.000)	-0.87 (0.000)	-12.00 (0.001)
Time-cost dummy	2.00 (0.000)	2.13 (0.000)	2.38 (0.000)	2.47 (0.000)	7.12 (0.015)
R ²	0.61	0.63	0.68	0.70	0.20

6.2.5 Overall efficiency

When only the sessions with time-cost are considered (Table 5), the estimated information type effects reveal that overall efficiency under ‘Best Offer + Price’ tends to be higher than

that under ‘No Information’ which again tends to be higher than that under ‘Best Offer’. However, t-test does not reveal any significant difference between them together with the low value of R^2 .

Table 5. Regression analysis of Trade volume, Overall efficiency and Transaction price (Only with time-cost sessions)

Variables	Coefficient (P-value)				Overall Eff.	Trans. Price
	Vol	Vol45	Vol190	Vol120		
Constant	5.67 (0.000)	3.93 (0.000)	5.07 (0.000)	5.33 (0.000)	74.13 (0.000)	122.90 (0.000)
Best Offer dummy	-0.47 (0.129)	-0.93 (0.004)	-0.93 (0.004)	-0.73 (0.023)	-4.90 (0.153)	0.61 (0.893)
Best Off + Price dummy	-0.60 (0.053)	-0.07 (0.826)	-0.80 (0.013)	-0.73 (0.023)	0.49 (0.885)	-18.61 (0.000)
R^2	0.10	0.22	0.21	0.15	0.07	0.36

7. CONCLUSIONS AND DISCUSSIONS

Motivated by the taxi refusal problems, particularly for passengers who have limited access to the services and when the trip destination is in a congested or a remote area, thus taxi drivers are often reluctant to provide services. This paper presents an experimental study of demand-supply matching for taxi services through double auction system. The surcharge is paid in addition to metered fare. Passengers can bid a higher surcharge if they are in need of taxi services, while drivers can also ask a desired surcharge to balance their disincentive. However, typical design of commodity auction without time-cost consideration may not be suitable for taxi service auction. We examine the design of information content for user interface by conducting laboratory experiments, and investigate whether or not the variable surcharge policy is better than the fixed policy. Important findings can be summarized as follows:

- Fixed surcharge policy is outperformed by the variable policy for most of the values of the surcharge considered. Only when the surcharge is fixed near the equilibrium point, the allocative efficiency of the fixed surcharge policy is comparable to that of the variable policy. However, trading volume in fixed policy is substantially lower in all values of surcharge considered. This illustrates that variable policy can offer a larger opportunity for passengers to get a taxi service.
- Time-cost does have an effect on individual bidding strategies as well as on the aggregate market efficiency. This highlights the need to have a further study on the design of auction market under time-cost environment. Our study attempts to fill a part of this gap particularly on the design of information content for bidders.
- We have found that different information contents result in significant differences in bidding strategies as well as in some aggregate performance measures.

- Under time-cost environment, providing information on the current best offer and the last transaction price seems to be the most efficient one according to the result of overall efficiency. Quite important result is on the average transaction price which is found to be significantly lower than that in the case of no information.
- Under time-cost environment, providing no additional information surprisingly results in early transactions, as evidenced in the results of highest early trade volume and highest %TCsaving. Whereas the overall efficiency is slightly lower than the case of providing information on the current best offer and the last transaction price.

To implement the online taxi auction system in reality, several issues need to be considered. These are about the distance between the taxis and the passengers and the time the driver takes to reach its passenger. This issue plays quite an important role for the success of the taxi auction system. In practice, the whole service area can be sub-divided into smaller zones with optimal zone size. This means the zone size should be small enough so that taxis can reach passengers within a certain limit of time. On the other hand, the zone size should be big enough so that there are sufficient number of taxis and passengers available within the zone and thus the desired competitiveness is obtained. The auction is organized separately for each origin-destination zone. To do this, we need some location technology platforms to identify which zone each individual taxi and passenger belongs to. Whether such an online auction market is feasible needs a more careful investigation. Several research directions are worth to explore. For instance, new technologies and developments cannot sustain without the acceptance from their users, both from the passengers' and the drivers' perspectives. Investigation of users' acceptances as well as user-centered design are therefore one of the research directions. Other aspects of the design, such as buyer bid auction and seller ask auction, may be investigated in comparison to double auction market. Detail investigation of the effects of different market institutional design under a more realistic environment shall be also explored.

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