The Design of Transportation Service Auction under Time-Cost Environment

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Abstract: Motivated by the taxi refusal problem, this paper presents a new idea of bidding for taxi services through double auction. This is equivalent to a variable surcharge policy as opposed to the existing situation of a fixed surcharge paid in addition to a regular meter fare. Unlike an auction for normal commodities, time-cost is relevant in an auction for taxi services. Thus, the typical design of an auction may not be suitable for a taxi auction. This paper examines one of the problems of auction design: design of information content for the user interface. We conducted laboratory experiments to investigate the effect of different levels of information content. We found that the fixed surcharge policy was outperformed by the variable surcharge policy for most of the values of the surcharge considered. Moreover, there is a significant time-cost effect, and providing bidders with greater information leads to the lowest average transaction price.

Keywords: Transportation Service Auction, Double Auction, Time-Cost, Information Content, Laboratory Experiment

1. INTRODUCTION

Taxis are one of the important transport modes in Bangkok and many cities. However, statistics reveal that taxis have received the most complaints among all public transport modes in Thailand. In particular, taxi refusal complaints have risen from 16.5% in 2010 to 47.4% in 2012 (Thailand’s Department of Land Transport, 2012). Promprechawut (2006) reported that 83.5% of taxi passengers interviewed in Bangkok indicated the need for taxi service improvement, and the major problem encountered was taxi refusal, particularly when the travel destination was in a congested area. A taxi refusal problem was also found in New York City (Sonny, 2006) and in Australia (Latitude insights 2012). Two possible explanations for the trip refusal issue are: 1) demand and supply of taxis is not at an equilibrium, as the fare is regulated by the government (Sonny, 2006), and 2) there is a financial motivation (disincentive) for providing a service; i.e., upon dropping off a passenger, taxi drivers do not want to get stuck in traffic or return with an empty cab (Schaller Consulting, 2006). Both situations result in drivers receiving revenue that may not be sufficient compared with the cost. Bruce and Jessop (2003) reported difficulty in obtaining taxi services in Australia. About half of the failures to obtain service were attempts to obtain a taxi by phoning a taxi company. A common problem was that passengers were told either that a taxi was not available or that the taxi was 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 both of the abovementioned situations apply: the trip destination is in a congested area (or a remote area with a low demand) and when the passenger has limited access to taxi services; i.e., only by means of phoning the taxi company. The latter situation is quite common in Bangkok, as many
people live far away from the main streets/arterials, and it is difficult for them to obtain a taxi by hailing. In this case, passengers have to call the taxi company and pay a fixed surcharge (20 Baht) in addition to the normal fare. Even though drivers can earn more from this additional fixed surcharge, often passengers still cannot obtain a taxi. Possible explanations may be similar to those for the refusal problem mentioned above: demand–supply is not at an equilibrium, and there is a disincentive for providing a service.

Instead of using a fixed surcharge, we hypothesize that a variable surcharge policy may alleviate such problems encountered by passengers who have limited access to services and when taxi drivers are reluctant to provide services (because the destination is in a congested or remote area). The variable surcharge policy can be implemented by means of an online double auction as shown in Figure 1. Note that the surcharge is paid in addition to the regular meter fare. Through an online marketplace, passengers can bid a higher surcharge if they are in need of a taxi service, while drivers can also ask for a desired surcharge to balance their disincentive. This is motivated by findings from past research, which show that double auction is highly efficient and that the market tends to reach its equilibrium (Hagel and Roth, 1997; Soberg 2002). Moreover, there has been growing attention to the application of online auction to transportation and logistics services. To name only a few, Rodrigo (2007) and Sangwareetip and Indra-Payoong (2008) examined the potential benefit of double auction for reducing empty backhaul. Song and Regan (2003) investigated the benefits for shippers and carriers when using combinatorial auction for transportation service procurement. In an attempt to tackle a congestion problem, Raux (2007), Yang and Wang (2011), and 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 industries.

Figure 1. Taxi service auction under double auction scheme

In this study, we investigate whether or not the variable surcharge policy by means of double auction is better than the fixed surcharge policy. Moreover, the problem of the institutional design of an auction for taxi services is also investigated. We refer to the institutional design of an auction as the decision of which auction format to use as well as what information content to show on the user interface. For the purpose of the current study, we fix the auction format to only double auction but vary the information content to three levels. Unlike the auction market for normal commodities, in which the buyers and sellers can delay their offer in expectation of a higher payoff in the future, delaying a trip, not getting a taxi, or not getting passengers may incur some losses to passengers and taxi drivers. Among them are the cost associated with waiting for the service, the opportunity cost of not being able to do business at the time wanted, and losses due to running empty in search of passengers. Throughout this paper, we term these losses as “time-cost.” With such a difference in nature, the same design of information content in an auction market for normal commodities may
provide different results when applied to a taxi service auction under a time-cost environment. Therefore, some questions arise regarding 1) whether or not individual bidding strategies under a time-cost environment are the same as those without time-cost, 2) whether or not the efficiency of the market is the same under with and without time-cost, and 3) what institutional design will provide more desirable properties under a time-cost environment.

The present paper attempts to answer the abovementioned questions by means of an economic laboratory experiment. In particular, 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 performance under a time-cost environment. In addition, the performance of the variable surcharge policy by means of double auction is evaluated in comparison with that of the fixed surcharge policy. In section 2, related literature is reviewed. Section 3 describes the experimental design in detail. Section 4 presents some hypotheses that will be investigated in this paper. Section 5 presents the results of comparison between the variable surcharge policy and the fixed surcharge policy. Section 6 first presents some informal results using descriptive statistics and graphical illustrations to see the general tendency of the results. Later, we provide a formal analysis based on linear regression to investigate the effect of time-cost and information levels on individual transaction price as well as some aggregate indicators that measure market efficiency. Finally, discussions are provided and conclusions are drawn.

2. RELATED LITERATURE

We refer to the problem of auction institutional design as the decision of which auction format to use as well as what information content to show. Examples of different types of auction formats are 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 considered, Hagel and Roth (1997) reported that double auctions perform better than other institutions. Soberg (2002) compared three auction formats; namely, bid auction, offer auction, and double auction. It was found that double auction prices tend to be higher than offer auction prices, which tend to be higher again than bid auction prices. However, all three formats resulted in high economic efficiency. Nevertheless, our focus in this study is not on the auction format but rather on the information content. We limit ourselves to the double auction format and consider only what information to show to the passengers and drivers at the time of bidding.

The effect of information on bidding strategies and price discovery, as well as on the market efficiency, was also a focus in past research, mostly in the field of finance and stock exchange. Most studies focused on the effect of information contained in a 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 has been offered to the public in many stock and currency trade markets worldwide. 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 last transaction prices contributes 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 a limit order book is informative regarding future price movements. Li and Zhang (2009) compared the information content before and after the top price levels shown to the public were increased from three to five levels in the Chinese stock market. They found that the fourth and fifth price levels were also informative for the price discovery process. Anufriev et al. (2011) investigated the effect
of information on market efficiency. Under full information regarding the action of others, they found that bidders tend to submit orders at prices 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. 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 the contribution to price discovery. Moreover, bidders act differently under different types of information obtained. This also results in different price patterns, but there was no evidence of a discrepancy in market efficiency. Note also that time-cost is not a concern in these studies.

The economic laboratory experiment is a useful tool for evaluating policy proposals as well as a testing ground for institutional design (Smith, 1962, 1994; Friedman and Cassar, 2004). Besides the field of 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) and irrigation (Cummings et al. 2004). However, to the best of our knowledge, time-cost has not been a major concern in past auction research, perhaps because of the nature of the 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 studies were conducted under the premise that time is a valuable resource. Note that time-cost was treated only implicitly in their experiments, one is by clock speed and another is whether the number of experimental periods in one session is fixed or not fixed. In the descending auction study, it was found that clock speed can have a significant effect on price. In the ascending auction study, 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. A similar result regarding jump bidding was found in a study by Peng et al. (2009). When time-cost is high, the jump bidding strategy would be preferred. Note that all of these results were obtained under some type of one-sided auction and not under a double auction market.

To summarize, it can be seen that there is a lack of knowledge about the design of an auction market under a time-cost environment. This paper attempts to fill this gap.

3. EXPERIMENTAL SETUP

We conducted a laboratory experiment regarding a taxi service double auction in which we investigated the effect of factors of interest while controlling all other factors. In this case, the factor of interest is the information content. The auction takes place separately for each zone-to-zone pair. For our purpose, we tried to keep the environment fixed; thus, a single zone-to-zone pair was considered. 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 the marketplace a desired surcharge to balance their disincentive according to their expected operation cost.

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

At the beginning of each session, participants were first given written instructions to read. To make sure that the participants understood the trading rules, the experimenter repeated them verbally and provided an exercise to check the subject’s understanding. Finally, any misunderstanding was clarified by the experimenter. Then, one training period was conducted separately before the experimental session was started, and the results of the training period were not reported.

3.1 Experimental Design

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

<table>
<thead>
<tr>
<th>Information Content</th>
<th>Time-cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>No Info</td>
<td>No Time-cost</td>
</tr>
<tr>
<td></td>
<td>With Time-cost</td>
</tr>
<tr>
<td>Best Offer</td>
<td>Session 1</td>
</tr>
<tr>
<td></td>
<td>Session 2</td>
</tr>
<tr>
<td>Best Offer + Price</td>
<td>Session 3</td>
</tr>
<tr>
<td></td>
<td>Session 4</td>
</tr>
<tr>
<td></td>
<td>Session 5</td>
</tr>
<tr>
<td></td>
<td>Session 6</td>
</tr>
</tbody>
</table>

Basically, the computer screen of each subject shows the subject’s private value (or cost), the remaining time in seconds, an input box where subject can submit the offer, the status of the offer (either the offer is already matched or not yet matched), and some additional information depending on the session being conducted. 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 matched yet, the subject is free to improve his/her offer by resubmitting the order, as long as there is still time remaining. Each subject can buy or sell the service at most once in each period.

In our experimental design, we considered 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 where all participants can 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 in real time, in addition to the basic information. 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, respectively. For sessions with time-cost, the computer screen also shows two more items of information: the amount of total time-cost value in case the subject ends the period without getting a taxi (hereafter called as “TCperiod”) and the amount of time-cost that accrued linearly as the time elapsed (hereafter called as “TCelapsed”). The latter is the amount of time-cost that the subject has already incurred 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 TCelapsed and time are possible in reality. However, in this study, we assume that this function is linear. A sample of a computer screen showing the case of “Best offer + price” is shown in Figure 2.
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 were drawn independently for each period from a uniform distribution between 20 and 200 experimental currency units (ECU), but these values and costs differ throughout a sequence of auction periods. The value was a private value, and subjects did not know the values of other subjects. We set the lowest value as 20 ECU to put it in line with the current surcharge for calling a taxi in Bangkok (20 Baht). The maximum surcharge rate, 200 ECU, was set arbitrarily so that it was not too high compared with 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 evaluate explicitly the effect of time-cost on bidding strategies in a thin market of six players on each side, we considered 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 set as 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 if the random value is greater or equal to 0.5, the high TCperiod is used. In one session, the values of TCperiod differ throughout a sequence of auction periods. However, the same set was used for all the sessions with time-cost (sessions 2, 4, and 6).

Unlike other studies, we allowed buyers/sellers to bid/ask more/less than their private value if they needed to do so. This setting was intended to capture the subjects’ trade-off behavior between the loss from trading and the loss from time-cost.

3.3 Individual Incentive

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

\[
\text{Profit}_{\text{buyer}}^{\text{No TC}} = \begin{cases} 
V_b - P, & \text{if auction succeeded} \\
0, & \text{otherwise}
\end{cases}
\] (1)

\[
\text{Profit}_{\text{seller}}^{\text{No TC}} = \begin{cases} 
P - V_s, & \text{if auction succeeded} \\
0, & \text{otherwise}
\end{cases}
\] (2)

\[
\text{Profit}_{\text{buyer}}^{\text{With TC}} = \begin{cases} 
V_b - P - c_b(t), & \text{if auction succeeded} \\
-c_b(t), & \text{otherwise}
\end{cases}
\] (3)

\[
\text{Profit}_{\text{seller}}^{\text{With TC}} = \begin{cases} 
P - V_s - c_s(t), & \text{if auction succeeded} \\
-c_s(t), & \text{otherwise}
\end{cases}
\] (4)

where \(V_b\) = buyers’ valuations, \(V_s\) = sellers’ costs, \(P\) = transaction price, and \(c(t)\) = TCelapsed as a function of time \(t\). Profits from all periods were added, and any loss incurred was subtracted. The higher the total profit the subject earns, the higher the subject’s reward. The total profit in ECU was then converted to Baht. To encourage volunteers in the first place, participants were also given 100 Baht as a show-up fee. The show-up fee and the sum of her/his period profits were paid together at the conclusion of each experimental session. The participants received an average payment of about 350 Baht, with a minimum and a maximum payment approximately at 180 Baht and 610 Baht, respectively (approximately US$1 is about 30 Baht).

4. HYPOTHESES

Before going to the results, 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 surcharge policy. The remaining hypotheses can be classified based on whether the individual subject or the aggregate market is considered. Moreover, in the case of an aggregate market, several aspects can be investigated. These include early trading behavior, average transaction price, and 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 regarding double auction will be compared with the theoretical results of the fixed policy.
4.2 Individual Transaction Price

When an individual transaction is subject to time-cost, 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 trade off between the gain from trading and the loss from time-cost in order to maximize his/her profit. Thus, private value and time-cost will determine the transaction price of the subject. Moreover, it can be hypothesized that additional information will play quite an important role in the subjects’ identification of a possible transaction price. This will reduce price volatility compared with the case of no information.

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

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

4.3 Early Trade Volume

It is expected that under a time-cost constraint, subjects will try to minimize their loss due to time-cost, and thus there will be 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 increasing trade volume early in the period, compared with the case 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 with that observed under a 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 with 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 a time-cost environment will be different from that of the no time-cost sessions. Similarly, an expected difference in individual transaction price will also result in a difference in average transaction price in each period under a different information level.

Hypothesis 5, $H_0$: Time-cost does not have an impact on the average transaction price in a given period as compared with that observed under a no time-cost situation.

Hypothesis 6, $H_0$: Additional information does not have an impact on the average transaction price in a given period as compared with that observed under no information.

4.5 Market Efficiency

Under a 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 percentage. It was found in the literature that double auction is highly efficient. However, under a “With time-cost” environment as in this study, subjects were 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 saving, we define the measure of time-cost saving (%TCsave) as

\[
%TCsave_i = \frac{\sum_{j=1}^{n_i} (TC_{period_{i,j}} - TC_{elapsed_{i,j}})}{\sum_{j=1}^{n_i} TC_{period_{i,j}}} \times 100
\]

where \( i \) = the index of the period, \( j \) = the index of the subject, and \( n_i \) = the number of subjects who succeeded in auction in period \( i \). Note that \%TCsave cannot be determined in the 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 saving. Mathematically, this is defined as

\[
%OverallEff_i = \frac{\sum_{j=1}^{N_i} (RealizedGain_{i,j}) + \sum_{j=1}^{n_i} (TC_{period_{i,j}} - TC_{elapsed_{i,j}})}{\sum_{j=1}^{N_i} (TheoreticalGain_{i,j}) + \sum_{j=1}^{n_i} TC_{period_{i,j}}} \times 100
\]

where \( N_i \) = 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 the price that they should submit to maximize the profit, thus improving the overall efficiency under a time-cost environment.

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

5. COMPARISON BETWEEN DIFFERENT SURCHARGE POLICIES

In this section, the performance of the variable surcharge policy is compared with that of 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 were manipulated from the laboratory results. We took 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 randomly generated private values were used to construct the demand and supply curves, and the performance indicators were then calculated analytically 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 results from the variable surcharge policy were also shown in the figures for comparison purpose. Analytical calculation for the fixed policy was 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 favorable assumption for the fixed policy, it is still mostly outperformed by the variable surcharge policy. Note that the efficiency of the fixed policy is maximized theoretically when the surcharge is charged at the equilibrium price (about

386
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 was made for the case of no time-cost only. Comparison under a time-cost environment requires another laboratory experiment, which will be a subject for our future research.

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, 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

First of all, a benchmark result under a no time-cost environment is shown. Figures 4(a) and 4(b) show a scatter plot of subjects’ valuation versus the transaction price of buyers and sellers, respectively. The plots used data from sessions 1, 3, and 5 only. It can be observed that the relationships are similar to what has been found in the literature. The plots are all below the diagonal line in the case of buyers and above the diagonal line in the case of sellers. This implies that under a 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. One important point to make from this is that buyers whose valuation was lower than 100 ECU had less success in getting a service. On the other hand, sellers whose cost was above 130 ECU also had less success in getting a customer.

Similar plots can also be made for the case of a “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 environments, respectively. Similar plots were made in Figure 6(a) and 6(b) but for the seller’s side.
It is observed that under a “with time-cost” environment, the plots scatter on a wider range on the x-axis compared with the case of no time-cost, implying that buyers with low values and sellers with high costs could also get or make a service, respectively. 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 was also made separately for buyers and sellers. These 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 had a longer transaction time than those with time-cost. In the case of the buyer’s plot, the data are densely scattered on the lower-right part of the plot. This implies that buyers with higher valuations could finish their auction earlier. For the seller’s plot, the figure seems to be a mirror image of the buyer’s plot and implies that sellers with lower costs also finished earlier. Nevertheless, it is more appropriate to characterize early trading behavior using another measure. This is because the numbers of successful trades are not the same, particularly for the with-time-cost and no-time-cost sessions, and thus averaging will be biased.

![Figure 7(a). Individual buyer’s transaction time, from all sessions](image1)

![Figure 7(b). Individual seller’s transaction time, from all sessions](image2)

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 used 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), respectively, 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 detail 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 with the average transaction time. Comparisons of the values of these measures between the cases of “No time-cost” and “With time-cost” under the same information level reveal significant differences between the two environments as also evidenced by the p-value from the t-test. This implies that participants were more willing to conclude the trade earlier under a time-cost environment.
Another interesting question concerns the difference in early trade volume between different institutions. Surprisingly, sessions with no additional information (sessions 1 and 2) appeared to have the largest 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 trades as well as the number of early trades.

Table 2. Aggregate measure

<table>
<thead>
<tr>
<th></th>
<th>Mean (STD)</th>
<th>No Info</th>
<th>Best Offer</th>
<th>Best Offer + Price</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Vol</td>
<td>Vol45</td>
<td>Vol90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>No TC</td>
<td>With TC</td>
<td>No TC</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td></td>
<td></td>
<td>p-value</td>
</tr>
<tr>
<td>Vol</td>
<td>3.27</td>
<td>5.67</td>
<td>3.40</td>
<td>5.20</td>
</tr>
<tr>
<td></td>
<td>(0.88)</td>
<td>(0.62)</td>
<td>(0.83)</td>
<td>(1.01)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Vol45</td>
<td>1.87</td>
<td>3.93</td>
<td>1.80</td>
<td>3.00</td>
</tr>
<tr>
<td></td>
<td>(0.52)</td>
<td>(0.59)</td>
<td>(0.77)</td>
<td>(1.00)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Vol90</td>
<td>2.53</td>
<td>5.07</td>
<td>2.13</td>
<td>4.13</td>
</tr>
<tr>
<td></td>
<td>(0.74)</td>
<td>(0.59)</td>
<td>(0.92)</td>
<td>(1.06)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Vol120</td>
<td>2.87</td>
<td>5.33</td>
<td>2.40</td>
<td>4.60</td>
</tr>
<tr>
<td></td>
<td>(0.92)</td>
<td>(0.62)</td>
<td>(0.74)</td>
<td>(0.99)</td>
</tr>
<tr>
<td></td>
<td>p-value</td>
<td>0.000</td>
<td>0.000</td>
<td>0.000</td>
</tr>
<tr>
<td>Trans. Price</td>
<td>112.37</td>
<td>123.05</td>
<td>111.41</td>
<td>123.23</td>
</tr>
<tr>
<td></td>
<td>(23.76)</td>
<td>(22.53)</td>
<td>(23.48)</td>
<td>(23.28)</td>
</tr>
<tr>
<td>%Alloc. Eff.</td>
<td>95.96</td>
<td>–</td>
<td>95.84</td>
<td>–</td>
</tr>
<tr>
<td></td>
<td>(7.73)</td>
<td>–</td>
<td>(7.82)</td>
<td>–</td>
</tr>
<tr>
<td>%TC save</td>
<td>–</td>
<td>85.11</td>
<td>–</td>
<td>76.06</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>(4.30)</td>
<td>–</td>
<td>(7.61)</td>
</tr>
<tr>
<td>%Overall Eff.</td>
<td>–</td>
<td>74.13</td>
<td>–</td>
<td>69.23</td>
</tr>
<tr>
<td></td>
<td>–</td>
<td>(8.59)</td>
<td>–</td>
<td>(10.30)</td>
</tr>
</tbody>
</table>

– 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.

6.1.3.2 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. An exception is found under the “Best Offer + Price” information level as evidenced by the p-value (0.375). Moreover, under the “Best Offer + Price” information level, the average value and standard deviation of transaction prices are smaller compared with other information levels. This result is in line with the result of Anufriev et al. (2011), who stated that additional information decreases price volatility (the least variation in transaction price).

6.1.3.3 Market efficiency

Results from Table 2 reveal that regardless of 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 can be observed 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 our hypotheses in more detail. 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.
6.2.1 Empirical models

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

6.2.1.1 Models for individual level

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

\[
y_i = \beta_0 + \beta_1 V_i + \beta_2 \text{Best}_i + \beta_3 \text{BPrice}_i + \beta_4 \text{TCLow}_i + \beta_5 \text{TCHigh}_i + \varepsilon_i
\]  

Equation (7)

where for subject \( i \left( i \in \{1, 2, ..., N_g, N_g + 1, N_g + 2, ..., N_g + N_s\} \right) \), \( N_B \) = the number of buyers who succeeded in the auction, and \( NS \) = the number of sellers who succeeded in the auction,

\[
\begin{align*}
y_i &= \begin{cases}
\text{buyer}'s transaction price (data from all 6 sessions) \\
\text{seller}'s transaction price (data from all 6 sessions) \\
\text{buyer}'s transaction price (data from 'with time-cost' sessions) \\
\text{seller}'s transaction price (data from 'with time-cost' sessions)
\end{cases}
\end{align*}
\]

\[
\begin{align*}
V_i &= \text{valuation or cost of subject } \text{of cost or valuation } V_i \\
\text{Best}_i &= \begin{cases}
1, \text{ if } i \text{ receives 'Best Offer' information} \\
0, \text{ otherwise}
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\text{BPrice}_i &= \begin{cases}
1, \text{ if } i \text{ receives 'Best Offer + Price' information} \\
0, \text{ otherwise}
\end{cases}
\end{align*}
\]

\[
\begin{align*}
\text{TCLow}_i &= \begin{cases}
1, \text{ if } i \text{ has low time - cost} \\
0, \text{ otherwise}
\end{cases}, \quad \text{TCHigh}_i &= \begin{cases}
1, \text{ if } i \text{ has high time - cost} \\
0, \text{ otherwise}
\end{cases}
\end{align*}
\]

6.2.1.2 Models for period level

The models for aggregate measures are described here. The dependent variables in the models 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 used two dummy variables to represent three levels of information type. However, in the 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” was 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.
\[ y_{it} = \alpha_0 + \alpha_1 Best_{it} + \alpha_2 BPrice_{it} + \alpha_3 TC_{it} + \epsilon_{it} \]  

(8)

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

\[
\begin{align*}
    y_{it} &= \begin{cases} 
      Vol_i : & \text{Total volume in period } i \text{ of session } t \\
      Vol_{45t} : & \text{Trade volume within 45 sec in period } i \text{ of session } t \\
      Vol_{90t} : & \text{Trade volume within 90 sec in period } i \text{ of session } t \\
      Vol_{120t} : & \text{Trade volume within 120 sec in period } i \text{ of session } t \\
      OverallEff_{it} : & \text{Overall Efficiency in period } i \text{ of session } t \\
      TransPrice_{it} : & \text{Average transaction price in period } i \text{ of session } t 
    \end{cases}
\end{align*}
\]

\[
\begin{align*}
    Best_{it} &= \begin{cases} 
      1, & \text{if information is 'Best Offer'} \\
      0, & \text{otherwise}
    \end{cases}
\end{align*}
\]

\[
\begin{align*}
    BPrice_{it} &= \begin{cases} 
      1, & \text{if information is 'Best Offer + Price'} \\
      0, & \text{otherwise}
    \end{cases}
\end{align*}
\]

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

**6.2.2 Individual transaction price**

The results of regression analyses based on the model in 6.2.1.1 are shown in Table 3. Several observations can be made. As expected, private valuation (cost) is significant and affects transaction price positively across all regressions. The \( R^2 \) is low, but its magnitude is comparable to many of the results in the experimental economics literature (for example, see 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 they have low time-cost, which is greater again 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 were 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

\[ y = \text{Individual Transaction Price} \]

<table>
<thead>
<tr>
<th>Buyer</th>
<th>Seller</th>
<th>Only 3 Sessions With Time-cost</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Buyer</td>
</tr>
<tr>
<td></td>
<td>Coef.</td>
<td>p-value</td>
</tr>
<tr>
<td>Constant</td>
<td>90.41</td>
<td>0.000</td>
</tr>
<tr>
<td>Value/Cost</td>
<td>0.17</td>
<td>0.000</td>
</tr>
<tr>
<td>Best Offer dummy</td>
<td>-0.78</td>
<td>0.000</td>
</tr>
<tr>
<td>Best Offer + Price dummy</td>
<td>-14.10</td>
<td>0.000</td>
</tr>
<tr>
<td>TC_Low</td>
<td>8.38</td>
<td>0.002</td>
</tr>
<tr>
<td>TC_High</td>
<td>13.69</td>
<td>0.000</td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.18</td>
<td>0.15</td>
</tr>
</tbody>
</table>

Table 4. Regression analysis of trade volume and transaction price (all sessions)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient (p-value)</th>
<th>Vol</th>
<th>Vol45</th>
<th>Vol90</th>
<th>Vol120</th>
<th>Trans. Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>3.47 (0.000)</td>
<td>1.83 (0.000)</td>
<td>2.61 (0.000)</td>
<td>2.87 (0.000)</td>
<td>113.80 (0.000)</td>
<td></td>
</tr>
<tr>
<td>Best Offer dummy</td>
<td>-0.17 (0.434)</td>
<td>-0.50 (0.027)</td>
<td>-0.67 (0.004)</td>
<td>-0.60 (0.009)</td>
<td>-0.05 (0.990)</td>
<td></td>
</tr>
<tr>
<td>Best Offer + Price dummy</td>
<td>-0.30 (0.160)</td>
<td>-0.60 (0.008)</td>
<td>-0.83 (0.000)</td>
<td>-0.87 (0.000)</td>
<td>-12.00 (0.001)</td>
<td></td>
</tr>
<tr>
<td>Time-cost dummy</td>
<td>2.00 (0.000)</td>
<td>2.13 (0.000)</td>
<td>2.38 (0.000)</td>
<td>2.47 (0.000)</td>
<td>7.12 (0.015)</td>
<td></td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.61 (0.000)</td>
<td>0.63 (0.000)</td>
<td>0.68 (0.000)</td>
<td>0.70 (0.000)</td>
<td>0.20 (0.000)</td>
<td></td>
</tr>
</tbody>
</table>

Table 5. Regression analysis of trade volume, overall efficiency, and transaction price (only with time-cost sessions)

<table>
<thead>
<tr>
<th>Variables</th>
<th>Coefficient (p-value)</th>
<th>Vol</th>
<th>Vol45</th>
<th>Vol90</th>
<th>Vol120</th>
<th>Overall Eff.</th>
<th>Trans. Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td>5.67 (0.000)</td>
<td>3.93 (0.000)</td>
<td>5.07 (0.000)</td>
<td>5.33 (0.000)</td>
<td>74.13 (0.000)</td>
<td>122.90 (0.000)</td>
<td></td>
</tr>
<tr>
<td>Best Offer dummy</td>
<td>-0.47 (0.129)</td>
<td>-0.93 (0.004)</td>
<td>-0.93 (0.004)</td>
<td>-0.73 (0.023)</td>
<td>-4.90 (0.153)</td>
<td>61.15 (0.893)</td>
<td></td>
</tr>
<tr>
<td>Best Offer + Price dummy</td>
<td>-0.60 (0.053)</td>
<td>-0.07 (0.826)</td>
<td>-0.80 (0.013)</td>
<td>-0.73 (0.023)</td>
<td>0.49 (0.885)</td>
<td>-18.61 (0.000)</td>
<td></td>
</tr>
<tr>
<td>(R^2)</td>
<td>0.10 (0.000)</td>
<td>0.22 (0.000)</td>
<td>0.21 (0.000)</td>
<td>0.15 (0.000)</td>
<td>0.07 (0.000)</td>
<td>0.36 (0.000)</td>
<td></td>
</tr>
</tbody>
</table>

### 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 are larger again 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. The “Best Offer + Price” case tends to have larger early trade volumes than the “Best Offer” case, while the “No Information” case has still larger early trade volumes. One important point to note from Table 5 concerns the trade volume within the first 45 seconds. Under this measure, it is observed that there is no statistically significant difference between Vol45 in the “Best Offer + Price” case and Vol45 in the “No Information” case.
6.2.4 Average transaction price

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

When only the sessions with time-cost are considered (Table 5), a much greater reduction in average transaction price was found for the information type “Best Offer + Price” relative to the “No Information” case (18.61 ECU lower). However, the average transaction price under the “Best Offer” case is not significantly different from that of the “No Information” case.

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 is not significantly different between all three information types.

7. DISCUSSION AND CONCLUSION

Motivated by taxi refusal problems—particularly for some passengers who have limited access to the service and when the trip destination is in a congested or remote area, such that taxi drivers are often reluctant to provide services—this paper presents a new idea based on a variable surcharge policy that can be accomplished by means of an online double auction. The surcharge is paid in addition to the metered fare. Passengers can bid through an online marketplace a higher surcharge if they are in need of taxi services, while drivers can also ask through the marketplace a desired surcharge to balance their disincentive. However, the typical design of the auction market for normal commodities, in which time-cost is not a concern, may not be suitable for a taxi service auction as time-cost is relevant in the latter case. We examined the problem of information content design for the user interface by conducting laboratory experiments. The problem of whether or not the variable surcharge policy is better than the fixed surcharge policy was also examined. Important findings can be summarized as follows.

- The fixed surcharge policy was outperformed by the variable surcharge policy for most of the values of the surcharge considered. Only when the surcharge is fixed near to the equilibrium point, the allocative efficiency of the fixed surcharge policy is comparable to that of the variable surcharge policy. However, the trading volume under the fixed policy was substantially lower for all values of surcharge considered. This illustrates that the variable surcharge policy can offer a larger opportunity for passengers to get a service.

- Time-cost does have an effect on individual bidding strategies as well as on the aggregate market performance. This highlights the need to have a new study on the design of the auction market under a time-cost environment. Our study attempts to fill part of this gap, particularly regarding the design of information content for the user interface.

- We found that different information contents result in significant differences in bidding strategies as well as in some aggregate performance measures.

- Under a time-cost environment, providing information on the current best offer and the last transaction price results in the least variation in transaction price, and the average
transaction price was found to be significantly lower than that in the case of no information.

- Under a 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 not significantly different from that of the other information contents.

This study focuses on the problem of the design of the taxi auction market. To implement the online taxi auction system in reality, some issues need to be considered. These concern the distance between the taxis and the passengers, and the time the driver takes to reach the passenger. This issue plays quite an important role for the success of the taxi auction system. In reality, the whole service area can be subdivided into smaller zones with an optimal zone size. “Optimal” in this case means that the zone size should be small enough so that taxis can reach passengers within a desired time limit. On the other hand, the zone size should also be big enough that there are a 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 technologies to identify which zone each individual taxi and passenger belongs to. We hypothesize that with the state of current communication technology, it is possible to know the location of all taxis and passengers (for example, by means of smartphones and tablets equipped with a global positioning system). Nevertheless, the issue of optimal zone size is beyond the scope of this paper, but will be included in our future research. Whether such an auction market is possible and feasible needs a more careful investigation of several issues. Several research directions are worth exploring.

First of all, the benefit of the variable surcharge policy compared with the existing situation should be investigated in more detail, particularly under a time-cost environment. Secondly, new technologies and developments cannot be sustained without the acceptance of their users, both from the passengers’ and the drivers’ perspectives. Investigation of users’ acceptance as well as user-centered design is therefore one of the research directions. Thirdly, other aspects of the design, such as buyer bid auction and seller ask auction, may be investigated in comparison with the double auction market, under a time-cost environment. Detailed investigation of the effects of different market institutional design under a more realistic environment should also be explored. This includes investigation under various combinations of time-cost levels for both passenger and driver sides.

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