Engineering Journal
issn: 0125-8281

*Article*

# Information Effect in Taxi Service Double Auction with Opportunity Cost: An Experimental Analysis

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**Abstract.** Inspired by the taxi refusal problem, we propose a double auction for taxi services with a variable supply-and-demand fare surcharge. In contrast to a conventional commodity double auction, our taxi service auction involves an opportunity cost that generally increases with time. Therefore, the bidding behaviour differs from that reported in the literature. We investigate experimentally the effects on bidding behaviour of the opportunity costs and private values of drivers and passengers, as well as of the types of given information. In addition, we compare the realized benefits between passengers and drivers. The results show that the degree of sensitivity to private value differs with opportunity cost and that transaction statistics vary with types of the information given to bidders. Moreover, we found that providing more information to bidders does not necessarily lead to better market performance and that giving suitable information to bidders could lead to a balanced benefit between passenger and driver.

**Keywords:** Double auction; opportunity cost; information; experimental economics; taxi; regression analysis

**ENGINEERING JOURNAL** Volume 22 Issue 1
Received 21 May 2017
Accepted 1 September 2017
Published 31 January 2018
Online at http://www.engj.org/
DOI:10.4186/ej.2018.22.1.77

DOI:10.4186/ej.2018.22.1.77

## 1. Introduction

Taxis are an important mode of transportation in the city of Bangkok in Thailand, often being the most convenient and comfortable way to travel within the city. However, statistics reveal that taxis account for 75.7% of complaints about public transport [1]. In particular, customer complaints about being refused taxi service rose from 14.7% in 2010 to 44.10% in 2015 [1]. This was despite the 1,000 Baht fine (approximately 30 USD) for refusing taxi service that was introduced in September 2012.

Pomprechawut (2006) [2] reported that 83.5% of interviewed taxi passengers in Bangkok cited taxi refusal as the problem that they encountered the most, particularly if the requested destination was in a congested area. Taxi refusal is also a major concern in other parts of the world, e.g. New York [3] and Australia [4]. One possible cause of taxi refusal is the fare, which is regulated by the government and may not correspond to actual supply and demand [3]. Another possible cause is a financial disincentive to providing the service, i.e. upon dropping off the passenger, the taxi driver does not want to be stuck in traffic or return with an empty cab [5]. Inherent to both these scenarios is the possibility of undesirably low revenue after deduction of service costs. Bruce and Jessop (2003) [6] reported the difficulties of taxi procurement in Australia. About half the failures to obtain service were those that occurred through a taxi call centre, a common problem being that prospective passengers would be told either that no taxis were available or that a taxi was on its way that subsequently did not materialise. Based on the results of these studies, the situation is expected to be even worse when two of the aforementioned situations occur simultaneously: the trip is to a congested area (or one that is remote and for which demand is low) and the passenger's only realistic way of accessing a taxi service is by calling a taxi company. The latter situation is quite typical in Bangkok, where hailing a taxi is difficult for the many people who live far away from the main streets. Under such circumstances, passengers have to call a taxi company, thereby incurring a fixed surcharge (20 Baht) in addition to the regular metre fare. Despite this extra payment, drivers still often refuse to provide the service. Nattapongwipas (2009) [7] found taxi call centres turning away about 20% of the prospective passengers who called during the morning peak, of whom 80% were given the explanation that no taxi was willing to pick them up.

Pueboobpaphan and Indra-Payoong (2015) [8] proposed a demand–supply matching of taxi services by means of a double auction. Figure 1 illustrates a taxi auction system whereby passengers and drivers can offer and ask for a surcharge in addition to the regular metre fare known as a variable surcharge policy. The effects of given information and opportunity cost on bidding behaviour and market efficiency were examined by conducting laboratory experiments. Pueboobpaphan and Indra-Payoong (2015) [8] found that the proposed (variable) surcharge policy outperforms the existing (fixed) surcharge policy in several aspects and that different given information has significantly different effects on transaction price and time. In addition, opportunity cost does have an effect on individual bidding behaviour. However, Pueboobpaphan and Indra-Payoong (2015) [8] considered only three different information levels and investigated only the main effect of opportunity cost. With a hypothesis that different information may lead to different behaviour and performance, the present paper extends the previous studies by considering new given information. It also explores in more detail the effect of opportunity cost on the behaviour of passenger and driver, as well as the interaction between opportunity cost and private value. In addition, the benefits of different given information to passenger and driver are compared to see whether there is any imbalance between the two parties.

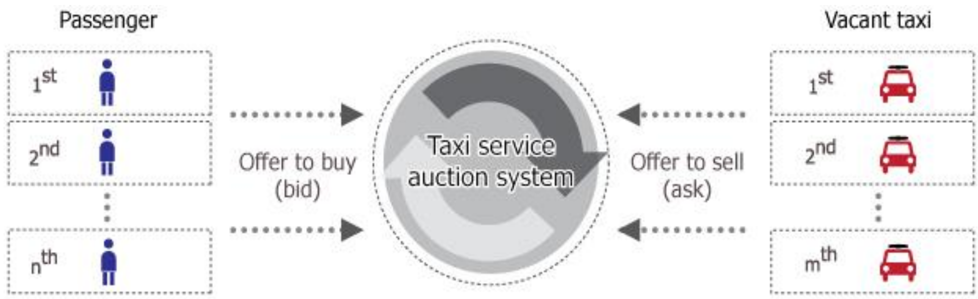



Fig. 1. Taxi service auction under double auction scheme.

This remainder of this paper is organised as follows. Section 2 presents a review of the related literature. Section 3 describes the experimental design in detail. Section 4 presents the new regression-based analytical models for quantifying the effect of interaction between private value and opportunity cost on transaction price and transaction time. Section 5 describes how passenger and driver benefits are determined. Section 6 provides and discusses the results from regression analyses and benefit comparison. Finally, Section 7 gives conclusions.

## 2. Related Literature

### 2.1. Taxi Studies

Srisurapanon et al. (2006) [9] studied the application of information technology in improving taxi services and reported various statistics associated with the taxi industry in Bangkok. Most vehicles were operated in two 12-h shifts. The average driving distance for one shift was approximately 247.5 km, one third of which was driven with an empty cab. There were an estimated 1.07 million taxi trips per day in Bangkok, and the average taxi fare was about 112 Baht [10]. The taxi refusal problem was also reported in the same study. The taxi call centres had to turn away about 20% of passengers who called in the morning peak, 80% of whom were told that no taxi was willing to pick them up. The same reason accounted for 54% during the off-peak period.

Various previous studies have dealt with taxi markets and their efficiency. The majority focused on the two main regulation issues: price and entry controls. To study price regulation and optimal service standard, Douglas (1972) [11] proposed an economic-based aggregate model of a taxi market. One important characteristic of that taxi market (in which a vacant taxi is engaged by being hailed) is that the passenger could not effectively transmit to the supplier his/her willingness to pay for a reduced waiting time. Following this work, several authors used a similar modelling approach to study the regulation of taxi markets [12, 13, 14 ]. However, one limitation of these aggregate models is that they do not consider the spatial structure of the taxi market, e.g. the road network and the origin/destination of the trips. Later, the alternative of applying network modelling to taxi services was proposed to deal explicitly with the spatial structure of the taxi market [15, 16, 17]. Yang et al. (2005) [18] extended this work by using a novel clock-network model to consider the temporal variation of taxi supply and customer demand throughout the day. In more recent work, Yang et al. (2010) [19] studied nonlinear pricing to address the problem of the over-supply of long-distance taxi services, particularly to and from the airport in Hong Kong. The aforementioned studies share a common objective of studying the impact of regulation issues (entry and price controls) on the efficiency and level of service of the taxi market. To the best of our knowledge, no work has yet investigated the problem of taxi refusal in detail.

### 2.2. Auction Studies

The effect of information on bidding strategies and market efficiency has been the focus of previous research, mainly in the field of finance and stock exchanges. Such studies were mostly concerned with the effect of the information contained in the 'limit order book', which is a database that records all outstanding quotes (bids and asks) as well as their corresponding volumes, sorted so that the best quotes on both the bid and ask sides are on the top. Cao, Hansch and Wang (2009) [20] considered the information content of a limit order book using data from the Australian Stock Exchange. They found that information regarding the best bid, best offer and final transaction price contributed to approximately 78% of the market price, with the rest coming from the information contained in all other parts of the book. Harris and Panchapagesan (2005) [21] also found the information in the limit order book to be informative for future price movements. Li and Zhang (2009) [22] compared the given information between two situations, i.e. before and after the top price levels shown to bidders are increased from three to five levels. They found that the fourth and fifth price levels are also informative to the price discovery process.

Anufriev et al. (2011) [23] investigated the effect of information on market efficiency. With full information about the action of others, bidders tend to submit orders at a similar price to the previously observed transaction price. Without such information, however, bidders tend to submit orders at prices that are closer to their own valuations/costings, causing higher price volatility. In addition, Anufriev et al. (2011) [23] found that market efficiency was similar with or without the information. Cao, Hansch and Wang (2008) [24] studied the effect of information on bidding strategies using data from the Australian

Stock Exchange. They found that the best bid and the best ask always affected order submissions, cancellations and amendments, while the rest of the book (i.e. the subsequent price levels) affected only cancellations and amendments. These results signify that the more information that is given to bidders, the more it contributes to price discovery. Moreover, Cao, Hansch and Wang (2008) [24] found that bidders acted differently depending upon the type of information they obtained. However, there was no clear difference in market efficiency under different levels of information.

### 2.3. Experimental Economic Studies

The economic laboratory experiment has become a useful tool for evaluating policy proposals and a testing ground for institutional design [25, 26, 27]. It has been applied in areas such as food policy [28], emission control and trading [29, 30], fishery [31, 32] and irrigation [33]. To the best of our knowledge, auctions with opportunity cost considerations have not been studied explicitly until now. Katok and Kwasnica (2008) [34] investigated the effect of timing on revenue in a descending auction, and Kwasnica and Katok (2007) [35] studied the effect of timing on jump bidding in an ascending auction. Both were conducted under the premise that time is a valuable resource, and hence wasting time can be considered as incurring an opportunity cost. In a descending auction, clock speed can have a significant effect on price. In an ascending auction, bidders respond by bidding in larger increments when time is more valuable. However, Kwasnica and Katok (2007) [35] reported that opportunity cost does not have an effect on economic performance. Similar results in jump bidding were also found by Peng, Cai and Chen (2009) [36], i.e. when the value of time (opportunity cost) is high, jump bidding is preferred. Note that all of these results were obtained for some type of one-sided auction rather than for a double auction market.

## 3. Experimental Design

The experimental design adopted here follows that used previously by Pueboobpaphan and Indra-Payoong (2015) [28]: an electronic double auction system for a taxi service. For ease of illustration, a single origin/destination pair is considered for the taxi service auction in the present study. Through an online marketplace, passengers can bid a higher surcharge if they are in need of a taxi, whereas drivers can ask for a desired surcharge to cover their operating costs.

The experiment was conducted at Suranaree University of Technology, Thailand using the z-Tree software system [37]. The bidders were undergraduate and master's students from different faculties who had never participated in an economics experiment. There are advantages and disadvantages to using students as experimental subjects; this issue is still a topic of much debate in the experimental economics research community [27]. On one hand, there is no guarantee that the behaviour of students would be similar to that of professional bidders or direct stakeholders. On the other hand, using professional bidders as experimental subjects can also be criticized as being unreliable because, if the outcome of the research is to be used to set policy, professional subjects might respond in ways that would secure them a positive advantage. In contrast, Friedman and Cassar (2004) [27] noted that students tend to know little about the research hypothesis and so do not intentionally bias the results.

Each session was conducted with 12 bidders chosen randomly upon arrival at the laboratory to form a group of six passengers (hereinafter called the 'buyers') and a group of six taxi drivers (hereinafter called the 'sellers'). Each bidder retained his/her assigned role (i.e. buyer or seller) throughout the experiment. We recognise that demand for taxi services at peak times can be greater than supply, resulting in a taxi shortage. Thus, an experiment with the same number of passengers and drivers may not be a good representation of such a situation. Nevertheless, even without such an imbalance during off-peak times, taxi drivers still often refuse to pick up passengers, especially if the requested destination is in a highly congested or remote area. For this reason, the experiment in this study was designed to capture the taxi refusal problem during off-peak times for which the proposed auction mechanism is more pertinent. In addition, the current setup allows us to simplify the experiment and to analyse the effect of opportunity cost by making a direct comparison between our results and those of most previous studies, which used equal numbers of participants on both sides. A future experiment involving unequal supply/demand populations could be considered if so desired.

Each session consisted of 15 consecutive auction periods, each of which lasted for 210 s. However, the actual time spent in a period may have been shorter if all offers were matched sooner. At the beginning of each session, the bidders were given a sheet of instructions to read. To make sure that the bidders understood the trading rules properly, the instructions were also described by the experimenters, and each bidder was given an exercise to test his/her understanding. Finally, before running each experimental session, a pilot test was conducted whose results were not included in the analysis.

In this study, two experimental factors were altered: the given information and the opportunity cost. Therefore, as shown in Table 1, the experiment consisted of eight sessions based on four levels of given information and whether or not the opportunity cost was considered.

Table 1. Summary of experimental design.

| Given information | Opportunity cost | |
|---|---|---|
| | Without opportunity cost | With opportunity cost |
| Basic information (*Basic*) | Session 1 | Session 2 |
| Matched Price (*MPrice*) | Session 3 | Session 4 |
| Best Offer (*BOffer*) | Session 5 | Session 6 |
| Matched Price + Best Offer (*Full*) | Session 7 | Session 8 |

### 3.1. Given Information

The computer screen of each bidder showed information about the bidder's private value, the remaining time in seconds and the offer status (whether or not the offer had been matched); there was also an input box in which the bidder could submit an offer. We refer to this bidder information as the 'basic' information. The screen could also show certain additional information that depended on which session was being considered. Buyers and sellers submitted their surcharge offers and the system showed the bidding results in real time, i.e. whether or not an offer had been matched. If an offer was not matched, the bidder was free to improve his/her offer by re-submitting the bid/ask as long as there was still auction time remaining. Each bidder could buy or sell no more than one unit of service in each period.

Our experimental design considered four levels of given information. The first level, *Basic*, represents the case in which no bidder received any information other than the basic content described above. The matched-price level, hereinafter called *MPrice*, represents the case in which all bidders could see the last transaction price in real time in addition to *Basic*. The best-offer level, hereinafter called *BOffer*, represents the case in which all bidders could see the current best bid and the current best ask in real time, in addition to *Basic*. In the final level, *MPrice* + *BOffer*, also known as *Full*, the current best bid and the current best ask were displayed in real time, along with *Basic* and the last transaction price.

### 3.2. Opportunity Cost

Two options are considered for opportunity cost: with or without it. For the sessions with opportunity cost, each computer screen gave two additional pieces of information: a constant OCperiod, the total opportunity cost were the bidder to end the period without getting a service; and a variable OCelapsed, the opportunity cost that accrued linearly as time elapsed. The latter is the opportunity cost that accrues to the bidder in real time; OCelapsed = OCperiod at the end of the auction if the bidder did not get a service. The on-screen value of OCelapsed was updated every second. Note that different time-dependent functional forms of OCelapsed exist in reality. However, in this study, a linear function is assumed. A simplified computer screen for session 8 (*Full* information and with opportunity cost) is shown in Fig. 2. More details of the experimental set up can be found in the work of Pueboobpaphan (2014) [38].

To evaluate explicitly the effect of opportunity cost on bidding strategies in a thin market of six bidders on each side, we consider only the two extreme values of OCperiod, namely 50 and 150 experimental currency units (ECU) for the low and high opportunity cost, respectively. To determine the value of OCperiod for each bidder, a random value was drawn from a uniform distribution between 0 and 1: OCperiod = 50 if the value was less than 0.5, OCperiod = 150 otherwise. In each session, the values of OCperiod differed throughout a sequence of auction periods. However, the same set of OCperiod values was used for all of the sessions with opportunity cost (sessions 2, 4, 6 and 8). In contrast to other studies, we allowed buyers/sellers to bid/ask higher/lower than their private value if they preferred. This condition was intended to capture the bidders' bidding behaviour in relation to whether or not they were willing to lessen their loss from opportunity cost.

DOI:10.4186/ej.2018.22.1.77

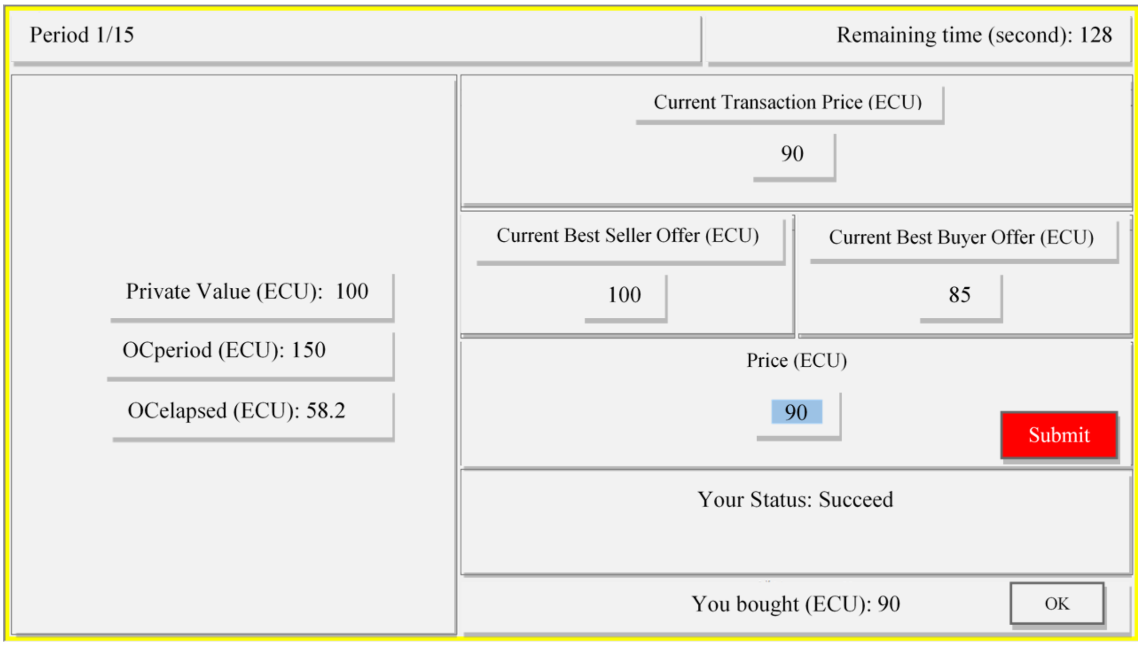



Fig. 2. Computer screen used in session 8 (Full, with opportunity cost).

### 3.3. Private Value

This research followed the general experimental guidelines of Friedman and Cassar (2004) [27]. The buyer's values and seller's costs were drawn independently for each period from a uniform distribution between 20 and 200 ECU. This same set of values was then used in all experimental sessions. Such parameters were private and not disclosed to other bidders during the experiment. The lowest value, 20 ECU, corresponded to the current fixed surcharge for calling a taxi in Bangkok (20 Baht). The maximum surcharge rate was set to 200 ECU which is comparable to the average taxi fare [10]. It is important to note that selecting a particular surcharge range does not affect the general conclusions of this research because the same range was used in all sessions.

### 3.4. Incentive

During the laboratory experiments, giving/receiving a service has no intrinsic value to the bidders, so preferences for them had to be induced. The concept here comes from induced value theory [39], which Friedman and Cassar (2004) [27] describe as being '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 was used as a reward in this study. The amount paid to each bidder was a function of the bidder's profit earned during the experiment. The profits for buyer and seller in each period in the case without opportunity cost are defined by Eq. (1) and (2), respectively, and in the case with opportunity cost by Eq. (3) and (4), respectively:

$$Profit_{buyer}^{Without\,OC} = \begin{cases} V_b - P & ,if \;\; auction \;\; succeeded \\ 0 & ,otherwise \end{cases} \tag{1}$$

$$Profit_{seller}^{WithoutOC} = \begin{cases} P - V_s & ,if \;\; auction \;\; succeeded \\ 0 & ,otherwise \end{cases} \tag{2}$$

$$Profit_{buyer}^{With\,OC} = \begin{cases} V_b - P - c_b(t) & ,if \; auction \;\; succeeded \\ -c_b(t) & ,otherwise \end{cases} \tag{3}$$

$$Profit_{seller}^{WithOC} = \begin{cases} P - V_s - c_s(t) & , if \ auction \ succeeded \\ -c_s(t) & , otherwise \end{cases} \tag{4}$$

Here, $V_b$ and $V_s$ denote buyers' and sellers' private valuations, $P$ denotes the transaction price, and $c_b(t)$ and $c_s(t)$ denote OCelapsed as a function of time $t$ for buyer and seller, respectively. Profits from all periods are added and any loss incurred is subtracted. The higher the total profit the bidder earns, the more the bidder is rewarded. The total profit in ECU is then converted to Thai Baht currency. To encourage volunteers, bidders were also given a participation fee of 100 Baht. All cash rewards were paid at the conclusion of each experimental session. The bidders received payment ranging from 180 to 640 Baht, with an average of 350 Baht (US$1 was approximately 30 Baht at the time of the study).

## 4. Regression Analysis

In this section, we examine the effect of different given information, private values and the interaction between opportunity cost and private value on bidding strategies. At individual level, there are three levels of opportunity cost (OC): 'without OC', 'low OC' and 'high OC'. As a result, the OC variable is manipulated as two dummy variables (low and high OC). There are also four levels of given information that are modelled using three dummy variables, namely *MPrice*, *BOffer* and *Full*. Using a subject's transaction price or time as the dependent variable, the models are presented in Eq. (5) and (6). We consider two models, the second of which differs from the first by containing two additional terms that represent the interaction between opportunity cost and private value:

$$\begin{aligned} y_{ij} = {} & \beta_{0j} + \beta_{1j} PV_i + \beta_{2j} MPrice_i + \beta_{3j} BOffer_i + \beta_{4j} Full_i + \beta_{5j} OC\_low_i \\ & + \beta_{6j} OC\_high_i + \varepsilon_{ij} \end{aligned} \tag{5}$$

$$\begin{aligned} y_{ij} = {} & \beta_{0j} + \beta_{1j} PV_i + \beta_{2j} MPrice_i + \beta_{3j} BOffer_i + \beta_{4j} Full_i + \beta_{5j} OC\_low_i \\ & + \beta_{6j} OC\_high_i + \beta_{7j} OC\_low_i * PV_i + \beta_{8j} OC\_high_i * PV_i + \varepsilon_{ij} \end{aligned} \tag{6}$$

Here, for subject $i$ ($i \in \{1, 2, ..., N_B, N_B + 1, N_B + 2 ..., N_B + N_S\}$), $N_B$ denotes the number of buyers who succeed at auction, $N_S$ the number of sellers who succeed at auction and $j$ = transaction price or time, depending on which is being analysed:

$$\begin{aligned} y_{ij} &= the \ value \ of \ dependent \ variable \ j \ of \ buyer \ (seller) \ i \\ &= \begin{cases} buyer \ (seller) \ i's \ transaction \ price \\ buyer \ (seller) \ i's \ transaction \ time \end{cases} , \end{aligned}$$

$$PV_i = Private \ value \ (value \ or \ cost) \ of \ subject \ i \quad ,$$

$$MPrice_i = \begin{cases} 1, \ if \ information \ is \ 'MPrice' \\ 0, \ otherwise \end{cases} ,$$

$$BOffer_i = \begin{cases} 1, \ if \ information \ is \ 'BOffer' \\ 0, \ otherwise \end{cases} ,$$

$$Full_i = \begin{cases} 1, \ if \ information \ is \ 'Full' \\ 0, \ otherwise \end{cases} ,$$

$$OC\_low_i = \begin{cases} 1, & if \;\; opportunity \;\; cost \;\; is \;\; low \\ 0, & otherwise \end{cases},$$

$$OC\_high_i = \begin{cases} 1, & if \;\; opportunity \;\; cost \;\; is \;\; high \\ 0, & otherwise \end{cases}.$$

## 5. Realized Benefit Comparison

This section explains how we determine realized benefits, which are compared between buyers and sellers to see whether there is a preferential benefit to either side. In this study, the realized benefit can be separated into two parts: benefit from trading profit, and benefit from opportunity cost saving. Eq. (7) provides a mathematical description of how to determine the realized benefit in each time period *p*. These are then averaged separately for buyers and sellers and for different given information *k*. Finally, a *t*-test was used to examine whether there is a preferential benefit to either side:

$$Realized\ Benefit_{pk} = \frac{\sum_{j=1}^{n_{pk}} (Trading\ \ profit_{pjk}) + \sum_{j=1}^{n_{pk}} (Opportunity\ cost\ saving_{pjk})}{n_{pk}} \tag{7}$$

Let *p* be the period index, *j* be the bidder index and *k* be the index of given information. Then $n_{pk}$ represents the number of bidders who win the auction in period *p* in the market with given information *k*.

Note that Eq. (7) considers only those bidders whose transactions were successful. Equation (3) or (4) is used to determine the trading profit indicated in the first term of Eq. (7), depending on whether the buyer or the seller is being considered. Inclusion of the second term was motivated by the fact that bidders are allowed to make negative trading profits to trade off the loss from opportunity cost. Thus, it is not sufficient to consider only the trading profit when describing the overall benefit. Therefore, the second term was proposed to capture the benefits of opportunity cost saving. Equation (8) provides a mathematical description of opportunity cost saving (*OCsaving*):

$$OCsaving_{pjk} = OCperiod_{pjk} - OCelapsed_{pjk}, \tag{8}$$

where *p*, *j* and *k* are the same as in Eq. (7), and the definition of *OCperiod* and *OCelapsed* are the same as described in Section 3. It is significant to note that *OCsaving* in the session can be determined using opportunity cost alone.

## 6. Results and Discussion

In this section, the results of regression analyses are presented. Individual transaction price or time was considered as the dependent variable in the models. In addition, the comparisons between the realized benefits of buyers and sellers are presented.

### 6.1. Individual Transaction Price

The regression results for individual transaction price are given in Table 2 for both buyers and sellers. Several inferences can be made from this table. In general, the coefficients of common variables are consistent across all models. The signs of all variables are also intuitively consistent. Although the adjusted $R^2$ is quite low compared to general regression studies, it is comparable to many results in the experimental economics literature (see, for example, Ketcham et al. (1984) [40]). Based on the adjusted $R^2$ value, we conclude that model 2, which includes the interaction terms, is superior to model 1; all further discussions will be based on model 2. Discussions that are generic for both buyer and seller are given first, followed by buyer/seller-specific discussions about the interaction terms.

DOI:10.4186/ej.2018.22.1.77

Table 2. Regression analysis of transaction price.

| Variable | Coefficient (p-value) | | | |
|---|---|---|---|---|
| | Buyer | | Seller | |
| | Model 1 | Model 2 | Model 1 | Model 2 |
| *Intercept* | 93.37 (0.00) | 78.95 (0.00) | 103.96 (0.00) | 86.39 (0.00) |
| *PV* | 0.14 (0.00) | 0.24 (0.00) | 0.14 (0.00) | 0.39 (0.00) |
| *MPrice dummy* | −11.30 (0.00) | −11.44 (0.00) | −11.43 (0.00) | −10.92 (0.00) |
| *BOffer dummy* | −0.72 (0.78) | −0.76 (0.76) | −0.10 (0.97) | −0.42 (0.87) |
| *Full dummy* | −14.05 (0.00) | −14.19 (0.00) | −13.07 (0.00) | −13.06 (0.00) |
| *OC_low dummy* | 8.77 (0.00) | 17.64 (0.03) | 0.59 (0.81) | 28.48 (0.00) |
| *OC_high dummy* | 14.99 (0.00) | 42.70 (0.00) | 5.06 (0.02) | 25.65 (0.00) |
| *OC_low dummy*PV* | | −0.05 (0.37) | | −0.34 (0.00) |
| *OC_high dummy*PV* | | −0.21 (0.00) | | −0.28 (0.00) |
| *Adjusted* $R^2$ | 0.17 | 0.19 | 0.17 | 0.22 |

We look first at the individual effect of each variable. As expected, Table 2 shows that private valuation is significant and affects the transaction price positively across all regressions. This implies that a buyer with a higher private value could afford to pay more for the service, whereas a seller whose costs were higher would naturally require a higher transaction price. The estimated information-type effects reveal that transaction prices under *MPrice* and *Full* information are significantly lower than prices under *Basic* information. However, the transaction prices under *BOffer* show no significant difference from the transaction prices under *Basic* information. From the buyer's point of view, *MPrice* and *Full* information are more desirable because they lead to lower transaction prices than those under *BOffer* and *Basic* information. However, the seller would prefer only *Basic* information to be available, because this leads to higher transaction prices.

Regarding the opportunity cost effect, it must be considered in conjunction with the interaction terms between opportunity cost and private value. By inserting the values of all coefficients that are statistically significant, the models for buyer's and seller's transaction prices are given by Eq. (9) and (10) respectively:

$$\begin{aligned} y_{buyer\,i} = {} & 78.95 + 0.24PV_i - 11.44MPrice_i - 14.19Full_i + 17.64OC\_low_i \\ & + 42.70OC\_high_i - 0.21OC\_high_i * PV_i \end{aligned} \tag{9}$$

$$\begin{aligned} y_{seller\,i} = {} & 86.39 + 0.39PV_i - 10.92MPrice_i - 13.06Full_i + 28.48OC\_low_i \\ & + 25.65OC\_high_i - 0.34OC\_low_i * PV_i - 0.28OC\_high_i * PV_i \end{aligned} \tag{10}$$

Finally, the models can be distinguished by low or high opportunity cost by inserting the values of the opportunity-cost dummy variables. Equations (11) and (12) show the reduced model form of the transaction price for buyers and sellers, respectively:

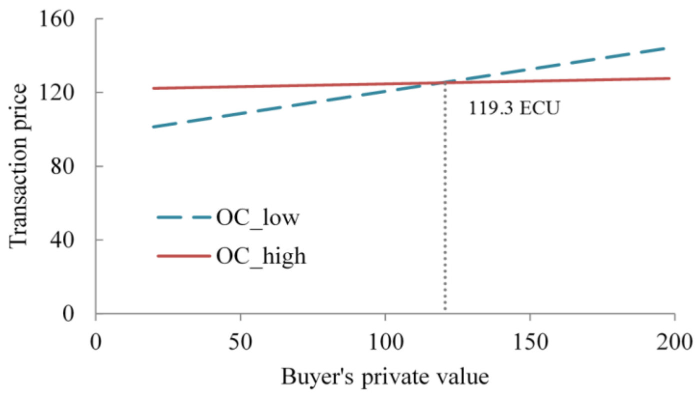
$$y_{buyer\,i} = \begin{cases} 96.59 + 0.24PV_i - 11.44MPrice_i - 14.19Full_i, \ if\ buyer\ i\ has\ low OC \\ 121.65 + 0.03PV_i - 11.44MPrice_i - 14.19Full_i, \ if\ buyer\ i\ has\ high OC \end{cases} \tag{11}$$

$$y_{seller\,i} = \begin{cases} 114.87 + 0.05PV_i - 10.92MPrice_i - 13.06Full_i, \ if\ seller\ i\ has\ low OC \\ 112.04 + 0.11PV_i - 10.92MPrice_i - 13.06Full_i, \ if\ seller\ i\ has\ high OC \end{cases} \tag{12}$$

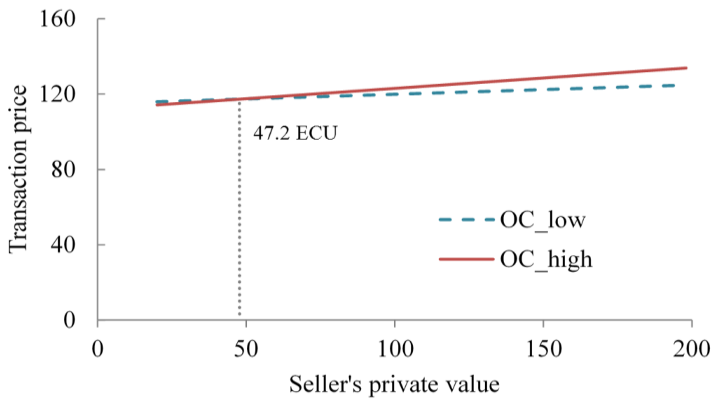
From Eq. (11), the intercept values imply that if the private value is close to zero and all else is equal, buyers with lower opportunity costs generally pay less than those with higher opportunity costs. The coefficients of private value in Eq. (11) reveal that buyer transaction price increases with private value. However, buyers with lower opportunity costs are more sensitive to private value than buyers with higher opportunity costs (0.24 compared with 0.03). When plotting Eq. (11) while considering the same level of information, we obtain Fig. 3(a) and see that the two lines for low and high opportunity cost intersect at the private value of 119.3 ECU. Considering the region to the left of the intersection point, buyers with higher opportunity costs tend to pay more than those with lower opportunity costs. This is reasonable because buyers with higher opportunity costs are more concerned about saving on opportunity cost than about earning from buying at a price lower than the private value. Thus, such buyers offer at relatively high prices and see their offers being matched very quickly. In contrast, buyers with lower opportunity costs are in less of a hurry and therefore can wait to get a better price. As a result, such buyers tend to pay less than those with higher opportunity costs.

Considering the region to the right of the intersection point (for buyers with private values larger than 119.3 ECU), the tendency is opposite. Buyers with lower opportunity costs tend to pay more than those with higher opportunity costs. This result is striking at first sight and requires careful thought as to the underlying reason, which it is worth noting is related to the findings from transaction time analysis that are discussed in the next section. For the present purpose, these are described here briefly. In general, buyers with higher opportunity costs tend to leave the auction sooner than those with lower opportunity costs; the former might start by making an offer at a relatively high price and have it matched very quickly, thus reducing the number of remaining sellers in the market. As time progresses, the sellers that remain in the market are usually those with higher costs. In contrast, buyers with lower opportunity costs might start offering at a relatively low price and therefore experience difficulty in having their offers matched. As time progresses, they need to improve their offers in order to match them with those of the remaining sellers. As a result, for buyers with larger private values, those with lower opportunity costs tend to pay more than those with higher opportunity costs.

Although the general tendencies are opposed, Eq. (12) and Fig. 3(b) for seller transaction price can be interpreted in much the same way as in the case of buyers, in which the two lines intersect at a private value of 47.2 ECU. To the left of the intersect point, sellers with higher opportunity costs tend to sell at a cheaper price than those with lower opportunity costs. This can be explained in a similar manner to that in the case of buyers, namely that sellers with higher opportunity costs are more concerned about opportunity-cost savings and thus are more willing to accept a lower price. To the right of the intersection point, sellers with higher opportunity costs tend to secure a higher price than those with lower opportunity costs. Once again, this result is striking at first sight but can be explained in a similar manner as in the case of buyers. The quick matching among the sellers with higher opportunity costs reduces the number of remaining buyers in the market. As time progresses, it becomes more difficult to find buyers with higher private values. As a result, sellers with lower opportunity costs need to decrease their price in order to be matched with the remaining buyers. Therefore, for sellers with large private values, those with lower opportunity costs tend to sell at a lower price than those with higher opportunity costs.




(a)




(b)

Fig. 3. Interaction effect between opportunity cost and private value on bidder's transaction price: (a) buyer's transaction price (Eq. (11)); (b) seller's transaction price (Eq. (12)).

### 6.2. Individual Transaction Time

Similar analysis was also made for individual transaction time; the results are given in Table 3 for both buyers and sellers. In the case of buyers, model 2 with the inclusion of interaction terms was preferred over model 1 because of the larger adjusted $R^2$ value. However, in the case of sellers, model 1 was chosen as it is simpler and there is no difference in the adjusted $R^2$ value. The effect of private value on transaction time is significant but different for the cases of buyers and sellers. A significant negative effect reveals that buyers with higher private values complete the auction earlier. In contrast, sellers with higher private values take longer to finish the auction because the estimated coefficient is significantly positive. This is logical because higher private values for sellers mean higher costs, and thus it is difficult for sellers to sell at prices that are higher than the cost.

The estimated effect of different given information shows that transaction time is significantly longer for *BOffer* and *Full* information than for *Basic* information. However, there is no significant difference between transaction times for *MPrice* and *Basic* information. Based on this result, it can be said that *MPrice* and *Basic* are more desirable because they could lead to a shorter transaction time.

Similar to transaction price, interpreting the effects of opportunity cost on transaction time requires consideration of the interaction between opportunity cost and private value. By following a similar procedure, Eq. (13) and (14) show the reduced models of transaction time for buyers and sellers, respectively:

$$y_i = \begin{cases} 108.37 - 0.79PV_i + 23.04BOffer_i + 22.44Full_i, & \text{if buyer } i \text{ has low } OC \\ 72.1 - 0.38PV_i + 23.04BOffer_i + 22.44Full_i, & \text{if buyer } i \text{ has high } OC \end{cases} \quad (13)$$

$$y_i = \begin{cases} -7.55 + 0.43PV_i + 23.33BOffer_i + 22.44Full_i, & \text{if seller } i \text{ has low } OC \\ -16.97 + 0.43PV_i + 23.33BOffer_i + 22.44Full_i, & \text{if seller } i \text{ has high } OC \end{cases} \quad (14)$$

In general, the effects of opportunity cost on individual transaction times are similar for buyers and sellers. It is found that opportunity cost has a significant negative effect on transaction time as revealed by the value of the intercepts. If the private value is close to zero and all else is equal, the transaction times of those with higher opportunity costs are shorter than those with lower opportunity costs. However, there is a small difference between buyers and sellers because the interaction term is statistically significant for buyers with higher opportunity costs but not for sellers. The coefficients of private value in Eq. (13) reveal that buyers with lower opportunity costs are more sensitive to private value than are those with higher opportunity costs, and thus have a sharper decrease in transaction time with increasing private value.

Table 3. Regression analysis of transaction time.

| Variable | Coefficient (p-value) | | | |
|---|---|---|---|---|
| | Buyer | | Seller | |
| | Model 1 | Model 2 | Model 1 | Model 2 |
| *Intercept* | 145.32 (0.00) | 180.13 (0.00) | 31.52 (0.00) | 26.50 (0.00) |
| *PV* | −0.56 (0.00) | −0.79 (0.00) | 0.43 (0.00) | 0.50 (0.00) |
| *MPrice dummy* | 3.14 (0.55) | 3.48 (0.51) | 3.75 (0.50) | 3.83 (0.49) |
| *BOffer dummy* | 23.13 (0.00) | 23.04 (0.00) | 23.33 (0.00) | 23.31 (0.00) |
| *Full dummy* | 22.44 (0.00) | 22.44 (0.00) | 22.44 (0.00) | 22.55 (0.00) |
| *OC_low dummy* | −41.72 (0.00) | −71.76 (0.00) | −39.07 (0.00) | −36.94 (0.00) |
| *OC_high dummy* | −52.13 (0.00) | −108.03 (0.00) | −48.49 (0.00) | −37.70 (0.00) |
| *OC_low dummy*PV* | | 0.19 (0.10) | | −0.05 (0.72) |
| *OC_high dummy*PV* | | 0.41 (0.00) | | −0.13 (0.30) |
| *Adjusted* $R^2$ | 0.32 | 0.33 | 0.24 | 0.24 |

### 6.3. Realized Benefit Comparison

Table 4 gives the average and standard deviation of the realized benefits of buyers and sellers under different given information. From this table, it is observed that the realized benefit of buyers differs from that of sellers only in the cases of *Basic* and *BOffer* information. Under these sets of information, sellers (taxi drivers) seem to gain more benefit than buyers (passengers). When looking at *MPrice* and *Full* information, no significant difference is found under these cases. This suggests that *MPrice* and *Full* would be more desirable as they lead to indifferent benefits for both sides. In addition, *MPrice* and *Full* information also pose some desired properties as reported by Pueboobpaphan and Indra-Payoong (2015) [8]. The *MPrice* information leads to the highest total trade volume as well as to quicker order matching, and therefore to quicker transactions. In contrast, *Full* information leads to the lowest average transaction price but to the slowest transactions. Based on these results, *MPrice* would be more desirable.

Table 4. Average realized benefit for buyers and sellers under different given information.

| Given Information | Average realized benefit, ECU (Standard Deviation) | | p-value |
|---|---|---|---|
| | Buyer | Seller | |
| *Basic* | 78.94 (78.42) | 107.56 (78.34) | 0.02 |
| *MPrice* | 86.35 (70.98) | 90.71 (79.12) | 0.70 |
| *BOffer* | 76.36 (64.14) | 104.23 (84.90) | 0.02 |
| *Full* | 107.42 (63.65) | 90.51 (79.48) | 0.15 |

## 7. Conclusions

This research was motivated by the taxi refusal problem that is faced particularly by passengers with limited access to taxi services or whose destination is in a congested or remote area. A supply-and-demand approach was proposed to match taxi services through a double auction framework in which both passenger and driver could negotiate a surcharge to be paid on top of the regular metre fare. As opposed to the existing fixed-surcharge policy, the proposed approach is equivalent to a variable surcharge policy in which passengers can offer a higher surcharge if in need of taxi services, whereas drivers can request a surcharge to compensate for disincentives. Such a taxi service auction involves opportunity costs that generally increase with time. Therefore, bidder behaviour in the auction may differ from those found in the literature. Laboratory experiments were conducted to examine the design of information that could be given to bidders. As a further extension of our previous study, this paper explored in more detail the effect of opportunity cost on the behaviour of passengers and drivers, as well as the effect of the interaction between opportunity cost and private value. The important findings are discussed below.

Despite conducting a more detailed regression analysis, the effects of different given information on transaction prices and times remain the same as in our previous study. Providing users with *MPrice* or *Full* information results in a significantly lower transaction price than that with *Basic* and *BOffer* information. In addition, transactions under *BOffer* and *Full* information take significantly longer than those under *Basic* and *MPrice* information. Based on these findings, if the system designer intends to give preference to passengers, the best option would be to provide users with *MPrice* information because this leads to lower transaction prices and quicker transactions.

It is found that the effect of private value on the transaction prices of both buyers and sellers is significant in the positive sense. This implies that buyers with higher private values could afford to pay more for the services, whereas sellers with higher costs would naturally require higher transaction prices. However, the degree of sensitivity to private value differs under different opportunity costs. Under some circumstances, the results are striking at first sight. Compared to those with lower opportunity costs, buyers with higher opportunity costs can secure a cheaper price and sellers with higher opportunity costs can sell at a higher price. It seems that a higher opportunity cost stimulates the subjects to make a quick match and, as a result, reduces the chances of those remaining in the market securing a good price. This finding provides further insight into the behaviour of subjects in relation to opportunity cost.

The effect of private value on transaction time is significant but different for buyers and sellers. A significant negative effect reveals that buyers with higher private values would complete the auction earlier. In contrast, sellers with higher private values would take longer to finish the auction because the estimated coefficient is significantly positive. The effect of opportunity cost is also significant; transactions tend to be quicker for larger opportunity costs. Different degrees of sensitivity to private value were also observed for buyers under different opportunity-cost levels. Buyers with lower opportunity costs were more sensitive to private value than were those with higher opportunity costs.

The realized benefits for buyers and sellers were compared to see whether there was any imbalance between the two sides. It was found that *MPrice* and *Full* information would be more desirable because they lead to indifferent benefit between both sides. However, *MPrice* is superior to the other types of information; our previous study also indicated that it dominates in respect of some other benefits.

The striking results discussed during the analysis of transaction price were based on experiments with a thin market. Although the literature suggests that this market size is sufficient to generate a competitive market, it may not be the case in this study because bidders too are subject to opportunity cost. In future research, we intend to conduct experiments with larger markets in order to test the above results.

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