6.1.3 Aggregate measures

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

6.1.3.1 Early trade volume

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

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

6.1.3.2 Average transaction price

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

6.1.3.3 Market efficiency

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

6.2 Hypothesis Testing

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

Table 2. Aggregate measure

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

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

6.2.1 Empirical models

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

6.2.1.1 Models for individual level

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

$$y_i = \beta_0 + \beta_1 V_i + \beta_2 Best_i + \beta_3 BPrice_i + \beta_4 TCLow_i + \beta_5 TCHigh_i + \varepsilon_i \tag{7}$$

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

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

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

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

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

6.2.1.2 Models for period level

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

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

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

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

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

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

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

6.2.2 Individual transaction price

The results of regression analysis based on the model in 6.2.1.1 are shown in Table 3. As expected, private valuation (cost) is significant and affect positively to transaction price across all regressions. Although the R^2 is relatively low, its magnitude is comparable to many of the results in experimental economics literature (see for example in Ketcham *et al.* (1984)).

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

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

Table 3. Regression analysis of individual transaction prices

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

6.2.3 Early trade volume

Results from Table 4 shows that there is a significant effect of time-cost on early trade volume. The estimated information type effects reveal that early trade volumes under 'No Information' are significantly larger than volumes under ‘Best Offer’ which again are larger than volumes under ‘Best Offer + Price’. This implies that the auctions under ‘No Information’ could be matched earlier and thus could result in a significant time saving.

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

6.2.4 Average transaction price

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

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

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

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

6.2.5 Overall efficiency

When only the sessions with time-cost are considered (Table 5), the estimated information type effects reveal that overall efficiency under ‘Best Offer + Price’ tends to be higher than that under ‘No Information’ which again tends to be higher than that under ‘Best Offer’. However, t-test does not reveal any significant difference between them together with the low value of R^2.

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

Variables	**Coefficient** *(P-value)*					
	Vol	***Vol45***	***Vol90***	***Vol120***	***Overall Eff.***	***Trans. Price***
Constant	5.67	3.93	5.07	5.33	74.13	122.90
	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)	(0.000)
Best Offer dummy	-0.47	-0.93	-0.93	-0.73	-4.90	0.61
	(0.129)	(0.004)	(0.004)	(0.023)	(0.153)	(0.893)
Best Off + Price dummy	-0.60	-0.07	-0.80	-0.73	0.49	-18.61
	(0.053)	(0.826)	(0.013)	(0.023)	(0.885)	(0.000)
R^2	0.10	0.22	0.21	0.15	0.07	0.36

7. CONCLUSIONS AND DISCUSSIONS

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

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

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

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

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