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Abstract

Construction work is often allocated to contractors via first price sealed bid auctions. American Nobel Prize winner and Economist William Vickery, however, has suggested that a second price auction (lowest bidder wins the contract at the second lowest price) may be more beneficial to those concerned due to the revenue equivalence theory (RET). This implies that, upon certain conditions being met, owners can, in the long run, expect to pay approximately the same amount to contractors irrespective of whether contracts are awarded according to a first price auction (FPA) or second price auction (SPA). At the same time, it is expected to be easier to bid in a SPA.

In the absence of any real world data, the likely effects of using SPA for construction were examined experimentally. This involved the participation of a group of experienced construction bidders over 60 identical first and second price construction auctions. Contrary to expectations, the bids for the second price arrangement were significantly higher, indicating that RET is unlikely to occur in practice in construction bidding. In other words, the results indicate that construction clients are likely to pay more if second price auctioning is used in the construction industry.

Keywords: Auctions, bidding, construction, revenue equivalence theory, second price, Vickery.

Introduction

The best strategy in a first price sealed low bid auction (FPA) (where the bidder submitting the lowest bid wins the contract at the value of the lowest bid) is for contractors to (1) assume theirs is the lowest bid, (2) determine their bid and (3) then adjust the bid upwards to the second lowest bid (Ramusen 1996). However, for construction contract auctions, the "compactness" of the bids (Dyer and Kagel 1996) makes it virtually impossible to estimate the value of the second lowest bid with sufficient accuracy and the problem facing contractors is that increasing their bid too little results in lost revenue to the contractor while increasing too much means losing the competition.

The second price sealed bid auction (SPA), or Vickery (1961) auction as it is sometimes known, attempts to overcome this difficulty by awarding the contract to the lowest bidder at the second lowest bid price. Upon certain conditions being met, Vickery has shown that contract sellers (i.e. clients) can, in the long run, expect to pay the same amount to contract buyers (i.e. contractors) irrespective of whether contracts are awarded to the lowest bidder at the lowest bid price or to the lowest bidder at the second lowest bid price. This is referred to in auction literature as the *revenue equivalence theory*. This implies that construction clients and contractors would be no worse off financially irrespective of whether a FPA or SPA is used. There is likely to be a psychological

difference, however, with contractors feeling they are getting a better deal. One outcome of this could be that contractors will be happier with their lot and less inclined to seek ways of extracting more money out of clients by cutting corners and/or claiming extras. In other words, a less disputatious industry may result – solving, at a stroke, what has been recognised over the years as the biggest problem facing the construction industry world-wide (e.g. Simon, 1944; Banwell, 1964; Latham, 1994, in the United Kingdom ; Business Round Table, 1994 in the USA and Gyles, 1992 in Australia).

Apart from introducing the revenue equivalence theory Vickery argued that using SPA would force bidders to be more truthful. This is because the dominant strategy in Vickery auctions is for bidders to bid without need to make competition adjustments (i.e. (1) assume theirs is the lowest bid and (2) determine their bid only). Hypothetical examples can be used to explain this phenomenon. Suppose a contractor is bidding in four separate competitions where the cost estimate for each competition happens to be exactly $10 million, the minimum mark up margin (including profit) is 10%. The contractor's private valuation becomes $11 million. A Vickery auction is used. Suppose the lowest rival bid in each of the four competitions is $10.6, $10.9, $11.3 and $11.8 million respectively. Table 1 shows that if the contractor submits a bid of $11 million the additional profit amounts to $1.1 million. If, however, the contractor submits a more competitive bid of $10.8 million it can be seen that the profit actually reduces by $100,000 to $1.0 million and if the contractor decides to increase its bid to $11.6 million the profit reduces further to $0.8million. Therefore the best strategy, in the long run, is for contractors to simply determine their bid without having to make the difficult upwards adjustment.

Despite the theoretical advantages of being simpler to bid and producing truthful bidding competitions TESTING VICKERY'S REVENUE EQUIVALENCE THEORY IN CONSTRUCTION AUCTIONS

, Vickery auctions are rare. Rothkopf et al (1990) have suggested two reasons for this. First, bidders have a natural reluctatnce to follow the truth revealing strategies just described, especially in competitions requiring subsequent negotiations. Second, Vickery auctions are not so robust with respect to cheating and the fear of cheating. Apart from collusion taking place, which adversely affects all types of auction designs, it is feared that some bidders may deliberately bid low to win the competition unfairly. Are contractors willing to take such risks in construction, especially on the larger contracts which involve huge sums of money? Although contractors may occasionally have some degree of success by deliberately bidding low, clearly this is a risky strategy. If more than one contractor deliberately bids low then the lowest bidder is likely to end up in financial ruin. It would therefore not be unreasonable to assume that, at least for the vast majority of contracts, the possibility of more than one contractor deliberately doing this should deter all the other contractors from deliberately bidding low. If this assumption is accepted, another key consideration is whether construction clients are likely to pay the same irrespective of using FPA or SPA. In other words, Does Vickery's revenue equivalence theory hold?

Bidding experiments in construction

The construction bidding process has been simulated in the classroom. For example, Lansley (1999) and Harris and McCaffer (1989) have developed software for contractor management games. Tthe main purpose of these games, however, is to simulate the running of a construction firm as a whole rather than to specifically focus on the bidding process and are therefore unable to compare alternative construction bidding designs.

Although these games do have the potential to generate the data needed, so many other variables would need to be considered that it would have taken the participants an unreasonably long time to bid for 60 first price auctions and second price auctions (the number of auctions needed to generate a reasonable data set). Also a classroom environment means that participants would have very little time to think about what bid level to submit. It was therefore decided to simplify the game format by focusing on a methodology that tests applicability of Vickery's revenue equivalence theory to construction auctions by directly comparing FPA and SPA results.

Bidding experiment methodology

Six professionals, with at least 15 years experience of organising and participating in bidding competitions in the Hong Kong construction industry, were invited to participate via email in the bidding experiment by (1) acting as senior managers for hypothetical contractors (labeled A to F) and (2) bidding for a total of 60 construction contracts. These were arranged in 10 rounds of 6 contracts so that feedback information could be given to the participants at the end of each round.

The participants' responses were arranged in two parts. In Part 1 the six participants were invited to submit bids for six contracts where a FPA was used. In Part 2 the six participants were invited to submit bids for the same six contracts using a SPA. In addition to submitting the bid price in Part 2 the participants were also requested to disclose what they thought the second lowest bid price would be. This was done to see if each participant's bid in the FPA was equal to the second lowest bid price in the SPA. Identical values indicate that the participant has bid according to their best strategy and in accordance with the revenue equivalence theory.

Each participant was given key information about each construction contract such as project type, client identity and location. The 60 contracts, based on real Hong Kong construction contracts, are from public and private sector clients. Contracts varied between HK$1 million and HK$450 million and comprised new build and alteration work contracts. Each participant was also given a unique cost estimate which was based on the bids contained in the bid reports.

In an attempt to make the experiment more realistic and maintain participant interest over 10 rounds, profit/ loss was generated for each contract by deducting a randomly assigned final cost from the winning bid. Participants were informed that the contractor's objective was to maximize profit and that the participant who generates the biggest profit at the end of 10 rounds would be declared the winner and receive a mystery prize. Feedback information given to the participants at the end of each round comprised (1)

winning bid, (2) identity of the successful contractor and (3) whether the contract won generated a profit or loss.

At the end of the experiment the 60 winning bids from the FPA were averaged and compared to the averaged winning bids from the SPA. A t-test was used to determine if there is a significant difference between the winning bid values. A significant difference between the average winning bids indicates that the revenue equivalence theory does not apply and vice versa.

Experiment limitations

Setting up a construction bidding experiment that truly reflects contractors bidding behaviour is quite difficult to do since there are so many different variables to consider. Flanagan and Norman (1982) state that contractor bidding behaviour, in general, is influenced by (1) size and complexity of construction work, (2) regional market conditions, (3) current and projected workload of the contractor, (4) type of client, (5) type of construction work. This experiment has captured some of the major bidding behaviour variables including size and type of construction work, location and client identity. The experiment, however, does not consider factors such as changing in market conditions or the contractor's current and projected workload relative to target turnover. The participants are told to assume normal market conditions and that the contractor has an unlimited contracting capacity (i.e. it is theoretically possible for one contractor to win all 60 contracts).

It is also recognised that the performance of economic agents tend to deteriorate substantially in the laboratory compared to field settings in general (Hogarth, 1981), auction markets (eg., Bazerman and Samuelson, 1983; Kagel 1995) and in contract bidding (Dyer and Kagel 1996), although it is felt that such experiments do provide realistic enough results (eg., Kagel and Dyer, 1996; Smith, 2001:28) maintain the .

Analysis

The following analysis compares the bid prices of the six participants when competing for the same 60 construction contracts using both first price and second price auctions. Table 2 shows the number of successes and winning bids of the six contractors for the first and second price auctions. It can be seen that in terms of successes Contractors C and D are equally tied in winning most FPA while Contractor D won most SPA. Contractor B won the least FPA. Both Contractor B and E won more SPA than FPA. An influencing factor is that two contractors reduced their mark ups the most when submitting their bids for the SPA. Contractor B's average mark up reduced from over 16% to less than 10% while Contractor E's average mark up is reduced from over 10% to less than 8%. Interestingly there was either no difference or the difference was less than one percent for mark ups of the remaining four contractors.

The winning bid for the FPA averaged out at HK$64.700 million. This compares to an average lowest submitted bid of HK$64.319 million for the SPA. This is adjusted to HK$65.607 million when the lowest submitted bid is adjusted to the second lowest price.

The results show that clients would therefore on average need to pay an average of almost HK$1million per contract more if a SPA was used in place of a FPA. A paired samples t-test used to compare winning bid prices of FPA and SPA (i.e. HK$64.700 and HK$65.607 million respectively) showed that there is a significant difference between the two means ($t = -3.469$, $df = 59$, $p=0.001$). In other words, t-test statistic shows that clients would on average expect to pay more if a second price sealed bid auction was used instead of a first price sealed bid auction. The results of this experiment suggests that Vickery's revenue equivalence theory is unlikely to occur in practice. This is not surprising given that four of the six contractors, on average, submitted almost the same bid prices for both the first and second price auctions. Interestingly, out of sixty contracts there were a total of 11 contracts where the first and second price winning bids were identical, 41 contracts where the second price winning bid was higher than the first price bid and only 8 contracts where the first price winning bid was higher than the second price winning bid.

Direct comparisons between the first and second price auction winning bids of each contractor cannot be made because although a particular contractor may have won the first price auction, it may not have won the second price auction and vice versa. The following winning bid ratio was therefore used so that direct comparisons could be made between contractors:

$$WBR = 2PWB/1PWB \quad (1)$$

Where:

WBR = Winning bid ratio

2PWB = Second price winning bid

1PWB = First price winning bid

Table 2 shows that, in the five SPA won by Contractor A, the average winning bid ratio is 1.057. In other words, for the five SPA by Contractor A, the client would have to pay 5.7% more than if a FPA was used. For Contractors C, D and F it can be seen that the corresponding winning bid ratios are 1.030, 1.043 and 1.031. These four ratios exceeding unity is to be expected given that the average bids for the first and second price auctions submitted by Contractors A, C, D and F was almost the same.

Interestingly for those two contractors who reduced their mark up between the two auction methods the most (i.e. Contractors B and E), the winning bid ratios are 1.000 and 1.018. In other words, with respect to the 10 second price auctions won by Contractor B the client would, on average, pay the same monetary amount and for Contractor E clients would pay on average 1.8% more.

This analysis seems to indicate that the applicability of Vickery's revenue equivalence theory in practice is dependent on the competing bidders' willingness to submit lower bid prices in SPA when compared to corresponding bids submitted in FPA.

Conclusions

A bidding experiment is used in this paper to test the applicability of Vickery's revenue equivalence theory in construction auctions. Although experimental results are limited, in that they do not fully account for all the real world complexities, they should provide useful insights into the relationships between different variables that would not otherwise have been revealed or found. In this case the focus is on comparing (1) winning prices of FPA (2) winning prices of SPA and (3) estimated winning prices.

T-test results show a significant difference between the winning bid prices of FPA and SPA, with the winning bid prices of SPA being significantly higher than FPA. If applied in reality, this means that clients would on average pay more if SPA was used instead of FPA.

The experiment also shows that the bidders involved do not bid optimally. Auction theory predicts that, in descending sealed bid auctions, bidders will assume that theirs is the lowest bid, determine their bid and then adjust their bid upwards to the second lowest bid. The results show that two of the six participants estimate that the lowest bid price would be lower than their submitted bid prices. In such cases there seems to be little point in competing since they are forecasting that they are not going to win the competition. Two contractors submitted identical bid prices for both the FPA and SPA while the theory indicates that the optimal bids in FPA should be higher than those in SPA.

The applicability of Vickery's revenue equivalence theory in practice appears to be dependent on the competing bidders' willingness to submit lower bid prices in second price auctions when compared to corresponding bids submitted in the first price auctions. For revenue equivalence theory to hold, however, bidders must behave rationally, be risk neutral and have independent estimates. It is suggested that future research directions in this area include investigating the extent to which contractors (1) bid rationally (2) are at least risk neutral and (3) are influenced by the bids of others.

The results show many instances of contractors not bidding in accordance with their best bidding strategy as defined by auction theory. It is suggested that a better understanding of auction theory within the construction industry would improve this situation.

Acknowledgement

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References

Banwell Report, (1964) *The placing and management of contracts for building and civil engineering works*, Ministry of Building and Works, London: HMSO.

Bazerman, M. H. and W.F. Samuelson (1983) I won the auction but I don't want the prize, *Journal of Conflict Resolution*, **27** 618-634

Business Round Table (1994) *Controlling the upwards spiral: construction performance and cost in the UK and mainland Europe*, The Business Round Table, London.

Dyer, D. and Kagel, J.H. (1996) Bidding in common value auctions: how the commercial construction industry corrects for the winners curse, *Management Science*, **42** 1463-75

Flanagan, R. and Norman, G. (1982) Making good use of low bids, *Chartered Quantity Surveyor*, March, 226-227

Gyles, R.V. (1992) *Royal Commission into productivity in the building industry in New South Wales*, Government of New South Wales, Sydney

Harris F. and McCaffer R. (1989) *Modern construction management*, BSP Professional Books, Oxford

Hogarth, R.M. (1981) Beyond discrete biases: functional and dysfunctional aspects of judgmental heuristics, *Psychology Bulletin*, **90** 197-217

Kagel, J.H. (1995) Auctions: a survey of experimental research, in J.H. Kagel and A.E. Roth (Eds.) *The handbook of experimental economics*, Princeton University Press, New Jersey

Lansley P. (1999) *AROUSAL VII - AROUSAL for Windows*, Management Reality

Latham, M. (1994) Constructing the team, *Final Report* of The Government/Industry Review of Procurement and Contractual Arrangements in The UK Construction Industry, *HMSO*, London, July

Ramusen, E. (1996) *Games and information*, Blackwell, Cambridge, Mass.

Rothkopf, M.H., Teisberg T.J. and Kahn, E.P. (1990) Why are Vickery auctions rare? *Journal of Political Economy*, **98** (1) 94 - 109

Simon (1944) *The placing and management of building contracts, Central Council for Works and Buildings*, HMSO, London

Smith, V.L. 2001. Method in experiment: rhetoric and reality. Interdisciplinary Centre for Economic Science, George Mason University, July.

Vickery, W. (1961) Counterspeculation, auctions and competitive sealed tenders, *Journal of Finance*, **16** (1) 8-37

Rival bid	Contractor's private valuation $11.0					
	Contractor bids $11.0		Contractor bids $10.8		Contractor bids $11.6	
	Profit/Loss	Outcome	Profit/Loss	Outcome	Profit/Loss	Outcome
$10.6	0	Lose competition: no profit / no loss	0	Lose competition: no profit / no loss	0	Lose competition: no profit / no loss
$10.9	0	Lose competition: no profit / no loss	-0.1	Win competition: Loss - 0.1	0	Lose competition: no profit / no loss
$11.3	+0.3	Win competition: Profit +0.3	+0.3	Win competition: Profit +0.3	0	Lose competition: no profit / no loss
$11.8	+0.8	Win competition: Profit +0.8	+0.8	Win competition: Profit +0.8	+0.8	Win competition: Profit +0.8
Overall	+1.1		+1.0		+0.8	

Table 1: Example showing that the best strategy in Vickery auctions is for contractors to bid their private valuation

Bidder	First price auction			Second price auction					2p win bid/ 1p win bid ratio	Av est. 2nd lowest bid
	No. of bid successes	Average win bid	Win bid mark-up	No. of bid successes	Average submit bid	Av. submit mark-up	Average win bid	Av. win bid mark-up		
A	8	104.354	7.248	5	41.512	7.603	41.844	13.759	1.057	41.962
B	4	24.890	9.827	10	94.065	5.838	94.928	7.926	1.000	97.354
C	16	65.974	5.753	12	65.792	5.482	67.596	9.216	1.030	65.414
D	16	70.679	4.381	14	51.362	4.633	52.743	9.122	1.043	51.941
E	7	19.746	9.133	10	61.649	5.258	62.989	7.987	1.018	62.390
F	9	69.217	4.166	9	65.097	3.412	66.498	7.119	1.031	65.499
Overall	60	64.700	6.014	60	64.319	5.172	65.607	9.038	1.028	65.148

Table 2: Successful bidding attempt analysis .

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In the absence of any real world data, the likely effects of using SPA for construction were examined experimentally. This involved the participation of a group of experienced construction bidders over 60 identical first and second price construction auctions. Contrary to expectations, the bids for the second price arrangement were significantly higher, indicating that RET is unlikely to occur in practice in construction bidding. In other words, the results indicate that construction clients are likely to pay more if second price auctioning is used in the construction industry.

Keywords: Auctions, bidding, construction, revenue equivalence theory, second price, Vickery.

Introduction

The best strategy in a first price sealed low bid auction (FPA) (where the bidder submitting the lowest bid wins the contract at the value of the lowest bid) is for contractors to (1) assume theirs is the lowest bid, (2) determine their bid and (3) then adjust the bid upwards to the second lowest bid (Ramusen 1996). However, for construction contract auctions, the "compactness" of the bids (Dyer and Kagel 1996) makes it virtually impossible to estimate the value of the second lowest bid with sufficient accuracy and the problem facing contractors is that increasing their bid too little results in lost revenue to the contractor while increasing too much means losing the competition.

The second price sealed bid auction (SPA), or Vickery (1961) auction as it is sometimes known, attempts to overcome this difficulty by awarding the contract to the lowest bidder at the second lowest bid price. Upon certain conditions being met, Vickery has shown that contract sellers (i.e. clients) can, in the long run, expect to pay the same amount to contract buyers (i.e. contractors) irrespective of whether contracts are awarded to the lowest bidder at the lowest bid price or to the lowest bidder at the second lowest bid price. This is referred to in auction literature as the *revenue equivalence theory*. This implies that construction clients and contractors would be no worse off financially irrespective of whether a FPA or SPA is used. There is likely to be a psychological

difference, however, with contractors feeling they are getting a better deal. One outcome of this could be that contractors will be happier with their lot and less inclined to seek ways of extracting more money out of clients by cutting corners and/or claiming extras. In other words, a less disputatious industry may result – solving, at a stroke, what has been recognised over the years as the biggest problem facing the construction industry world-wide (e.g. Simon, 1944; Banwell, 1964; Latham, 1994, in the United Kingdom ; Business Round Table, 1994 in the USA and Gyles, 1992 in Australia).

Apart from introducing the revenue equivalence theory Vickery argued that using SPA would force bidders to be more truthful. This is because the dominant strategy in Vickery auctions is for bidders to bid without need to make competition adjustments (i.e. (1) assume theirs is the lowest bid and (2) determine their bid only). Hypothetical examples can be used to explain this phenomenon. Suppose a contractor is bidding in four separate competitions where the cost estimate for each competition happens to be exactly $10 million, the minimum mark up margin (including profit) is 10%. The contractor's private valuation becomes $11 million. A Vickery auction is used. Suppose the lowest rival bid in each of the four competitions is $10.6, $10.9, $11.3 and $11.8 million respectively. Table 1 shows that if the contractor submits a bid of $11 million the additional profit amounts to $1.1 million. If, however, the contractor submits a more competitive bid of $10.8 million it can be seen that the profit actually reduces by $100,000 to $1.0 million and if the contractor decides to increase its bid to $11.6 million the profit reduces further to $0.8million. Therefore the best strategy, in the long run, is for contractors to simply determine their bid without having to make the difficult upwards adjustment.

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Analysis

The following analysis compares the bid prices of the six participants when competing for the same 60 construction contracts using both first price and second price auctions. Table 2 shows the number of successes and winning bids of the six contractors for the first and second price auctions. It can be seen that in terms of successes Contractors C and D are equally tied in winning most FPA while Contractor D won most SPA. Contractor B won the least FPA. Both Contractor B and E won more SPA than FPA. An influencing factor is that two contractors reduced their mark ups the most when submitting their bids for the SPA. Contractor B's average mark up reduced from over 16% to less than 10% while Contractor E's average mark up is reduced from over 10% to less than 8%. Interestingly there was either no difference or the difference was less than one percent for mark ups of the remaining four contractors.

The winning bid for the FPA averaged out at HK$64.700 million. This compares to an average lowest submitted bid of HK$64.319 million for the SPA. This is adjusted to HK$65.607 million when the lowest submitted bid is adjusted to the second lowest price.

The results show that clients would therefore on average need to pay an average of almost HK$1million per contract more if a SPA was used in place of a FPA. A paired samples t-test used to compare winning bid prices of FPA and SPA (i.e. HK$64.700 and HK$65.607 million respectively) showed that there is a significant difference between the two means ($t = -3.469$, $df = 59$, $p=0.001$). In other words, t-test statistic shows that clients would on average expect to pay more if a second price sealed bid auction was used instead of a first price sealed bid auction. The results of this experiment suggests that Vickery's revenue equivalence theory is unlikely to occur in practice. This is not surprising given that four of the six contractors, on average, submitted almost the same bid prices for both the first and second price auctions. Interestingly, out of sixty contracts there were a total of 11 contracts where the first and second price winning bids were identical, 41 contracts where the second price winning bid was higher than the first price bid and only 8 contracts where the first price winning bid was higher than the second price winning bid.

Direct comparisons between the first and second price auction winning bids of each contractor cannot be made because although a particular contractor may have won the first price auction, it may not have won the second price auction and vice versa. The following winning bid ratio was therefore used so that direct comparisons could be made between contractors:

$$WBR = 2PWB/1PWB \quad (1)$$

Where:

WBR = Winning bid ratio

2PWB = Second price winning bid

1PWB = First price winning bid

Table 2 shows that, in the five SPA won by Contractor A, the average winning bid ratio is 1.057. In other words, for the five SPA by Contractor A, the client would have to pay 5.7% more than if a FPA was used. For Contractors C, D and F it can be seen that the corresponding winning bid ratios are 1.030, 1.043 and 1.031. These four ratios exceeding unity is to be expected given that the average bids for the first and second price auctions submitted by Contractors A, C, D and F was almost the same.

Interestingly for those two contractors who reduced their mark up between the two auction methods the most (i.e. Contractors B and E), the winning bid ratios are 1.000 and 1.018. In other words, with respect to the 10 second price auctions won by Contractor B the client would, on average, pay the same monetary amount and for Contractor E clients would pay on average 1.8% more.

This analysis seems to indicate that the applicability of Vickery's revenue equivalence theory in practice is dependent on the competing bidders' willingness to submit lower bid prices in SPA when compared to corresponding bids submitted in FPA.

Conclusions

A bidding experiment is used in this paper to test the applicability of Vickery's revenue equivalence theory in construction auctions. Although experimental results are limited, in that they do not fully account for all the real world complexities, they should provide useful insights into the relationships between different variables that would not otherwise have been revealed or found. In this case the focus is on comparing (1) winning prices of FPA (2) winning prices of SPA and (3) estimated winning prices.

T-test results show a significant difference between the winning bid prices of FPA and SPA, with the winning bid prices of SPA being significantly higher than FPA. If applied in reality, this means that clients would on average pay more if SPA was used instead of FPA.

The experiment also shows that the bidders involved do not bid optimally. Auction theory predicts that, in descending sealed bid auctions, bidders will assume that theirs is the lowest bid, determine their bid and then adjust their bid upwards to the second lowest bid. The results show that two of the six participants estimate that the lowest bid price would be lower than their submitted bid prices. In such cases there seems to be little point in competing since they are forecasting that they are not going to win the competition. Two contractors submitted identical bid prices for both the FPA and SPA while the theory indicates that the optimal bids in FPA should be higher than those in SPA.

The applicability of Vickery's revenue equivalence theory in practice appears to be dependent on the competing bidders' willingness to submit lower bid prices in second price auctions when compared to corresponding bids submitted in the first price auctions. For revenue equivalence theory to hold, however, bidders must behave rationally, be risk neutral and have independent estimates. It is suggested that future research directions in this area include investigating the extent to which contractors (1) bid rationally (2) are at least risk neutral and (3) are influenced by the bids of others.

The results show many instances of contractors not bidding in accordance with their best bidding strategy as defined by auction theory. It is suggested that a better understanding of auction theory within the construction industry would improve this situation.

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References

Banwell Report, (1964) *The placing and management of contracts for building and civil engineering works*, Ministry of Building and Works, London: HMSO.

Bazerman, M. H. and W.F. Samuelson (1983) I won the auction but I don't want the prize, *Journal of Conflict Resolution*, **27** 618-634

Business Round Table (1994) *Controlling the upwards spiral: construction performance and cost in the UK and mainland Europe*, The Business Round Table, London.

Dyer, D. and Kagel, J.H. (1996) Bidding in common value auctions: how the commercial construction industry corrects for the winners curse, *Management Science*, **42** 1463-75

Flanagan, R. and Norman, G. (1982) Making good use of low bids, *Chartered Quantity Surveyor*, March, 226-227

Gyles, R.V. (1992) *Royal Commission into productivity in the building industry in New South Wales*, Government of New South Wales, Sydney

Harris F. and McCaffer R. (1989) *Modern construction management*, BSP Professional Books, Oxford

Hogarth, R.M. (1981) Beyond discrete biases: functional and dysfunctional aspects of judgmental heuristics, *Psychology Bulletin*, **90** 197-217

Kagel, J.H. (1995) Auctions: a survey of experimental research, in J.H. Kagel and A.E. Roth (Eds.) *The handbook of experimental economics*, Princeton University Press, New Jersey

Lansley P. (1999) *AROUSAL VII - AROUSAL for Windows*, Management Reality

Latham, M. (1994) Constructing the team, *Final Report* of The Government/Industry Review of Procurement and Contractual Arrangements in The UK Construction Industry, *HMSO*, London, July

Ramusen, E. (1996) *Games and information*, Blackwell, Cambridge, Mass.

Rothkopf, M.H., Teisberg T.J. and Kahn, E.P. (1990) Why are Vickery auctions rare? *Journal of Political Economy*, **98** (1) 94 - 109

Simon (1944) *The placing and management of building contracts, Central Council for Works and Buildings*, HMSO, London

Smith, V.L. 2001. Method in experiment: rhetoric and reality. Interdisciplinary Centre for Economic Science, George Mason University, July.

Vickery, W. (1961) Counterspeculation, auctions and competitive sealed tenders, *Journal of Finance*, **16** (1) 8-37

Rival bid	Contractor's private valuation $11.0					
	Contractor bids $11.0		Contractor bids $10.8		Contractor bids $11.6	
	Profit/Loss	Outcome	Profit/Loss	Outcome	Profit/Loss	Outcome
$10.6	0	Lose competition: no profit / no loss	0	Lose competition: no profit / no loss	0	Lose competition: no profit / no loss
$10.9	0	Lose competition: no profit / no loss	-0.1	Win competition: Loss - 0.1	0	Lose competition: no profit / no loss
$11.3	+0.3	Win competition: Profit +0.3	+0.3	Win competition: Profit +0.3	0	Lose competition: no profit / no loss
$11.8	+0.8	Win competition: Profit +0.8	+0.8	Win competition: Profit +0.8	+0.8	Win competition: Profit +0.8
Overall	+1.1		+1.0		+0.8	

Table 1: Example showing that the best strategy in Vickery auctions is for contractors to bid their private valuation

Bidder	First price auction			Second price auction					2p win bid/ 1p win bid ratio	Av est. 2nd lowest bid
	No. of bid successes	Average win bid	Win bid mark-up	No. of bid successes	Average submit bid	Av. submit mark-up	Average win bid	Av. win bid mark-up		
A	8	104.354	7.248	5	41.512	7.603	41.844	13.759	1.057	41.962
B	4	24.890	9.827	10	94.065	5.838	94.928	7.926	1.000	97.354
C	16	65.974	5.753	12	65.792	5.482	67.596	9.216	1.030	65.414
D	16	70.679	4.381	14	51.362	4.633	52.743	9.122	1.043	51.941
E	7	19.746	9.133	10	61.649	5.258	62.989	7.987	1.018	62.390
F	9	69.217	4.166	9	65.097	3.412	66.498	7.119	1.031	65.499
Overall	60	64.700	6.014	60	64.319	5.172	65.607	9.038	1.028	65.148

Table 2: Successful bidding attempt analysis .