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Using Game Theory to Study Bidding for Software Projects

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**Abstract**

Cost estimation is only one part in obtaining software projects. Another important aspect is pricing and the related activity of bidding for projects. In order to obtain a software project, companies may have several bidding strategies. We used game theory in a bidding study to increase the understanding of bidding behaviour. It is the first time that game theory is used to study bidding for software projects. We show that game theory is applicable to evaluate bidding for software projects. The main results from the study are that risks do not pay off and that it is hard to recover from loses.

*Keywords: Game theory, software project, bidding behaviour, strategy*

## 1. Introduction

Cost estimation has been studied extensively in software engineering, since the pioneering work by Boehm (Boehm, 1981). However, in many cases it is not sufficient to estimate the actual cost for a software project, i.e. the cost for developing the software. Software projects (in most cases) produce software products that are either developed for a specific customer or sold to customers on a general market. This means that it is not sufficient to have a cost; the software product must have a price. Thus, pricing is an important issue in software engineering. Pricing has however not been studied to the same extent as cost estimation.

One-way to study pricing is to look at bidding. Bidding is important in situations when several potential developing companies place bids on a software project to

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obtain the project for development. This scenario is used here in a study to shed some light on the bidding process. This paper investigates the strategies of the bidders, with the use of game theory. The primary objective is to study bidding for software projects and hence also to provide an insight into pricing of software projects.

Game theory (Von Neumann and Morgenstern, 1944) is a mathematical tool for analysing decisions, which has been used for several decades now. It is a widely used tool for analysing decisions in game situations. The process of bidding for projects where a customer determines which software developing company should obtain a project can be seen as a game as well. To the best of our knowledge, this is a rather novel way of using game theory in software engineering.

In this study, we focus on the conception phase (Nicholas, 2001) of software projects. In this phase, it is determined which software development company will perform a software project. The conception phase consists of two stages. The first stage, *project initiation*, establishes that a "need" exists and that the need is worthy of investigation. During the second stage, *project feasibility*, a detailed investigation is conducted and a solution (in sufficient detail) is developed to determine if it is economically viable and worth of development. In situations where a company looks for another company to develop the software, a request for proposals is issued to identify a company that can conduct the feasibility study and potentially also develop the software product. Interested software developing companies respond to the request by providing information about how they intend to perform the development and by stating a price for performing the work. The statement of a price is often referred to as bidding for the project.

The bidding is studied in an empirical study using game theory. A scenario is presented to a set of individuals that plays the roles of different companies. The individuals bid on several projects and the outcome of the bidding process is studied. Given the design of the study, it is possible to get a first insight into which strategies are most useful in bidding for projects.

In summary, the objective of the paper is twofold. First, the intention is to study whether game theory is suitable to use for studying bidding behaviour, in particular in the software domain. Secondly and most importantly, the main aim is to study the behaviour of people bidding for software projects.

The paper is outlined as follows. Section 2 provides a brief introduction to the most relevant parts, for this study, of game theory. Some related work is presented in

Section 3 and the bidding study is presented in Section 4. The results are discussed in Section 5, and conclusions and some further work are presented in Section 6.

## 2. Game Theory

Game theory distinguishes between two different types of games based on when players perform actions: strategic games and extensive games (Osborn and Rubinstein, 1995). In strategic games, each player chooses his or her plan once and for all, and all players' decisions are made simultaneously and independently. This type specifies a set of possible actions for each player and a preference ordering over the set of possible action profiles. The situation where each player holds the correct expectation about the other player's behaviour and acts rationally is called Nash equilibrium (Nash, 1950), and it is a sort of steady state in the game. The second type, an extensive game, specifies the possible orders of events. Each player can consider his or her plan of actions not only at the beginning of the game but also whenever a decision has to be made. In extensive games, it is impossible to have a Nash equilibrium because a player can change his or her plan of action. However, a steady state may also be achieved in extensive games. This is called sub-game perfect equilibrium (Osborn and Rubenstein, 1995) wherein the strategy is optimal after the known history. To be able to keep track of this optimal history a strategy profile is used.

In this paper we use the concept of extensive games. We use this concept because when defining the possible actions once and for all, it is not possible to determine the bidding behaviour when a player reacts on a certain outcome (based on previous actions from other players). In our case, the outcome is whether the player obtained the last project or not. This is further discussed in the design of the study. When a player receives the outcome, the player can be informed in two different ways: perfect or imperfect. Osborn and Rubinstein (Osborn and Rubenstein, 1995) define an extensive game with perfect information as: "*A detailed description of the sequential structure of the decision problems encountered by the players in a strategic situation. There is perfect information in such a game if each player, when making any decision, is perfectly informed of all events that have previously occurred*". In extensive games with imperfect information players are only imperfectly informed about some (or all) of the choices that have *already* been made. Because the players are only partially informed about the actions taken by the other players, it is impossible to have a Nash equilibrium or sub-game perfect equilibrium. The solution for extensive games with imperfect information is called sequential equilibrium (Osborn and Rubenstein, 1995). It consists of both a strategy profile and a belief system. The belief system specifies, for each information set, the beliefs held by the players who have to move at that information set. This information set provides information about the history occurred.

Another consideration is whether it should be a finite or infinite game, which means that the horizon of the games may be finite or infinite.

The study in this paper is designed as an infinite game with imperfect information because:

- bidders never know how long the customer continues to ask them to bid for new software projects, so the players should not know when the game would end. This means that it is reasonable to model the bidding for projects as an infinite game.
- when bidders place their bids, they normally do not get to know the bids of their competitors afterwards. This motivates the use of games with imperfect information.

## 3. Related Work

As stated above, there is a clear distinction between costing and bidding: costing relates to the estimated costs and bidding relates to the offered price to perform the work.

Cost estimation in software engineering is reasonably investigated. Several techniques are developed. For example, Fenton and Pfleeger (Fenton and Pfleeger, 1997) make a distinction between four techniques for estimation (expert opinion, analogy, decomposition and models) and Boehm and Sullivan (Boehm and Sullivan, 1999) identify six techniques to estimate costs (expertise-based, model-based, regression-based, composite-Bayesian, learning-oriented, and dynamic-based). In spite of using completely different distinctions both conclude that decomposition, or more specifically the work breakdown structure (WBS) (Nicholas, 2001), is the most commonly used and preferred technique. Another well-known approach is the model-based technique and the most common model is the constructive cost model (COCOMO) (Boehm, 1981). However, the focus in the paper is on bidding.

The bidding activity is the process of making bids and each bid is the offer to do a piece of work for a particular price. This particular price is:

$$\boxed{\text{Price} = \text{Cost} + \text{Profit}}$$

The cost is derived from the cost estimation and the profit is the desirable amount that the bidder would like to earn for performing the project. Kitchenham et al. (Kitchenham et al., 2001) also suggest a contingency element: the risk associated with rare events that are not included in the project plan. Given that the main objective here is to study the bidding behaviour, this element is not included here. Bidding behaviour in general is also reasonably investigated in economical papers. Bodington (Bodington, 1999) investigates the bidding behaviour on acquiring domestic generating assets (e.g. gas and electric). One of his main conclusions is that bids of less than 50% percent of the average bid are common, and bids between 150 percent and 200 percent of the average are not unusual. The main reason to intentionally submit a high bid is to gain an exclusive negotiation position. But for three of the four investigated projects, the highest bids were rejected because of the risk. Another conclusion was that well-informed and experienced bidders often have substantially different views on the value of a project (i.e. future energy prices, operating costs, contract changes, etc.). Another article, written by Meyer (Meyer, 1988), provides some evidence from the rice market by investigating competition and bidding behaviour. His main conclusion is that increasing the competition (number of bidders) increases the bid, even when the product has an uncertain value.

The results of both articles are interesting, but they are different from our approach in that they are not based on game theory. Instead the bidding behaviour is based on auctions.

To investigate behaviour, a game is a good approach because a game offers:

- Competition.
- A returning observed phenomenon.
- Players’ strategies.
- Different views/opinions of players.
- Intuition of players.
- An outcome (a winner).

Games are also used to investigate bidding behaviour. Although not all articles found explicitly refer to game theory, the studies certainly contain some characteristics of game theory. For example Ivanova-Stenzel (Ivanova-Stenzel, 2001) uses a game to perform an experiment carried out in two different social and economical cultures to analyse the bidding behaviour. Four different game types were implemented to evaluate the bidding behaviour and to draw conclusions. Her main conclusion was the similarity of individual behaviour in both countries (Germany and Bulgaria). But no other conclusions of individual bidding behaviour were drawn. An article that uses game theory to investigate bidding behaviour is an article by Pitchik and Schotter (Pitchik and Schotter, 1998). The article presents an experimental study of bidding behaviour in sequential auctions where there are budget constraints and perfect information. Their main conclusion is that budget constraints affect the behaviour of bidders. Berk et al. (Berk et al., 1996) investigate the television game show "The Price Is Right" as a laboratory to conduct a preference-free test of rational decision theory. In this game, four opponents sequentially guess a retail price of durable goods without going over the retail price. Their main conclusions are that the fourth player has the biggest chance to win and that learning during the show reduces the frequency of strategic errors.

The articles found have one major drawback in common of why they are not applicable for this study: they are based on auctions. However, most auctions are extensive games with perfect information (Section 2). Auctions fit perfectly in this game concept because this concept contains a sequential structure: a player offers a bid after another player. The study presented here focuses on simultaneous moves, which is deemed to be more realistic when bidding for software projects. There exists one kind of auction that captures the idea of simultaneous moves: sealed bid auctions (Dufwenberg and Gneezy, 2002). In sealed bid auctions the bidders bid simultaneously and they do not know the bid of others. But no empirical data could be found about this kind of auctions related to bidding behaviour in extensive games with imperfect information.

Another important drawback of auctions is that in auctions the highest bidder wins. But in this study it is the other way around: the lowest bidder wins. There is one type of auction that fulfils the criteria of the lowest bidder wins: Dutch auctions (Auction Cheat Sheet, 2000). In Dutch auctions, the seller lists multiple identical items and all winning bidders pay the same price: the lowest successful bid. The problem with this kind of auctions is (for this paper at least) that bidders bid for multiple items with the idea of the more we buy, the cheaper it becomes. A good example of a Dutch auction is the Internet site eBay: <http://www.ebay.com/> (8 September 2002).

It can be concluded that auctions are seen as the "normal" bidding process and that the focus of our research is rather novel: no empirical data could be found about extensive games with imperfect information related to bidding behaviour, and in particular not in the software domain.

## 4. Study Design

This section contains information about the design of the study in terms of players, preparation, rules of the game and the operation.

### *4.1. Players*

Before the actual start of the game, the players are selected. It is decided to select researchers and teachers from the Department of Software Engineering and Computer Science (called IPD) of Blekinge Institute of Technology, Ronneby, Sweden. The players may be viewed similar to software engineers since they teach future software engineers and perform research in the area. However, there are still differences between them. Two out of four are primarily teachers and the other two are researchers. Both researchers have knowledge of game theory and the teachers did not. It should also be noted that they all know each other so it cannot be guaranteed that they did not talk to each other, but probably they are so competitive that they did not.

### *4.2. Game Initiation*

The game is initiated with an introduction meeting where the selected players are invited. During this meeting they get a short presentation of the study, they all receive the experimental design description[1] and the possibility to ask questions. The experimental design description describes the general instructions for the players, like an overview of the game, goals of the game, rules of the game and how the game is performed. It also contains a pre-estimated cost of a project that may be seen as the result of the conception phase (see Section 1). But this pre-estimated cost is just a fixed amount of units, which in some sense could be compared with a certain project size. It is decided that all the projects have a pre-estimated cost of 100 units, which of

[1] The experimental design description is available on-line at http://jbuisman.web1000.com/thesis/.

course is unrealistic but it serves our purpose since the primary interest is to study the behaviour of the bidders. The actual estimation is not performed because the emphasis of this game is on the bidding behaviour and not on the exact cost.

The activity that the players is asked to perform is bidding. The aim for the players is to gain at least an average profit of 15% above the pre-estimated cost. In this study this implies that the players have to try to set a price that has an average of 115 units. Some of the rules are hidden for the players and some other rules need some motivation. The next section gives an explanation of certain rules.

### *4.3. Rules*

The *number of rounds* is not given to the players because the game is set up as an infinite game with imperfect information. However, the plan is to perform approximately 10 rounds, but the exact number is dependent on the results.

The study design gives no information about the *type of price agreement* (Nicholas, 2001) because of the following reasons:

- It is not important for evaluating the bidding behaviour.
- The players probably do not have any knowledge about the types of price agreement so they will not consider this either.
- It may create unnecessary confusion.

Anyhow, the type of price agreement used is a fixed price: once agreed upon, the price cannot be adjusted.

It is decided that a *cost for bidding* will not be used because the cost is the same for all players. There is a chance that a player bids the same price all the time, without it costing anything. However, it is not likely that this would result in getting a large number of projects.

It is also decided that the players do not have a specific *budget* because this gives the players an idea of when the game may be ended. This is in contradiction with an infinite game with imperfect information. To be able to determine the overall winner, the costs for each player are logged during the game. This means that the player, that makes the most profit, wins the game.

To be able to perform the bidding process as realistically as possible, the game contains a kind of *boundary* in the form *of a distrust value*. Every player starts with a distrust value of zero and the maximum value is 25. Every time a player underbids, the player's distrust value increases, but the value can never decrease. If a player reaches the value of 25, all further bids for that player are ignored without notifying the player. So the player continues bidding, even without winning projects. This is the price the player has to pay. It is decided to let the player continue because this is also common in real situations. It is also decided that there is no distrust value for overbidding. It is possible but it does not add any value to this study because with a high bid, a player will never win anyway. Another kind of boundary is the *threshold boundary*. For example, if two bidders bid with a certain difference, it is not always the case that the project goes to the lowest bidder. If the higher bidder won the previous project, why not continue with this bidder? The threshold boundary is a fixed amount of five units. The players do not know this exact figure, but they know that there exists an internal rule that may mean that the lowest bid does not always win. The main reason for this threshold boundary is that, like in real situations, business relations can be created and maintained (e.g. a good price and that both parties are satisfied). The study can also be performed with a higher or lower threshold boundary. In these two cases it would be possible to study either a stronger relationship or really hard competition.

### *4.4. Game performance*

After the introduction meeting, the actual game starts. This game is performed as an iterative process with the following activities in each round of the game:

- The players place their bids for a new project, but the costs will be the same. They also give a short motivation of the strategy for their specific bid (to understand their behaviour better).
- The customer (researchers) collects all bids and motivations.
- The customer determines the winner (only based on the bid, not the motivation).
- The customer informs all the players with the following information:
    - If the player is the winner or not.
    - If the game continues, or if it was the final round.

The game may be terminated at any time. The major reasons to terminate a game are:

1. Enough information is collected from a research point of view.
2. There is no significant difference with the previous round, i.e. a sequential equilibrium may have been reached.

## 5. Results

This section provides the results of, and a discussion about, the performed study. Table 5-1 shows the offered bids for each player in each round of the game.

| | Round | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Player | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** |
| **1** | 101 | 109 | 114 | 114 | 114 | **114** | **115** | **115** | 11500 |
| **2** | 102 | **89** | **96** | **115** | 135 | 125 | 125 | 120 | **114** |
| **3** | **75** | 90 | 90 | 90 | 70 | NB[2] | NB | NB | NB |
| **4** | 99 | 115 | 115 | 115 | **98** | 120 | 120 | 117 | 118 |

**Table 5-1 Offered bid for each player and each round**

The bold numbers in the table represent the winner of each round. To get a better overview, the table is converted into a graph that shows the differences, and/or similarities, between each player during the game. This is shown in Figure 5-1.

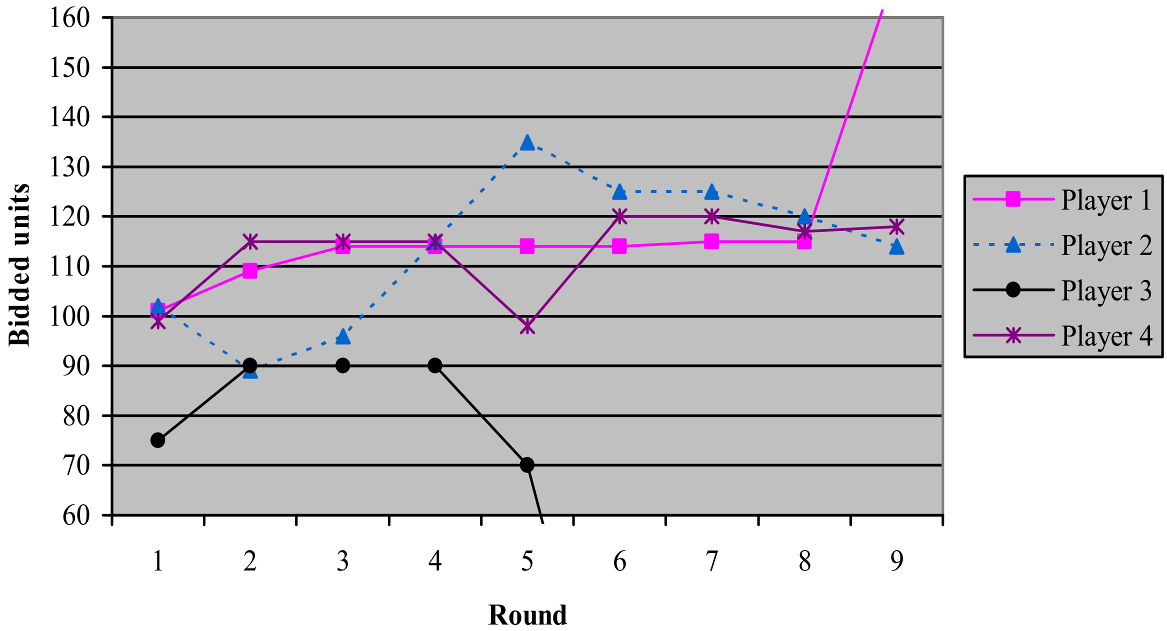


**Figure 5-1 Differences, and/or similarities between each player**

One of the first things that attract attention is player 3. The player started by offering a bid of 75 units. This number of units was exactly on the boundary of acceptance, but with this number of units the player lost all the credits of the distrust value (25). The player's motivation was that if you are new, you have to conquer the market. But then the player underbid again. So therefore all of the following bids are

[2] NB = no bid

ignored. Probably player 3 noticed this and stopped bidding after several rounds, i.e. no bid is provided after round 5.

It is interesting to see that the other three players started the game similarly. They all placed a bid around the cost unit. Their general motivation was that they do not dare to take too much risk, but they all admit that it has to cost to establish a relationship with the customer. Then two of the three players decide to go back to the initial conditions and know that if they do not win a project, other players do not earn money. Only player 2 decides to underbid with the following motivation[3]: “Since the last round of bids did not go that well, I am aiming at winning a bid and become one of the co-operators for the customer. Have to win a bet to be able to do this.” In the third round, player 2 underbid again, but not so low: 96. The player’s approach was that in order to achieve a relationship with the customer, it might be necessary to take a cost in the beginning. But in the fourth round, the player tries to climb towards breakeven by bidding 115. Player 2 wins this round based on the threshold boundary of 5 units, but when player 2 tries to recover from the loses, player 4 decides to underbid. The player’s motivation was: "98: From time to time one must try to get a project (and hope for the customer to stick to me long enough for me to gain it in later projects)." So player 4 wins this round. But player 4 will only succeed for one round because player 1 still bids 114 and player 4 bids 120. Player 1 was a really stable bidder. The player’s opinion was that everyone must soon understand that the only way to get around 15% profits is not to underbid. Player 1 keeps the stable bid around 115 units and the other players do not dare to underbid again. They know that if they win a project with an underbid, they actually loose money that they have to recover in the next rounds. So therefore player 1 wins three rounds because the other two players cannot compete anymore. Only when player 1 tries to make more profit, the other two players will have the opportunity to win a project without loosing money. This happens in round 9, where player 2 wins a project again.

This last round (9) is a kind of special case because of two reasons:

1. Player 1 thinks that the game is set up to fool the players by letting all the players win several projects and see their reaction.
2. Player 4 starts to offer a standing bid by applying an exponentially increasing payoff. Depending on if the player wins or not, a calculation is performed to offer the next bid. But this is going to look as a strategic game (see Section 2).

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[3] All the individual motivations are available on-line, see http://jbuisman.web1000.com/thesis/.

After this round it is decided to stop the study because:

- The situation described above (the two reasons of the special last round).
- The initial plan of performing approximately 10 rounds in which sufficient data is collected.

Table 5-1 also shows that there is no player that reached the goal of earning 15 units on average and that player 2 won most projects. So if only looking to the number of projects, player 2 should have been the winner of the game. However, the real winner is the player with the highest profit, and then player 1 is the overall winner with 3 projects and a profit of 44 units, which is very close to an average profit of 15 units.

So when looking to player 1's behaviour the main conclusion of this study is that taking risks do not pay off when other bidders do not take as much risk. When a player decides to take a risk and there is/are other player(s) who do not take risks at all (meaning bidding around the stated average value every round) it is really hard to recover from this loss. At least this is the case when having approximately ten rounds. Perhaps in the really long run a player will be able to recover, but this is outside the feasibility of this research and therefore no evidence is available.

It is too early to say that a sequential equilibrium has been identified, in particular with the behaviour of the first bidder in the last round. However, it seems reasonable to believe that a sequential equilibrium may occur if the bidders continued the game. This is however an issue for further research.

## 6. Conclusions and Further Work

The literature study indicates that the research presented here is novel in the sense that game theory has rarely been applied to bidding to the best of our knowledge. In particular the use of extensive games with imperfect information is a new approach to understand and evaluate the bidding behaviour for software projects. The only existing data on bidding behaviour is data from auctions where the bidder with the highest price always wins. This is, however, a completely different constraint and therefore it is not possible to compare.

The objective of this paper was to investigate the opportunity of using game theory as a tool for studying bidding for software projects. Moreover, the intention was to study the behaviour of the bidders to obtain a better understanding of the bidding as an important software engineering activity. With this research we have shown that (at least some parts of) game theory is applicable to investigate bidding for software projects.

The concepts used in this paper are an extensive game with imperfect information and it is also an infinite game, since no end is defined beforehand. The concepts have been used in a study to evaluate the bidding behaviour of software engineers. The performed study concludes that when a bidder takes a risk, it is really hard for this bidder to recover when there is at least one bidder that does not take risks. The study indicates that the most likely best strategy is to bid close to the “correct” bid. In other words, it is neither beneficial to underbid, since it takes quite some time to recover, nor to overbid, since it means that the projects will not be won. Player 1 in this study applied the strategy of bidding close to the value where the cost was covered and the expected profit was gained.

In the study presented, game theory is mainly used as a practical tool. One possible future research direction would be to take a more mathematical approach to the study, i.e. to use the underlying mathematical models in game theory.

Unfortunately the study was performed with only four players. The original intention was to have more players. However, this was not possible. Thus, in the future, it would be interesting to replicate the study or perform a similar study with more players and see if the results differ.

Another possible extension of the study would be the number of rounds. The study is performed over nine rounds. It would be interesting to see if there is a significant difference in the outcome if the study was conducted over more rounds. This would provide an opportunity to study whether it is possible to recover from loses and also to study if a sequential equilibrium is reached.

The study was conducted in a university setting, which is quite natural given that the approach was novel and that the researchers wanted to get a first understanding of the opportunity of using game theory to study bidding for software projects. Thus, it would be interesting to perform and evaluate the study with real software projects. In a real situation, it would also be interesting to include factors such as quality of the software, company size, real cost estimation, deliverance time, and so forth.

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**References**


Auction Cheat Sheet, 2000. Pc Computing, Vol. 13 Issue 2, February, p151, 2/5p.

Berk, J.B., Hughson, E., Vandezande, K., 1996. The Price Is Right, But Are the Bids? An Investigation of Rational Decision Theory. The American Economic Review, Vol. 86 No. 4, September, 954-970.

Bodington, J., 1999. Bidding Behavior. Independent Energy, October, 32–35.

Boehm, B.W., 1981. Software Engineering Economics, Prentice-Hall: Englewood Cliffs, NJ, USA.

Boehm, B., Sullivan, K., 1999. Software Economics: Status and Prospects. Information and Software Technology, 41, 937-946.

Dufwenberg, M., Gneezy, U., 2002. Information Disclosure in Auctions: An Experiment. Journal of Economic Behavior & Organization, Vol. 48 Issue 4, August, 431-445.

Fenton, N.E., Pfleeger, S.L., 1997, second edition. Software Metrics: A Rigorous and Practical Approach, International Thomson Computer Press: London, UK.

Ivanova-Stenzel, R., 2001. Auctions and Fair Division Games – a Cross-country Bidding Experiment. Journal of Socio-Economics, 30, 367-374.

Kitchenham, B., Pickard, L., Linkman, S.G., Jones, P., 2001. A Preliminary Risk-based Software Bidding Model: Keele University Technical Report TR/SE-0103, September.

Meyer, D.J., 1988. Competition and Bidding Behavior: Some Evidence From the Rice Market. Economic Inquiry, Vol. XXVI, January, 123-132.

Nash, J., 1950. Equilibrium points in n-person games. Proceedings of the National Academy of Sciences, Vol. 36, 48-49.

Neumann, Von J., Morgenstern O., 1944. Theory of Game and Economic Behavior. John Wiley and Sons: New York.

Nicholas, J.M., 2001, second edition. Project Management for Business and Technology, Prentice-Hall: Upper Saddle River, NJ, USA.

Pitchik, C., Schotter, A., 1998. Perfect Equilibria in Budget-constrained Sequential Auctions: an Experimental Study. RAND Journal of Economics, Vol. 19, No. 3, Autumn.

Osborn, M.J., Rubinstein, A, 1995, second edition. A Course in Game Theory, The MIT Press: Cambridge.