Experimental Economics and Experimental Computer Science: A Survey

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ABSTRACT

In surprisingly many computer science research projects, system outcomes may be influenced by computerized or human agents with different economic incentives. Such studies include P2P networks, routing protocols, agent systems, and attacker-defender security games. Even the most technical system raises a pressing economic question: what incentives will drive the success or failure of deployment?

Traditional computer science techniques, in isolation, may overlook factors that are critical to the overall outcome. In these situations, human-subject experiments may form a useful complement, broadening our understanding through the formulation and testing of economically motivated hypotheses.

I argue that these efforts can benefit from the large body of work that has been conducted in the field of experimental economics in the last 30 to 40 years. I discuss the methodology of experimental economics and review recent work that falls on the boundary of computer science and economics experiments and is likely unfamiliar to many professionals and researchers in technical fields.

Categories and Subject Descriptors

J.4 [**Social and Behavioral Sciences**] – *economics, psychology*

General Terms

Economics, Experimentation, Human Factors

Keywords

Experimental Economics, Human Subjects, Experimental methodology

1. INTRODUCTION

Computer science is a quickly evolving field covering diverse areas such as computer networks, security, artificial intelligence, nanotechnology, and computer architecture. Although research often emphasizes development of theory, one central goal of computer science research remains practical deployment.[1] Methods of experimental computer science, such as simplified or small-scale implementation, simulation, and computational experimentation, provide tools for analyzing performance, reliability, and stability, and highlight plausible deployment scenarios while also influencing theory in a feedback loop [15][44]. Observed discrepancies between theory and fact can motivate incremental progress or even create new paths for overcoming dogmatic beliefs held within disciplines [37].

The resulting interaction between theory and the gathering and analysis of data can follow different experimental approaches [57]: theory testing, discrimination between competing theories, exploration of a particular theory's failure, identification of empirical regularities as a basis for new theory, comparison of institutions or design of new institutions, and evaluation of specific policy proposals.[2]

In recent years, formal methods of economic modeling and analysis were extended to many fields in computer science, based on the observation that in computer systems, as in previously studied applications, agents compete for scarce resources. Examples include shared access to bandwidth [3], scheduling of resources aboard a spacecraft [46], and the interaction between email spammers and end-users [39]. Such examples have only become more common with the recent push for decentralization of computing resources.

Much like computer science, economics has both theoretical and experimental modes of inquiry, and a useful parallel may be drawn linking these modes in either discipline. Theoretical economics, when used in isolation, has fundamental limitations that are relevant to the computer science researcher. The favored approach in economic theory is to assume that agents behave fully rationally in that they aggregate and process all available information, and identify and eventually choose the option that results in the highest utility. Many issues of concern to computer scientists, such as combinatorial algorithms, cannot meet this standard due to computational constraints or the infeasibility of computing optimal solutions. Although recent work in economics offers relaxations from full rationality [9][13][22], there is no settled alternative for predicting human behavior. Therefore,

[1] This is particularly important for technologies with little prior deployment results such as clean-slate design proposals.

[2] Experiments also have important pedagogical purposes [21].

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economic theory, much like computer science theory, necessarily leaves open questions regarding practical deployment.

To continue the analogy, experimental economics, in the form of human-subject experiments, is used to investigate how humans behave “in the wild.” Experimental economics serves as a complement to economic theory: It interacts with economic theory in all the same ways that are familiar from the computer science realm – validating theories, suggesting new theories, and so forth. For the computer science researcher, economic experimentation provides insight into realistic behaviors by human participants and their expected impact on system outcomes.

Of course, many situations of interest to computer scientists involve both human actors and the technical systems they interact with. In this arena, the line between experimental economics and experimental computer science is blurred, and it often becomes impossible to decompose an experiment into separate economic and technical components. Some of the most interesting questions in both fields appear at this boundary, challenging the researcher to evaluate economic, psychological, and technical influences under realistic assumptions.

In this paper, I will review selected studies that straddle this narrow frontier between disciplines. Although a wide range of economics research is relevant to computer science (such as fairness models or auction theory) my focus will be on those studies that make a genuine effort to communicate to both economics and computer science researchers.

Such efforts have yielded contributions to many fields of computer science. In this review, I restrict attention to research in computer networks and agent systems. Other areas where cross-disciplinary efforts have been successful include security [36][38][50], privacy [27][62], and human-computer interaction [26].

An important theme will emerge from examining the papers in this literature: Experimental studies benefit from a clear and concise theory about the underlying workings of an economic institution (e.g., a market or auction) and expectations about how agents react to incentives in this environment. This theory does not always require a formal mathematical model but need only be sufficient to propose sensible hypotheses concerning differences in choices made by agents based on experimental manipulations.

My goal is to acquaint the computer science researcher with the methodology of experimental economics. I hope that the reader who completes this survey will be better equipped to read papers from this interesting area, applying the framework of experimental economics and placing papers in the proper perspective. The examples presented here will attest to the value of researchers that understand both computer science and economics research, and are able to find new opportunities for cross-fertilization.

In Section 2, I discuss the guiding principles of experimental economics research and expand on many other important design considerations. Section 3 reviews recent experiments with relevance for computer networks research and agent systems. Section 4 completes the paper with concluding remarks.

2. METHODOLOGY OF EXPERIMENTAL ECONOMICS

2.1 Guiding principles

In this section, I will discuss major principles that were developed in the experimental literature and have become somewhat codified.

2.1.1 Realism of Experimental Economics Results

The central goal of experimentalism is to identify causes that produce certain results unconditionally of background assumptions. However, the complexity of economic systems prevents experimenters but also theorists from correctly identifying all defining aspects of a decision-making situation or market. Therefore, both groups are forced to make simplifying assumptions about an economic problem to derive tractable solutions.

In the philosophy of science the resulting problem is related to the Duhem-Quine thesis which reminds scientists of the impossibility to test a scientific theory in isolation because every empirical test requires assumptions about background (or auxiliary) aspects. Consequently, a failure of a theory in the laboratory can always be attributed to more or less convincing auxiliary hypotheses [57]. It appears obvious that few experiments could survive such a strong test of external validity.

Economic experimentalists aim for a more local form of external validity test called parallelism in which they evoke a more narrow relationship between small-scale experiments and realistic markets. Given main characteristics of the economic environment observed in the field and modeled in the laboratory they argue that observations from the experiment will then carry over into these closely related real world institutions and can be further validated by field data. Of course, researchers will also speculate about conclusions that can be drawn for a wider set of economic decision-making situations. This process can lead to critical discussion and can be a strong driver for further experimentation [58]. Of course, proponents as well as skeptics can and should design further experiments.

2.1.2 Control and Repetition

A leading tenet of good experimentation (as well as theoretical modeling) is simplicity. The researcher wants to be able to relate differences in observations to the manipulation of the experimental environment.

Formal economic models form good bases for experimental designs. In many aspects, models can be considered more simplistic; for example, they leave out important details that need to be addressed in an experimental protocol such as when exactly and what type of information is disseminated to the subjects and in what form. On the other hand, models can also be considered more general since experimental setups require specific parameter values (such as demand and supply functions).

In designing an experiment based on theory, a researcher faces a tradeoff. Closely following theoretically derived results allows the researcher to formulate and rigorously test hypotheses. However, sticking too close to the theory will diminish the ability to learn whether results also extend to an environment that departs from the very stringent assumptions made for analytic purposes. Statistical methods or simulations are more likely to reveal logical mistakes in theories [21].

A strength of the laboratory method is that the experimenter can iteratively add and remove aspects of the field environment and carefully study the impact of the manipulation.

An important limitation is that even in an experiment, many characteristics of human participation can only be determined with difficulty, e.g., intrinsic motivation of subjects, type of risk preferences, heterogeneity of prior experience and expectations with relevance to the experiment, and strength of selfish or other-regarding preferences. In fact, many experiments in economics and psychology have shown that subtle aspects such as framing of instructions can (depending on the study) take significant influence on the results.

It is, therefore, an important and enforced practice in experimental economics to clearly describe all aspects of the laboratory environment. Instructions and possible screenshots (or code) used for the experiments are often available in the appendices or from the authors. Many researchers also allow others to access their raw data to conduct their own analysis.

The goal is to allow for repetition, comparability and incremental variations of the experiment. In particular, for experiments analyzing individual decision-making behavior that is often subject to individual biases or misconceptions researchers have been motivated to test the robustness of the results repeatedly (see, for example, research on preference reversal or the endowment effect).

The result is a much better global understanding of many games, e.g., the prisoners' dilemma that has been subject of hundreds of experimental studies.

2.1.3 Induced value theory

One central aspect of control in experiments is the design and utilization of an incentive structure for participants. The experimenter wants to induce certain characteristics in the subject population that relate to a market institution. For example, the incentive structure in a market should motivate individuals to demand or ask for prices and/or quantities that yield the subject a higher payoff. Another aspect is that outside characteristics of the participants become less important. Experimenters refer to this design process as induced value theory [58].

Formally, three conditions have to be met to control for agent's characteristics [21]: First, monotonicity requires that subjects prefer more of the reward medium to less and that subjects will not become satiated. Second, salience is achieved if individuals' payoffs depend on their actions, actions by other agents and the characteristics of the institution in an understandable fashion. Third, dominance is guaranteed if participants' utility (and motivation) stems overwhelmingly from the reward structure so that other influences receive little attention.

The concept of salience most clearly distinguishes experimental economics studies from surveys containing questions about past self-reported economically relevant behavior or hypothetical choice scenarios. Similarly, most examples from participatory simulations with human subjects [30] or business simulations [63] do not meet these requirements. To further discuss the permeable boundary between agent studies and human subjects experiments see also the detailed review article by Duffy [16] that offers a comprehensive discussion of the empirical validity of agent-based modeling approaches in terms of explaining data from experiments with human players. Interested readers might also want to consider Guttman *et al.* [29] who review research on agent-mediated electronic commerce.

Results from these different approaches are often comparable or even largely identical to experimental economics results depending on the context and the incentive structure of the economic institution under investigation. But such a comparison has to be made on a case by case basis. See, for example, [32] and [60] for a discussion of experimental evidence on this topic. Furthermore, experiments bundled with surveys and/or hypothetical scenarios can deliver fruitful research on a number of issues, e.g., the regressions on experimental results and survey data in the paper by Glaeser *et al.* [24] on social capital and trust.

2.2 Other design considerations

The guiding principles set the baseline for experiments, however, leave many research design questions unanswered. Below I will discuss a few aspects (among several more such as tools and methods for analysis of experimental data) that need to be considered by every experimenter that aims to design an experiment from scratch.

2.2.1 Type and size of rewards

Many universities have research laboratories that define conventions for an adequate average compensation of subjects in experiments. In absence of such regulations researchers should take into consideration the average wage that the selected target population could receive within the time of the experiment if they would conduct their typical occupation. The principle of dominance also requires that subjects feel motivated during the experiment to earn higher returns, therefore, a combination of show-up fees and incentive-compatible payments that depend on subjects' actions should not be structured in a way that the flat fee dominates other payments. Note that payments need not always be of monetary nature. Subjects can also be paid with physical goods (e.g., mugs in endowment experiments) or even immaterial goods (such as better recommendations for a planned purchase [62]).

Several types of experiments (such as auctions) can lead to widely different variable payments to the subjects. Experimenters can balance payments by, for example, switching the role of buyers and sellers or changing private valuations for auction goods. However, there are limits to such attempts. For example, many experiments are conducted only once (so called one-shot games) and some participants might be disadvantaged by their initial bargaining position.

An often voiced criticism of experimental economics is that conclusions on real world markets or choices are drawn that involve high stakes based on experiments with relatively small rewards. In response several researchers have replicated well-known experiments but with larger relative rewards, for example, by conducting experiments in countries with a lower personal income level. E.g., Slonim and Roth [55] found that behavior of inexperienced traders is largely insensitive to the size of rewards.

However, learning in multiple iterations of a game can reveal differences between different reward schemes.

2.2.2 Subject Pool

The large majority of experiments have been undertaken with student populations at research institutions. In abstract settings students generally behave similar to subjects with professional experiences [4]. In experiments with rich context differences between subject populations are more likely. However, that does not mean that professional experts always achieve higher returns in experiments that concern their domain of expertise. Abbink and Rockenbach [1] found that experienced financial traders received lower returns compared to student subjects. They attributed this to the more intuitive approach by financial analysts to the game experiment.

There is also a rich body of literature on gender differences concerning risk attitudes, ambiguity avoidance, savings behavior and many other topics.

Depending on the nature of the research study self-selection of subjects might bias the results, e.g., if a study on social norms that includes a survey part is conducted. Similarly, experimenters should avoid raising specific expectations with their behavior or in the instructions. This can lead to the so-called experimenter effect in which subjects are mainly concerned with guessing what behavior might be expected from them (e.g., an experiment on financial market bubbles should probably avoid mentioning this or other terms relating to behavioral exuberance). Experimenters should also preserve anonymity of the subjects and secrecy of the payments to limit concerns of subjects regarding their privacy.

To allow for comparison of study results reports should include a clear description of the larger subject pool, the recruiting procedures and data about the actual participants.

It is a widely enforced standard in experimental economics to avoid deception of subjects. The contention is that misleading subjects would lead to psychological responses by the subjects that are undesirable and endanger the validity of experimental results and even has the potential to pollute the larger subject pool. Deception can be desirable when used as a treatment variable or as a proxy to influence systematically the beliefs of human subjects about other treatment variables. See [5] and [41] for a critical discussion of this standard. Note that many experiments involve withholding information from subjects (i.e., they are 'economical with the truth') which is often acceptable. However, intentionally distributing false information is met with suspicion by experimentalists.

2.2.3 Complete or Incomplete Information

An important consideration for experimental design is the amount of information that individuals possess about the functioning of the economic environment, the number and endowed characteristics of other players, and their own strategic choices and the mapping of choices to payoffs. Depending on the type of experiment the impact of information can be highly different.

Some market institutions have been shown to achieve very high efficiency and high participation under a wide range of design choices, for example, the double auction market. These auction markets are usually conducted under limited information conditions where participants know only their own private valuations and payoffs, but market prices and market bids are common knowledge. In contrast, Smith *et al.* [59] and Peterson [45] have undertaken pure common value markets. In these cases, traders are endowed with only public and no private information regarding the expected common value. In these markets occurring trades are attributed to factors such as different risk attitudes and other unobservable characteristics of the traders (e.g., differences in individual price forecasts, accuracy of decision making due to experience or bounded rationality, and varying expectations concerning the other traders' strategies). Smith and Williams [61] found that providing full information about other player's payoffs can stifle participation and increase market volatility. In other scenarios such as bargaining games the impact of incomplete information is often found to be stronger.

Leaving information about important aspects of the experimental environments incomplete is tempting since in most real world scenarios including issues in computer science (e.g., such as routing costs) full information about all economically relevant variables is unrealistic. Experimenter, however, have to consider that subjects in absence of information players will rely on their personal beliefs about these characteristics which are hard to observe and control.

2.2.4 Number of players and parameterization

'Four are few and six are many' is one rule of thumb which applies to experiments on oligopoly markets [53]. The author showed that collusion is sustainable with four, but not with six firms. In the context of computer networks Friedman *et al.* [20] demonstrated that altering the group size from 2 to 8 participants drastically changed aggregate behavior for a cost sharing game.

More generally, the exact number of subjects and the resulting individual behavior and market performance depends on the details of the institution. Fortunately, many experiments have been conducted on this topic so that interested researchers can orient themselves on past results to determine an appropriate group size for experiments that leave this design consideration open.

Experimentation usually involves the choice of specific parameters for the economic environment. This is a very crucial part of experimentation. The parameters should allow for survival of non-equilibrium observations such as overbidding and underbidding on auction markets. In games with multiple equilibria subjects' choice should be easily recognizable from the data even if individuals do not always choose perfectly. Experimenters should be aware of focal points in their setup attracting attention of subjects (if that is not intended) which might bias the data.

3. EXPERIMENTAL ECONOMICS STUDIES AND COMPUTER SCIENCE

My review focus is on research experiments concerning networked systems and electronic markets.

The experiments presented in this section range from experimentation with careful manipulation of variables and hypotheses testing to simple performance of proof-of-concept studies.

3.1 Applications in Networked Systems

There is an abundance of game-theoretic models regarding networked systems. With the introduction of more user control on the routing level (e.g., user directed routing), application level (e.g., file-sharing clients) and other network related issues human behavior increasingly has an impact on network performance. Behavioral treats that permeate the research literature such as maliciousness, fairness, free-riding, and learning motivate the exploration with methods of experimental economics. But not all scenarios avail themselves to this methodology since many aspects of networks' functioning are completely opaque from users' perspective.

Below I discuss selected examples of experiments with rigorous methodology that explore areas of relevance for network researchers. For these experiments instructions and detailed experimental setup descriptions are included in the paper or available from the authors.

3.1.1 Study of Congestion Dynamics

The real-time experimental study reported in [18] explores dynamics for a simple congestion game. It also sheds light on the interaction of human players and automated agents in a networked system. Players (human or artificial) are rewarded for downloading complete data packets but penalized for delay due to congestion. Formally, they model network interaction as a game with the following objective function for player's profit $\Pi = rN - cL$. Value r is the reward per successful download, N is the number of successful downloads, c is the delay cost per second, and L is the total latency time summed over all download attempts in that period. The experimental environment includes a network capacity constraint C determining the number of users being able to download at the same time without delay penalty. The delay algorithm is a noisy version of a single server queue model known in the literature as M/M/1. Subjects have asynchronous binary choices (to download or not) at endogenously determined times. The authors compute equilibrium predictions for a simple but intuitive player strategy and derive testable hypotheses for the experiment.

Software agents employed a selfish and myopic strategy. Human players were made aware about the agents' presence and informally notified about the approximate strategy of the agent. In their setting most players incur an overall loss and artificial players do significantly less well on average. Only in treatments with high capacity or large background noise agents compete successfully with human traders. Humans are observed to be slower and less able to exploit excess capacity whereas bots are capable of executing their strategy perfectly in those networks. However, agents' failure to internalize the difference between observed congestion and anticipated congestion stands in contrast to humans who react more flexible to changes in delay. The authors observe that the Nash equilibrium comparative statics explain the data rather well. Players cannot move towards the social optimal outcome. Rather, the common result is overdissipation of rent, that is aggregate profits are lower than any Nash equilibrium.

The results by Friedman and Huberman [18] contribute to the more general discussion that agents based on statistical analysis of historical market data or static strategies may be insufficient for the efficient operation of markets (an observation made by Miller [43]). For example, van Boening and Wilcox [64] discuss the requirement for agents to also possess forward-looking attention. In their paper they compare the performance of human agents and zero-intelligence agents [25] in a double auction market environment with large avoidable cost. They observe that efficiency and stability are undermined in markets with human traders, however, markets populated with zero-intelligence traders perform even less satisfactory.

3.1.2 Queueing systems with endogenously chosen arrival times

Closely related to Friedman and Huberman's experiment, Rapoport *et al*. [47] study situations in which the queueing system is in a transient state and the arrival time of each player is endogenously determined modeling occasions when individuals can decide whether and when to join a queue. In contrast to Friedman and Huberman [18] individuals cannot leave a queue and can order service only once. This queueing game is example for an experiment on tacit coordination, however, in a large-scale economic system with direct relevance on network performance.

The authors compute pure and symmetric mixed strategy equilibria. Given the experimental data they find the mixed strategy equilibrium predictions to map major statistics of aggregate behavior in the queueing game well (i.e., the relative frequency distribution of arrival time, the relative frequency distribution of interarrival time, and the relative frequency distribution of queue waiting time).

Subjects participated in 75 queueing trials and had to decide whether they wanted to enter the queue and at what time. However, learning behavior across trails was low attributable to limited information about the individual payoff drivers. In particular, subjects did not know a loss was the result of a particular entry time chosen, too many players trying to receive service, or both.

3.1.3 Cost Pricing Mechanisms in Limited Information Contexts

Chen [10] conducted an experimental analysis of the serial and average cost-sharing game in discrete time. While in a full information treatment both mechanisms converge well to the Nash equilibrium, the experiment shows that in limited information contexts the serial cost sharing mechanism performs more robustly. Chen concludes that traditional solution concepts such as Nash equilibrium analysis and dominance-solvability are unsuitable to explain and predict these results. Chen and Khoroshilov [11] fit learning models to the data but find that none of the models explains the experimental data well for the average cost mechanism. However, a payoff-assessment learning model and experience-weighted attraction learning track the experimental data for the serial cost sharing mechanism sufficiently.

Friedman *et al*. [20] study convergence behavior in Cournot oligopoly and serial cost sharing games in an asynchronous continuous-time low-information setting. For the oligopoly game they report that convergence improves only with an increase in the number of players in the game. In the serial cost sharing game convergence is significantly more robust, however, deteriorates with an increase in the number of players. Friedman *et al*. propose the use of an alternative solution concept to explain these results. They define a strategy to be overwhelmed if the maximum payoff obtainable under that strategy is less than the minimum payoff obtainable under some other strategy [19]. They suggest that in limited information environments it is easier to avoid overwhelmed than dominated strategies (the cost-sharing game is solvable by the iterated deletion of overwhelmed strategies, whereas dominance-solvability leads to a unique prediction in the Cournot oligopoly game). The authors further observe that experimentation by subjects (i.e., periodical trying of different values) is common and quite methodical which does not conform to assumptions made in most learning models.

3.1.4 Incentives Engineering for Structured P2P Systems

For many protocols used in unstructured or structured peer-to-peer (P2P) networks reliability and correctness of query routing and response depends on the cooperation of participants of the network. In P2P systems as well as in many related economic games (e.g., the Ultimatum, Dictator, Trust or Helping game) cooperation is predicted to fail if agents are purely self-interested. Schosser *et al*. [51] conduct an experiment with human subjects using protocol characteristics of the Content-Addressable-Network (CAN) proposed by Ratnasamy *et al*. [48].

Using the strategy method to elicit complete strategy profiles of participants post-experimentally [52][54] they find that most participants use versions of simple cut-off strategies to decide whether to forward or respond to a query. For example, participants feel motivated to respond if x% of their prior queries were routed and responded to successfully or if they received a certain number of responses exceeding an absolute threshold. The results also indicate that subjects intend to directly reciprocate to behavior of other nodes.

In treatment 1 only few participants in their experiments free-ride before the experimenters introduce a malicious agent (they report a service rate of above 70%). With the participation of the unresponsive agent the service rates and average payoffs drop across all observed experimental sessions (treatment 2). While the non-cooperating agent receives higher payoffs than all other agents his earnings are less than the payoff of agents in the treatment without malicious participants.

The authors note that agents might also be motivated by relative payoffs compared to other participants. However, in P2P systems payoffs of other players are usually not directly observable. They do not provide for an experiment that would test this hypothesis.

The authors show a weak positive on payoffs for the introduction of direct feedback between participants (treatment 3). They argue that the impact could likely be higher if the free-riding problem would be more prevalent in treatments 1 & 2.

3.1.5 Demand for Bandwidth by End Users

In the INDEX project (that was running from April 1998 to December 1999) researchers at UC Berkeley provided 70 residents in the surrounding of the campus with integrated services digital network (ISDN) access [68]. Users' traffic was routed through a gateway that allowed for monitoring, billing and the implementation of an experimental regime. During most of the experiment users could choose between several different bandwidths with different charges (a combination of per minute and a per MB tariff).

With a free 8-kilobit/sec service available most users did not choose faster service rates (75%). The remaining demand was approximately equally split between the other available costly choices. Regressions showed that about 20 percent of the variance in demand could be explained by price variation, about 75 percent by individual specific effects, leaving 5 percent unexplained. The data motivated the creation of an economic model of user demand for bandwidth.

Researchers found that the voluntary subscribers placed a very low value on time (which can be attributed to the participant population which mostly consisted out of students with more rigid budgetary constraints). Also the state of the Internet of 1999 did not allow for more sophisticated applications limiting the demand for more bandwidth. Varian called this a chicken and the egg problem. Without more application demand will not rise and vise versa.

A highly interesting subexperiment measured the willingness to pay by subjects to participate in a flat-fee pricing regime rather than the per-minute plan. In this sample 80 percent of the users opted for the fixed price plan. Consumers paid, on average, a 50 percent premium for the flat fee but consumed 9 times more bandwidth. Ex-post 26 percent of these consumers would have fared better with the flexible plan.

3.1.6 Bandwidth Trading between Internet Service Providers

Research has demonstrated that ISPs are hampered in their ability to create efficient on-demand routes with the result that they have to lease or buy the maximum bandwidth they may need in the long run rather than reacting flexible to current demand situations [17]. Part of the problem is that sharing routing information is a cumbersome problem in protocols such as the Border Gateway Protocol (BGP). Another aspect is that negotiations with multiple network providers can lead to the exposure problem [42] (e.g., in sealed bid uniform price auctions for bandwidth without the opportunity to bid for link packages). I.e., if strong synergies exist between parts of a desired link combination potential bidders will be tempted to submit bids above the standalone value of an individual link in order to increase the probability of winning the desired set. However, bidders could be discouraged from this beneficial strategy by the risk of not receiving the complete desired set of links and incurring a loss. The opposing forces of synergy and exposure may result in out-of-equilibrium play and decrease of efficiency as shown experimentally by Kagel and Levin [33]. They find evidence for reluctant bidding, but also that bids are monotonically increasing in bidders' valuations of the bundles showing that experimental subjects behaved economically sensibly.

The exposure problem can be alleviated through the utilization of combinatorial auction mechanisms. Kaskiris *et al*. [34] conduct such a combinatorial auction experiment for bandwidth markets. They design a network with three links with different private values for buyers and sellers of bandwidth. All buyers experience strong synergy effects between the three links, however, the exact distribution of valuation is private. The auction market used is two-sided allowing buyers and sellers to simultaneously participate in the market. During the market clearing process at the end of each round the system matches the combination of seller and buyer bids which generates the highest surplus. Uniform prices are generated for each link and each participant pays the combination of prices based on their successful bids.

The authors report buyer efficiencies of at least 60% and seller efficiencies of about 65%, and discuss observed over- and underbidding behavior and learning of subjects over time. Future experiments are planned to explore the role of varying the number of market participants. Further it would be interesting to compare the results to an equivalent setup without buyers' ability to submit bids for link bundles. This would enable the authors to quantify the efficiency gain that is resulting from using a combinatorial mechanism.

3.2 Electronic Markets

In the following I will discuss more research on negotiation agents and electronic markets. The first set of studies does not necessarily conform to the strict guidelines of experimental economics, for example, research takes more issue with proof-of-concept considerations or simple performance testing rather than controlled experimentation. But the experiments show potential for further more thorough exploration of important determinant of negotiation behavior. The remained of the section is addressing market behavior.

3.2.1 Negotiations Agents

Byde *et al*. [8] use a laboratory experiment to study the interaction between a procurement negotiation and bidding agent and three human bidders. The authors comment on the question whether it is possible to identify the agent and whether the agent delivers adequate performance compared to human buyers. The experimenters informed human bidders that a software agent was participating in the negotiations. According to exit interviews, experiment participants were not able to identify the artificial trader. However, the results indicate that the automated trader is not always successful in achieving a good balance between total cost and target quantity purchased when human bidders are present.

Providing a more complex setting, Kobayashi and Terano [35] study human and artificial players in a business game with procurement, manufacturing and sales decisions. Six software agents using different strategies (random, simple prediction rules, and human trader strategies that were observed earlier) compete with four human traders. It is not possible to draw detailed conclusions from their reported data. They note, however, that one human trader dominates the population in total earnings, whereas the other humans perform on average worse than the software agents.

Bosse *et al*. [6] present a system for the analysis of traces for multi-issue negotiations. They formalize the dynamic properties of different negotiation processes and implement a prototype for test experiments. They conduct an experiment with 74 high school subjects on a car sales negotiation example. Subjects use the system to negotiate with other anonymous human participants. The experiment is mainly exploratory in nature and shows the capabilities of the analysis system. Interestingly, none of the negotiations resulted in a pareto-efficient allocation or Nash equilibrium outcome. This highlights the difficulty of humans to negotiate the allocation of complex goods optimally. The negotiation process followed rarely a pattern of strict pareto monotony, however, some parts of the human negotiation traces obeyed weak pareto monotony.

3.2.2 Agent Tournaments

Tournaments present a straightforward way to compare agents' performance in a fair environment. In the artificial intelligence community agent tournaments are conducted in an increasingly complex environment, see for example, the Trading Auction Competition (TAC) described by Wellman *et al*. [66][67]. In the 2001 TAC agents arranged in groups of eight are assigned the role of travel agents charged with the task of arranging and automatically shopping for trips. The challenging part for agents' design is to address the interdependence of the tasks necessary to complete a trip, and the ability to reason about others' strategies in a thin market of automated agents and in a continuous timeframe.

In experimental economics community work on programmed strategies has also been done by conducting tournaments [2][49][54]. Rust *et al*. [49] report on the Santa Fe Double Auction tournament, where researchers were invited to submit software agents that compete on a continuous double auction market against one another. The most successful strategy in this tournament can be described as rather parasitic sitting in the background and exploiting the strategies of other agents. In addition, they report about an evolutionary tournament, where the percentage of agents was adjusted in accordance to the success of a strategy over time. Parallel to the tournament there has been a discussion on the lower bound of trading agents' intelligence to act similarly to human traders in a market institution [12][25][64][65].

McCabe *et al*. [40] reiterate an interesting anecdote from the Santa Fe tournament: 'The computer programmer who was responsible for developing the protocols and code used to execute the tournament would regularly match himself (at a speed of course that he could handle) against a randomly chosen subset of the automatons submitted. After a brief learning period he would never lose, even against the ultimate winners. This is important because in a world where multitudes of complex trade opportunities (many of them much more complicated than the double auction) begin to present themselves, the ability to inject sophistication (potential to learn, reciprocate, punish, etc.) into intelligent agents will be worth millions, of dollars.'

3.2.3 Agents on Markets and Auctions

Das *et al*. [14] conducted an experimental series where human traders interacted with software agents. They followed the design proposed by Smith [56] for two-sided market where participants were assigned fixed roles as either buyer (submitting only bids) or seller (submitting only asks) and received a private valuation (cost) for the traded good as a buyer (seller). In their study the experimental conditions of supply and demand were held constant over several successive trading periods and were then exposed to a random shock that changed market parameters. Experimental sessions involved 6 human traders and 6 agents. In addition, a baseline session with 12 human traders was run. Two types of agents were used that applied either a modified Zero-Intelligence-Plus strategy [12][25] or a modified Gjerstad-Dickhaut algorithm [23] They note in their report that bidding strategies of the employed agents were not discussed in detail with the human traders during the instructional phase. It appears, however, that human participants knew they competed with agents.

In general, human-agent markets show convergence to the predicted equilibrium and improved efficiency compared to a market with human traders only [14]. Agents reaped average profits well above those of human traders. Between 30 and 50 percent of the trades were done between agents and human traders.

The results above have been used as a proxy for comparison with other agent algorithms. In [31] the authors developed algorithms that employ heuristic fuzzy rules and fuzzy reasoning mechanisms. In direct comparison to other benchmark algorithms (including those in [14]) they achieve superior performance. According to them, these results are particularly promising since the benchmark strategies have been shown to outperform human bidders (referring to the results in [14]).

Grossklags and Schmidt [28] introduce software agents into a more complex and natural trading environment. This includes the following: a trader acts both as a buyer and seller; information about the fundamental value of the securities changes in every round; orders allow for multiple units of a specific contract; and the market institution does not provide a spread improvement rule. Additionally, many other continuous double auction experiments (e.g., [14]) rely on a single observation for each treatment. To add robustness to their results Grossklags and Schmidt collected six statistically independent observations for each treatment.

The main contribution is the introduction of an information condition into a human-agent experiment. Two treatments were conducted with experimental parameters held constant except for the information available about the software agents: in one treatment the participation of the software agent was made common knowledge, and in the other treatment subjects were not informed about the existence of software agents. In addition, the data is compared to a third treatment (called baseline treatment) without software agents or information about the presence or absence of software agents.

The authors formulate hypotheses with regards to the influence of software agents on human traders. Following the results of related work (e.g., [14]) they expect the arbitrage agent will improve market efficiency. The agent follows predefined rules and does not make mistakes with respect to its algorithm. In addition, the arbitrage agent can process more data in a given time span and interact faster with the software interface than human traders are able to interact with the graphical user interface.

More importantly, the introduction of the information condition allows formulating a central hypothesis about the reactions that can be expected from human traders when information on software agents is provided. Human traders suffer from the uncertainty about the agents' capabilities, e.g., their speed in calculating strategies and in processing transactions. This uncertainty might lead agents to crowd out humans from the market. It is a strong hypothesis that would require human traders not to trade at all when information about the existence of software agents is available. However, in the context of the double auction market institution, traders cannot observe if a particular trade is done with a human or a robot. Thus, an alternative hypothesis can be formulated according to which humans compare themselves with other human traders only and neglect the existence of software traders. This hypothesis would predict no difference in human behavior when information is provided.

Grossklags and Schmidt [28] find that agents do not crowd out human traders in the treatment with common knowledge on software agents. Instead, common knowledge on the presence of software agents has a significantly positive effect on human traders' ability to converge to equilibrium in the presence of the arbitrageur agent. Furthermore, intuition would suggest a higher efficiency in an environment with software agents when compared to no software agents. Surprisingly, when compared to the baseline treatment the introduction of an arbitrage seeking type of software agent results in lower market efficiency in the no information treatment. The authors discuss several interpretations for this surprising result.

4. CONCLUSIONS

I have discussed foundational principles and other important design considerations of experimental economics studies. Using computer networks and electronic markets as examples, I have shown that such experimentation is feasible and promising in a wide range of scenarios. Not all studies presented here follow the outlined principles closely (and certainly this was not always the intended goal). Some aspects of the studies could be improved with a different manipulation of treatment variables and more thorough exploration of hypotheses in advance.

Many aspects of experimental practice in economics are worth considering for experimental computer scientists (and are partly adhered to already). First, providing enough information on experimental setup, instructions, source codes, and hardware is necessary to allow for replication of results and research that builds on published work. Second, making data available to other scientists can allow for meta-studies and secondary data analysis for a different research question or by different analysis methods. Third, drawing on theory wherever possible strengthens the experimental hypotheses and allows for clearer interpretation of results. Theory need not always be purely mathematical but can also be qualitative or cite behavioral regularities. Fourth, studying the sensitivity of results to important auxiliary assumptions is important and necessary. For example, does the number of subjects in a study matter, does experience of subjects play a decisive role, or does the choice of parameters favor one particular hypothesis? Experimenters, however, should not be afraid of results falling apart under more scrutiny, but rather recognize that inconsistencies are a stepping stone on the path to a more nuanced understanding of the research question.

The relationship between experimental economics and computer science is not a one-way street. In fact, there are already examples of successful cross-fertilization. Interdisciplinary teams such as in Friedman *et al.* [20] can make tremendous contributions to both fields. Electronic market design is another field in which cooperation has already carried fruits. For example, Brewer and Plott [7] use a combination of operations research methods and experimental economics (they call it a laboratory test-bed methodology) to design and validate a cost-minimizing back-haul market.

Of course, experimental economics is just one helpful addition to the experimental computer science toolkit. And it is fair to add that experimental economics studies often require a substantial amount of preparation, such as review by the local internal review board for human subject studies, a laboratory that adheres to accepted standards, recruitment of subjects, and grant writing to receive funding for experiments. Further, attending experimental sessions takes time.

Nevertheless, it is worth it. Researchers in computer science should seize the opportunity to bring new and exciting research to bear on how technologies and protocols perform under human scrutiny and in absence of too many assumptions about agents' behavior.

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6. REFERENCES

[1] Abbink, K., and Rockenbach, B. Option pricing by students and professional traders: a behavioural investigation. *Managerial and Decision Economics*, vol. 27, no. 6 (Sep. 2006), 497–510.

[2] Abreu, D., and Rubinstein, A. The Structure of Nash Equilibrium in Repeated Games with Finite Automata. *Econometrica*, vol. 56, no. 6 (Nov. 1988), 1259–1281.

[3] Archer, A., Feigenbaum, J., Krishnamurthy, A., Sami, R., and Shenker, S. Approximation and collusion in multicast cost sharing. *Games and Economic Behavior*, vol. 47, no. 1 (Apr. 2004), 36–71.

[4] Ball, S., and Cech, P. Subject pool choice and treatment effects in economic laboratory research. In Isaac, R.M. (Ed.) *Research in Experimental Economics*, vol. 6, JAI Press, Greenwich, CT, 1996, 239–292.

[5] Bonetti, S. Experimental economics and deception. *Journal of Economic Psychology*, vol. 19, no. 3 (June 1998), 377–395.

[6] Bosse, T., Jonker, C.M., and Treur, J. Experiments in Human Multi-Issue Negotiation: Analysis and Support. In *Proceedings of the Third International Conference on Autonomous Agents and Multiagent Systems (AAMAS'04)* (New York, NY, July 19–23, 2004). IEEE Computer Society, Washington, DC, 671–678.

[7] Brewer, P.J., and Plott, C.R. A Decentralized, Smart Market Solution to a Class of Back-Haul Transportation Problems: Concept and Experimental Test Beds. *Interfaces*, vol. 32, no. 5 (Sep.-Oct. 2002), 13–36.

[8] Byde, A., Yearworth, M., Chen, K., and Bertolino, C. AutONA: A System for Automated Multiple 1-1 Negotiation. In *Proceedings of the IEEE International Conference on E-Commerce (CEC'03)* (Newport Beach, CA, June 24–27, 2003). IEEE Computer Society, Los Alamitos, CA, 59–67.

[9] Camerer, C.F. *Behavioral Game Theory: Experiments in Strategic Interaction*, Princeton University Press, Princeton, PA, 2003.

[10] Chen, Y. An Experimental Study of the Serial and Average Cost Pricing Mechanisms. *Journal of Public Economics*, vol. 87, no. 9–10 (Sep. 2003), 2305–2335.

[11] Chen, Y., and Khoroshilov, Y. Learning under Limited Information. *Games and Economic Behavior*, vol. 44, no. 1 (July 2003), 1–25.

[12] Cliff, D., and Bruten, J. *Minimal-intelligence agents for bargaining behaviors in market-based environments*. HP Labs Technical Reports HPL 97–91, Hewlett-Packard Laboratories, Bristol, UK, Aug. 1997.

[13] Christin, N., Grossklags, J., and Chuang, J. Near Rationality and Competitive Equilibria in Networked Systems. In *Proceedings of ACM SIGCOMM'04 Workshop on Practice and Theory of Incentives in Networked Systems (PINS'04)* (Portland, OR, September 3, 2004). ACM Press, New York, NY, 213–219.

[14] Das, R., Hanson, J.E., Kephart, J.O., and Tesauro, G. Agent-Human Interactions in the Continuous Double Auction. In *Proceedings of the International Joint Conference on Artificial Intelligence (IJCAI 2001)* (Seattle, WA, August 4-10, 2001). Morgan Kaufmann Publishers, San Francisco, CA, 1169–1187.

[15] Denning, P.J. Performance analysis: experimental computer science as its best. *Comm. ACM*, vol. 24, no. 11 (Nov. 1981), 725–727.

[16] Duffy, J. Agent-based models and human-subject experiments. In Judd, K.L., and Tesfatsion, L. (Eds.) *Handbook of Computational Economics, Volume 2*, Elsevier, Amsterdam, The Netherlands, 2006, 949–1011.

[17] Ferreira, P., Mindel, J., and McKnight, L. Why have bandwidth trading markets not matured? Analysis of technological and market issues. *International Journal of Technology, Policy and Management*, vol. 3, no.2 (2003), 142–160.

[18] Friedman, D., and Huberman, B. Internet Congestion: A Laboratory Experiment. In Rapoport, A., and Zwick, R. (Eds.) *Experimental Business Research, Economic and Managerial Perspectives ,Volume II*, Springer, New York, NY, 2005, 83–102.

[19] Friedman, E., and Shenker, S. *Synchronous and asynchronous learning by responsive learning automata*. Mimeo, Department of Economics, Rutgers University, 1996.

[20] Friedman, E., Shor, M., Shenker, S., and Sopher, B. An experiment on learning with limited information: nonconvergence, experimentation cascades, and the

advantage of being slow. *Games and Economic Behavior*, vol. 47, no. 2 (May 2004), 325–352.

[21] Friedman, D., and Sunder, S. *Experimental Economics: A Primer for Economists*. Cambridge University Press, Cambridge, UK, 1994.

[22] Gigerenzer, G., and Selten, R. *Bounded Rationality: The Adaptive Toolbox*. The MIT Press, Cambridge, MA.

[23] Gjerstad, S., and Dickhaut, J. Price Formation in Double Auctions. *Games and Economic Behavior*, vol. 22, no. 1 (Jan. 1998), 1–29.

[24] Glaeser, E.L., Laibson, D.I., Scheinkman, J.A., and Soutter, C.L. Measuring trust. *The Quarterly Journal of Economics*, vol. 115, no. 3 (Aug. 2000), 811–846.

[25] Gode, D.K., and Sunder, S. Allocative Efficiency of Markets with Zero-Intelligence Traders: Market as a Partial Substitute for Individual Rationality. *J. Polit. Economy*, vol. 101, no. 1 (Feb. 1993), 119–137.

[26] Good, N.S., Grossklags, J., Mulligan, D., and Konstan, J. Noticing Notice: A large-scale experiment on the timing of software license agreements. In *Proceedings of the ACM Conference on Human Factors in Computing Systems (CHI'07)* (San Jose, CA, April 28–May 3, 2007). ACM Press, New York, NY, 607–616.

[27] Grossklags, J., and Acquisti, A. When 25 cents is too much: An Experiment on Willingness-To-Sell and Willingness-To-Protect Personal Information. In *Proceedings of the Sixth Workshop on the Economics of Information Security (WEIS 2007)* (Pittsburgh, PA, June 7–8, 2007).

[28] Grossklags, J., and Schmidt, C. Software Agents and Market (In)Efficiency - A Human Trader Experiment. *IEEE Transactions on System, Man, and Cybernetics: Part C, Special Issue on Game-theoretic Analysis & Simulation of Negotiation Agents*, vol. 36, no. 1 (Jan. 2006), 56–67.

[29] Guttman, R.H., Moukas, A.G., and Maes, P. Agent-mediated Electronic Commerce: A Survey. *Knowl. Eng. Rev.*, vol. 13, no. 2 (Jul. 1998), 147–159.

[30] Guyot, P., Drogoul, A. and Honiden, S. Power and Negotiation: Lessons from Agent-Based Participatory Simulations. In *Proceedings of the Fifth International Joint Conference on Autonomous Agents and Multiagent Systems (AAMAS'06)* (Hakodate, Hokkaido, Japan, May 8–12, 2006). ACM Press, New York, NY, 27–33.

[31] He, M., Leung, H., and Jennings, N.R. A fuzzy logic based bidding strategy for autonomous agents in continuous double auctions. *IEEE Trans. Knowledge Data Eng.*, vol. 15, no. 6 (Nov. –Dec. 2003), 1345–1363.

[32] Jamal, K., and Sunder, S. Money vs. Gaming: Effects of Salient Monetary Payments in Double Oral Auctions. *Organizational Behavior and Human Decision Processes*, vol. 49 (June 1991), 151–166.

[33] Kagel, J.H., and Levin, D. Multi-Unit Demand Auctions with Synergies: Behavior in Sealed-Bid versus Ascending-Bid Uniform-Price Auctions. *Games and Economic Behavior*, vol. 53, no. 2 (Nov. 2005), 170–207.

[34] Kaskiris, C., Jain, R. Rajagopal, R., and Varaiya, P. Combinatorial Auction Bandwidth Trading: An Experimental Study. In *Developments in Experimental Economics: New Approaches to Solving Real-World Problems*, Lecture Notes in Economics and Mathematical Systems, Springer, New York, NY, 2007.

[35] Kobayashi, M., and Terano, T. Human-Agent Participation in a Business Simulator," in Terano, T., Deguchi, H. and Takadama, K. (Eds.) *Meeting the Challenge of Social Problems via Agent-Based Simulation*, Springer, Tokyo, Japan, 2003, 91–106.

[36] Kraut, R.E., Sunder, S., Telang, R., and Morris, J. Pricing Electronic Mail to Solve the Problem of Spam. *Human-Computer Interaction*, vol. 20, no. 1–2 (2005), 195–223.

[37] Kuhn, T.S. *The Structure of Scientific Revolutions*. University of Chicago Press, Chicago, IL, 1962.

[38] Lee, U., Choi, M., Cho, J., Sanadidi, M.Y., and Gerla, M. Understanding Pollution Dynamics in P2P File Sharing. In *Proceedings of the 5th International Workshop on Peer-to-Peer Systems (IPTPS'06)* (Santa Barbara, CA, February 27–28, 2006).

[39] Loder, T., van Alstyne, M., and Wash, R. An Economic Solution to Unsolicited Communications. *Advances in Economic Analysis & Policy*, vol. 6, no. 1, Article 2 (Mar. 2006).

[40] McCabe, K., Rassenti, S., and Smith, V.L. Designing auction institutions for exchange. *IIE Transactions*, vol. 31 (1999), 803–811.

[41] McDaniel, T., and Starmer, C. Experimental economics and deception: A comment. *Journal of Economic Psychology*, vol. 19, no. 3 (June 1998), 403–409.

[42] Milgrom, P. *Putting Auction Theory to Work (Churchill Lectures in Economics)*. Cambridge University Press, Cambridge, UK, 2004.

[43] Miller, R.M. *Don't let your robots grow up to be traders: Artificial Intelligence, Human Intelligence, and Asset-Market Bubbles*. Economics Working Paper No. 0306001, Economics Working Paper Archive at WUSTL, Apr. 2003.

[44] National Research Council, Committee on Academic Careers for Experimental Computer Scientists. Academic Careers for Experimental Computer Scientists and Engineers. 1994.

[45] Peterson, S.P. Forecasting Dynamics and Convergence to Market Fundamentals. Evidence from Experimental Asset Markets. *Journal of Economic Behavior & Organization*, vol. 22, no. 3 (Dec. 1993), 269–284.

[46] Porter, D. and Wessen, R. A market-based approach for manifesting shuttle secondary payloads. *Journal of Spacecraft and Rockets*, vol. 36, no. 11 (Nov. 1998), 142–147.

[47] Rapoport, A., Stein, W.E., Parco, J.E., and Seale, D.A. Equilibrium play in single-server queues with endogenously determined arrival times. *Journal of Economic Behavior & Organization*, vol. 55, no. 1 (Sep. 2004) 67–91.

[48] Ratnasamy, S., Francis, P., Handley, M., Karp, R., and Shenker, S. A Scalable Content-Addressable Network. In *Proceedings of the 2001 conference on Applications, technologies, architectures, and protocols for computer*

communication (SIGCOMM 2001) (San Diego, CA, Aug 27–31, 2001). ACM Press, New York, NY, 161–172.

[49] Rust, J., Miller, J.H., and Palmer, R. Characterizing effective trading strategies. Insights from a computerized double auction tournament. *J. Econ. Dynam. Control*, vol. 18, no. 1 (Jan. 1994) pp. 61–96.

[50] Schechter, S., Dhamija, R., Ozment, A., and Fischer, I. The Emperor's New Security Indicators. In *Proceedings of the IEEE Symposium on Security and Privacy (S&P 2007)* (Berkeley/Oakland, CA, May 20-23, 2007). IEEE Computer Society.

[51] Schosser, S., Böhm, K., Schmidt, R., and Vogt, B. Incentives engineering for structured P2P systems - a feasibility demonstration using economic experiments. In *Proceedings of the 7th ACM Conference on Electronic Commerce (EC'06)* (Ann Arbor, MI, June 11–15 2006). ACM Press, New York, NY, 280–289.

[52] Selten, R. Die Strategiemethode zur Erforschung des eingeschränkt rationalen Verhaltens im Rahmen eine Oligopolexperiments. In Sauermann, H. (Ed.) *Beiträge zur experimentellen Wirtschaftsforschung*, J.C.B. Mohr (Paul Siebeck), Tübingen, Germany, 136–168, 1967.

[53] Selten, R. A simple model of imperfect competition, where 4 are few and 6 are many. *International Journal of Game Theory*, vol. 2, no. 1 (Dec. 1973), 141–201.

[54] Selten, R., Mitzkewitz, M., and Uhlich, G.R. Duopoly Strategies Programmed by Experienced Players. *Econometrica*, vol. 65, no. 3 (May 1997), 517–555.

[55] Slonim, R., and Roth, A. Learning in High Stakes Ultimatum Games: An Experiment in the Slovak Republic. *Econometrica*, vol. 66, no. 3 (May 1998), 569–596.

[56] Smith, V.L. An Experimental Study of Competitive Market Behavior. *J. Polit. Economy*, vol. 70, no.2 (Apr. 1962), 111–137.

[57] Smith, V.L. Economics in the Laboratory. *Journal of Economic Perspectives*, vol. 8, no. 1 (Winter 1994), 113–131.

[58] Smith, V.L. Experimental Economics: Induced Value Theory. *American Economic Review*, vol. 66, no. 2, Papers and Proceedings of the Eighty-eight Annual Meeting of the American Economic Association (May 1976), 274–279.

[59] Smith, V.L., Suchanek, G.L. and Williams, A.W. Bubbles, Crashes, and Endogenous Expectations in Experimental Spot Asset Markets. *Econometrica*, vol. 56, no. 5 (Sep. 1988), 1119–1151.

[60] Smith, V.L., and Walker, J.M. Monetary Rewards and Decision Cost in Experimental Economics. *Economic Inquiry*, vol. 31, no. 2 (Apr. 1993), 245–261.

[61] Smith, V.L., and Williams, A.W. Experimental Market Economics. *Scientific American* (Dec. 1992).

[62] Spiekermann, S., Grossklags, J., and Berendt, B. E-privacy in 2nd generation E-Commerce: privacy preferences versus actual behavior. In *Proceedings of the Third ACM Conference on Electronic Commerce (ACM EC'01)* (Tampa, FL, October 14-17, 2001). ACM Press, New York, NY, 38–47.

[63] Terano, T., Shiozawa, Y., Deguchi, H. Kita, H. Matsui, H. Sato, H. Ono, I., and Nakajima, Y. U-Mart: An Artificial Market Testbed for Economics and Multiagent Systems. In Terano, T., Deguchi, H., and Takadama, K. (Eds.) *Meeting the Challenge of Social Problems via Agent-Based Simulation*, Springer, Tokyo, Japan, 2003, 53–65.

[64] van Boening, M.V., and Wilcox, N.T. Avoidable cost: Ride a Double Auction Roller Coaster. *American Economic Review*, vol. 86, no. 3 (June 1996) 461–477.

[65] Walia, V., Byde, A., and Cliff, D. Evolving Market-Design In Zero-Intelligence Trader Markets. In *Proceedings of the IEEE International Conference on E-Commerce (CEC'03)* (Newport Beach, CA, June 24–27, 2003). IEEE Computer Society, Los Alamitos, CA, 157–164.

[66] Wellman, M.P., Greenwald, A., Stone, P. and Wurman, P.R. The 2001 Trading Agent Competition. In *Proceedings of the Fourteenth Annual Conference on Innovative Applications of Artificial Intelligence (IAAI'02)* (Edmonton, Canada, July 28 – August 1 2002). AAAI Press/MIT Press, Providence, RI, 935–941.

[67] Wellman, M.P., Wurman, P.R., O'Malley, K., Bangera, R., Lin, S., Reeves, D., and Walsh, W.E. Designing the market game for a trading agent competition. *IEEE Internet Computing*, vol. 5, no. 2 (Mar. 2001), 43–51.

[68] Varian, H.R. The Demand for Bandwidth: Evidence from the INDEX Project. In Crandall, R.W., and Alleman, J.H. (Eds.) *Broadband: Should We Regulate High-Speed Internet Access?* Aei-Brookings Joint Center for Regulatory Studies, American Enterprise Institute Press, 2003, 39–56.