Job allocation in a temporary employment agency via multi-dimensional price VCG auctions using a multi agent system

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***Abstract*—We consider the problem of how a temporary employment agency allocates temporary agency workers to jobs. To address this problem we extend the Vickrey-Clarke-Groves auction to a mechanism in which agents make bids in a multi-dimensional contract space. That is agents can specify how much a work contract consisting of several components such as wage per hour, days of leave, overtime premiums and hours of work is valued. We show that the mechanism we develop satisfies Incentive Compatibility and Pareto Efficiency.**

***Index Terms*—Multi Agent System, Mechanism Design, Vickrey-Clarke-Groves Auction, Electronic Human Resource Management, Multi-dimensional Price**

I. Introduction

Consider a Temporal Employment Agency (TEA) that has a number of Temporary Agency Workers (TAWs) under work contract. We are interested in the problem as how to assign the TAWs to requests made by companies seeking to employ temporary staff. A comprehensive introduction to temporary employment and TEAs can be found in [1]. Around the globe temporary employment has become a hugely successful business model with a staggering market size of US$ 341.000.000.000 in 2007 [1, page 11, figure 3.1] with over 9.500.000 TAWs [1, page 14, table 3.3].

Before addressing the technical part of the problem we lay out the problem enabling us to later justify model assumptions.

A. Setting the Scene

We now briefly introduce the business model of a TEA. When a company C is looking to flexibly and/or temporarily increase its workforce it can either painstakingly do so itself or it can contact a TEA to avoid the lengthy and costly process of hiring new staff. The TEA in turn has a number of TAWs under work contract. When a TAW is working on a job assigned by the TEA, the TEA receives a fixed commission every month the TAW does the job, currently this amounts to up to 80% of the workers' pay including social security contributions and margin (depending on national social security laws) .

In the current business model the TEA manually assigns the TAWs to companies, which have asked the TEA to provide TAWs, in a way that is most beneficiary to the TEA. This task is labor intensive and expensive. A TAW does hence not have a direct influence on the wage earned nor on the jobs she will be doing. Coupled with a wage that is significantly lower than that of a permanent worker doing the same job, this leads to a rather low job engagement of TAWs [2]. Furthermore the violation of the longstanding principle of *same pay for same work* can lead to tensions among between permanent employees and TAWs and to tensions between TAWs and management [3], [4].

While it is certainly true that the TEA takes a considerable part of a workers wage there are advantages to work for a TEA. A TEA provides help with paperwork and some support with legal work issues. Furthermore persons who had in the past many short work contracts or have trouble writing appealing resumes benefit from working for a TEA. Also people that interview poorly but do a good job once hired can benefit from being employed by a TEA. Finally looking for jobs consumes time and energy. A TAW working for a TEA does not need to look for new jobs, hence this time and energy can be saved to be spent elsewhere.

B. Goal Statement

It has become a poorly kept secret that electronic systems and Internet technology can dramatically reduce transaction costs [5]. Indeed electronic Human Resource Management (eHRM) is quickly growing all around the world. The relative young field of empiric scientific investigations of eHRM is surveyed in [6].

In the following we develop a Multi Agent System (MAS) that helps allocating workers to jobs and which outputs contracts, satisfying several objectives.

- Bring down operating costs. Currently the matching of jobs and workers is done by hand, leading to significant costs, which are ultimately paid by the employees and the customers of the TEA.

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- Improve the job satisfaction and employee engagement. As TAWs now have some control over their work environment (i.e. who they will work for and how much they will earn).
- Creating more value for customers of the TEA. By firstly lowering transaction costs and secondly more engaged and better motivated TAWs perform better see [7].
- Finally we hope that a business model using the here developed system is perceived by stakeholders and the general public to be *fairer*. Such a view will lead to wider social acceptance and a less low social standing of temporary agency workers and reduce the stigma carried by temporary work.

Formally we design a relatively simple *strategy-proof* (Incentive Compatibility) coordination mechanism, that yields an *optimal* (Pareto Efficiency) allocation.

Results presented in [8] show that new technologies are more likely to be accepted if they are understandable to stakeholders. Auctions are deeply ingrained in human culture dating back to Babylonian times, as a negotiation mechanism they are among the simplest known to mankind. In fact, the debate is ongoing as to whether auctions are negotiations at all, due to the often-used definition that a negotiation is a dialogue between at least two partners. Internet based auctions have gained tremendous popularity in the last decade on websites such as www.ebay.com. A MAS using an auction format is hence in our view a sensible design choice.

The rest of the paper is organized as follows, Section II contains the state of the art, in Section III we develop our mechanism, then we discuss further real world applications in Section IV and conclude in Section V.

II. Literature Review and State of the Art

A *mechanism* is a protocol that takes announced preferences of a set of agents and returns an *outcome*. Mechanism Design (MD), see [9]–[13], is concerned with the design of protocols to implement an outcome with desirable properties in systems with self-interested agents that have private preferences. Lacking a conscious, these agents will misrepresent their utilities, if there is something to be gained by doing so. MD can hence be seen as game theory of order two.

One such protocol to achieve an efficient and strategy-proof allocation of resources are Vickrey auctions [14]. In a Vickrey auction every bidder submits one bid in a sealed envelope to the auction issuer. The highest bidder receives the auction item for which the *second* highest bid has to be paid. It is well known that the optimal strategy in Vickrey auctions is for everyone to bid the true private valuation for the item under the hammer.[1] Besides Incentive Compatibility Vickrey auctions satisfy Pareto Efficiency and Individual Rationality. Barrot et al. [15] recently empirically observed that Vickrey auctions are better suited for estimating realistic price demand functions than English auctions. In the late 1980's the name of *Vickrey Clarke and Groves (VCG) auctions* was coined by [16]. Such auctions [14], [17]–[19] allow the simultaneous auction of multiple items while keeping the attractive properties of Vickrey auctions.[2]

In a forward auction there are bidders bidding on an item with the aim to *buy* it. In a reverse auction there are sellers bidding with the aim to *sell*. In a reverse VCG auction there are multiple items to be sold simultaneously. Although VCG auctions do have appealing properties such a mechanism is not without drawbacks, see for instance [22]–[25]. The main other alternative to auction off multiple items at the same time are *combinatorial auctions*, see [26]–[28].

The role of emotional effects (such as reference points, framing, regret, prospect, anger) have been thoroughly investigated in negotiations in general[3], and in particular in auctions, see e.g. [29]. By now it is well known that the idealizations in game theory do not always carry over to the real world, for some of the latest results on real-world auctions see [30].

Multi-dimensional auctions, where the multi-dimensionality refers to the auction *item*, have been studied by [31], [32]. They show that if the buyers utility function on multi-dimensional items is known, then the multi-dimensional model can be mapped into a one-dimension independent private model. However their results hold for standard, one item at a time, auctions. The case of VCG auctions and their more complex payment rule have not been studied yet when bids are elements of a multi-dimensional price (mdp) space. Multi attribute auctions have become an own area of research [32]–[34]. For (reverse) multi-attribute Vickrey auctions see for instance [31], [35], [36] and for reverse multi-attribute combinatorial auctions [37], [38]. While in mdp VCG auctions the exchange of utility is conducted via a multi-dimensional process,[4] VCG auctions that do not rely on a common commodity to exchange utility (i.e. money) have been introduced in [40] under the name *Qualitative Vickrey Auction*.

Recent work on the architecture of Multi Agent Systems (MAS) for electronic job markets can be found in [41], [42]. In these systems agents negotiate on the basis of fuzzy [43] preferences. Finally we want to mention a further MAS for e-employment [44] which uses two-sided matching algorithms.

[1] Do note that the private valuation of the highest bidder is not revealed to the other bidders, nor are the unsuccessful bids revealed.

[2] It was later found [20] that the essentially same mechanism is described in [21] under the name: Generalized Vickrey Auctions.

[3] For a broad overview see the special issue on Emotions in Negotiation, *Group Decision and Negotiation*, Volume 17, Number 1, January 2008

[4] How multi-dimensional prices are (wrongly) perceived by consumer is an interesting psychological question, see [39] for some answers.

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We here present a reverse auction with mdp bids. This allows the output of work contracts containing more than one wage component, giving TAWs more freedom to chose a work contract better satisfying their needs. In the special one-dimensional case these auctions are in fact reverse VCG auctions.

III. A Multi-dimensional Price VCG Auction

Let $M_1, \dots, M_z$ be the wage components (e.g. pay per hour, sick pay, bonuses, period of notice, training measures) and put $\mathcal{M} := M_1 \times \dots \times M_z$. The mechanism begins with the TEA announcing the set of jobs $\{j_1, \dots, j_g\} =: J$ to be allocated to the currently idle workers $\{a_1, \dots, a_n\} =: A$. Every such worker is represented by a computer agent ag_i. Furthermore the TEA openly communicates a utility function $U_{TEA} : \mathcal{M} \to \mathbb{R}$ detailing her preferences on different contracts to every ag_i. To ease the notation we make the following

Definition 1: For natural numbers $1 \leq l \leq n$ put $[n] := \{1, \dots, n\}$ and $[n_l] := [n] \setminus \{l\}$. Let $\mathcal{P}$ denote the power set. A set of jobs $X \in \mathcal{P}(J)$ is *feasible* for i, if and only if a_i is sufficiently qualified to do every job $x \in X$ and the combined working hours do not exceed the legal maximum.[5] A function $f : A \to \mathcal{P}(J)$ is *feasible*, if and only if $f(a_i) \in \mathcal{P}(J)$ is feasible for all $i \in [n]$.

From now on we implicitly assume that every allocation f of workers to jobs is feasible. In more detail: for later use we make the convention that for every $l \in [n]$ there is at least one feasible allocation $f_l : A \setminus \{a_l\} \to \mathcal{P}(J)$. We furthermore assume that *bidders do not collude* and that workers are *exchangeable*, i.e. the TEA is indifferent as to which worker does a certain job, we will later drop the latter assumption.

The problem now posed to an agent ag_l is how to bid, given the preferences of a_l in the mechanism described below. In the first step the agent has to learn the worker's preferences. The techniques of preference elicitation [45] and [27, Chapter 10] are outside the scope of this paper. An overview of preference elicitation methods for fuzzy [43] multi attribute problems can be found in [46]. For the *meaning* of fuzzy numbers see the enlightening [47].

We assume that every agent ag_l elicits an *additive* utility function $u_l : \mathcal{P}(J) \times \mathcal{M} \to \mathbb{R}$ with $u_l(X, m) = U_l(X) + r_l(m)$ where $U_l : \mathcal{P}(J) \to \mathbb{R}$ and $r_l : \mathcal{M} \to \mathbb{R}$.[6] [7] The assumption that the bidders utility functions are quasi-linear is standard for Vickrey auctions, observe that the notion of an additive utility function generalizes the notion of quasi-linear utility functions to multi-dimensional prices.

Having elicited preferences every agent securely transmits a secret *bid* for every set of feasible jobs. That is n partial function $R_l : \mathcal{P}(J) \to \mathcal{M}$ are communicated in *sealed envelopes* to the TEA.

The TEA now finds the feasible function $f^* : A \to \mathcal{P}(J)$ which maximizes

$$\sum_{i \in [n]} U_{TEA}(R_i(f^*(a_i))) \tag{1}$$

under the constraints that

$$\text{for all } 1 \leq i < k \leq n \text{ we have } f^*(a_i) \cap f^*(a_k) = \emptyset \tag{2}$$

and

$$\bigcup_{1 \leq l \leq n} f^*(a_l) = J. \tag{3}$$

The first constraint implies that there is at most one worker working on a job and the second that every job will be done by someone. So overall (3) expresses that for every job there is one and only one worker doing it. The second constraint is nonstandard in Vickrey auctions. Here we justify it by the TEAs' wish to satisfy its' customers and the standing implicit assumption that a TAW not being idle is good for the TEA. All allocations are from now on tacitly assumed to satisfy the constraints on top of being feasible.

Worker a_l is then assigned jobs $f^*(a_l)$ for which she receives a wage, that is an element of $\mathcal{M}$. For $\lambda \in \mathbb{R}$ let $U^\lambda_{TEA} := \{M \in \mathcal{M} | U_{TEA}(M) = \lambda\}$, U^λ_{TEA} is the level set of U_{TEA} at level λ. Now define $\langle \lambda \rangle_l$ as the $M \in U^\lambda_{TEA}$ such that $r_l(M)$ is maximal. Furthermore for $M \in \mathcal{M}$, $r_l : \mathcal{M} \to \mathbb{R}$ and $\mu \in \mathbb{R}$ we let $\mu + M$ be an $S \in \mathcal{M}$ such that $\mu + r_l(M) = r_l(S)$, observe that this $S \in \mathcal{M}$ is not uniquely defined. Eventually let

$$\begin{aligned} Wage(a_l) := & \sum_{i \in [n_l]} U_{TEA}(R_i(f^*(a_i))) \\ & + \langle - \sum_{i \in [n_l]} U_{TEA}(R_i(f_l(a_i))) \rangle_l. \end{aligned} \tag{4}$$

This formula generalizes the standard payment rule of Vickrey auctions, also known as *Vickrey discount*. $Wage(a_l)$ takes into account losses of utility the presence of a_l inflicts upon the other bidders.

Our above conventions guarantee the existence of the above allocations f^* and of the f_l.

Note that the last sum cannot be influenced by the bids of agent ag_l. So any rational bidding strategy ag_l follows does not depend on it, and we hence denote it by K_l. Although this term certainly affects the wage a_l receives, we can assume it to be irrelevant to the bids made by ag_l. Observe that ag_l wants to maximize the overall utility

[5] In practice time needed for commuting between different jobs can be taken into account as well.

[6] Vickrey auctions using more general preferences than quasi-linear utility functions have also been studied in [48], [49].

[7] The commensurateness problem of how much wage and job satisfaction correlate in the real world is investigated by organizational behavior studies [50], [51].

received, i.e. the sum of the utility of working a set of jobs and the utility gained from the wage. This sum equals

$$U_l(f^*(a_l)) + \sum_{i\in[n_l]} U_{TEA}(R_i(f^*(a_i))) + r_l(K_l). \qquad (5)$$

Recall from (1) that f^* maximizes $\sum_{i\in[n]} U_{TEA}(R_i(f^*(a_i)))$. Now assume that $U_l = U_{TEA} \circ R_l$. Then (1) and (5) differ only by a term we consider to be constant (namely $r_l(K_l)$). And since f^* was chosen to maximize (1) it also maximizes (5).
It is hence an optimal strategy for agent ag_l to bid such that $U_l = U_{TEA} \circ R_l$. This means that is ideal for ag_l to express the perceived worth of a job truthfully; via U_{TEA}.

Theorem 1: The above auction satisfies Incentive Compatibility and Pareto Efficiency.

Proof: We have just seen the first half of the above statement, for the second part observe that in case every agent follows the optimal strategy of bidding its' true value, i.e. $u_i = U_{TEA} \circ R_i$ for all $i \in [n]$, then

$$\sum_{i\in[n]} U_{TEA}(R_i(f^*(a_i))) = \sum_{i\in[n]} u_i(f^*(a_i)). \qquad (6)$$

Recall that f^* is the function, that maximizes the left hand side for fixed U_{TEA} and fixed R_i. Since we assumed that $U_{TEA} \circ R_i = u_i$, f^* also maximizes the right hand side.

Overall, if all bids reflect true values, then the allocation f^* maximizes the sum of utilities of all participants, the constants K_l are again inconsequential. Hence it is not possible to assigning jobs in a different way that improves the utility of at least one TAW while not decreasing the utility of any TAW. ■
Do note that in (4) some information about the level sets of the utility function r_l was indirectly used. In the later calculations however, only the utility a_l obtains from $Wage(a_l)$ matters. So Incentive Compatibility and Pareto Efficiency can be shown without any knowledge of the r_l. To actually calculate $Wage(a_l)$ as an element of $\mathcal{M}$ certain information about r_l is required.

Such effects should not come as a surprise, as in one-dimensional price VCG auctions with quasi-linear utility functions, the utility functions $r_l : \mathcal{M} \to \mathbb{R}$ are actually all simply the identity function $id : \mathbb{R} \to \mathbb{R}$. Furthermore in these auctions it is a standing assumption that all TAW have such appreciation of the monetary scale is public knowledge.

Example 1: Let $A = \{a_1, a_2, a_3\}$ and suppose that there is only one job to be allocated. Denote by Bid_i the worth of the bid of a_i (i.e. $Bid_i = U_{TEA}(R_i(Job))$) with $Bid_1 = -4, Bid_2 = -4.2$ and $Bid_3 = -5$ and suppose that the bids for the empty set of jobs are zero. Furthermore we assume that these bids reflect true valuations.

By complete inspection the job is allocated to a_1. In $wage(a_1)$ the first term in (4) is zero and the second term only depends on Bid_2. Hence a_1 can chose a contract in $-U_{TEA}^{-4.2}$ that suits her best. Do note that due to the fact that U_{TEA}^{λ} is a level set the TEA does not mind which contract in this set a_1 choses to work for.

For $i \in \{2, 3\}$ we have that for a_i there is no job, however there is some "compensation"; $wage(a_i) = -4 + \langle -U_{TEA}^{-4} \rangle_i$. Observe that if the level sets of r_i and the TEA agree (modulo $\pm$), then idle workers do not "get paid". Note that if ag_2 bids -3 to secure the job, the overall utility for a_2 is $-4.2 + \langle -U_{TEA}^{-4} \rangle_2$, which is less than had ag_2 bid the true valuation of the job and a_2 subsequently remained idle.

A. Extensions

Recall that we assumed that the same contract for different employees is of the same utility to the TEA (exchangeability assumption). We can change this by considering utility functions U_{TEA}^i with $i \in [n]$ that assign every a_i and every contract in $\mathcal{M}$ a utility. For this straight-forward generalization the above results do hold as well which can be proved by simply substituting $U_{TEA}^i \circ R_i$ for $U_{TEA} \circ R_i$ in the above. Such an employee dependent utility function enables the TEA for instance to express the preference invest in training in younger TAWs than in TAWs which will retire soon and that a TAW is of higher utility because her future earning potential, once the temporary assignment has concluded, is greater.

Now consider two close friends that work as constructors for the same TEA. Clearly they would welcome the option to express the wish of working on the same site. To allow this bids are placed on allocations of jobs instead of jobs alone. That is every ag_i reports a bid to the TEA for every feasible allocation of jobs satisfying the constraints. Extending the framework to allow such externalities [52] increases the notational complexity, however the above proofs remain mutatis mutandis the same.

Such a procedure is in praxis highly impracticable due to great number of bids every ag_i has to make. It is more sensible to assume that bids of the ag_i only depend on which job(s) a_i will be doing and only in a few selected circumstances will it matter how the other jobs are allocated.

Finally we want to state that it is possible to take externalities and employee dependent utility functions into account at the same time and prove a version of Theorem 1. The notation however becomes barely readable and we will refrain here from doing so.

B. Real World Considerations

An *auction issuer*, see [53], can be used to safeguard that the allocation function f^* is computed properly and the TEA does not obtain private information its' employees are not comfortable to share.

So far we have studied rationality aspects of the behavior of the ag_i. We noted that bidding *true preferences* maximizes utility. The question naturally arises: "Is it possible for the TEA to gain an advantage by not truthfully reporting U_{TEA}?" The answer we want to give here is twofold. First recall that for fixed λ there was a free choice in U^{λ}_{TEA}. Since the wage is payed by the TEA dishonestly reporting the shape of the level sets U^{λ}_{TEA} does in general not yield a benefit to the TEA; see also Example 1.

Now take a fixed level set U^{λ}_{TEA} and consider the unique contract with all components equal to the legal minimum, if there is such a minimum, and zero if such minimum does not exist with the exception of the component of wage per hour. This yields a simple parameterization of the level sets and how much the TEA reports that they are worth. If a worker feels that the TEA does not offer fair value and that he can get a better job elsewhere, he is free to give due notice and look for work elsewhere.

Note that if all agents bid value zero for the empty set of jobs and if $f^*(a_l) = \emptyset$, then

$$\sum_{i\in[n_l]} U_{TEA}(R_i(f^*(a_i))) = \sum_{i\in[n_l]} U_{TEA}(R_i(f_l(a_i))). \quad (7)$$

Hence, in case of $r_l = -U_{TEA}$ and the above assumption, idle workers receive a wage that is of utility zero to them and to the TEA. It is of course possible to simply *impose* the standard *normality condition* here. However such an assumption restricts, in our view unnecessarily so, the agents' capabilities to do the workers bidding.

Computational considerations: Do note that it is in general quite complex to compute the allocation f that maximizes the distributed utility. This is due to the large number of possible allocations, i.e. the number of complete matchings in a bipartite graph. However observe that the problem of calculating the allocation f simplifies significantly in case that the graph consists of disjoint connected components. It is well known that finding connected components in such a graph can be done in linear time. If in practice after the decomposition into connected components the time required to compute the allocation f is still long, approximation algorithms [28], [54] can be used to calculate an allocation that is close to the efficient allocation.

IV. Discussions

Before concluding we briefly discuss the above mechanism in different settings.

The above findings are interesting in a general *social choice* setting, dealing with the problem of how to allocate limited resources among different individuals. There the focus is on the complex question as to how to increase public welfare.

Consider a *law firm or a business consultancy* where the partners have recently acquired a new client. Due to their busy schedules the new client will be handed over to an employee. The above mechanism can then be used to determine who will work with the new client and to calculate the fee.

Last but certainly not least we want to mention *cloud and grid computing* as a possible areas of application. The jobs to be allocated here are no jobs in the physical world but electronic computing services or tasks.

An experimental evaluation via computer simulation is not given due to space constraints.

V. Conclusions and Future Work

We have shown how a MAS based on reverse multi-dimensional price VCG auctions can be applied to allocate jobs to the employees of a TEA. Satisfying Pareto Efficiency and Incentive Compatibility such auctions satisfy minimal requirements any such allocation mechanism should have. We have also demonstrated that not only benefit the TAWs from revealing their true preferences, there are also strong incentives for the TEA to be honest.

Any real-world implementation of a MAS might not be accepted by its human users due to a too high complexity. We were here aiming to design a MAS capable of outputting multi-attribute work contracts generated by some negotiation protocol. To keep the users input as simple as possible we opted for an auction system that only requires evaluations of jobs and contracts as inputs but does not need any negotiation parameters as input. That is we only require the minimum amount of information to make any such system operate properly.

Designing a Pareto Efficient and Incentive Compatible mechanism with or without multi-dimensional prices that requires no knowledge of the utility functions r_l is in our view an interesting open challenge.

Finally we want to mention positive economical effects an implementation of our MAS produces. Reducing transaction costs leads to a lowering of labor costs resulting in an increase in employment, consumption and tax revenues.

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References

[1] International Labor Organization - WPEAC. (2009) Private employment agencies, temporary agency workers and their contribution to the labour market. issues paper for discussion at the workshop. International Labor Organization. [Online]. Available: http://www.ilo.org/public/english/dialogue/sector/techmeet/wpeac09

[2] H. Lengfeld and T.-M. Kleiner, "Flexible Beschäftigung und soziale Ungleichheit: Eine Synthese des Stands der Forschung," *Arbeit*, vol. 18, no. 1, pp. 46–62, 2009.

[3] J. S. Adams, "Toward an understanding of inequity," *J Abnorm Soc Psychol*, vol. 67, no. 5, pp. 422–436, 1963.

[4] ——, *Inequity in social exchange*. New York, USA: Academic Press, 1965, vol. 2, pp. 267–299.

[5] T. W. Malone, J. Yates, and R. I. Benjamin, "Electronic markets and electronic hierarchies," *Commun. ACM*, vol. 30, no. 6, pp. 484–497, 1987.

[6] S. Strohmeier, "Research in e-HRM: Review and implications," *Hum Resour Manage R*, vol. 17, no. 1, pp. 19–37, 2007.

[7] J. A. Gruman and A. M. Saks, "Performance management and employee engagement," *Hum Resour Manage R*, vol. 21, no. 2, pp. 123–136, 2011.

[8] B. Dineen, R. Noe, and C. Wang, "Perceived fairness of web-based applicant screening procedures: Weighing the rules of justice and the role of individual differences," *Hum Resour Manage*, vol. 43, no. 2-3, pp. 127–145, 2004.

[9] R. K. Dash, N. R. Jennings, and D. C. Parkes, "Computational-mechanism design: A call to arms," vol. 18, pp. 40–47, 2003.

[10] M. O. Jackson, "Mechanism theory," in *The Encyclopedia of Life Support Systems*. EOLSS Publishers, 2000.

[11] P. Klemperer, "What really matters in auction design," *The Journal of Economic Perspectives*, vol. 16, no. 1, pp. 169–189, 2002.

[12] P. R. Milgrom and R. J. Weber, "A theory of auctions and competitive bidding," *Econometrica: Journal of the Econometric Society*, vol. 50, no. 5, pp. 1089–1122, 1982.

[13] R. B. Myerson, "Incentive-compatibility and the bargaining problem." *Econometrica*, vol. 47, no. 1, pp. 61–73, 1979.

[14] W. Vickrey, "Counterspeculation, auctions, and competitive sealed tenders," *The Journal of Finance*, vol. 16, no. 1, pp. 8–37, 1961.

[15] C. Barrot, S. Albers, B. Skiera, and B. Schäfers, "Vickrey vs. eBay: Why Second-Price Sealed-Bid Auctions Lead to More Realistic Price-Demand Functions," *International Journal of Electronic Commerce*, vol. 14, no. 4, pp. 7–38, 2010.

[16] L. Makowski and J. Ostroy, "Vickrey-clarke-groves mechanisms and perfect competition," *J Econ Theory*, vol. 42, no. 2, pp. 244–261, 1987.

[17] E. H. Clarke, "Multipart pricing of public goods," *Public Choice*, vol. 11, no. 1, pp. 17–33, 1971.

[18] T. Groves, "Incentives in teams," *Econometrica: Journal of the Econometric Society*, vol. 41, no. 4, pp. 617–631, 1973.

[19] V. Krishna, *Auction Theory*. Academic Press, 2002.

[20] K. Suzuki and M. Yokoo, "Secure generalized Vickrey auction using homomorphic encryption," in *Financial Cryptography, Proceedings*, ser. LNCS, Wright, RN, Ed. Springer, Berlin, 2003, vol. 2742, pp. 239–249.

[21] H. R. Varian, "Economic mechanism design for computerized agents," in *Proceedings of the 1st conference on USENIX Workshop on Electronic Commerce - Volume 1*. Berkeley, USA: USENIX Association, 1995.

[22] M. Jackson, "Non-existence of equilibrium in vickrey, second-price, and english auctions," *Review of Economic Design*, vol. 13, pp. 137–145, 2009.

[23] P. Milgrom, *Putting auction theory to work*. Cambridge University Press, 2004.

[24] M. Rothkopf, T. Teisberg, and E. Kahn, "Why are Vickrey auctions rare?" *Journal of Political Economy*, vol. 98, no. 1, pp. 94–109, 1990.

[25] T. Sandholm, "Issues in computational vickrey auctions," *Int. J. Electron. Commerce*, vol. 4, pp. 107–129, March 2000.

[26] J. Abrache, T. G. Crainic, M. Gendreau, and M. Rekik, "Combinatorial auctions," *Annals of OR*, vol. 153, no. 1, pp. 131–164, 2007.

[27] P. Cramton, Y. Shoham, and R. Steinberg, *Combinatorial auctions*. MIT Press, 2006.

[28] T. Sandholm, "Algorithm for optimal winner determination in combinatorial auctions," *Artif Intell*, vol. 135, no. 1-2, pp. 1–54, 2002.

[29] P. Astor, M. T. P. Adam, C. Jähnig, and S. Seifert, "Measuring Regret: Emotional Aspects of Auction Design," in *Proceedings of the 19th European Conference on Information Systems (ECIS)*, Helsinki, Finland, 2011.

[30] A. Lange and A. Ratan, "Multi-dimensional reference-dependent preferences in sealed-bid auctions - how (most) laboratory experiments differ from the field," *Games Econ Behav*, vol. 68, no. 2, pp. 634–645, 2010.

[31] Y. Che, "Design competition through multidimensional auctions," *Rand Journal of Economics*, vol. 24, no. 4, pp. 668–680, 1993.

[32] S. E. Thiel, "Multidimensional auctions," *Econ Lett*, vol. 28, no. 1, pp. 37–40, 1988.

[33] F. Branco, "The design of multidimensional auctions," *Rand J Econ*, vol. 28, no. 1, pp. 63–81, 1997.

[34] J. E. Teich, H. Wallenius, J. Wallenius, and A. Zaitsev, "A multi-attribute e-auction mechanism for procurement: Theoretical foundations," *Eur J Oper Res*, vol. 175, no. 1, pp. 90–100, 2006.

[35] M. Bichler, "An experimental analysis of multi-attribute auctions," *Decis Support Syst*, vol. 29, no. 3, pp. 249–268, 2000.

[36] P. Milgrom. (2000, October) An economist's view on the b-to-b marketplace: An executive white paper. Perfect Commerce.

[37] T. Suyama and M. Yokoo, "Strategy/false-name proof protocols for combinatorial multi-attribute procurement auction," *Auton Agent Multi Agent Syst*, vol. 11, no. 1, pp. 7–21, 2005.

[38] K. Suzuki and M. Yokoo, "Secure multi-attribute procurement auction," in *Information Security Applications*, ser. LNCS, Song, J and Kwon, T and Yung, M, Ed. Springer, Berlin, 2006, vol. 3786, pp. 306–317.

[39] H. Estelami, "Consumer perceptions of multi-dimensional prices," *Adv Consum Res*, vol. 24, pp. 392–399, 1997.

[40] P. Harrenstein, M. de Weerdt, and V. Conitzer, "A qualitative vickrey auction," in *ACM Conference on Electronic Commerce*, J. Chuang, L. Fortnow, and P. Pu, Eds. ACM, 2009, pp. 197–206.

[41] K. Kurbel and I. Loutchko, "A model for multi-lateral negotiations on an agent-based job marketplace," *Electronic Commerce Research and Applications*, vol. 4, no. 3, pp. 187–203, 2005.

[42] F. Teuteberg and I. Loutchko, *FuzzyMan: An Agent-based E-Marketplace with a Voice and Mobile User Interface*, ser. Whitestein Series in Software Agent Technologies. Birkhäuser, 2005, ch. 5, pp. 281–306.

[43] L. A. Zadeh, "Fuzzy sets," *Information and control*, vol. 8, no. 3, pp. 338–353, 1965.

[44] W. Gates and M. Nissen, "Designing agent-based electronic employment markets," *Electronic Commerce Research*, vol. 1, no. 3, pp. 239–263, 2001.

[45] L. J. Savage, "Elicitation of personal probabilities and expectations," *J Am Stat Assoc*, vol. 66, no. 336, pp. 783–801, 1971.

[46] R. A. Ribeiro, "Fuzzy multiple attribute decision making: A review and new preference elicitation techniques," *Fuzzy Set Syst*, vol. 78, no. 2, pp. 155–181, MAR 11 1996.

[47] D. Dubois and H. Prade, "The three semantics of fuzzy sets," *Fuzzy Set Syst*, vol. 90, no. 2, pp. 141 – 150, 1997.

[48] H. Saitoh and S. Serizawa, "Vickrey allocation rule with income effect," *Economic Theory*, vol. 35, pp. 391–401, 2008.

[49] T. Sakai, "Second price auctions on general preference domains: two characterizations," *Economic Theory*, vol. 37, pp. 347–356, 2008.

[50] T. A. Judge, D. Heller, and M. K. Mount, "Five-factor model of personality and job satisfaction: A meta-analysis," *J Appl Psychol*, vol. 87, no. 3, pp. 530–541, 2002.

[51] T. A. Judge, R. F. Piccolo, N. P. Podsakoff, J. C. Shaw, and B. L. Rich, "The relationship between pay and job satisfaction: A meta-analysis of the literature," *J Vocat Behav*, vol. 77, no. 2, pp. 157–167, 2010.

[52] P. Jehiel, B. Moldovanu, and E. Stacchetti, "How (not) to sell nuclear weapons," *American Economic Review*, vol. 86, no. 4, pp. 814–829, 1996.

[53] M. Naor, B. Pinkas, and R. Sumner, "Privacy preserving auctions and mechanism design," in *Proceedings of the 1st ACM conference on Electronic commerce*, ser. EC '99. New York, USA: ACM, 1999, pp. 129–139.

[54] N. Nisan and A. Ronen, "Computationally feasible VCG mechanisms," *J Artif Intell Res*, vol. 29, no. 1, pp. 19–47, 2007.