Abstracts

Competition in Ride-Hailing Markets

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One of the salient and understudied features of ride-hailing markets is that riders and drivers can move between platforms with relatively low friction or have a presence on several applications at the same time. This feature of the market has created an intense competition among platforms. The goal of this paper is to understand the dynamics and outcome of this competition. We aim to answer the following questions: What is the impact of platform competition on prices as well as the overall throughput of the market? Could competition lead to a "tragedy of the commons" and market failure as the platforms compete over the shared resource of open cars?

To address these questions, building on the market dynamics framework developed in [1] for a single platform, we propose and study a game-theoretic model in which two ride-hailing platforms compete for market share via pricing. Riders and drivers seek to maximize their own utilities and can choose to be present on only a single platform or participate in both platforms simultaneously. We see that at any equilibrium, all users will patronize both platforms which must offer equal prices; an equilibrium that results in a potential market failure always exists, but we show surprisingly that under many realistic settings, other more promising equilibria also exist.

This result is additionally supported by numerical analysis, using parameters estimated from Uber data to define the demand model, and simulations. We observe that if riders are not very sensitive to waiting times, the loss of efficiency due to competition could be small, corresponding to the second equilibrium outcome of the above theorem.

Reference

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The full paper can be found here: http://ssrn.com/abstract=3461119.

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Persuading Risk-Conscious Agents: A Geometric Approach

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Abstract. Motivated by practical concerns in applying information design to markets and service systems, we consider a persuasion problem between a sender and a receiver where the receiver may not be an expected utility maximizer. In particular, the receiver's utility may be non-linear in her belief; we deem such receivers as *risk-conscious*. Such utility models arise, for example, when the receiver exhibits sensitivity to the variability and the risk in the payoff on choosing an action (e.g., waiting time for a service). In the presence of such non-linearity, the standard approach of using revelation-principle style arguments fails to characterize the set of signals needed in the optimal signaling scheme. Our main contribution is to provide a theoretical framework, using results from convex analysis, to overcome this technical challenge. In particular, in general persuasion settings with risk-conscious agents, we prove that the sender's problem can be reduced to a convex optimization program. Furthermore, using this characterization, we obtain a bound on the number of signals needed in the optimal signaling scheme.

We apply our methods to study a specific setting, namely *binary persuasion*, where the receiver has two possible actions (0 and 1), and the sender always prefers the receiver taking action 1. Under a mild convexity assumption on the receiver's utility and using a geometric approach, we show that the convex program can be further reduced to a linear program. Furthermore, this linear program yields a canonical construction of the set of signals needed in an optimal signaling mechanism. In particular, this canonical set of signals only involves signals that fully reveal the state and signals that induce uncertainty between two states. We illustrate our results in the setting of signaling wait time information in an unobservable queue with customers whose utilities depend on the variance of their waiting times.

Keywords: Bayesian persuasion · Non-expected-utility-maximizers · Revelation principle

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Scrip Systems with Minimal Availability

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Abstract. In economies without monetary transfers, scrip systems serve an alternative to sustain cooperation, improve efficiency and mitigate free riding. This paper considers a marketplace, in which at each time period, one agent requests a service, one agent provides the service, and a unit of artificial currency is used to pay for service provision. We ask whether agents can sustain cooperation when the market is thin, in the sense that only few agents are available to provide the requested service. To study this problem, we analyze the stability of the scrip distribution assuming that among the available agents, the one with the minimum amount of scrips is selected to provide service. When exactly one random agent is available to provide service, the scrip distribution is unstable, since the number of scrips each agent has behaves like a simple random walk in one dimension. However, already when just two random agents are available to provide service, the scrip distribution is stable, in the sense that agents do not deviate much from their initial endowment, with high probability. This suggests that even with minimal liquidity in the market, cooperation can be sustained by balancing service provisions among agents. We further explore cases, in which agents request and become available to provide service at different rates, and generalize our positive results to the case, in which the request and availability rates of each agent are equal. Our theory builds on the literature on the power of two choices paradigm and load balancing problems. Finally, our results suggest that scrip systems can lead to efficient outcomes in kidney exchange platforms by sustaining cooperation between hospitals.

Keywords: Scrip systems · The power of two choices · Kidney exchange

A full draft of the paper is available at https://web.stanford.edu/iashlagi/papers/scrips.pdf

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The Capacity Constrained Facility Location Problem

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Abstract. We initiate the study of the capacity constrained facility location problem from a mechanism design perspective. In the capacity constrained setting, the facility can serve only a subset of the population, assumed to be the k-closest with respect to agents' true locations (this can be justified as the essentially unique equilibrium outcome of a first-come-first-serve game induced by the facility location). The main result is a complete characterization of dominant-strategy incentive compatible (DIC) mechanisms via the family of generalized median mechanisms (GMMs). Thus, the framework we introduce surprisingly provides a new characterization of GMMs, and is responsive to gaps in the current social choice literature highlighted by Border and Jordan [1983] and Barbarà, Massó and Serizawa [1998]. We also provide algorithmic results and study the performance of DIC mechanisms in optimizing welfare. Adopting a worst-case approximation measure, we attain tight lower bounds on the approximation ratio of any DIC mechanism. Interestingly, the standard median mechanism achieves the optimal approximation ratio for smaller capacity settings.

ArXiv link: https://arxiv.org/abs/1806.00960.

Keywords: Facility location · Mechanism design without money · Capacity · Approximation

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The Price of Anarchy in Routing Games as a Function of the Demand

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Most of the literature concerning the price of anarchy (PoA) has focused on the search of tight worst case bounds for specific classes of games, such as congestion games and, in particular, routing games. Some papers have studied the PoA as a function of some parameter of the model, such as the traffic demand in routing games, and have provided asymptotic results in light or heavy traffic. Other studies have empirically shown that in real networks, for intermediate levels of traffic the PoA oscillates and exhibits some kinks at specific values of the demand, often without reaching the worst case bounds.

The shape and number of these oscillations is the object of this paper, where we provide theoretical results for the behavior of the PoA. We first present some results for general nonlinear costs, and then we focus on affine cost functions. We establish some smoothness properties of Wardrop equilibria and social optima. Under mild assumptions, we show that the price of anarchy is a smooth function of the traffic inflow, except at values of the demand where the set of paths used in equilibrium changes. We call these values *break points*. We then turn our attention to a class of cost functions that are heavily used in applications, namely, the ones proposed by the Bureau of Public Roads, and we show that for these costs we have a scaling law between the equilibrium and optimum flows which induces a similar scaling for the break points. Moreover, for affine cost functions we show that the number of break points is finite for any given network, and we present an example showing that this number can be exponential in the number of paths.

The relevance of break points is due to the fact that between break points the PoA is either monotone or it has a unique minimum, therefore, the PoA can have a local maximum only at a break point. The main fact that supports these results is that, with affine costs, if an equilibrium uses a certain set of paths at two different demand levels, then it uses the same set of paths at all intermediate demands. Finally, we show that this does not hold for less regular cost functions.

The details of the proofs and the relevant references can be found in [1].

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The Value of Personalized Pricing

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Abstract. Increased availability of high-quality customer information has fueled interest in personalized pricing strategies, i.e., strategies that predict an individual customer's valuation for a product and then offer a customized price tailored to that customer. While the appeal of personalized pricing is clear, it may also incur large costs in the form of market research, investment in information technology and analytics expertise, and branding risks. In light of these trade-offs, our work studies the value of personalized pricing strategies over a simple single price strategies.

We first provide tight, closed-form upper and lower bounds on the ratio between the profits of an idealized personalized pricing strategy and a single price strategy. Our upper bounds depend on simple statistics of the valuation distribution and shed light on the types of markets for which personalized pricing has the most potential. Our lower bounds depend on simple statistics as well as a unimodal assumption and shed light on which markets are ill served by a fixed price. Second, we demonstrate how to obtain bounds that depend on arbitrary moments of the valuation distribution via infinite dimensional linear programming duality. Finally, we show how to transform our upper and lower bounds on idealized personalized pricing strategies to stronger bounds on feature based personalized pricing strategies that better model current industry practices.

Keywords: Price discrimination · Personalization · Market segmentation

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Sophisticated Attacks on Decoy Ballots: A Devil's Menu

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Abstract. Voting systems based on decoy ballots aim at preventing real ballots from being bought. Decoy ballots do not count in election outcomes, but are indistinguishable from real ballots. We introduce a "Devil's Menu" consisting of several price offers and allocation rules, which can be used by a malevolent third party—called the adversary—to curb the protection offered by decoy ballots. In equilibrium, the adversary can buy the real ballots of any strict subset of voting districts at a price corresponding to the willingness to sell them. By contrast, the voters holding decoy ballots are trapped into selling them at a low or negligible price. Decoy ballots may thus be ineffective against vote-buying even if the adversary's budget is limited.

Keywords: Voting · Decoy ballots · Adversary · Mechanism design · Attacks · Adverse selection

JEL Classifications: C72 · D4 · D82 · D86

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Markets Beyond Nash Welfare for Leontief Utilities

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Abstract. We study the allocation of divisible goods to competing agents via a market mechanism, focusing on agents with Leontief utilities. The majority of the economics and mechanism design literature has focused on *linear* prices, meaning that the cost of a good is proportional to the quantity purchased. Equilibria for linear prices are known to be exactly the maximum Nash welfare allocations.

Price curves allow the cost of a good to be any (increasing) function of the quantity purchased. We show that price curve equilibria are not limited to maximum Nash welfare allocations with two main results. First, we show that an allocation can be supported by strictly increasing price curves if and only if it is *group-domination-free*. A similar characterization holds for weakly increasing price curves. We use this to show that given any allocation, we can compute strictly (or weakly) increasing price curves that support it (or show that none exist) in polynomial time. These results involve a connection to the *agent-order matrix* of an allocation, which may have other applications. Second, we use duality to show that in the bandwidth allocation setting, any allocation maximizing a CES welfare function can be supported by price curves.

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Capacity and Price Competition in Markets with Congestion Effects

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We study oligopolistic competition in service markets where firms offer a service to customers. The service quality of a firm – from the perspective of a customer – depends on the level of congestion and the charged price. A firm can set a price for the service offered and additionally decides on the service capacity in order to mitigate congestion. The total profit of a firm is derived from the gained revenue minus the capacity investment cost. Firms *simultaneously* set capacities and prices in order to maximize their profit and customers *subsequently* choose the services with lowest combined cost (congestion and price). For this basic model, Johari, Weintraub and Van Roy [1] derived the first existence and uniqueness results of pure Nash equilibria (PNE) assuming mild conditions on congestion functions. Their existence proof relies on Kakutani's fixed-point theorem and a key assumption for the theorem to work is that demand for service is *elastic*, that is, there is a smooth inverse demand function determining the volume of customers given the effective customers' costs.

In this paper, we consider the case of *perfectly inelastic demand*. This scenario applies to realistic cases where customers are not willing to drop out of the market, e.g., if prices are regulated by reasonable price caps. We investigate existence, uniqueness and quality of PNE for models with inelastic demand and price caps. We show that for linear congestion cost functions, there exists a PNE. This result requires a completely new proof approach compared to previous approaches, since the best response correspondences of firms may be empty, thus standard fixed-point arguments are not directly applicable. We show that the game is C-secure (see Reny [3], and McLennan, Monteiro and Tourky [2]), which leads to the existence of PNE. We furthermore show that the PNE is unique, and that the efficiency compared to a social optimum is unbounded in general.

A full version of this paper is available at https://arxiv.org/abs/1905.05683.

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Equality of Power and Fair Public Decision-Making

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Abstract. Ronald Dworkin's *equality of resources* and the closely related concept of envy-freeness, are two of the fundamental ideas behind fair allocation of private goods. The appropriate analog to these concepts in a public decision-making environment is unclear, since all agents consume the same "bundle" of resources (though they may have different utilities for this bundle). Drawing inspiration from equality of resources and the Dworkin quote below, we propose that equality in public decision-making should allow each agent to cause equal cost to the rest of society, which we model as equal externality. We term this *equality of power*. The first challenge here is that the cost to the rest of society must be measured somehow, and it is generally impossible to elicit the scale of individual utilities (in the absence of monetary payments). Again drawing inspiration from foundational literature for private goods economies, we normalize each agent's utility so that every agent's marginal utility for additional power is the same. We show that for quadratic utilities, in the large market limit, there always exists an outcome that simultaneously satisfies equal power, equal marginal utility for additional power, and social welfare maximization with respect to the normalized utilities.

The full version of the paper can be found at: https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3420450.

"Equality of resources supposes that the resources devoted to each person's life should be equal. That goal needs a metric. The auction proposes what the envy test in fact assumes, that the true measure of the social resources devoted to the life of one person is fixed by asking how important, in fact, that resource is for others. It insists that the cost, measured in that way, figure in each person's sense of what is rightly his and in each person's judgment of what life he should lead, given that command of justice."

Ronald Dworkin, *What is Equality? Part II: Equality of Resources,* 1981

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How to Hire Secretaries with Stochastic Departures

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Abstract. We study a generalization of the secretary problem, where decisions do not have to be made immediately upon candidates' arrivals. After arriving, each candidate stays in the system for some (random) amount of time and then leaves, whereupon the algorithm has to decide irrevocably whether to select this candidate or not. The goal is to maximize the probability of selecting the best candidate overall. We assume that the arrival and waiting times are drawn from known distributions.

Our first main result is a characterization of the optimal policy for this setting. We show that when deciding whether to select a candidate it suffices to know only the time and the number of candidates that have arrived so far. Furthermore, the policy is monotone non-decreasing in the number of candidates seen so far, and, under certain natural conditions, monotone non-increasing in the time. Our second main result is proving that when the number of candidates is large, a single threshold policy is almost optimal.

Keywords: Secretary problem · Online algorithms · Threshold policy

The full paper can be found at http://arxiv.org/abs/1909.08660.

Part of this work was done while the authors were visiting the Simons Institute for the Theory of Computing.

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Almost Quasi-linear Utilities in Disguise: Positive-Representation an Extension of Roberts' Theorem

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Abstract. This work deals with implementation of social choice rules using dominant strategies for unrestricted preferences. When monetary transfers are allowed and quasi-linear utilities w.r.t. money is assumed, Vickrey-Clarke-Groves (VCG) mechanisms were shown to implement any affine-maximizer, and by the work of Roberts only affine-maximizers can be implemented whenever the type sets of the agents are rich enough.

In this work, we generalize these results and define a new class of preferences: Preferences which are *positive-represented by a quasi-linear utility*. That is, preferences which can be modeled using quasi-linear utilities on a subspace of the outcomes: outcomes with non-negative utility. We show that the characterization of VCG mechanisms as the incentive-compatible mechanisms extends naturally to this domain. We show that the original characterization of VCG mechanism is an immediate corollary of our generalized characterization. Our result follows from a simple reduction to the characterization of VCG mechanisms. Hence, we see our result more as a fuller more correct version of the VCG characterization than a new non quasi-linear domain extension.

This work also highlights a common misconception in the community attributing the VCG result to the usage of transferable utility. Our result shows that these results extend naturally to the non-transferable utility domain. That is, that the incentive-compatibility of the VCG mechanisms does not rely on money being a common denominator, but rather on the ability of the designer to fine the agents on a continuous (maybe agent-specific) scale.

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We think these two insights, considering the utility as a representation and not as the preference itself (which is common in the economic community) and considering utilities which represent the preference only for the relevant domain, would turn out to fruitful in other domains as well.

Keywords: Mechanism design · Strategy-proofness · Dominant strategy incentive compatibility · Non Quasi-linear Utilities · Positive-representation · Roberts' Theorem

Information Design in Spatial Resource Competition

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Abstract. We consider information design in spatial resource competition, motivated by ridesharing platforms sharing information with drivers about rider demand. Each of N co-located agents (drivers) decides whether to move to another location with an uncertain and possibly higher resource level (rider demand), where the utility for moving increases in the resource level and decreases in the number of other agents that move. A principal who can observe the resource level wishes to share this information in a way that ensures a welfare-maximizing number of agents move. Analyzing the principal's information design problem using the Bayesian persuasion framework, we study both private signaling mechanisms, where the principal sends personalized signals to each agent, and public signaling mechanisms, where the principal sends the same information to all agents. We show:

(1) For private signaling, computing the optimal mechanism using the standard approach leads to a linear program with 2^N variables, rendering the computation challenging. We instead describe a computationally efficient two-step approach to finding the optimal private signaling mechanism. First, we perform a change of variables to solve a linear program with $O(N^2)$ variables that provides the marginal probabilities of recommending each agent move. Second, we describe an efficient sampling procedure over sets of agents consistent with these optimal marginal probabilities; the optimal private mechanism then asks the sampled set of agents to move and the rest to stay.
(2) For public signaling, we first show the welfare-maximizing equilibrium given any common belief has a threshold structure. Using this, we show that the optimal public mechanism with respect to the sender-preferred equilibrium can be computed in polynomial time.
(3) We support our analytical results with numerical computations that show the optimal private and public signaling mechanisms achieve substantially higher social welfare when compared with no-information and full-information benchmarks.

Keywords: Bayesian persuasion · Spatial resource competition

The full paper is available at http://arxiv.org/abs/1909.12723. K. Iyer gratefully acknowledges support from the NSF under grants CMMI-1462592 and CMMI-1633920. P. Frazier gratefully acknowledges support from NSF and AFOSR.

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