One-sided Matching with Dynamic Preferences

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1. INTRODUCTION

In recent years, the problem of allocating indivisible resources to self-interested agents has generated an interesting, rich interplay at the interface of computer science, economics, and game theory. Most theoretical frameworks and empirical studies for resource allocation encompass a wide range of desirable economic properties such as efficiency, truthfulness, and fairness. In addition, a broad array of real-life allocation problems, in fact, prohibit the use of transferable currencies (such as money): allocating human organs to patients (e.g. kidney exchange), assigning campus housing or college courses to students, allocating precious medical resources to patients, assigning faculty members or legislators to committees, and allocating teaching load among faculty are real-life examples of the myriad types of application domains [Roth et al. 2004; Sönmez and Ünver 2010a; 2010b; Dickerson et al. 2012].

The absence of monetary transfers has promoted new types of markets, mainly matching and assignment markets. In the context of mechanism design, researchers have been extensively studying these problems and their game-theoretical properties [Gale and Shapley 1962; Shapley and Scarf 1974; Abdulkadiroğlu and Sönmez 1998]. Although these markets are quintessential to many realistic scenarios, a large number of economic and game-theoretical properties remain unstudied in environments where agents’ preferences are dynamically changing. The inevitable advent of online platforms and web-based applications (e.g. shift scheduling or reservation systems) has also imposed a more dynamic nature on the market design problem rather than a static one. Mainly, decisions must be made when agents’ underlying private preferences over objects evolve based on what is perceived and learned whilst interacting with the outside world. These dynamics present a few new challenges when seeking to sustain desirable decision policies in multiagent systems with self-interested agents. There has been a recent interest in dynamic allocation mechanisms that incentivize truthful behavior and fairness while assuring efficiency in terms of social optimality or revenue maximization [Parkes 2007; Cavallo 2009; Bergemann and Välimäki 2010; Athey and Segal 2013]. However, almost all of these works consider cardinal utilities with monetary transfers.

My research combines algorithmic and computational aspects of mechanism design and game theory with insights from theoretical and empirical economics. In particular, my research focuses on analyzing the game-theoretical and incentive properties of matching problems in the presence of dynamic ordinal preferences. My goal is to theoretically investigate the dynamic matching markets, along with experimental study of various matching mechanisms in dynamic environments.

2. MATCHING WITH DYNAMIC ORDINAL PREFERENCES

Inspired by the seminal random matching mechanisms for fair assignment of goods and alternatives to selfish agents (e.g. Random Serial Dictatorship due to Abdulka-
I proposed a generic sequential stochastic decision process, where each decision represents a matching from the set of alternatives to the set of agents. In static environments, the Random Serial Dictatorship mechanism (RSD) guarantees strategyproofness, fairness (in terms of equal treatment of equals), and ex post efficiency [Abdulkadiroğlu and Sönmez 1998]. The first result of this work shows that, in contrast to static settings, RSD is prone to manipulation under dynamic preferences. These findings show that an agent may strategically misreport her true idiosyncratic preference and sacrifice her immediate random assignment to alter the decision trajectory, and subsequently, benefit in the future. Nevertheless, I showed that a nicely crafted *history-dependent* matching policy, namely RSD with adjusted priorities (ARSD), guarantees the global truthfulness while sustaining the local properties of fairness and ex post efficiency in each round. The proposed strategyproof mechanism, ARSD, uses the future matching decisions to incentivize truthful behavior in the current period. Moreover, as a result of balancing the agents’ priority orderings, this elegant random mechanism provides some guarantee on the maximum ex post envy among the agents.

While matching with dynamic arrival or departure of agents has recently attracted attention (e.g. [Abdulkadiroğlu and Loerscher 2007; Kurino 2014; Ünver 2010]), none of these works consider the decision problem and strategic behavior of agents over a desired planning horizon. Hence, to the best of our knowledge, this paper is the first to examine the repeated matching problem when agents’ private underlying preferences change over time.

3. EFFICIENCY AND STRATEGYPROOFNESS IN SEQUENTIAL MATCHING POLICIES

The global strategyproofness requirement in dynamic settings is a strong requirement, which requires truthfulness given any transition of agent preferences, and for the space of all utility models consistent with agents’ preferences. In this work, I restricted attention to a special class of dynamic matching where a homogeneous set of agent are endowed with identical utility models. In particular, I studied the game-theoretic aspects of dynamic matching problems, where each agent’s best response strategy is conditioned upon the truthful revelation of all other agents [Hosseini et al. 2015b]. In fact in reality, incentive compatibility in many dynamic mechanisms only requires a weaker concept of *ex post Nash equilibrium* [Bergemann and Välimäki 2010; Cavallo 2009] as opposed to dominant strategy equilibria.

Restricting the incentive compatibility notion, I model the sequential matching problem via a Markov Decision Process (MDP), where states correspond to preference profiles of agents. The ordinal nature of preferences urges particular mapping from preferences to reward functions in the MDP model. I first show that even under the Markovian assumption, no optimal matching policy (whether deterministic or stochastic) satisfies the truthful notion of *within-period ex post incentive compatibility*. Furthermore, I investigate various game-theoretic properties of matching problems under Borda utilities. The result shows that even in this restrictive setting, the sequence of RSD-induced matching decisions are easily manipulable when there are more than 2 agents. Nonetheless, some applications do not require a full preference model, namely those where players are single-minded and are only interested in their top choice in each period, or when players have rotational preferences and lose their desires after receiving an object (e.g. book reading club). I show that these restrictions on agent
preferences give rise to a few intriguing subclasses of problems that satisfy the notion of within-period ex post incentive compatibility.

4. TRUTHFUL-IN-EXPECTATION EFFICIENT POLICIES FOR SEQUENTIAL MATCHING

The incompatibility of efficiency and strategyproofness in static matching problems [Bogomolnaia and Moulin 2001], and its counterpart in dynamic environments poses a few intriguing questions. Although I showed that a history-dependent RSD mechanism satisfies global strategyproofness for all possible transitions [Hosseini et al. 2015a], it is still unclear how much efficiency is being sacrificed. In fact, no optimal policy can even guarantee the weaker notion of within-period ex post incentive compatibility. Nonetheless, there may still exist some efficient policies in the policy space that satisfy truthfulness in expectation without ensuring the desired local properties. Thus, I am investigating the existence of truthful policies through linear programming, where the constraints of the program coincide with the constraints of within-period ex post incentive compatibility. In other words, I am looking for efficient policies wherein given truthful preferences of other agents and a common-knowledge transition kernel, each agent's best response, looking forward into the future, is to report truthfully. Certainly such efficient policies are not required to satisfy local properties of ex post efficiency and strategyproofness; that is, at some steps the policy may yield a Pareto dominated matching decision while maximizing the expected matching outcomes.

5. FUTURE DIRECTIONS

There are many compelling open problems in the area of dynamic matching without monetary transfers. To date, the literature on matching and random assignment has been mostly focused on studying the random mechanisms in the context of economics and mechanism design. Yet, similar to dynamic mechanisms that allow for monetary exchange [Parkes 2007; Cavallo 2009; Bergemann and Välimäki 2010], the advancement in computational methods of decision theory and the recent interest in game-theoretical approaches have provided a rich and vibrant framework for analyzing matching problems under various premises. One immediate future direction is to study dynamic matching models where agents are capable of learning the preferences and reporting strategies of other participating agents in the market. The design of such decision policies and the analysis of their properties is a promising future direction, both from theoretical and experimental point of view.

In static matching settings, the two influential mechanisms (namely, random serial dictatorship and probabilistic serial rule) are actively being studied and deployed in various real-world applications. However, despite a few recent efforts to characterize such random mechanisms [Bade 2013; Mennle and Seuken 2014; Aziz et al. 2014], the existence of other strategyproof or efficient mechanisms is still an open problem. It may be possible to design an efficient random mechanism that is not stochastically dominated by the probabilistic serial rule while satisfying some incentive property for a particular class of preferences. Moreover, the computational aspects of random mechanisms are yet to be fully studied.

I expect to continue my research in characterizing the theoretical foundations of matching mechanisms and investigating the evaluations of various matching properties through empirical simulations. I believe that empirical findings can motivate novel approaches to matching problems and, possibly, provide new insights into other resource allocation techniques. My research will serve to further elucidate a principled approach to decision making in dynamic models of resource allocation to fill the current gap between stochastic reasoning models and the matching theory.
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