Designing Price Incentives in a Network with Social Interactions

MSOM 2013 Extended Abstract

Introduction

The recent ubiquity of social networks allows firms to collect unprecedented volumes of data about their customers, their buying behavior, their social interaction with other customers and on the structure of the network. The challenge, which confronts every firm, from big to small, is how to process this data and turn it into actionable policies so as to increase profitability. In this paper, we focus on how a firm that is selling indivisible goods can tap into the wealth of data potentially available through social networks (such as Twitter and Facebook) and design effective pricing strategies to improve profitability.

According to a recent study, 74% of consumers rely on social networks to guide their purchase decisions (SproutSocial). It is clear that people influence each other willingness to pay for an item. For example, when an individual buys an item and posts a positive review on his Facebook page or tweets this information to his followers, he can influence his friends to also purchase the same item or service. According to other recent surveys, consumers are 71% more likely to make a purchase based on social media referrals (Hubspot) and 81% of US respondents indicated that friends’ social media posts directly influenced their purchase decision (Forbes). As a result, we believe that by tapping into the wealth of data on social interactions, we can improve pricing strategies for retailers and consequently increase profitability.

Our goal is to propose a tractable model that incorporates social interactions between agents within a network and design efficient algorithms that compute optimal price incentives for each buyer. We also show how this improves the retailer’s profitability relative to the case where the social interactions are ignored. Based on our models and algorithms, we also want to numerically understand the value of incorporating social connections, the impact of the network topology and develop some insights on pricing influencers.

Literature review

Several recent papers explicitly include the interactions among agents in social networks. These papers study social network’s effects on various marketing problems such as identifying the most influential agents [DK03], recommending the optimal pricing strategies [JH08, OC12, CLS+11] and narrowing down to the best product design [GR12]. Hartline, Mirrokni and Sundararajan focus on viral marketing strategies for revenue maximization where agents are offered the product in a sequential manner [JH08]. Candogan, Bimpikis and Ozdaglar study the optimal pricing strategies of a divisible good or service so as to maximize profitability. They propose a two-stage game model
where the seller first sets the prices whereas the agents respond by playing a one shot simultaneous game to make their purchasing decisions, assuming non-negative network externalities [OC12]. They provide efficient algorithms to compute fully discriminatory prices as well as the uniform optimal price and show that the problem is NP-hard when the monopolist is restricted to two pre-specified prices. The paper by Chen et. al. [CLS+11] focuses on the case of indivisible products and provides an efficient uniform pricing algorithm for revenue maximization under incomplete information. This algorithm unfortunately fails to generalize to the case of fully discriminatory prices which forms the benchmark for the maximum achievable profitability. Our work is in the similar light of [OC12, CLS+11] but addresses the different pricing strategies for the case of indivisible products under complete information. We develop efficient algorithms for fully discriminatory pricing as well as for uniform optimal price using a general optimization approach that can be extended to various settings. The methodology that we propose uses Linear Programming techniques and is very different from the approach adopted in [CLS+11]. Because of the modeling flexibility of our approach, we describe interesting extensions of the model and present several numerical insights about the optimal prices.

Model and assumptions

In this paper, we consider a setting where a monopolist sells an indivisible good to consumers embedded in a social network. Consumers have their own value for the item but also are influenced by their friends who own the same item. We assume a simple additive valuation model, where the total value of the item for each consumer is the sum of his own value and the values derived from the influences of his friends who own the item. We assume that the retailer has complete information about both the individual values and the influences of consumers in the network. In addition, we assume non-negative network externalities between the agents in the network. We consider a setting where the retailer first offers prices to all the consumers and then the agents respond by deciding whether or not to buy the item at the offered price so as to maximize their own payoff. We model this two stage decision making problem by a profit maximization objective for the retailer while incorporating the utility maximizing behavior of the consumers with social interactions. In this model, the second stage can be viewed as an equilibrium purchasing game played collectively by all the consumers in the network in response to the prices offered by the retailer. The two stage model is a non-convex programming problem. Our goal is to transform this model to a tractable/operational formulation and propose efficient algorithms to solve it.

Results and contributions

Our first main result is the proof of the existence of a pure strategy Nash Equilibrium for any given vector of prices. Using duality theory for the equilibrium constraints, we first reformulate the optimization problem faced by the retailer into a single non-convex continuous optimization problem. We then transform this problem into an equivalent Mixed Integer Programming (MIP) formulation that is linear but includes some binary variables. Since we are interested in solving the problem efficiently, we divide the analysis into different cases depending on the pricing policy chosen by the monopolist: discriminatory or uniform pricing. In the first case, the retailer allows fully discriminatory prices i.e., prices for the same item may differ for each agent in the network. We then show that the continuous relaxation of the MIP is tight so that one can solve the corresponding
Linear Programming (LP) relaxation and still obtain the desired optimal solution. Consequently, the problem of discriminative prices can be solved efficiently and is scalable even if the number of agents is very large since we only need to solve a continuous LP problem. In some practical situations, implementing fully discriminatory prices may be difficult and we therefore address the problem of identifying the optimal uniform price acknowledging the presence of social interactions. For this case, we first observe that the LP relaxation is no longer tight. Instead, we propose an efficient algorithm that iteratively solves the fully discriminatory price problem and computes the uniform optimal price in polynomial time with respect to the number of agents.

We also briefly discuss an interesting extension where the retailer can enforce the agents to impart their social influence by taking an action such as writing a review or endorsing the item on the social network platform. Indeed, in most previous related works consumers are assumed to always influence their peers after purchasing the item. In this paper, we propose a model where the monopolist can design incentives that guarantee the influence of the buyers on other agents, which in effect provides additional guarantees on the realized profits in practice. More precisely, the retailer proposes two different prices to each agent: full and discounted. The potential buyers can then decide whether to buy the item, but also whether to influence their friends in exchange of a certain incentive. We would like to highlight that our modeling methodology is very general and allows to incorporate different business constraints on prices from diverse practical applications. In addition, our MIP formulation can be used as an operational tool to derive the optimal prices. We are currently exploring efficient and/or approximate algorithms for this setting.

Finally, we present several computational experiments to study the effects of social interactions, network topologies and pricing strategies. First, we highlight the importance for the retailer to incorporate the network externalities relative to the case where one is ignoring these effects under different pricing strategies. Second, we show an interesting scenario where it is beneficial for the seller to earn negative profits on some influential agents in order to extract significant positive profits on others. Third, we show the impact of the network structure by comparing different topologies and their corresponding solutions for various pricing strategies. In addition, we run an experiment to study the scalability of our LP based algorithm with the number of agents. Last, we present the benefits of having a richer model that includes incentives in order to guarantee social influence between consumers.

References


