Games and Economic Behavior 102 (2017) 162–178

Contents lists available at ScienceDirect

Games and Economic Behavior

www.elsevier.com/locate/geb

Monopoly pricing and diffusion of social network goods ☆

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ARTICLE INFO

Article history:
Received 19 February 2015
Available online 9 December 2016

JEL classification:
D42
L12
L14

Keywords:
Degree distribution
Diffusion
Monopoly pricing
Social networks
Social network good

ABSTRACT

I present a model of dynamic pricing and diffusion of a network good sold by a monopolist. In the model, the network good is a *subscription social network good*. This means that in each period, each consumer has to pay a subscription price to use the good, and the utility derived from subscribing to the good increases as more of her neighboring consumers subscribe. Consumers myopically optimize their subscription decisions, and the monopolist chooses a sequence of subscription prices that maximizes his discounted sum of per-period profits. Three main results emerge. First, I characterize a unique steady state of the monopoly market. Second, I find that optimal sequences of subscription prices oscillate around the subscription price at the steady state. Third, I analyze how changes in the monopolist's discount factor and the density of the social network affect the subscription price, subscription rate, and deadweight loss at the steady state.

1. Introduction

1.1. Overview

There are many goods for which a consumer's valuation is influenced by her existing social relationships. For instance, when a consumer is thinking of joining an online communication service (e.g., Skype or WhatsApp), she considers how many of her friends and co-workers are currently subscribing to the same service. Because of this interdependency of valuations, demand for a good depends on social relationships between all consumers. Social relationships between all consumers can be represented by a *social network* that consists of consumers and a set of links between them. It then follows that a monopolistic seller would factor social network structures into his optimal marketing strategy.

In this paper, I analyze optimal dynamic pricing strategies for a *subscription social network good* sold by a monopolist. The good is a social network good in the sense that positive network effects are generated only between consumers sharing a link within a social network. Subscription means that in each period, consumers need to pay a subscription price (e.g., monthly service fees for cell phone services) to use the good.[1] For this monopoly market, I answer the following questions. What are the intertemporal tradeoffs the monopolist faces, and how does he balance them over time? To what extent, as

☆ This paper is part of my Ph.D. dissertation at Caltech. I am indebted to Leeat Yariv for her invaluable guidance and encouragement. I thank two anonymous reviewers for their insightful comments. I have also benefited from conversations with Hyoung Jun Ahn, Matthew Chao, Jaypil Choi, Federico Echenique, Rahul Deb, Matthew Elliott, Itay Fainmesser, Ben Golub, Chris Hagel, Jong-Hee Hahn, Jin Huang, Jinwook Hur, Matthew Jackson, John Ledyard, SangMok Lee, Chris Shannon, and Matthew Shum. All remaining errors are mine.

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[1] In my model, in each period, there is only one posted subscription price that applies to all the consumers.

http://dx.doi.org/10.1016/j.geb.2016.12.004
0899-8256/

a function of the underlying social network structure, does the social network good diffuse? How does the deadweight loss from monopoly depend on the social network structure?

The current monopoly market for a subscription social network good is different from other types of network good markets. First, in contrast with a network good market in which each consumer benefits from all other subscribers, a consumer benefits only from her neighboring consumers' subscription. I assume that consumers know only their own *degree*, the number of their neighboring consumers, and are uncertain about the subscription decisions of other consumers. Thus, all other things equal, a consumer's value from subscribing to the good depends on her degree. For this reason, consumer heterogeneity is summarized by the *degree distribution* of the social network. Thus, the monopolist takes the degree distribution into account when determining his optimal *pricing plan*, a sequence of subscription prices, to maximize the discounted sum of per-period profits.

Second, in contrast with a durable good market in which a consumer permanently leaves the market after her initial purchase, no consumer permanently leaves the market for a subscription good. Thus, the monopolist does not price discriminate consumers through the timing of their initial subscription decisions. Rather, his dynamic problem is how to adjust the size of positive network effects by changing subscription prices over time, as a function of the degree distribution.

To model diffusion behavior in a social network, I employ a standard *mean-field approximation* technique in the literature: each consumer myopically best responds to population behavior in the previous period. With respect to this diffusion behavior, the monopolist balances an intertemporal tradeoff in each period: maximizing the current profit versus increasing future profits by encouraging more consumers to subscribe to the good in the current period. Specifically, in period t, if the monopolist lowers the subscription price below the price that maximizes profit in period t, more consumers subscribe to the good. This will lead consumers to expect that their neighboring consumers are more likely to subscribe to the good in period $t+1$; the demand shifts up, and it provides a chance for the monopolist to obtain a higher profit in period $t+1$. The monopolist balances the above tradeoff across periods in order to maximize his discounted sum of per-period profits.

I characterize a unique steady state of the monopoly market where both the monopolist and consumers do not change their decisions. Interestingly, optimal pricing plans not staying at the steady state price level oscillate around the steady state price level. In addition to the restricted attention to myopic consumers, the oscillating pattern originates from the fact that, for example, when the size of network effects is high due to a high subscription rate in the previous period, the monopolist has an incentive to set a high subscription price in order to obtain a higher profit in that period. As a consequence, the resulting sequence of subscription rates also exhibits oscillating patterns.

The rest of my analysis focuses on properties of the unique steady state of the monopoly market.[2] First, given the steady state subscription price, the subscription rate at the steady state is highest among the subscription rates satisfying a self-fulfilling expectation of consumers's beliefs. Because of this, the steady state is robust to small perturbations in consumers' belief regarding the subscription rate. Second, I find a closed-form expression for the deadweight loss from monopoly that consists of two parts: welfare loss from excluded consumers and welfare loss from the lost network effects for all consumers. By using the expression of the deadweight loss, I prove that the deadweight loss decreases as the monopolist's discount factor increases. Third, I examine the effects of changes in the density of social networks. Due to the presence of a monopolist who balances his intertemporal tradeoff at the steady state of the market, this comparative static analysis requires the monotone likelihood ratio property of the degree distribution.

1.2. Related literature

The current paper is related to the literature on diffusion in social networks. Bass (1969) introduces a non-strategic diffusion model of product adoptions, and expresses changes of the adoption rate by using ordinary differential equations. Granovetter (1978) proposes an alternative dynamic model where in each period, each agent best responds to population behavior in the previous period. Both Bass (1969) and Granovetter (1978) do not account for the impact of social network structures on diffusion outcomes. Several recent papers highlight the impact of particular social network structures (e.g., Jackson and Rogers, 2007; Jackson and Yariv, 2007; Lopez-Pintado, 2008; Young, 2009). Although these models can be used to analyze consumers' adoption behavior, they do not introduce a firm that might influence diffusion processes in order to maximize his profit. I take the framework by Jackson and Yariv (2007) and consider a monopolist who changes subscription incentives by changing subscription prices. This leads my model to predict a unique steady state.

The current paper is also related to the growing literature on optimal marketing strategy when consumers, connected to one another in a social network, influence one another (e.g., Fainmesser and Galeotti, 2016; Campbell, 2013).[3] Fainmesser and Galeotti (2016) consider a *static* price discrimination problem rather than the dynamic setting I consider. Specifically, they consider a monopolist who knows the in-degree and out-degree distributions of the underlying social network. They show that the average and variance of the two degree distributions are sufficient statistics to characterize the optimal price

[2] Since I consider an incomplete information setting, the unique steady state can be interpreted as a perfect Bayesian equilibrium (Jackson and Yariv, 2007).

[3] In the computer science literature, several papers study the complexity of finding an optimal strategy in various settings. For example, Hartline et al. (2008) and Arthur et al. (2009) consider a setting in which a monopolist sequentially approaches consumers and offers a different price for each consumer. Since finding an optimal strategy is NP-hard, the authors of these papers propose an algorithm that generates a simple strategy that returns approximately the maximum expected revenue.