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E-commerce and traffic congestion: An economic and policy analysis

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ABSTRACT

E-commerce, due to its ability to re-direct consumers from physical stores to online, can potentially alleviate traffic congestion. In this paper, we set up a theoretic model to analyze interactions between a firm's distribution strategy and traffic congestion. In an unregulated economy, we first characterize the private firm's optimal strategy concerning e-commerce under the influence of traffic congestion. We then examine a centralized economy where the firm is publicly owned and derive the distribution strategy that maximizes social welfare. Comparing the two cases, we show that the private firm's incentives may deviate from the socially optimal decisions, which leads to inefficiency. We identify two effects, i.e., monopoly effect and congestion externality effect, which drive the private firm to deviate from the social optimum. Based on our analysis, we propose a differentiated tolls/rebates policy to achieve maximum social welfare. Under such a policy, the firm will not only adopt the socially optimal distribution strategy but offer the socially optimal quantities.

1. Introduction

In order to resolve the traffic congestion conundrum, regulators resort to various approaches to reduce demand for road capacities. Demand management mechanisms such as congestion pricing have been extensively studied and highly advocated in the literature (Lindsey and Verhoef, 2001; de Palma and Lindsey, 2011; Pigou, 1912; Vickrey, 1963). However, it is noteworthy that alternative demand management approaches such as promotion of telecommuting and public transport can also be effective in alleviating traffic congestion, because they can potentially shift the entire traffic demand curve inwards (Verhoef et al., 1996b).

E-commerce, due to its ability to re-direct consumers from physical stores to online, can be a potential alternative demand management mechanism that alleviates traffic congestion. Since consumers who purchase online do not need to drive to physical stores, online shopping incurs less traffic than shopping at the traditional channel. Although delivery to online customers also incurs road usage, it typically takes less road capacities due to economy of scale in delivery. A case study using simulation based on empirical data in Finland indicates that replacement of traditional retailing by electronic retailing can potentially lead to 54–93% reduction in traffic depending on delivery methods (Punakivi, 2003; Siikavirta et al., 2003).

Therefore, from a social point of view, e-commerce should be broadly adopted to reduce traffic congestion. However, when private firms choose between e-commerce and traditional distribution, their objectives are to maximize their own profits. As a result, conflicts may arise between private firms' incentives for distribution strategies and social objectives. In particular, in order to maximize social welfare, a social planner considers both the welfare in the product market and congestion costs of all road

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users. However, although a private firm also considers influence of traffic congestion on its demand and profit, the firm ignores the congestion externality incurred by its decisions. Hence, a private firm's marginal benefit and cost of adopting e-commerce generally differ from the marginal social benefit and cost.

In order to achieve higher social welfare, a social planner should understand private firms' incentives for e-commerce and address the following questions: First, what distribution strategy leads to maximum social welfare? Second, under a specific distribution strategy, what is the socially optimal quantity to be offered to consumers? Third, how would a private firm deviate from the socially optimal decisions? Finally, what policies should be used to induce a firm to choose the socially optimal decisions?

To analyze these issues, we set up a theoretic model where a monopolist firm produces and sells a single product to consumers. Consumers who drive to the physical store to purchase the product suffer a delay cost due to traffic congestion; whereas consumers who purchase online can avoid this cost. However, consumers have lower valuation for the firm's product sold online than that at a physical store due to lack of service, delayed satisfaction, and difficulty to return at the online store. The firm may choose from three distribution strategies: (1) a traditional strategy where it distributes products through a physical store, (2) an electronic strategy where it distributes through an online store, and (3) a mixed strategy where it distributes through both stores.

Under this model, we first consider an unregulated economy where the private firm makes decisions to maximize its own profit. We characterize the firm's optimal distribution strategy, taking into account influence of traffic congestion on consumer demands for the product. We show that the firm's optimal distribution strategy depends on consumers' acceptance of e-commerce as well as road users' congestion costs.

We then examine a centralized economy where the firm is publicly owned; and the social planner makes decisions to maximize social welfare. We derive the socially optimal distribution strategy and quantities. Comparing the unregulated and centralized cases, we show that the private firm's incentives may deviate from the socially optimal decisions. We identify two effects that drive the firm's quantity decisions to deviate from the socially optimal ones in opposite directions. In particular, the monopoly effect causes the firm to choose a too low quantity compared with the social optimum, while the congestion externality effect leads to a too large quantity under the unregulated equilibrium. The net effect determines the direction of the private firm's incentive distortion.

Finally, we propose a differentiated tolls/rebates policy to achieve maximum social welfare. When the congestion externality effect outweighs the monopoly effect, the social planner should charge a congestion toll to fix the too large quantity. On the other hand, when the monopoly effect outweighs the congestion externality effect, the social planner should offer a rebate to increase the quantity to reach the socially optimal level. We show that the differentiated tolls/rebates policy will not only induce the firm to choose the socially optimal quantities, but ensure the firm to adopt the socially optimal distribution strategy.

We highlight the main contributions of our paper as follows:

- We construct a theoretic model to investigate interactions between a firm's distribution strategy concerning e-commerce and traffic congestion.
- We show that the private firm's incentive may deviate from the social objective and identify the underlying effects that cause the private firm's incentive distortion.
- To achieve maximum social welfare, we propose a differentiated tolls/rebates policy that is able to induce the firm to adopt the socially optimal distribution strategy and quantities.

The rest of the paper is organized as follows: We first review the related literature in Section 2. We then set up the model in Section 3. In Section 4, we examine the firm's optimal distribution strategy in an unregulated economy. In Section 5, we derive the socially optimal distribution strategy and quantities. In Section 6.2, we discuss the private firm's incentive distortions and propose public policies that elicit the social optimum. Finally, in Section 7 we conclude the paper and suggest future research directions.

2. Related literature

While a few papers examine the effects of e-commerce on traffic congestion and environment through case studies (Edwards et al., 2010; Matthews et al., 2001; Punakivi, 2003; Weber et al., 2009), we use an analytical approach to investigate interactions between firms' distribution strategy involving e-commerce and traffic congestion.

Employing analytical approaches, a good number of works in the Transportation literature investigate traffic congestion and its solutions. Congestion pricing, in particular, has been intensively studied due to its effectiveness in managing traffic congestion and achieving social optimum (Brueckner, 2002, 2009; Lindsey and Verhoef, 2001; de Palma and Lindsey, 2011; Pigou, 1912; Vickrey, 1963; Walters, 1961; Zhang and Czerny, 2012). Researchers examine various factors that may influence optimal congestion pricing policies such as time of day, road link, usage of road, information provision, demand uncertainty, and user characteristics (Chung et al., 2012; Daganzo and Lehe, 2015; Lou et al., 2010; Verhoef et al., 1996a; Wie and Tobin, 1998; Yang and Huang, 2004; Zhang and Yang, 2004). However, the above papers do not investigate the impact of firms' distribution strategies on traffic congestion and welfare.

On the other hand, a rich literature in Marketing, Economics, and Operations uses analytical models to study a firm's optimal distribution decisions (Bernstein et al., 2009; Chiang et al., 2003; Dumrongsiri et al., 2008; Tsay and Agrawal, 2004; Yoo and Lee, 2011). However, this literature does not consider the influence of traffic congestion on firms' decisions.

What is more, our work is also related to research on telecommuting, which is another alternative demand management approach. Using empirical or case studies, several papers investigate factors that affect employees' choice and frequency of