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Price competition, free entry, and welfare in congested markets

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ABSTRACT

In this paper we study the problem of price competition and free entry in congested markets. In particular, we consider a network with multiple origins and a common destination node, where each link is owned by a firm that sets prices in order to maximize profits, whereas users want to minimize the total cost they face, which is given by the congestion cost plus the prices set by firms. In this environment, we introduce the notion of *Markovian Traffic Equilibrium* to establish the existence and uniqueness of a pure strategy price equilibrium, without assuming that the demand functions are concave nor imposing particular functional forms for the latency functions. We derive explicit conditions to guarantee existence and uniqueness of equilibria. Given this existence and uniqueness result, we apply our framework to study entry decisions and welfare, and establish that in congested markets with free entry, the number of firms exceeds the social optimum.

1. Introduction

In many environments, such as communication networks in which network flows are allocated, or transportation networks in which traffic is directed through the underlying road architecture, congestion plays an important role in terms of efficiency. In fact, over the last decade the phenomenon of congestion in traffic networks has received attention in a number of different disciplines: economics, computer science, and operations research.

The main question is how to achieve a socially optimal outcome, which is intimately linked to the assessment of congestion effects. This feeds into the identification of socially optimal regulatory actions in such markets. Indeed, a social planner may use a sort of economic mechanisms in order to induce users' behavior toward the socially optimal outcome. In fact, since the seminal work of Pigou (1920), it is well known that an efficient outcome in a network subject to congestion can be reached through the *centralized implementation* of a toll scheme based on the principle of *marginal cost pricing*. Under this mechanism users pay for the negative externality that they impose on everybody else.

Concretely, under a Pigouvian tax scheme users face two sources of cost: one due to the congestion cost and the second due to the toll. Nonetheless, Pigou's solution is hard to implement in practice, because it requires that the social planner charges the tolls in a centralized way, which from a practical and computational perspective is a very complex task. Thus, the natural alternative is to consider a market-based solution, where every route (or link) of the network is owned by independent firms who compete setting prices in order to maximize profits.[1]

[1] For an early discussion of price mechanisms in congested networks, we refer the reader to Luski (1976), Levhari and Luski (1978), Reitman (1991), and MacKie-Mason and Varian (1995).

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Despite the relevance of and the increasing interest in implementing decentralized pricing mechanisms to reduce and control congestion in networks, little is known about the theoretical properties of such solutions for general class of network topologies. Indeed, little is known about the existence and uniqueness of equilibrium prices for general classes of network topologies.

In addition to the problem of the existence and uniqueness of a price equilibrium, a second problem that is raised in congested markets is the analysis of free entry and welfare. In particular, every firm can be viewed as a link, so the number of firms that enter the market will determine the network topology. Thus the socially optimal topology can be identified with the optimal number of firms in the market. Similarly to the study of existence and uniqueness of a price equilibrium, little is known about the free entry problem in general networks.

1.1. Our contribution

In this paper we develop and study a general oligopoly model in a network subject to congestion effects. Our contribution is threefold. First, we study oligopoly pricing in congested networks exploiting an alternative notion of equilibrium in traffic networks, which we denote as *Markovian Traffic Equilibrium*. Our equilibrium concept is based on the idea that users choose their optimal paths in a recursive way. The idea that users can find their optimal paths in a recursive way turns out to be different to the standard notion of Wardrop equilibria. In particular, our equilibrium concept allows for heterogeneous users and general network topologies.[2] We are not aware of previous papers studying price competition in congested markets using the notion of Markovian Traffic Equilibrium.

Second, we show the *existence* and *uniqueness* of a pure strategy price equilibrium. Our result is general: we do not assume that demand functions are concave nor impose particular functional forms for the latency functions (congestion costs) as is commonly assumed in the extant literature. We derive *explicit conditions* to guarantee existence and uniqueness of equilibria. We stress that our existence and uniqueness result does not rely on a specific network topology. In fact, our result applies to any directed acyclic network with multiple origins and a common destination node.

Our third contribution is the study of entry decisions and welfare in congested markets. We show that the number of firms that enter the network exceeds the social optimum. In terms of network design the excess entry result means that the observed topology will not be the socially optimal. Because we obtain this result for a general network, we think of that our excess entry result may be useful in studying problems of optimal design of networks.

Formally, we study a network with multiple origins and a common destination node, where every link is owned by a firm that sets prices in order to maximize profits. In this environment, users face two sources of cost: the congestion cost plus the price set by the firms. The congestion in every link is captured by a latency function, which is strictly increasing in the number of users utilizing it. In order to solve the users' problem, we adapt the Markovian Traffic model proposed by Baillon and Cominetti (2008), to the study of price competition in congested networks. This Markovian model is based on *random utility models* and *dynamic programming*. The use of random utility models allows for heterogeneity in users' behavior, i.e., instead of assuming homogeneous users, we model the utility of choosing a certain route as a random variable. In addition, and considering the stochastic structure of users' utilities, we assume that users solve a dynamic programming problem in order to construct the optimal path in a recursive way. Thus, at each node users consider the utility derived from the available links plus the continuation values associated to each link.

Furthermore, the introduction of random utility models has the advantage of generating a *demand system*, which shows how prices and congestion externalities induce users' choices.[3]

Combining the previous elements, we solve a complete information two stage game, which can be described as follows: In the first stage, firms owning the links maximize profits setting competitive prices *a là* Bertrand. In the second stage, given firms' prices, users choose routes in order to maximize their utility, namely the cheapest route. We solve this game using backward induction, looking for a pure strategy sub-game perfect Nash equilibrium, which we call the *Oligopoly Price Equilibrium*.

Despite being a stylized model, an important real world situation where our framework may be useful is the case of road pricing in transportation networks. In particular, in transportation networks commuters from different locations (sources) want to travel to a common destination, let us say d. In order to reach the destination d, commuters must choose among different paths, where the total cost faced by commuters is given by the price charged by firms (operators) plus congestion. In real world transportation networks, the links of different paths are managed by different private operators, by local governments, or by a mix of private and public operators.[4] For example, the transportation network in Europe has received attention because commuters must choose paths across different countries, where the prices are set by a mix of different

[2] The assumptions of homogeneous users and very specific network topologies, like parallel serial link networks, have been recognized as one of the main limitations of the previous studies of pricing in congested networks. For a survey of the different models of pricing in congested networks we refer the reader to Nisan et al. (2007, Ch. 22).

[3] We stress that our approach differs with the one known as aggregation in oligopoly markets proposed by Caplin and Nalebuff (1991). The main technical difference is due to our demand system being defined in terms of a fixed point equation, which reflects the existence of congestion externalities in users' choices, while the results in Caplin and Nalebuff (1991) do not apply to the case of demand systems with externalities (positive or negative).

[4] For a detailed discussion of road pricing under different ownership schemes we refer the reader to Yang and Huang (2005) and Small and Verhoef (2007, Ch. 6).