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Retail location competition under carbon penalty

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ABSTRACT

We study the retail location problem in a competitive linear market in which two retailers simultaneously choose their locations. Both retailers procure identical products from a common supplier and each consumer purchases from the closest retailer. Each retailer incurs transportation costs for inventory replenishment from the warehouse and consumer travels to the store. We consider two carbon tax schemes imposed on retailers: for supply-chain-related transportation and for consumer-related transportation. Our analysis indicates that intense competition between retailers leads to a "minimal differentiation" equilibrium, which substantially increases the total system emissions. According to our numerical experiments with realistic parameter values, carbon tax on supply-chain-related transportation does not affect retail location decisions. Carbon tax on consumer transportation, however, may effectively induce the retailers to approach the middle of their respective markets, reducing the total system emissions. Our analysis also indicates that a low carbon price, relative to market profitability, only reduces the total system profit without any effect on emissions. Our findings suggest that the central policymaker avoid a uniform carbon price across different sources of emission and sectors with different characteristics.

1. Introduction

Increasing concentrations of greenhouse gases (GHGs) contribute to the change in global climate patterns and global warming. Carbon dioxide, methane, ozone, chlorofluorocarbons, nitrous oxide, and water vapor are the main GHGs existing in the atmosphere. Anthropogenic activities such as energy consumption, burning fossil fuels, deforestation, and transportation increase the amount of GHGs. Since the Industrial Revolution, the atmospheric concentration of carbon dioxide has increased by about 40%, mostly due to the combustion of carbon-based fossil fuels, such as coal, oil, and gasoline (Intergovernmental Panel on Climate Change (Staff, 2014b), and Environmental Protection Agency (Staff, 2015)).

Transportation has been the second biggest source of GHG emissions in the U.S. and Europe in 2015, with shares of 27% and 23%, respectively (Staff, 2016a; 2016b). In fact, in European Union, the transportation sector emissions did not follow the same gradual decline as in the other sectors, making the issue even more severe, considering the aggressive target of reaching 60% lower than the 1990 values by mid-century (Staff, 2017). In the U.S., about 61% of the total transport emissions in 2015 was produced by vehicles of personal use whereas 23% is attributed to medium-and-heavy-duty trucks (Staff, 2016a). Similarly, the total road transport is responsible for more than 70% of Europe's transport emissions of 2014 (Staff, 2017).

Many countries, including Ireland, Australia, Chile, Sweden, Finland, Great Britain, and Canada, impose carbon taxes to reduce emissions. In British Columbia, for instance, "a carbon tax is usually defined as a tax based on GHG emissions generated from burning fuels. By reducing fuel consumption, increasing fuel efficiency, using cleaner fuels and adopting new technology, businesses and individuals can reduce the amount they pay in carbon tax, or even offset it altogether" (Staff, 2016c). With this progressive carbon tax policy enforced on individuals as well as businesses, the per-person fuel consumption in British Columbia dropped by 16% from 2008 to 2014, while it increased by 3% in the rest of Canada (Staff, 2014a).

Distances between a retailer and its suppliers greatly influence the total amount of carbon emissions in the transportation domain of a supply chain. But a retailer's location also influences the patronage to that retailer and the carbon emissions generated by consumers for their store visits. Hence the retail location with respect to both suppliers and consumers plays a key role in environmental performance of the market. Emissions from a retailer's own supply chain, including transportation, are generally classified as scope 1 emissions and tend to be the focus in carbon footprinting or any firm-focused regulation; see, for example, Toffel and Sice (2011). Alternatively, emissions that involve consumer

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travels and further down the supply chain for a retailer are generally classified as scope 3 emissions, and not a critical concern for retailers or policymakers.

In this paper, we study a competitive retail location problem under carbon penalty for transportation, including both upstream transportation to warehouse and downstream consumer visits to retailers. In a duopolistic market, by characterizing the changes in equilibrium locations, profits, and emissions, we investigate the effectiveness of different carbon tax schemes on transportation in the retailer's own supply chain versus on consumer travels. We also compare the duopolistic market performance with a benchmark: a monopolist retailer that determines the locations of its two stores in the market. In addition, we evaluate the "emission overage" by comparing our results with the environmentally-optimal locations that minimize the total system emissions. In all settings, the retail stores procure identical products from a common supplier on the unit line in a full truck-load fashion, consumers are distributed uniformly on the unit line, each consumer travels to the closest store to purchase the product, and both retail stores sell their products at the same price.

The retailers take into account transportation costs due to both inventory replenishment and consumer travels in their profit calculations. Both types of transportation costs include fuel consumption and possible carbon emission costs. Supply-chain-related transportation poses a direct cost for the retailer. Consumer-related transportation costs also influence retailers' profit performance. This may arise when carbon tax is enforced on consumers based on their fuel consumption, and retailers subsidize consumers through promotions and marketing campaigns (also known as "uniform delivered pricing"). This may also arise when retailers are liable for consumer-related transportation emissions (i.e., scope 3 emissions) and the related carbon tax.

Through an extensive numerical study, we find that without carbon tax enforced on transportation, retailers may choose locations that produce undesirable emission levels. Carbon tax on consumer-related transportation is substantially more effective in reducing total system emissions than carbon tax on supplier-related transportation. In many cases, supplier-related transportation tax hurts retailer profits without any effect on emissions.

The competition intensity in the market is another critical factor in determining the effectiveness of the carbon policy. Accountability for both types of transportation is sufficient to align the monopolist retailer's location decisions with emission minimization. Even at very low carbon prices, the monopolist retailer easily achieves the minimum emission level possible in a fully functional market. However, in competitive markets, emissions tend to be substantially higher due to the "minimal differentiation" equilibrium. Competing retailers respond to carbon tax only when it is high enough, compared to the market profitability. A low carbon price in competitive markets only reduces the total system profit without any effect on emissions.

Based on our findings, we recommend that the central policymaker avoid a uniform carbon price across different sources of emission and sectors with different characteristics. By adjusted tax levels, emissions can be effectively reduced with minimum impact on business performance. In addition, carbon footprinting and accountability for the emissions directly involved with an organization's own operations (i.e., scope 1 emissions), as widely observed in practice, may fail to be effective or useful in a retail setting. As confirmed by the big share of transportation in overall emissions, and the substantial contribution of personal vehicles to transport emissions (Staff, 2016a), accountability for the consumer-contact and recovery of consumer-related carbon taxes from retailers will likely be an effective strategy towards reducing GHG emissions.

Our work is closely related with recent studies investigating the effect of carbon emission regulations on firms' operational decisions and the resulting emission levels. Several papers focus on the effect of carbon policy on the decisions involved with supply chain (e.g., Benjaafar, Li, and Daskin, 2013; Cachon, 2014; Caro, Corbett, Tan, and Zuidwijk, 2013; Hoen, Tan, Fransoo, and van Houtum, 2014, and Park, Cachon, Lai, & Seshadri, 2015), facility location (e.g., Islegen, Plambeck, & Taylor, 2016), co-products (e.g., Sunar & Plambeck, 2016), and choice of green technology (e.g., Krass, Nedorezov, & Ovchinnikov, 2013).

In this stream of literature, Cachon (2014) and Park et al. (2015) are the closest papers to ours; they both analyze the effect of carbon tax in the downstream part of a supply chain, from the inventory replenishment of retail stores to the consumer trips to stores. Although we share the main goal and several modeling assumptions with these two papers, we have significant differences in research questions, model details, and some insights. Cachon (2014) considers the operational trade-offs of a monopolist retail chain when she faces carbon tax, and examines the store location decisions alongside the size and number of stores to offer in an area. Unlike Cachon (2014), we focus on the effect of carbon tax in a competitive market. Park et al. (2015) consider both cases of monopoly and monopolistic competition, by endogenizing consumers' shopping frequency decisions. Unlike Park et al. (2015), we consider perfectly substitutable staple products, i.e., demand in each of our retailers is purely based on its (relative) location in the market via a Hotelling model. We find that carbon cost should be substantially high to be effective in the competitive market and taxing consumer travels is more effective than taxing retailer logistics operations, contradicting with the findings of Park et al. (2015).

Our research contributes to the carbon-regulated operations management literature a competitive location model in which retailers sell perfectly substitutable products and determine their locations in the presence of transportation costs due to both consumer travels and inventory replenishment from warehouse. We provide guidance to policymakers by characterizing the trade-off between the economic loss in the market versus the achieved reduction in emissions due to the carbon tax. We show that a possible retailer liability for consumer-related transportation is a crucial instrument in regulating retail locations in a competitive market. This finding calls into question the policymakers' traditional approach of monitoring and regulating scope 1 emissions only, which leaves scope 3 emissions unaccounted for despite their key role in achieving emission reduction.

Our work is also related with the competitive location literature, which is a mature research stream that can be dated back to Hotelling (1929). Most of this literature investigates the existence of, proposes methods to find, and/or characterizes the location equilibria. The papers in this stream can be roughly classified with respect to attributes such as location space, number of firms, existence of non-location decisions (e.g., price, quality, or capacity), pricing policy, timing of moves, demand (in)elasticity, and customer behavior. For a detailed survey and taxonomy of the competitive location literature, see Eiselt, Laporte, and Thisse (1993); Eiselt and Sandblom (2004); Graitson (1982); Plastria (2001); ReVelle and Eiselt (2005). Location space may be merely the unit interval (i.e., linear city) as we adopt in this paper (e.g., Dasci & Laporte, 2005; D'Aspremont, Gabszewicz, & Thisse, 1979; De Palma, Ginsburgh, & Thisse, 1987; Granot, Granot, & Raviv, 2010; Hotelling, 1929). The linear city model lends itself to the horizontal differentiation and product positioning problems. Location decisions may also take place in a multi-dimensional space (e.g., Diaz-Banez, Heredia, Pelegrin, Perez-Lantero, & Ventura, 2011), in a network (e.g., Buechel & Roehl, 2015; Dobson & Karmarkar, 1987; Hakimi, 1983), or across a set of potential discrete locations (e.g., Aboolian, Berman, & Krass, 2007; Godinho & Dias, 2010; 2013; Küçükaydın, Aras, & Altınel, 2011). Duopolistic competition, as we study in this