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Vehicle fuel-efficiency choices, emission externalities, and urban sprawl

Jinwon Kim

Department of Economics, 1250 Bellflower Boulevard, SSPA, California State University, Long Beach, CA 90840, United States

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ABSTRACT

This paper shows that a city where both a congestion externality and an externality from greenhouse gas emissions are corrected by efficient policies is more compact than the laissez-faire equilibrium city. Motivated by recent empirical studies showing a positive relationship between population density and vehicle fuel-efficiency, the consumer is assumed to choose vehicle fuel-efficiency jointly with housing consumption and residential location. By incorporating the consumer's vehicle choice into the urban spatial model, we can represent the total amount of vehicle emissions released by the city residents. We first establish the well-known result that the congestion externality as a source of market failure is associated with excessive urban sprawl. We then show that vehicle emissions are an additional source of market failure, which also leads to excessive urban sprawl. The source of excessive sprawl arising from the emission externality is the use of larger and less-fuel efficient vehicles in more sprawled cities, which is different from that of the congestion externality. We also analyze the effect of the Corporate Average Fuel Economy (CAFE) standards on urban spatial structure and its efficacy as a second-best tool for correcting the emission externality.

1. Introduction

The phenomenon of urban sprawl, which characterizes the land development pattern in the US since 1950, has become a major concern for policymakers in many countries, especially in the US. While the standard urban model suggests that cities' spatial expansion is a natural consequence of changes in several fundamental economic forces,[1] the expansion may be *excessive* compared to the socially desirable level. Specifically, cities' spatial expansion is excessive when the operation of sprawl-inducing forces involves market failures or equivalently when the urban developer fails to fully account for the social cost of suburban development (Brueckner, 2000, 2001; Brueckner and Helsley, 2011).

Among other sources, traffic congestion is the most studied source of market failures associated with urban sprawl.[2] With unpriced traffic congestion, the social cost of commuting exceeds the private cost because every driver on the road slows down other drivers while this external congestion cost is ignored by himself. Commute trips are thus excessively long, and the market equilibrium would generate the city that is too spread out compared to the socially desirable level. Consistent with this intuition, the congested-city models suggest that a city where congestion externalities are internalized by congestion tolls is denser and spatially smaller than the other city where congestion externalities are left uncorrected (e.g., Arnott, 1979; Wheaton, 1998; Brueckner, 2007).

While traffic congestion is a widely recognized vehicle-related externality leading to excessive urban sprawl, there are also other kinds of vehicle-related externalities in the urban economy. These externalities include global air pollution (especially greenhouse gas emissions), local air pollution, the country's oil dependence, and traffic accidents (Parry et al., 2007). Like congestion externalities, these kinds of externalities, especially air pollution, are also potentially related to the phenomenon of urban sprawl because longer commutes and increased passenger vehicle travels induced by low-density suburban development would mean greater air pollution released by the city residents. This hypothesis is supported by a number of empirical papers, which find that lower population density of the resident's neighborhood increases vehicle mileage traveled and energy consumption (e.g., Boarnet and Crane, 2001; Bento et al., 2005; Brownstone and Golob, 2009;

E-mail address: jinwon.kim@csulb.edu

[1] The fundamental forces leading to urban spatial growth include rising incomes, lowered transport cost, and falling agricultural rents (Wheaton, 1974; Brueckner, 1987).

[2] For example, Wheaton (1998) and Brueckner (2007) investigate the effect of traffic congestion in a closed-city model. Anas and Pines (2008) extend the analysis to a system of congested cities. Besides traffic congestion, other sources of market failure leading to excessive sprawl of urban areas include the failure to account for the amenity value of open space and the failure to fully account for the social cost of infrastructure development (Brueckner, 2000, 2001; Brueckner and Helsley, 2011).

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Kim and Brownstone, 2013). Moreover, the increased vehicle travels are responsible for a significant portion of the increased greenhouse gas emissions (Glaeser and Kahn, 2010; Glaeser, 2011). Therefore, according to these empirical papers, real-world cities are too spread out in the sense that such sprawled cities emit too much air pollution.[3] While vehicle emissions have been recognized as an important source of urban externalities in the empirical studies, urban economic models analyzing this kind of externality are relatively rare compared to the large literature on urban traffic congestion.[4] This paper fills this gap by analyzing both the congestion and the emission externalities in an urban economic model framework to ask whether the optimal city is more compact than the laissez-faire city.

We treat vehicle fuel-efficiency as a key variable in analyzing the emission externality because vehicle fuel-efficiency (or vehicle size and weight) chosen by the city residents is a key determinant of the city's emission level. Specifically, the city's emission amount will be greater as the consumers choose bigger and less-fuel efficient vehicles, holding their vehicle utilization levels fixed.[5] Indeed, vehicle fuel-efficiency has been recognized as an important policy target by the government in its goal of reducing greenhouse gas emissions. For example, the US government has been implementing various energy policies for vehicles, such as fuel taxes, vehicle fuel-efficiency standards, and financial subsidies and penalties for the purchase of high- and low-efficiency vehicles.[6] Along the same lines, we also treat vehicle fuel-efficiency as a key variable in analyzing vehicle emission externalities.

There is another group of relevant empirical studies that motivate us to treat vehicle fuel-efficiency as a key variable. These empirical papers suggest that consumers' vehicle fuel-efficiency choices (or emissions per vehicle) interact with their location and housing consumption choices. Specifically, consumers residing in less-dense suburban areas tend to choose less fuel-efficient vehicles than those located in denser areas, controlling for the consumers' other aspects such as incomes (Brownstone and Golob, 2009; Kim and Brownstone, 2013).[7] According to these papers, consumers living in lower-density neighborhoods tend to emit disproportionate air pollution because they not only drive more but also choose less fuel-efficient vehicles. This suggests that urban expansion will be inefficient unless vehicle emission externalities are corrected by efficient policies.

Our model provides a theoretical framework to see whether this intuition is correct. In the model, the consumer is assumed to choose vehicle fuel-efficiency jointly with housing consumption, conditional on her residential location, and as a result, the empirical relationship between population density and vehicle fuel-efficiency emerges in equilibrium.[8] By endogenizing consumers' vehicle fuel-efficiency choices in this way, we are able to represent the total amount of vehicle emissions released by the city residents. The city's total vehicle emission is proportional to the residents' aggregate fuel consumption, more accurately to the weighted summation of residents' commute distances with weights set at vehicle sizes (capturing fuel-*in*efficiency). After analyzing the consumer's problem, we next turn to the social planner's problem to investigate how the social planner's choices are different from the consumers' choices.

We first establish that a city where congestion externalities are internalized via appropriate congestion tolls is more compact than the laissez-faire city. We then incorporate the vehicle emission externality into the model to see how the result would be modified. We show that under the presence of both congestion and emission externalities, the optimal city, where both kinds of externalities are corrected by efficient policies, is more compact than the city where the externalities are left uncorrected. The sprawl effect of the emission externality does not rely on the effect of the congestion externality, which implies that the emission externality is an independent source of market failures leading to excessive urban sprawl. While both the congestion and the emission externalities are associated with excessive urban sprawl, the source of this outcome is different between the two cases. Under traffic congestion, urban sprawl is undesirable because longer commute distances induced by urban sprawl generate more external congestion costs. Meanwhile, under emission externalities, urban sprawl is undesirable because residents in more sprawled cities tend to use excessively larger and less-fuel efficient vehicles, emitting disproportionate air pollution.

In our model, the first-best optimal policy for correcting the emission externality is vehicle fuel taxes. But, we also analyze the effect of an alternative vehicle fuel-efficiency regulation, in particular Corporate Average Fuel Economy (CAFE) standards in the US, on the variables of interest including land-use patterns, emission levels, the consumer welfare. The analysis shows that the CAFE regulation reduces the city's spatial size and increases consumer welfare from the laissez-faire equilibrium, but not by as much as the first-best optimal fuel taxes. There have been many papers to evaluate the efficiency implications of various second-best anti-sprawl policies.[9] However, the emission externality is additionally considered in our paper, and therefore this is to best of our knowledge the first attempt to evaluate the effect of the CAFE regulation as a second-best anti-sprawl policy in a spatial framework.

The rest of the paper is organized as follows. Section 2 proposes the model and analyzes the laissez-faire equilibrium. Section 3 analyzes the central planner's problem to show whether traffic congestion and vehicle emissions are sprawl-inducing externalities. Section 4 characterizes the equilibrium under the policy of the CAFE standards. Section 5 provides numerical examples of various policy regimes to numerically investigate the effects of various policies. Finally, Section 6 concludes.

[3] While a majority of urban economists are in favor of high density, based on the empirical effect of density on the environment (e.g., Glaeser, 2011; Gaignè et al., 2012) argue that this conclusion is not always true if the general equilibrium effect of firms' and consumers' location choices on the emission level is taken into account.

[4] An exception is Riley (1974), who considers local pollution and its interaction with traffic congestion. A recent paper by Tscharaktschiew and Hirte (2010) also investigates the effect of congestion tolls and emission charges on urban spatial structure in a polycentric city model framework, relying on numerical simulations.

[5] Fatal traffic accidents are another example of vehicle externalities that are greater as the consumer's vehicle size is greater. There is recent empirical evidence that the probability of committing a fatal traffic accident is significantly greater for heavier and larger vehicles (Anderson and Auffhammer, 2014; Van Ommeren et al., 2013).

[6] See Small (2012) for discussion of the costs and effectiveness of these energy policies.

[7] Similar vehicle-choice patterns are found in West (2004) and Fang (2008). Note that these studies indicate a negative relationship between fuel efficiency and vehicle usage when these variables are interacted with residential density. But, holding residential density fixed, improved fuel efficiency may cause additional travel by reducing the monetary cost of travel. Researchers have long estimated this “rebound-effect” (e.g., Small and Van Dender, 2007).

[8] Kim (2012) also considers a similar framework, where the consumer chooses vehicle size jointly with housing consumption. But, there is no efficiency analysis in Kim (2012) while it is the main focus of this paper.

[9] For example, Bento et al. (2006) compare the effects of various policies such as urban growth boundaries, development taxes, property taxes, and fuel taxes on efficiency and on land-use patterns.

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