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The fundamental law of highway congestion revisited: Evidence from national expressways in Japan ☆

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ABSTRACT

The fundamental law of highway congestion states that when congested, the travel speed on an expanded expressway reverts to its previous level before the capacity expansion. In this paper, we propose a theory that generalizes this statement and finds that if there exists a coverage effect, that is, the effect of longer road length on traffic conditional on capacity, then the new equilibrium travel speed could be lower than its previous level. Given the fundamental law, the theory predicts that the elasticity of traffic to road capacity is at least 1. We estimate this elasticity for national expressways in Japan and test this prediction. Using the planned national expressway extension as an exogenous source of variation for capacity expansion, we obtain elasticity estimates ranging between 1.24 and 1.34, consistent with the prediction of our theory. We further investigate the sources of the larger-than-unity elasticity and find that the coverage effect plays a critical role, compared with the effect due to lane expansion.

"[E]xpansion of road capacity – no matter how large, within the limits of feasibility – cannot fully eliminate periods of crawling along on expressways at frustratingly low speeds."
– *Anthony Downs (2004, p. 85)*

1. Introduction

When urban residents complain about traffic congestion, or, in other words, they are not satisfied with the current travel speed on a certain portion of the road system, the most likely improvement option adopted is to expand the capacity of the congested roads. Whereas expanding road capacity seems intuitive, many economists have argued that this "building your way out of congestion" approach is likely to be fruitless. As Downs (1962) and many other authors[1] explain, this approach may fail because when there are alternatives to driving on congested routes, such as driving on less congested routes, using alternative transport modes, scheduling alternative travel times, or simply not traveling, latent travel demand exists. That is, potential traffic flows are not observed simply because the congestion itself deters them. When road capacity is expanded, however, the resulting increase in travel speed brings back the previously deterred potential traffic, thus leaving the congested routes as congested as they were before. This paradox is called the fundamental law of traffic/highway congestion, hereafter the fundamental law.

As the fundamental law is concerned with how traffic responds to road capacity expansion, it has implications for this elasticity. A large body of literature has estimated this elasticity to investigate whether, and how much, capacity expansion induces new traffic. The elasticity estimates obtained are almost always positive, confirming the existence of induced travel demand, but are typically significantly below 1, ranging from 0.2 to 0.8.[2] Recently, a strikingly different result was found by Duranton and Turner

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[1] For example, Holden (1989), Arnott and Small (1994), and Small (1997).

[2] For example, Hansen and Huang (1997), Noland and Cowart (2000), and Cervero and Hansen (2002). For more thorough reviews, see Goodwin (1996), Cervero (2002), and Small and Verhoef (2007).

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(2011, hereafter DT) who obtained estimates close to 1. Most importantly, they argue that this is evidence for the fundamental law. DT's work differs from previous studies in two important ways: (i) they estimate elasticity for the most congested type of roads in the US – the interstate highways in metropolitan statistical areas (MSAs); and (ii) they employ innovative and sensible instrumental variables (IV) to account for the possible endogeneity between traffic and road capacity.[3] Note that quantitative differences in the elasticity estimates have qualitatively different implications regarding whether the "building your way out of congestion" approach is likely to have some degree of success. As we will explain shortly, an elasticity smaller than 1 indicates that congestion could still be somewhat relieved by road expansion even though latent demand exists, whereas an elasticity of 1 or higher may suggest a complete failure of this approach.[4] Thus, DT's results convey a strong message, and their approach deserves further examination and/or application.

This paper contributes to both the theoretical and empirical literature on the fundamental law. We propose a simple and yet general theory of road capacity and traffic to guide our empirical analysis. We first clarify the conditions under which the fundamental law holds and then derive the equilibrium road elasticity of traffic. The theory postulates that road users care about not only the travel speed, which is a function of capacity and traffic, but also the coverage of the road system.[5] Under some weak conditions on the travel speed function, we show that this elasticity is at least 1 when the fundamental law holds. In particular, if there is no coverage effect, and if the travel speed function features constant returns to scale, that is, proportional increases in road capacity and traffic entail the same travel speed, then this elasticity equals unity. This is analogous to the demand-and-supply analysis for unit elasticity assuming that travel demand is perfectly elastic and total cost exhibits constant returns to scale (see Small and Verhoef, 2007; Duranton and Turner, 2009). In this case, testing unit elasticity is equivalent to testing the fundamental law. Nevertheless, the road elasticity of traffic could be larger than 1 either when there are increasing returns to scale, in the sense that an increase in capacity can accommodate a more than proportional increase in traffic while keeping the same travel speed, or when there is a significant coverage effect, or both.

On the empirical front, we estimate the road elasticity of traffic using another national-scale panel data set – road traffic data in Japan. Similar to DT, who focus on interstate highways in the US, we focus on national expressways, which are the highest-ranked roads in Japan. Following DT, we aggregate traffic (measured by vehicle kilometers traveled (VKT)) and road capacity (measured by lane kilometers) to the urban employment areas (UEAs), the Japanese version of MSAs, and conduct our analysis using the UEA-level aggregate data. In an earlier version of this paper, we conducted the empirical analysis at the prefecture level. The results are qualitatively similar to the UEA-level analysis. We begin with the ordinary least squares (OLS) estimations of the road elasticity of VKT by pooling the data from five traffic censuses. To address the potential correlation between road capacity and unobserved determinants of VKT at the UEA level, we also employ a UEA fixed-effect model to examine the relationship between growth in VKT and roadway capacity expansion conditioning out time-invariant UEA-level determinants. Our OLS and fixed-effect estimates of the road elasticity of VKT are always larger than 1, consistent with the necessary condition of the fundamental law – a road elasticity of at least 1 – predicted by our theory. Moreover, as their differences to 1 are rather small, our estimates are also generally consistent with DT's test of unit elasticity.

To further address the potential endogeneity of roadway capacity expansion in the fixed-effect model, we identify a new instrument for the growth of national expressways and carry out IV estimations using a fixed-effect model. Our instrument is based on Japan's 1987 National Expressway Network Plan. More specifically, we use the planned extension in the 1987 plan for a UEA smoothed by the national-level completion rate of the plan as the instrument for the growth of national expressways in this UEA over time. This identification strategy is similar to that of Baum-Snow (2007) who employs the 1947 US national highway plan to instrument for the growth of the number of highway rays in central cities in an MSA fixed-effect model to examine the effect of new highway rays on suburbanization. We obtain elasticity estimates ranging between 1.24 and 1.34 in the fixed-effect IV estimations, which are consistent with the prediction of our theory but can reject unit elasticity at the conventional significance levels. In light of these larger-than-unity estimates, we investigate the possible reasons for the elasticity to be larger than 1 by extending the fixed-effect specifications to further incorporate the roadway length and the capacity share of one-lane routes to account, respectively, for the coverage effect and the increasing returns to scale in the speed function, both of which can lead to the larger-than-unity elasticity as implied in our model. The empirical evidence suggests that the coverage effect may play a more important role in explaining the larger-than-unity elasticity, compared with the effect due to lane expansion.

In sum, whereas our general message is similar to that conveyed by DT, we differ from them in three important ways. First, we propose a theory that generalizes the statement of the fundamental law and the link between the law and road elasticity of traffic. Second, we find some evidence suggesting that the elasticity may be larger than 1 and further investigate the possible reasons for the larger-than-unity elasticity. Third, as no instrument was employed in DT's fixed-effect estimations, our fixed-effect IV exercise is also an innovation over DT's empirical analysis.

The remainder of this paper is organized as follows. Section 2 presents a model to guide our empirical work. Section 3 describes the data sets. Section 4 presents our empirical results. Section 5 concludes.

2. A model of road capacity and traffic

Building on the work of several authors, including Downs (1962), Holden (1989), Arnott and Small (1994), and Duranton and Turner (2009), we present in this section a theory of the fundamental law and the road elasticity of traffic to guide our empirical analysis. We then analyze whether increasing road capacity is welfare-improving in various situations.

2.1. Model setup

Suppose there are two different (sets of) routes, e and a, for drivers to choose from, where e annotates expressways and a annotates alternative routes. The two routes e vs. a can also be interpreted as two different modes, such as highways vs. subways, or as different travel schedules such as peak hours vs. off-peak hours, or as driving vs. staying at home. We adopt the standard assumption on how speed and traffic are related on roads. For $i = e, a$, let K_i and Q_i denote, respectively, the total capacity and traffic in route/system i, and assume that the average speed on route/system i is given by

[3] The three instruments used by DT are the routes of the major exploration expeditions between 1835 and 1850, the major rail routes in 1898, and the routes proposed in the 1947 interstate highway plan.

[4] Whether the "building your way out of congestion" approach does fail completely depends on the relative size of this elasticity to the returns to scale in the speed function, as we illustrate in further detail in Section 2.

[5] As we explain in Section 2, conditional on travel speed, a larger coverage of a given system may bring extra utility for drivers because it allows them to reach more places that would previously be reachable only by other systems (perhaps with a lower speed) or simply not reachable.