Existence of Hypercongestion in Highways: A truth or a fallacy?

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1. Introduction

The transportation engineering literature defines hypercongestion as a phenomenon of drop in capacity or flow in a road section with very high level of traffic densities or demand. In the standard representation of the relationship between traffic flow q and density k as shown in figure 1, hypercongestion is identified as the region where traffic densities exceed the jam density k_m of the road section. This relationship is commonly known as the fundamental relationship of traffic flow . The fundamental relationship can equivalently be expressed as flow-speed or speed-density relationship using the average vehicle speed v of the road section (see figure 1).

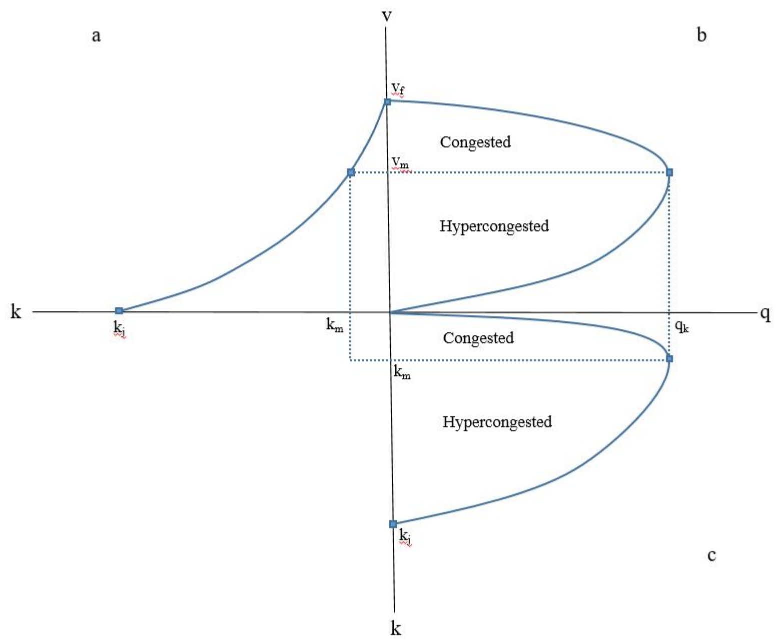

Figure 1: The Fundamental diagram of traffic flow.

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There is a recent debate in the transportation economics literature on the existence of hypercongestion. Urban economists assume that the fundamental relationship for a road section represents the supply curve for travel in that road section (Small et al., 2007). Based on this assumption, Anderson and Davis (2018) examine the existence of hypercongestion in a highway section in the absence of any supply shock like road construction, lane closures, weather and so on. According to Anderson and Davis (2018), capacity of a highway section is determined by both demand and supply. So, when any exogenous shifter in demand is used to estimate the supply curve underlying highway travel, the capacity doesn't fall when demand is very high. Thus, they conclude that the flow-density relationship for a highway section should not have the hypercongested branch (Anderson and Davis, 2018). This result is inconsistent with the well-established transportation engineering literature that presents enormous evidence to conclude the existence of hypercongestion in highway sections. We contribute to this debate by re-examining the question on existence of hypercongestion.

In this research, we examine the sources of this inconsistency between the two strands of the transportation literature in this area: one from engineers and the other from economists. We aim to estimate a causal relationship between flow and density or speed conditional on factors unanimously identified in the literature, in order to reconcile the two diverging strands of the transportation literature. Transportation engineers suggest that if traffic conditions on a given road section are stationary, it is reasonable to assume that the fundamental relationship is a property of the road section, the environment and the population of travellers (Daganzo, 1997). This is because on an average, drivers show the same behaviour under same average conditions (Daganzo, 1997).

Moreover, we also argue that it is unreasonable to treat the flow-speed relationship as the road travel supply curve because of the absence of a market mechanism in this case that could allow suppliers and buyers to interact in order to facilitate an exchange between travel time and amount of travel. What is supplied in true sense is only the road infrastructure and its properties, that essentially remain fixed in the absence of any supply shocks or change in environmental conditions. Therefore, the only quantity that is varying is the population of drivers or demand and related characteristics. Thus, referring to the flow-speed relationship as the travel supply curve for a road section can be confusing and quite misleading.

In estimating the causal relationship, we control for confounding from unobserved average driving characteristics. For instance, we recognise that the fundamental relationship estimated using data from an average population of conservative drivers would be different from the one from an average population of non-conservative drivers. We thus use relevant and exogenous instruments that are strongly correlated with the independent variable but not with the dependent variable in our model to control for any confounding bias. We also take into account the direction of causality in the fundamental relationship, something that has received insufficient attention in the transportation literature estimating this relationship.

2. Data and Methods

In this study, we use traffic data from a standard highway bottleneck located in the westbound Caldecott Tunnel in Oakland, California. The high-quality data is publicly available from the California Department of Transportation website and has flow and speed observations averaged over every 5-minute duration. A schematic representation of this bottleneck is shown in figure 2. At this location, the number of lanes decrease from four to two as traffic approaches the tunnel, thus traffic delays are common. We use observations from evening peak period between 16:00 to 19:00 for a working week in any summer month in the period 2005-2010. We only include periods of observation when no supply shock in form of lane closures, traffic incidents and so on are present and when weather conditions are good and favourable for drivers. Is is worth noting that there are no reasonable alternative routes to the tunnel, so the average driver population using the tunnel during the afternoon peak is almost the same during weekdays.

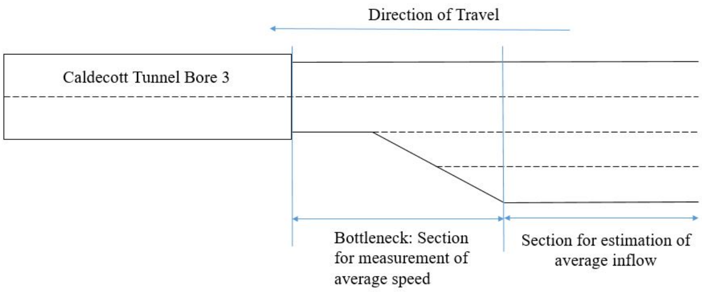

Figure 2: When causality comes from downstream.

We estimate the causal relationship for average inflows q_t at time t as a function of average speed v_t inside the bottleneck at time t as given by equation 1. The direction of causality is consistent with the transportation engineering literature (see Daganzo (1997) for details). We use a flexible semi-parametric specification to capture the non- linearities in the relationship.

$$q_t = f(v_t) + \epsilon_t. \tag{1}$$

To control for confounding from unobserved driving characteristics, we use instrumental variables that are relevant and exogenous, that is, strongly correlated with v_t and uncorrelated with ϵ_t. We use observations for v_s from a different time period s, such that $s \neq t$, when one lane in the tunnel was closed due to a traffic incident as shown in figure 3. We argue that because there are no alternative routes to the tunnel, the average population of drivers remain same in both situations, that is, whether only one lane or both the lanes are operational. So average speeds inside the bottleneck in the two situations are correlated as average speed is determined by elements of highway geometry and the average population of drivers using it and our instrument F-statistics indicate the same. However, flows in the two situations are not correlated as with one lane closed the flow pattern over time gets changed.

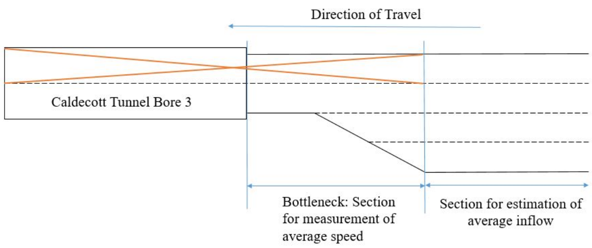

Figure 3: Instrumental variables

3. Expected Results

In this research, we adopt a causal econometric approach to understand the flow-speed relationship for a highway section and present evidence on the existence of hypercongestion:

1. We estimate the relationship with due attention to the direction of causality between flow and density.
2. We adopt a flexible semi-parametric specification to sufficiently capture the non-linearities in the relationship.
3. We investigate whether use of instrumental variables increases the error variance such that the hypercongested part of the model becomes insignificant.
4. We account for auto-correlation of the errors in estimating the relationship.

Our preliminary investigation of the data suggests that the phenomenon of hypercongestion does exist for highway sections in the absence of any supply related or environmental shocks. We aim to further explore our data in the above listed directions.

4. Summary and Relevance

The understanding of the flow-density relationship underlying travel in a highway section is important for both transportation engineers as well as transportation economists. For engineers, this relationship is useful in the practical design of highways and forms the basic crux of highway design manuals adopted for government analysis, like the Highway Capacity Manual (HCM) of the US government and the Cost Benefit analysis (COBA) manual of the UK government. The relationship is also used for control of traffic in highway sections via ramp metering and so on.

For economists, this relationship determines the technology driving congestion in highways. Therefore, it is central to pricing and investment analysis. For instance, estimation of efficient Pigouvian taxes to minimise the negative externalities of congestion is based on the knowledge of this congestion technology. We thus develop a comprehension of the flow-density relationship that is consistent and relevant for both economists and engineers.

References

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