The Fundamental Law of Highway Congestion

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Congestion

- Congestion is a chronical urban problem. What's the remedy?
- Building roads is intuitive, but ....
- Duranton and Turner (2011, *American Economic Review*): one percent increase in road capacity induces one percent increase in traffic (*unit elasticity*).
- I.e., **the fundamental law of highway congestion**.

Fundamental Law of Highway Congestion

- An old idea starting from Anthony Downs (1962) who said:
  - *On urban commuter expressways, peak-hour traffic congestion rises to meet maximum capacity.*
- Intuition: there are latent travel demand which is not observed because congestion itself deters them.
- Alternatives to driving on the congested routes:
  - Driving on less congested routes;
  - Scheduling alternative travel times;
  - Using alternative transport modes;
  - Simply not traveling at all.

Fundamental Law of Highway Congestion

- Several authors illustrated the fundamental law using simple equilibrium models, e.g., Arnott and Small (1994). (did not explain elasticity)
- A simple example:
  - Suppose two modes, subway and highway, to connect two points A and B. To travel time is fixed at T_s if taking subway. (simply squeez in people....), but the travel time T for driving is a function of number of drivers, Q, (which reflects the number of vehicles) and road capacity K. Denote this relation as $T = T(Q, K)$. The travel time increases in Q, while it decreases in K.
  - If for given level of Q and K, $T(Q, K) > T_s$, some drivers would want to switch to the subways, decreasing Q.
  - If $T(Q, K) < T_s$, then some subway patrons would like to drive, increasing Q.
  - In equilibrium,

$$T(Q, K) = T_s$$

Fundamental Law of Highway Congestion

- Now, consider an increase in road capacity from K° to K'.
- At the original equilibrium Q°, $T(Q^\circ, K') < T(Q^\circ, K^\circ)$, creating incentives for some subway patrons to start driving.
- Q thus increases from Q° to Q'. See diagramatic analysis. Equilibrium Q' must be such that

$$T(Q', K') = T_s = T(Q^\circ, K^\circ).$$

- The travel time was the same as before: Downs' fundamental law holds!

Fundamental Law of Highway Congestion

- Suppose the distance between A and B is D. If the travel speed on the highway is a function of *traffic density* $\frac{Q}{K}$, i.e., speed $S = g\left(\frac{Q}{K}\right)$ for some decreasing function g. Then,

$$\frac{D}{g\left(\frac{Q'}{K'}\right)} = T\left(Q', K'\right) = T\left(Q^\circ, K^\circ\right) = \frac{D}{g\left(\frac{Q^\circ}{K^\circ}\right)},$$

  which, in turn, implies that

$$\frac{Q'}{K'} = \frac{Q^\circ}{K^\circ},$$

  that is, in equilibrium, $Q = \lambda K$, for some positive λ.

- This imlies that the elasticity of traffic to road capacity is

$$\frac{dQ}{dK}\frac{K}{Q} = 1.$$

  : one percent increase in road capacity induces one percent increase in traffic. (Duranton and Turner's fundamental law).

Estimating Road Elasticity of Traffic

- A large literature prior to Duranton and Turner (2011) obtain an elasticity significantly below 1.
  - Usually ranging from 0.2 to 0.8 (Small and Verhoef, 2007)
- Quantitative differences have qualitatively different implications.

Duranton and Turner (2011)

- DT is the first paper testing the unit elasticity hypothesis.
- Focus on interstate highways in U.S. metropolitan statistical areas (MSAs), and find support for the unit elasticity.
- Main differences between DT and prior studies:
  - Use a comprehensive nationwide panel data set
  - Focus on interstate highways in MSAs, the most congested roads in the US. (note that the fundamental law doesn't hold everywhere.)
  - Employ innovative and sensible instrumental variables (IV) for road capacity.
- Note the reverse causality issue and potential common cause between Q and K.

$$\ln Q_{it} = \rho \ln K_{it} + \mathbf{X}'_{it}\beta + \tau_t + \varepsilon_{it}, \tag{1}$$

The Case of Japan

- Hsu and Zhang (2011) estimates road elasticity of traffic using Japan's national expressways.
- Our results generally concur with DT: the unit elasticity hypothesis cannot be rejected.
- Our estimates are a little higher than 1.
- Question: does the fundamental law holds if the alternative is not a mode, is instead, say, uncongested roads, staying at home, or travel during off-peak hours?