# Challenges of Implementing Incentive Mechanisms for Reducing Infrastructure Congestion


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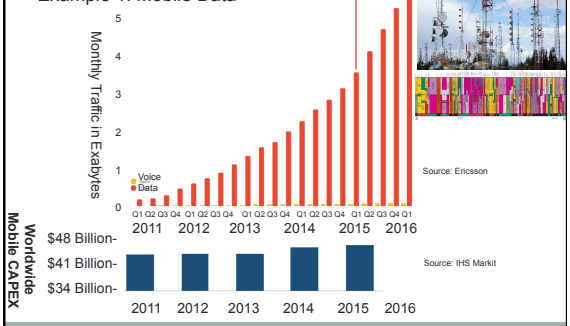
## Congestion is Here to Stay

60% YOY Growth

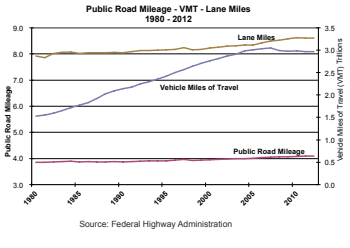
Example 1: Mobile Data






## Congestion is Here to Stay

Example 2: Highways




Source: Federal Highway Administration

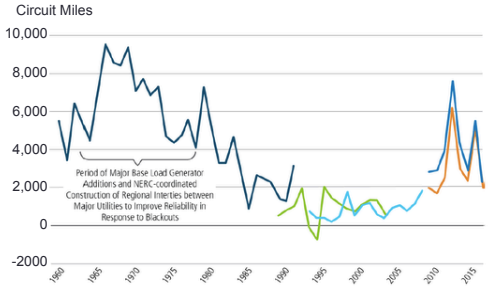


## Congestion is Here to Stay




## Congestion is Here to Stay

Example 2: Electricity Generation, Transmission and Distribution






## Congestion Externalities

Externality: An actor's choice effects other's utility

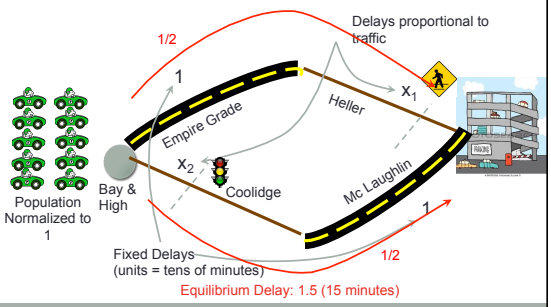
- E.g. My decision to drive during rush hour increases the delay of other drivers on my route

Congestion Externality: The more actors choose an action (route) the worse it gets

Figure 1: SUV driver imposing an externality on a pedestrian.

## Congestion Externalities

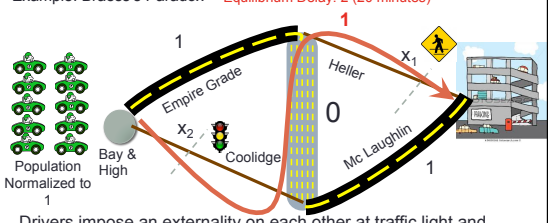
Example: Braess's Paradox






## Congestion Externalities

Example: Braess's Paradox Equilibrium Delay: 2 (20 minutes)



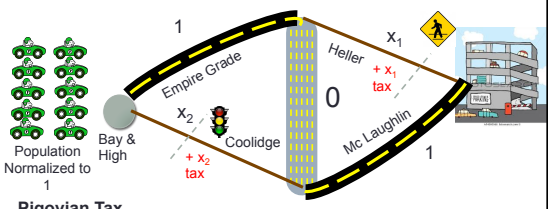

Drivers impose an externality on each other at traffic light and crosswalk queues

- Total crosswalk delay: $x_1^2$ (Delay times population suffering it)
- Marginal cost to whole population for increasing crosswalk traffic: $2x_1$
- …But each driver only sees cost of $x_1$. Make them pay!



## Congestion Externalities

Example: Braess's Paradox Equilibrium Delay: 2 (20 minutes)

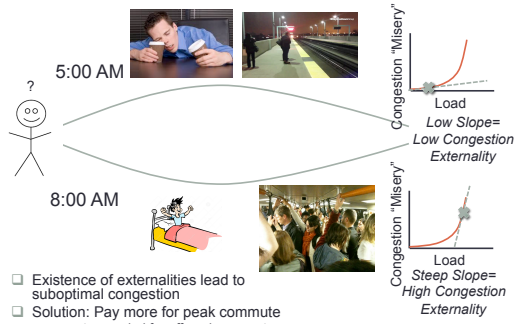



**Pigovian Tax**

- Make people pay for their externality
- Aligns individual and social optimization problems to make optimum achieved
- Lots of challenges for practical implementation
  - E.g. Monetary value of time different for different people, measurement difficulties, disincentive for revealing willingness to pay, etc…



## Congestion Externalities




- Existence of externalities lead to suboptimal congestion
- Solution: Pay more for peak commute
  - …or get rewarded for off peak commute



## Incentives in Transit

**Incentives for Singapore's Commuters**

Travel off-peak and increase your chance of winning.

NEWS

BART readies cash rewards for off-peak riders

**An Incentive Mechanism for Decongesting the Roads: A Pilot Program in Bangalore**

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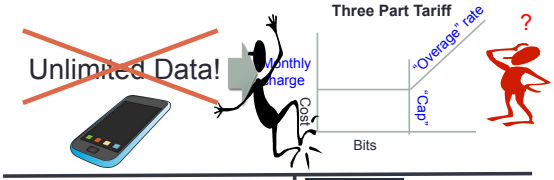
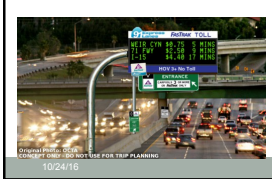
N. S. Rama, Infosys Technologies Bangalore, ramans@infosys.com

(NetEcon 2009)



## More Incentives



## Externalities and Public Goods

Public Good
- Cannot easily exclude others from enjoying
- Consumption by one doesn't impair others from consuming

Problem
- One cannot capture full value from investing in
- A non-contributor can still enjoy
- Depending on voluntary donations will lead to severe underinvestment in public goods
- Most common fix: government + taxes


Free Rider

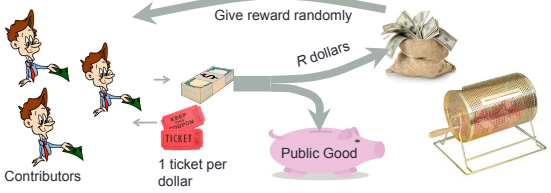



## Lotteries and Externalities

Financing Public Goods by Means of Lotteries

JOHN MORGAN
*Princeton University*

(Review of Economic Studies 2000)






## Lotteries and Externalities

Money for public good increases vs. voluntary contributions! (Morgan 2000)
- Even though prize is "skimmed" from the proceeds

Intuition
- Voluntarily contributing to public creates positive externality
  - One underinvests since individual can't capture full benefit
- Lottery creates negative externality
  - Contributing decreases others' expected winnings
  - Partially offsets the positive externality, hence
  - Better alignment of individual and social objectives



## Lotteries for Congestion



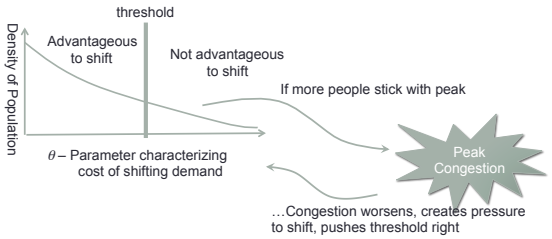
Incentive Scheme:
- Earn ticket for shifting demand to off-peak
- Reward given randomly



Incentive Mechanisms for Internet Congestion Management: Fixed-Budget Rebate *versus* Time-of-Day Pricing

Patrick Loiseau, Galina Schwartz, John Musacchio, Saurabh Amin and S. Shankar Sastry
(IEEE Transactions on Networking 2014)

Feedback Loop 1:



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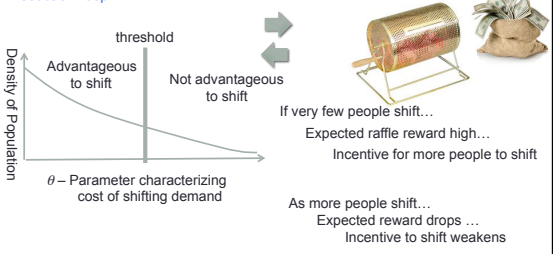
Feedback Loop 2:



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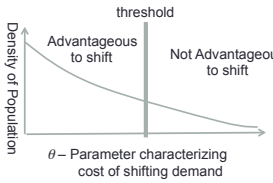


Alternative: Time of Day Pricing

- Challenge: Setting Prices
  - Too little discount → no one shifts
  - Too big of a discount → too many (or everyone!) shifts



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Key Finding:

- Raffle Scheme more robust to parameter uncertainty than fixed time of day prices



## Challenges for Incentive Schemes

Raffle Based Schemes

- How do you identify a shift in demand from a fake demand?
  - E.g. Download bogus movies at night to get rewarded for downloading in advance
    - A usage based pricing component could be disincentive enough, but what about plans that are free up to a cap?
  - Maybe one should be forced to watch it to qualify for bonuses?



## Challenges for Incentive Schemes

All schemes

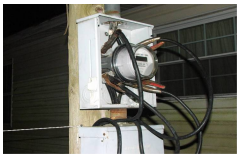
- How to communicate/educate user of effect of decisions:
  - How much is streaming this movie going to cost me?
  - How much is running turn by turn directions on google maps going to cost me in a foreign country?
  - How much is shifting the clothes dryer run to night going to save me?
- Can bonuses be made more personalized to reduce cost?



## Challenges for Incentive Schemes

Tampering and Theft

- Pricing dependent on more observables → more opportunities to gain from hacking, tampering, etc.

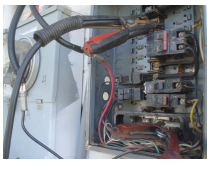




## Challenges for Incentive Schemes

Data Tampering and Theft

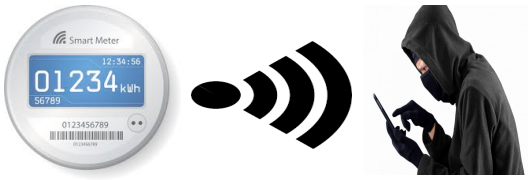
- Need better schemes to identify using multiple data sources
  - E.g. inferring sensor tampering from other measurements of electrical distribution system



## Challenges for Incentive Schemes

Privacy

- Collection of more behavioral data can be used in unintended ways






## Closing Thoughts

- Ability to cost-effectively collect data from millions of users, and offer them behavior-dependent incentives is relatively new opportunity
- Challenges abound
  - Scheme design, user education and willingness to accept, security, privacy, etc.
- Infrastructure congestion necessitates moving forward with new incentive schemes