Road Pricing in a Green Economy: An Unintended Consequence or a Useful Contribution?

Theoretical background

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Outline

1. Road pricing for demand management
   - Congestion relief
   - Other benefits

2. Road pricing and investment
   - Road capacity
   - Public transit fares and service

3. Do toll revenues pay for optimal roads?
   - The self-financing theorem
   - Revenue generation

4. Goals & potential benefits of road pricing
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Basic model of congestion pricing (Walters, 1961)

\[ MC = c(V) + \frac{dc(V)}{dV} V \]
Basic model of congestion pricing (Walters, 1961)

\[ MC = c(V) + \frac{dc(V)}{dV} \]

\[ Toll = \frac{dc(V_o)}{dV} V_o \]

Cost per trip

\[ p_O \]

\[ p_E \]

Toll revenue

Number of trips, \( V \)

\[ V_O \]

\[ V_E \]

Efficiency gain

Demand

\( c(V) \)
Extensions

Road networks

*First-best*: All links are tolled efficiently.

- Toll formula for one link still applies

*Second-best*: Some links untolled or mispriced

- Toll formulas become very complicated. Tolls depend on whether mispriced links are substitutes or complements.

Traffic dynamics

Optimal tolls vary with the level of congestion. Benefits from tolling increase with the number of toll steps.

Vehicle heterogeneity

Tolls vary with vehicle characteristics that affect external costs. Truck congestion measured by Passenger Car Equivalents
Other externalities

Road damage
   Tolls based on axle load, pavement type.

Accidents
   Pay As You Drive (PAYD) vehicle insurance.

Local pollution
   Tolls based on vehicle emissions characteristics. Possibly also population density and weather.

Greenhouse gas emissions
   Fuel taxes are efficient.

Noise
   Vehicle design standards and traffic movement regulations may be more practical than tolls.

Sprawl? Appendix: Effect of road pricing on land use
Summary

Advantages of tolls over fuel taxes

• Tolls can target transport externalities much more accurately (except for greenhouse gas emissions)
• Effects not undermined by rising vehicle fuel economy, advent of alternative-fueled vehicles. (Likewise for revenue generation.)

Caveats

• For full efficiency, tolls must be comprehensive and vary by road link, time of day, and vehicle characteristics
• Tolls need to be indexed to inflation (unlike US fuel tax)
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Road pricing and road investment

Optimal road capacity determined by trade-off:
+ Quicker and more reliable trips
+ Potential reductions in accidents, emissions, noise
- Construction costs
- Operations and maintenance costs

Capacity and toll decisions are interdependent
Tolls should be set optimally conditional on capacity
Capacity decisions should take into account resulting toll levels and their effect on usage.
Long-run effects of road pricing

Two opposing forces:

1. Fewer trips can benefit from capacity expansion
   Tolls usually seen as a substitute for investment

2. Tolls curb induced demand
   New unpriced capacity tends to fill up with traffic.

Net effect depends on elasticity of induced demand.
Estimates vary widely:

*Literature review*
  0.2 to 0.8: Small and Verhoef (2007)

*Recent U.S. studies*
  0.186 in the long run: Hymel et al. (2010) using state data
  Close to 1: Duranton and Turner (2011) using city data
Conclusions:

1. Optimal road capacity is reduced by tolling unless conventional price elasticity of demand is fairly high ($< -1$ in simple models).

2. Volume/capacity falls unambiguously $\rightarrow$ less congestion (Arnott and Yan, 2000).
Road pricing and public transit

Effect on fares
Public transit service is usually heavily subsidized:

1. Equity reasons
2. Scale economies: marginal cost pricing does not cover full cost
3. Alleviates traffic congestion and other externalities

Road pricing eliminates rationale 3. Suggests fares should increase.
Road pricing and public transit

Effect on transit capacity

Three opposing forces:

1. With higher fares, fewer trips can benefit from capacity (-)
2. Higher fares curb induced demand for transit (+)
3. Tolls create a direct modal shift to transit (+)

The net effect depends on whether transit service has a dedicated right of way:

**With a dedicated right of way:** Optimal transit capacity reduced by tolling unless transit demand is very elastic to fare (Kraus, 2003).

**With a shared right of way:** Road pricing allows buses to speed up. Creates a virtuous circle of less congestion, increasing bus ridership & service expansion (Small, 2004). Travelers can benefit even without toll-revenue recycling (Ahn, 2009).
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The Cost Recovery Theorem

Mohring and Harwitz (1962)

Assumptions:

i. Constant returns to scale in user costs

ii. Neutral scale economies for road capacity

iii. Road capacity is perfectly divisible

Then congestion toll revenues just cover the costs of optimally-sized roads.
Significance of the Theorem

No conflict between pricing for efficient usage and pricing for revenue generation.

No need to subsidize roads. And no justification for making roads a cash cow.

Surpluses/deficits provide a signal that capacity should be expanded/reduced.
Extensions of the *Theorem*

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**Extensions for which the *Theorem* holds**

- Road networks
- User heterogeneity (value of time, demand elasticity…)
- Time-varying demand
- Non-stationary environments
- Non-competitive factor markets
- Road damage
- Pollution and other externalities (provided revenues not allocated to road investment)

**Requirements**

- Assumptions i, ii, iii continue to hold
- Tolls are sufficiently flexible to price usage at marginal cost
Empirical support for the *Theorem*

- Assumptions i, ii, iii are likely to be satisfied approximately in heavily traveled corridors where many traffic lanes are built.

- Surpluses and deficits on individual links may average out so that total costs are approximately recovered on large networks.
Main caveats regarding the *Theorem*

1. **Capacity indivisibilities**
   - Important for rural roads
   - Congestion tolls and road damage charges unlikely to cover a large fraction of total road costs (CTAR Panel)
   - Greater cost recovery calls for Ramsey pricing (i.e., maximizing a weighted sum of social surplus and revenue)

2. **Revenue generation incentives**
   - Most revenue sources impose a deadweight loss
   - Tolls (may) yield a double dividend
   - Provides an incentive to use roads as a cash cow!
Self-financing with a fuel tax

Rizzi (2011)

The Theorem would hold for a fuel tax if:
• Fuel consumption were proportional to congestion
• Fuel efficiency were exogenous

With endogenous fuel efficiency a fuel tax is inefficient because it encourages purchase of more fuel efficient vehicles. This is inefficient if the market supplies the optimal level of fuel efficiency in the absence of intervention.
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## Goals of existing schemes

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Revenue generation</th>
<th>Congestion relief</th>
<th>Pollution reduction</th>
<th>Transit promotion</th>
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<td>Conventional toll roads</td>
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<td>HOT lanes</td>
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<td>US Vehicle Miles Traveled fee (proposed)</td>
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Relative importance of goals

**Congestion relief benefits**
- Increase with amount of infrastructure that is tolled
- Sensitive to degree of time variation in tolls

**Environmental benefits**
- Pollution reduction & climate change benefits dominated by congestion relief *(Anas and Lindsey, 2011)*
- Caveat: Growing awareness of health costs of driving *(Lin and Yu, 2008; Currie and Walker, 2009; Taylor, 2012)*.

**Revenue generation**
- Revenue benefits can dominate direct benefits from congestion relief *(de Palma, Lindsey & Proost, 2007)*.
References


References


Appendix

Effect of road pricing on land use
Effect of road pricing on land use

**Monocentric city model**
- All jobs located at CBD
- All trips are commuting
- Traffic congestion increases with proximity to CBD

Rent curve with no tolls
- Housing density declines with distance

![Graph showing land rent ($/meter^2) vs. distance from CBD.](image)
Effect of road pricing on land use

- Congestion toll increases cost of travel
- Rent curve with tolls
- Rent curve with no tolls
- Housing density declines more quickly
- Residential city boundary shrinks.
Effect of road pricing on land use

Beyond the monocentric city model

- Polycentric urban structures
- Firms and households can locate in multiple centres
- Households can adapt to congestion by changing place of work
- Firms can adapt to congestion by moving closer to workers

Current research

- Uses detailed land use & transportation models
- Complications: Long-lived & irreversible decisions.
- Simulation results vary widely. Some studies suggest urban sprawl alleviates traffic congestion (e.g., Anas, 2011)
Thank you

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