Urban Economics

Lecture 5: Congestion externality

Spring 2023
Tuukka Saarimaa

Outline

In this lecture we will analyze road congestion and the externalities related to traffic

We also analyze policies to correct for the externalities, e.g. congestion toll/charge

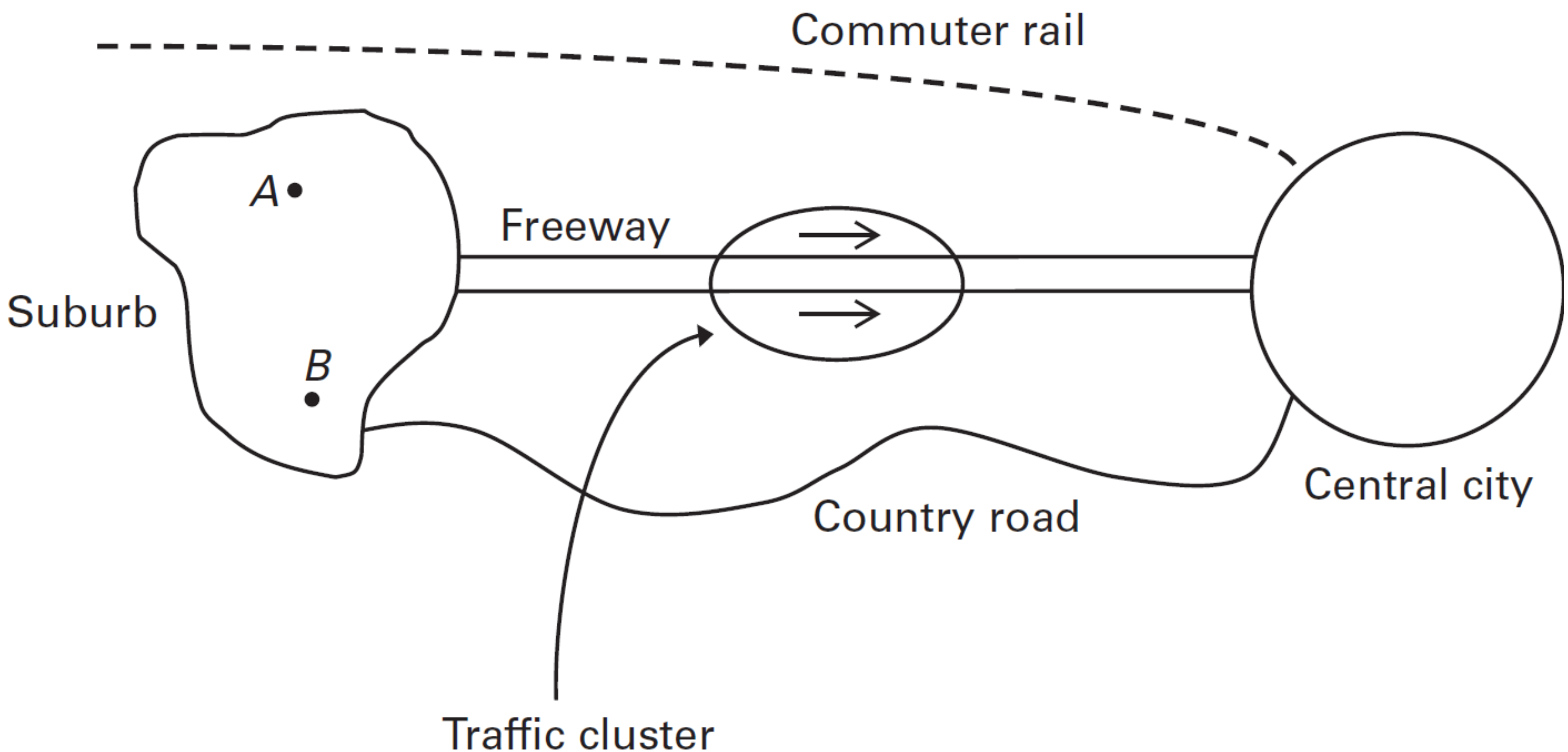
Empirical examples

The lecture follows Brueckner's Chapter 5

Set-up

- **The analysis is conducted in an environment where residential locations are fixed**
- **Commute trips occur between a suburb and the central city on a freeway of fixed length or an alternate route**
- **Commuters respond to congestion tolls not by changing the length of their commute, but by choosing**
  - A different way to commute
  - A different time of day to commute (uncongested time)
- **In reality, some people would also adjust their residential location (in the longer run, remember previous lectures)**

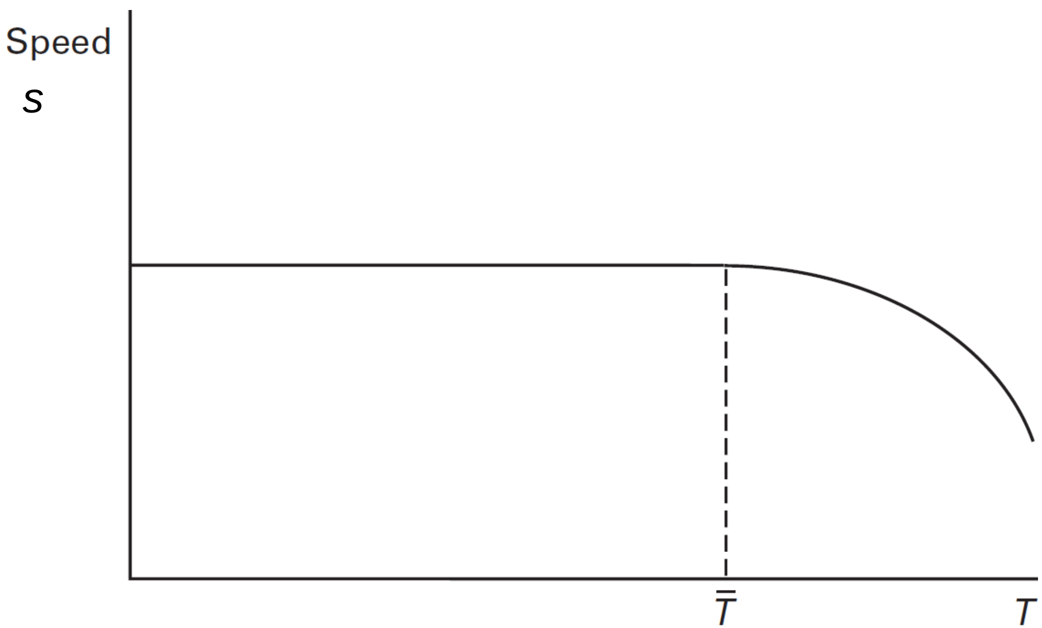
Spatial setting



Spatial setting

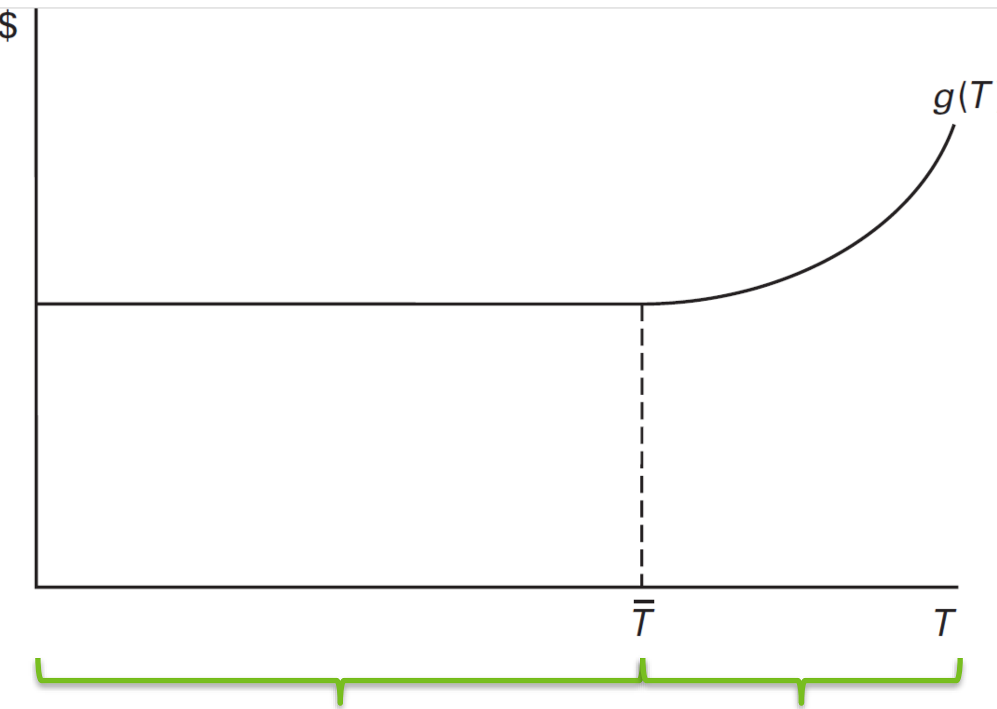
- **A freeway connects a suburb to the central city**
- **During the morning rush hour, a cluster of commuters travels down the freeway to work**
- **The extent of congestion on the freeway depends on how many commuters are present**
  - The speed of the traffic cluster depends on how big the cluster is
  - The larger the cluster, the slower it moves
- **Alternate routes to work are the smaller country road and the commuter rail**

Speed on the freeway



- T = number of cars on the freeway (size of the cluster) and s = traffic speed
- Speed is unaffected by traffic if T is low
- As T increases to the freeway's capacity ($\bar{T}$), traffic slows down

Commuting cost and congestion



Uncongested => *T* has no effect on *s* or *g*(*T*)

Congested => increasing *T* decreases *s* and increases *g(T)*

- m = monetary cost for the commute
- D = length of the highway
- Time duration of the trip = D/s
- If commuting time is valued at the hourly wage w, time cost equals wD/s
- Total costs (for an individual driver) $g = m + wD/s$

Congestion externality

- **To see the externality, we need to consider how an increase in *T* affects the aggregate commuting cost**
  - Aggregate commuting cost = $Tg(T)$ (#cars times cost per car)
- **The marginal cost is the effect of adding one extra car on the aggregate cost**
- **This can be found by taking the derivative of the aggregate cost with respect to *T***

$$MC = \frac{dTg(T)}{dT} = g(T) + Tg'(T)$$

Cost to the driver → $g(T)$

Externality damage → $Tg'(T)$

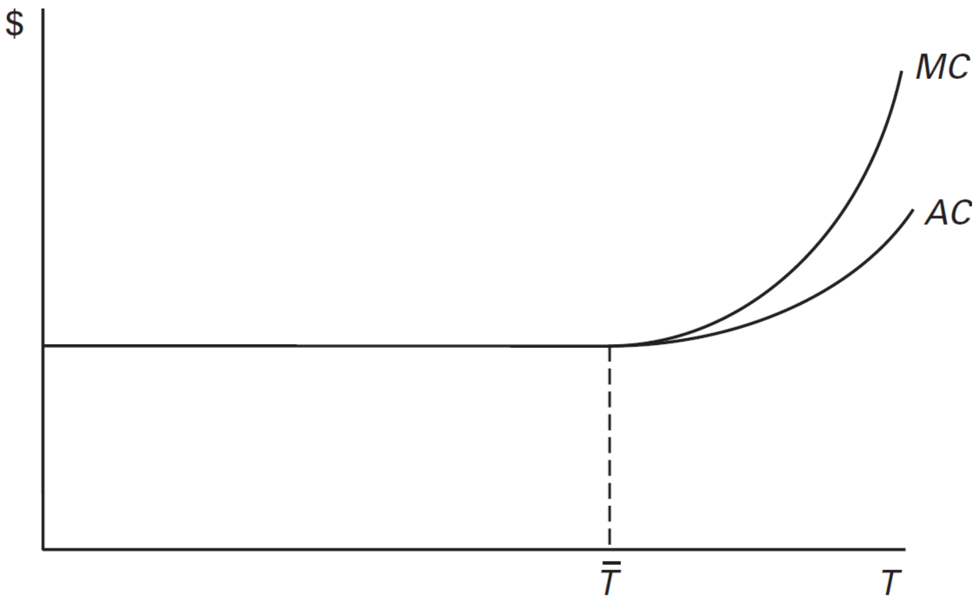
Private and social costs

- **In addition to the marginal cost, we have the average cost *AC***

$$AC = \frac{Tg(T)}{T} = g(T)$$

- **This means that**
  - *MC = AC + externality damage resulting from an added car*
- **In terms of private and social costs:**
  - *Social cost = private cost + externality damage*

Private and social costs



- Both *MC* and *AC* depend on the traffic volume *T*
- If the freeway is uncongested, the externality damage is zero (*MC* = *AC*)
- When the freeway is congested, the MC curve lies above the AC curve
- Vertical distance between the curves equals the externality damage from an added car

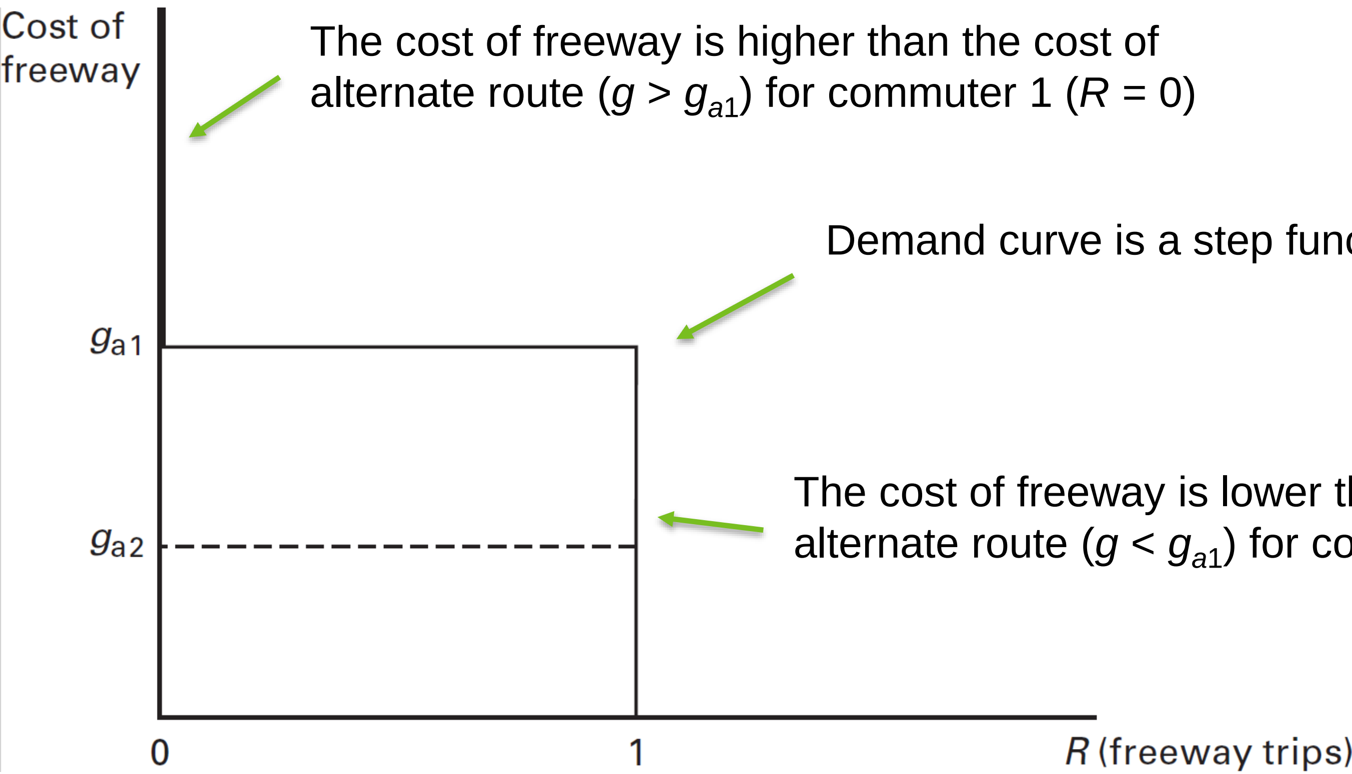
Demand for freeway use

- **To derive the demand for use of freeway, we need to consider the alternate routes that can be used to access the central city**
- **The best alternate route may differ across commuters**
  - Compare locations A and B in the spatial setting figure
- **The preferred alternate route is the one that has the lowest cost among the alternatives**
- **The lowest alternate cost is g_a, and it varies across commuters, whereas the cost of freeway is the same g for all**

Individual's demand for freeway

- **An individual's demand curve for use of the freeway gives the quantity chosen as a function of cost (price)**
- **For a single day, the quantity can either be 0 or 1**
  - The individual either uses the freeway (1) or doesn't (0)
  - In the latter case, the alternate route is used

Individual's demand for freeway

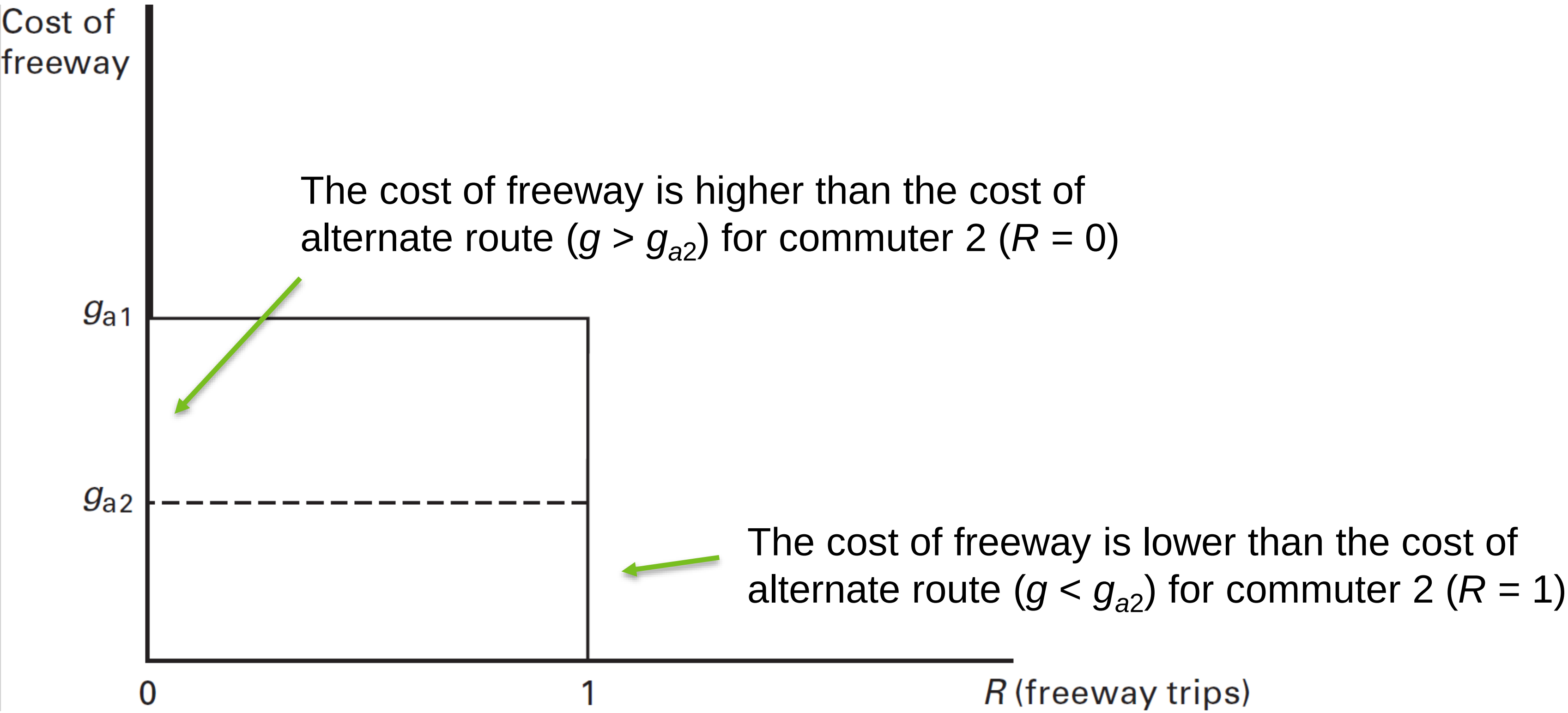


The cost of freeway is higher than the cost of alternate route ($g > g_{a1}$) for commuter 1 ($R = 0$)

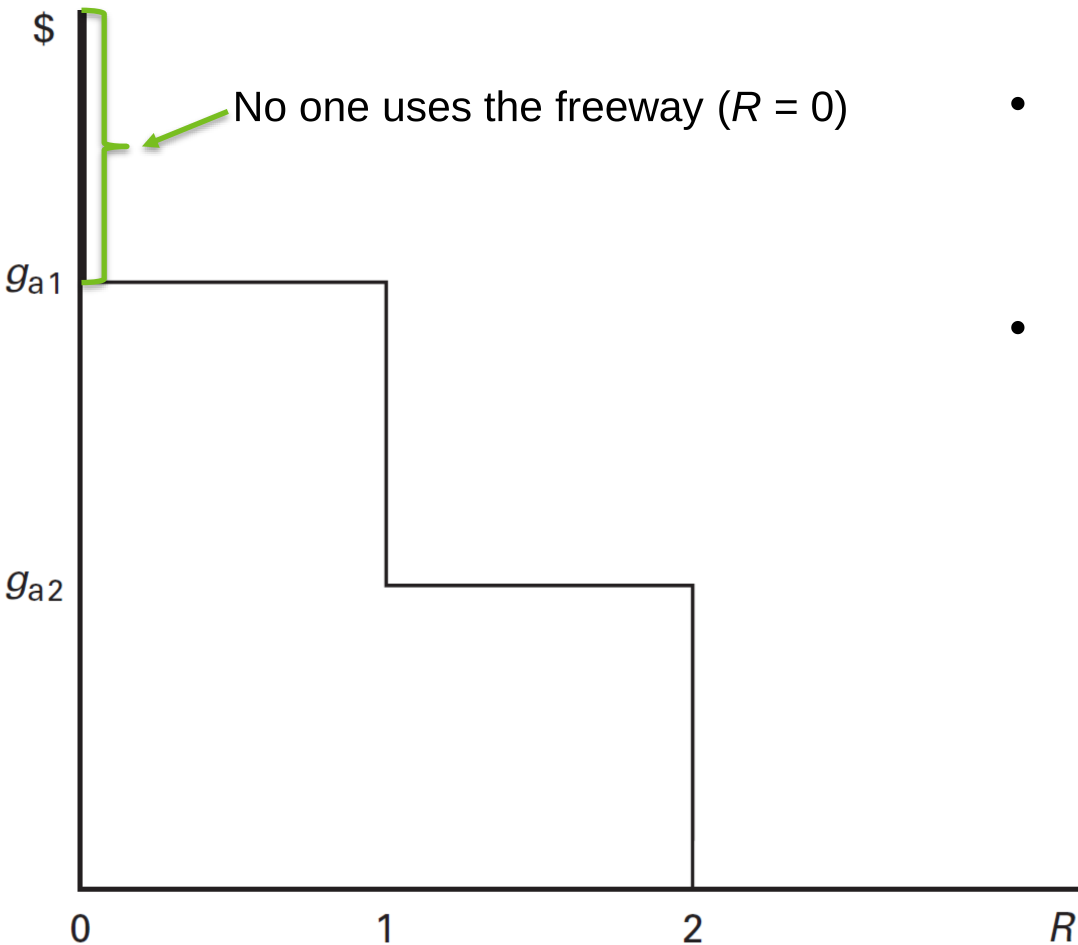
Demand curve is a step function

The cost of freeway is lower than the cost of alternate route ($g < g_{a1}$) for commuter 1 ($R = 1$)

Individual's demand for freeway

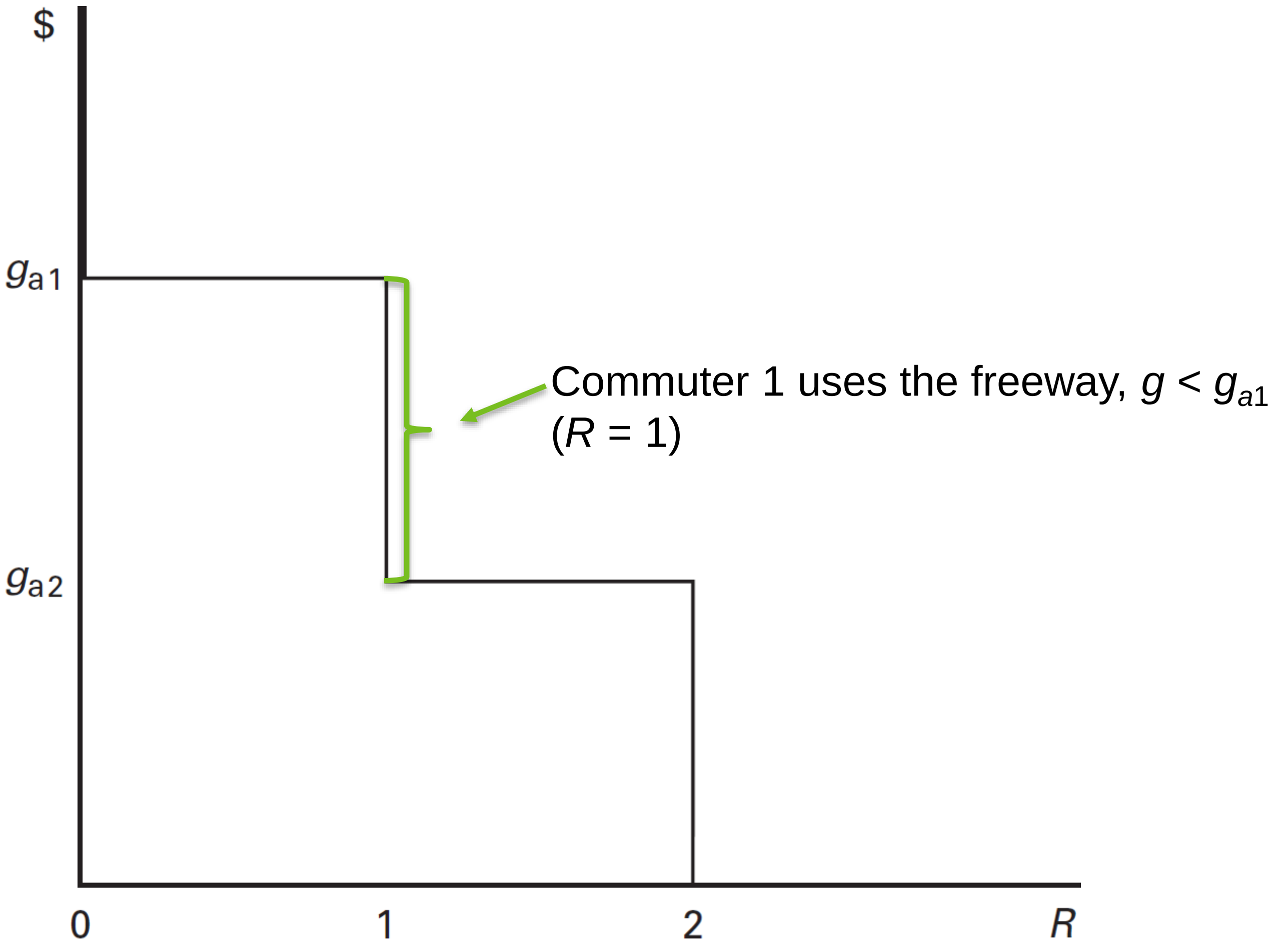


Aggregate demand for freeway

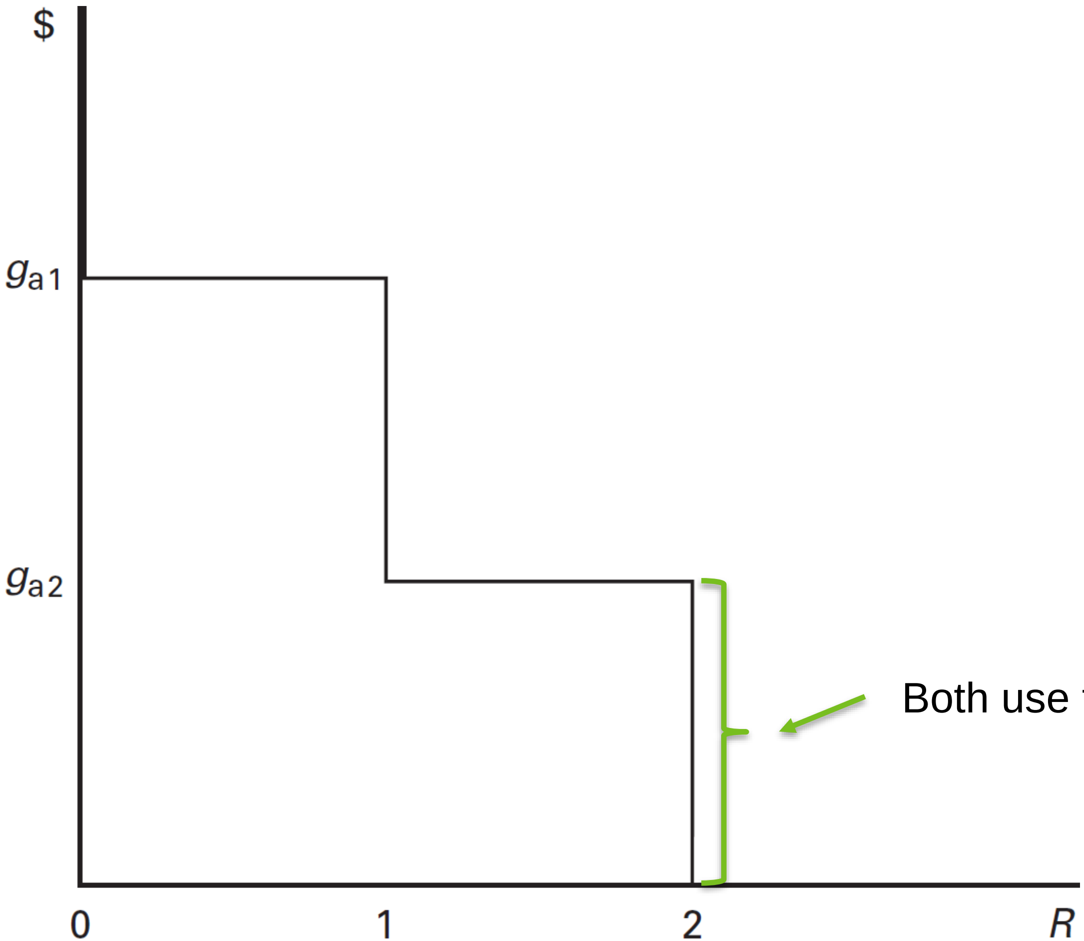


- With only these two commuters, the aggregate demand curve would look like this
- The aggregate demand curve is the horizontal sum of the individual curves

Aggregate demand for freeway



Aggregate demand for freeway

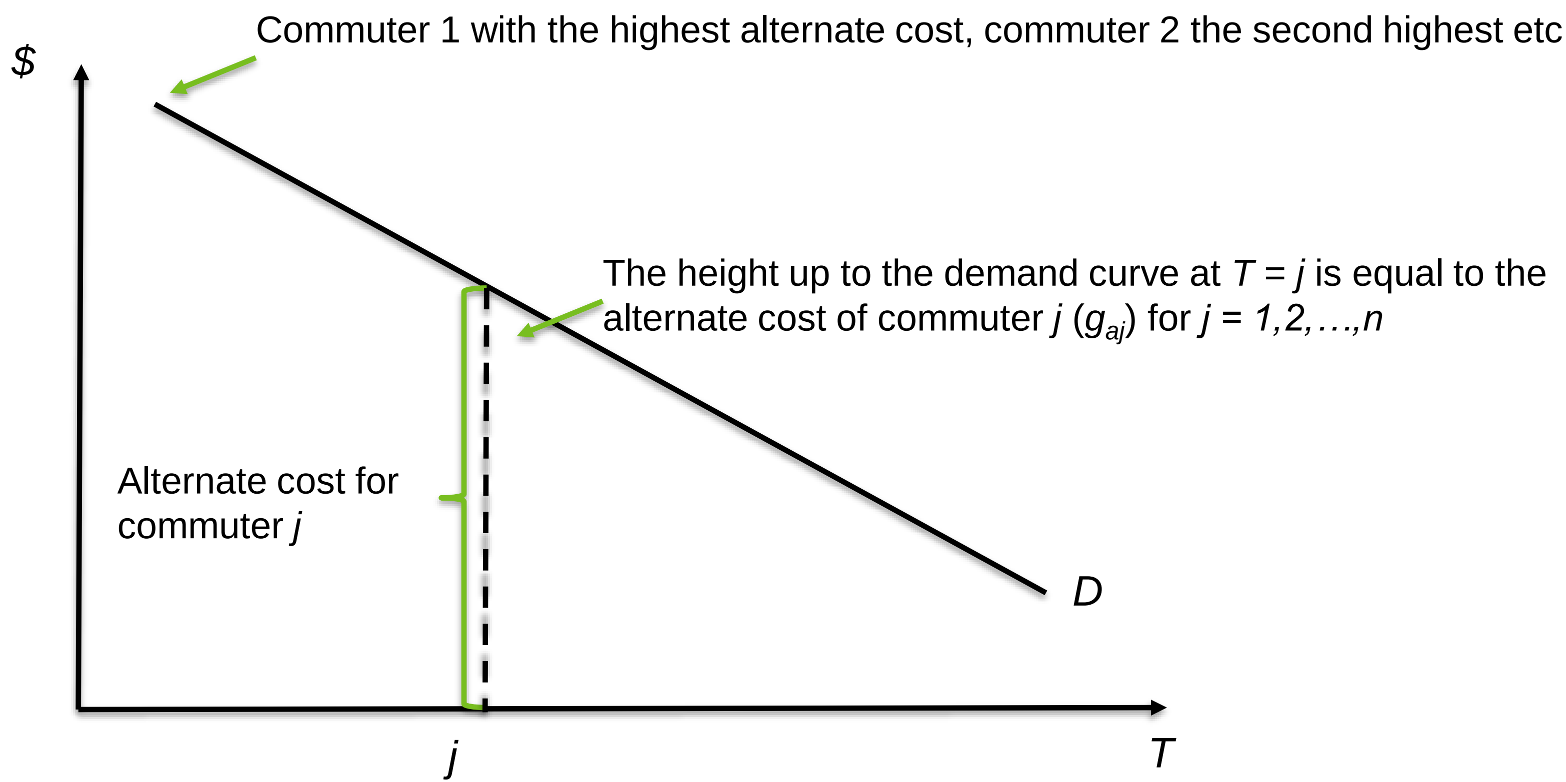


Both use the freeway, $g < g_{a2}$ ($R = 2$)

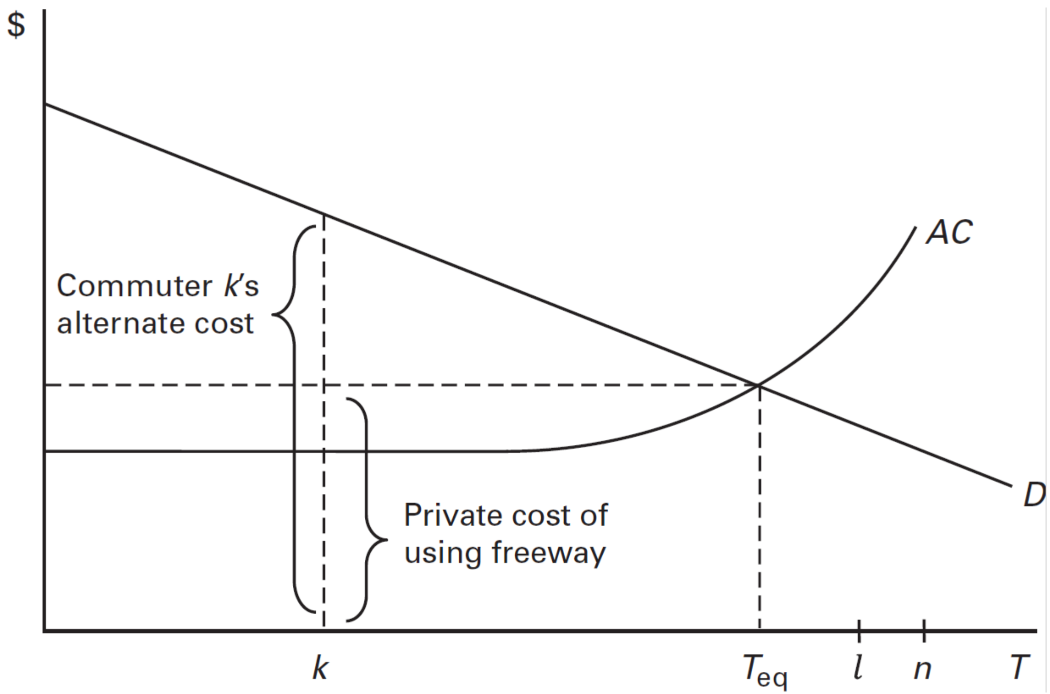
Aggregate demand with many commuters

- **When the suburb contains many commuters (*n*), each with a different alternate cost, the aggregate demand curve will be a step function with a large number of steps**
  - Each step will be very small and so the aggregate demand curve can be approximated with a smooth curve as shown in the figure on the next slide
- **In the figure, *R* is replaced with *T* on the horizontal as the number of trips equals the number of cars**

Aggregate demand with many commuters



Equilibrium



- In equilibrium, commuters 1 through T_{eq} use the freeway, while commuters T_{eq} + 1 use their alternate routes

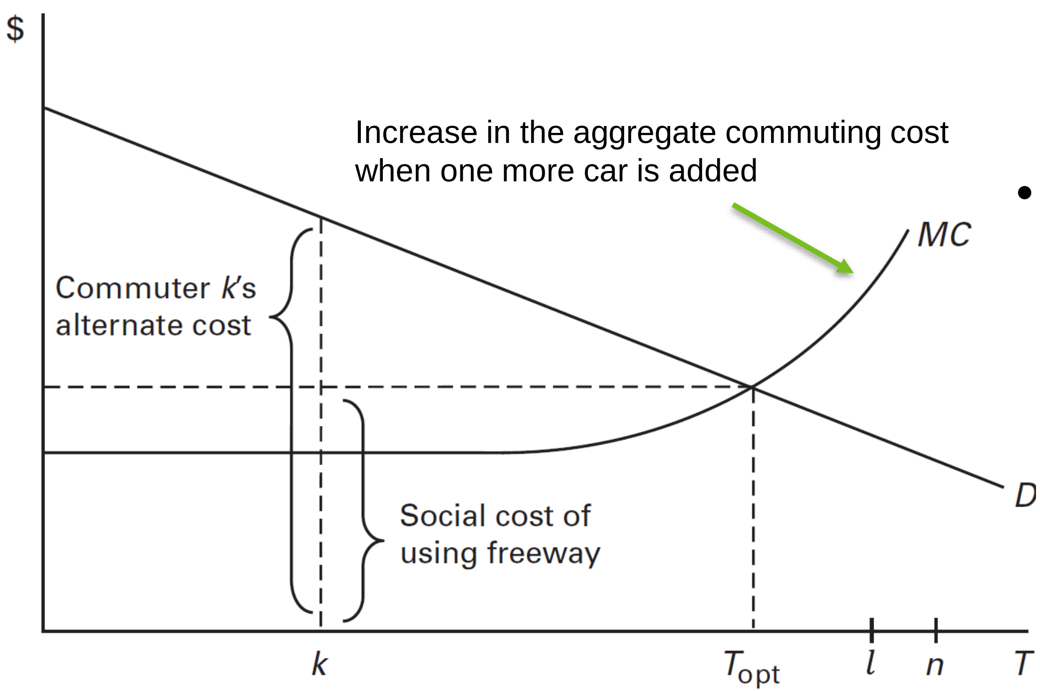
Here equilibrium means that no commuter has an incentive to switch routes

Check: Does commuter k have an incentive to switch? What about l?

Social optimum

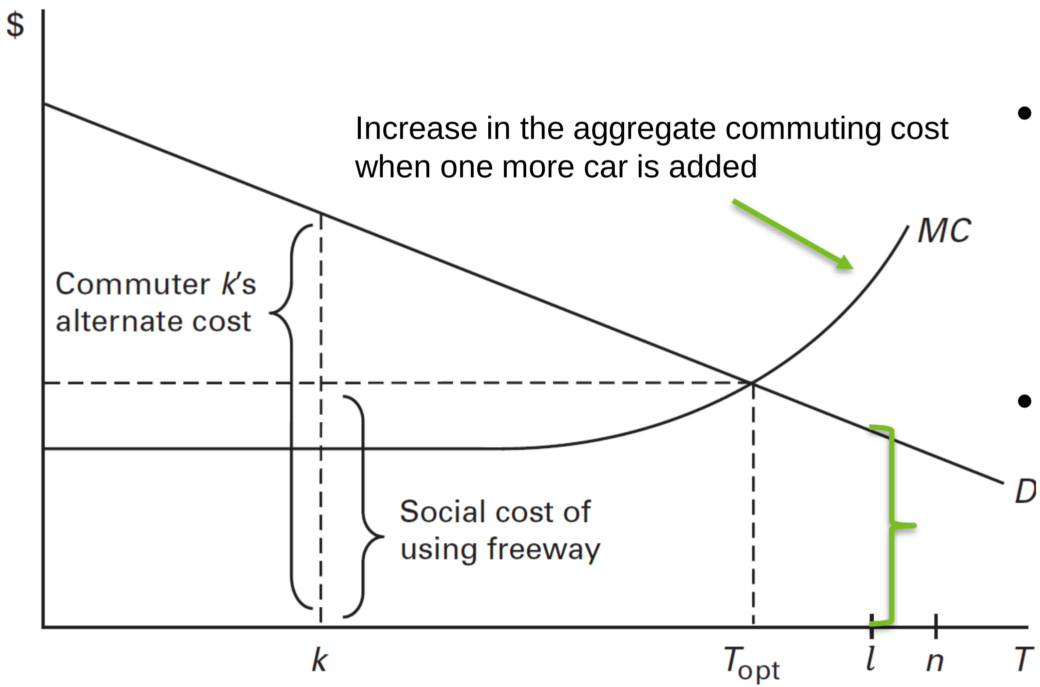
- **Socially optimal traffic allocation:**
  - Minimizes the total cost of commuting including the costs of both freeway users and alternate-route users
- **Or equivalently:**
  - Total commuting costs cannot be reduced by switching any commuter between routes
- **How would a social planner allocate commuters to the freeway and the alternate routes?**

Social optimum



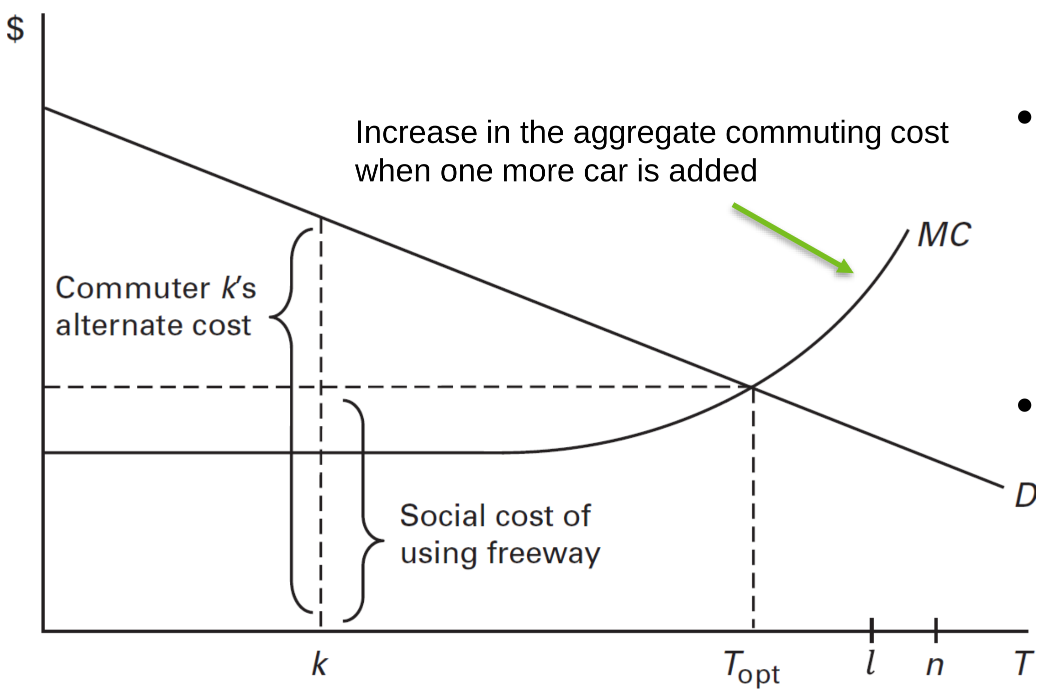
- In social optimum, commuters 1 through T_{opt} use the freeway, while commuters $T_{opt} + 1$ use their alternate routes
- To verify that this is optimal, we consider the effect of switching, for example, *k*'s or *l*'s route on total commuting costs

Social optimum



- Switching *l* to use the freeway increases the aggregate cost on the freeway by the height of the dashed line
- After switching, *l* does not incur her alternate cost, which is equal to the height of the demand curve at *l*
- However, the first height is larger than the second, so total costs of commuting would increase due to the switch

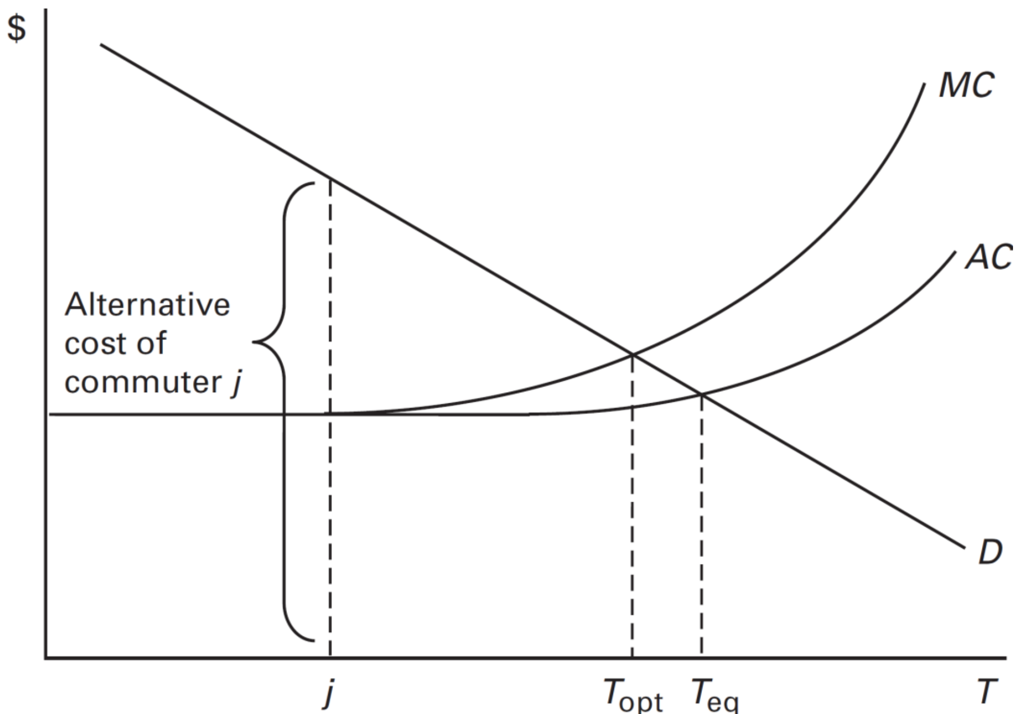
Social optimum



- Switching *k* to use her alternate route decreases the aggregate cost on the freeway by the height of the dashed line
- After switching, *k* incurs her alternate cost, which is equal to the height of the demand curve at *k*
- Now, the first height is smaller than the second, so total costs of commuting would again increase due to the switch

Equilibrium vs. social optimum

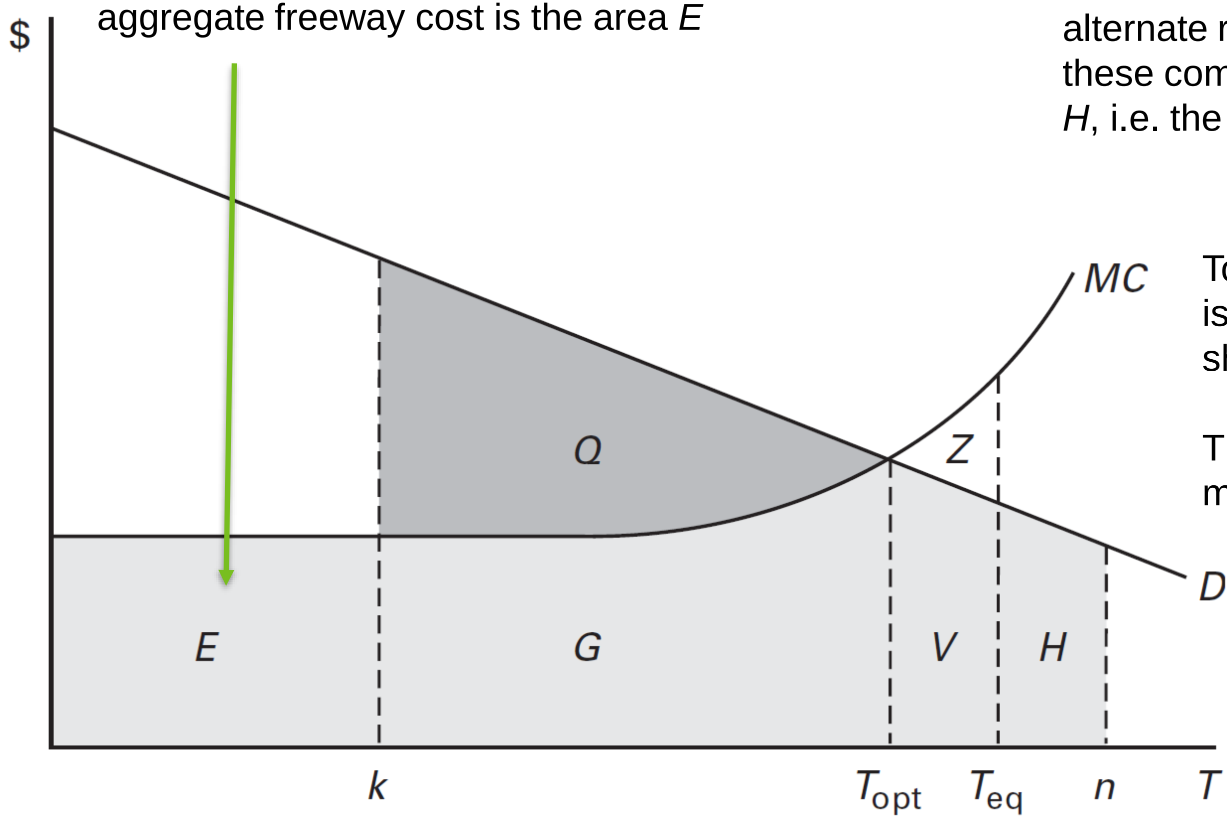
- $T_{\text{opt}} < T_{eq}$



Another approach to find the social optimum

If the freeway cutoff value is *k* the aggregate freeway cost is the area *E*

All commuters from *k* + 1 to *n* use their alternate routes. The aggregate cost for these commuters is the area *Q* + *G*+ *V* + *H*, i.e. the area under the demand curve



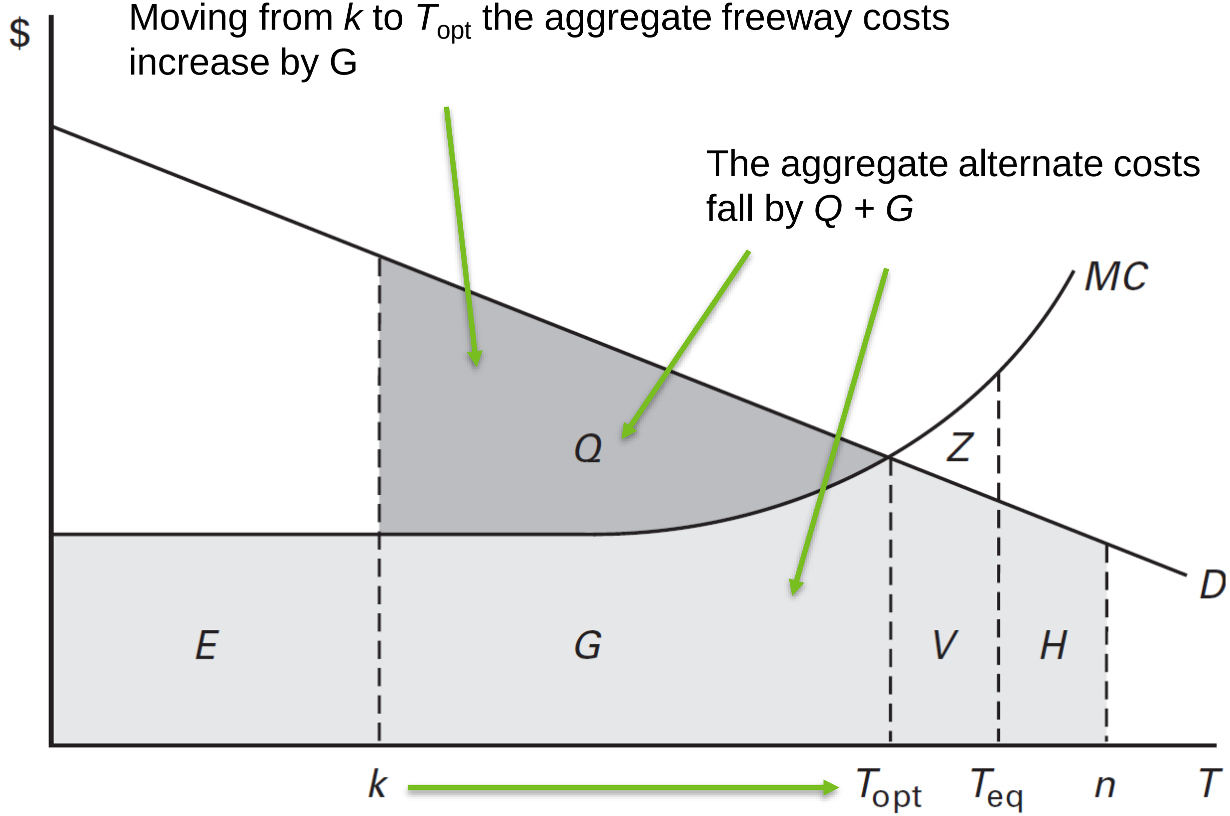
Total commuting costs under this scenario is equal to *E* + *Q* + *G*+ *V* + *H*, i.e. the shaded area in the figure

The optimal cutoff value is the one that minimizes the shaded area

Another approach to find the social optimum

Moving from k to T_{opt} the aggregate freeway costs increase by G

The aggregate alternate costs fall by $Q + G$



Total commuting costs decrease by $(G + Q) - G = Q$

Social optimum

- **Note that at the social optimum (*D* = *MC*) the *MC* curve is increasing meaning that the freeway remains congested**
- **This may seem counterintuitive**
- **However, commuters' alternatives are costly, and society will want to weigh these costs against the cost of freeway congestion**
- **Although congestion is too high in the equilibrium, reducing is to zero through a large diversion of traffic to alternate routes is not in society's interest**

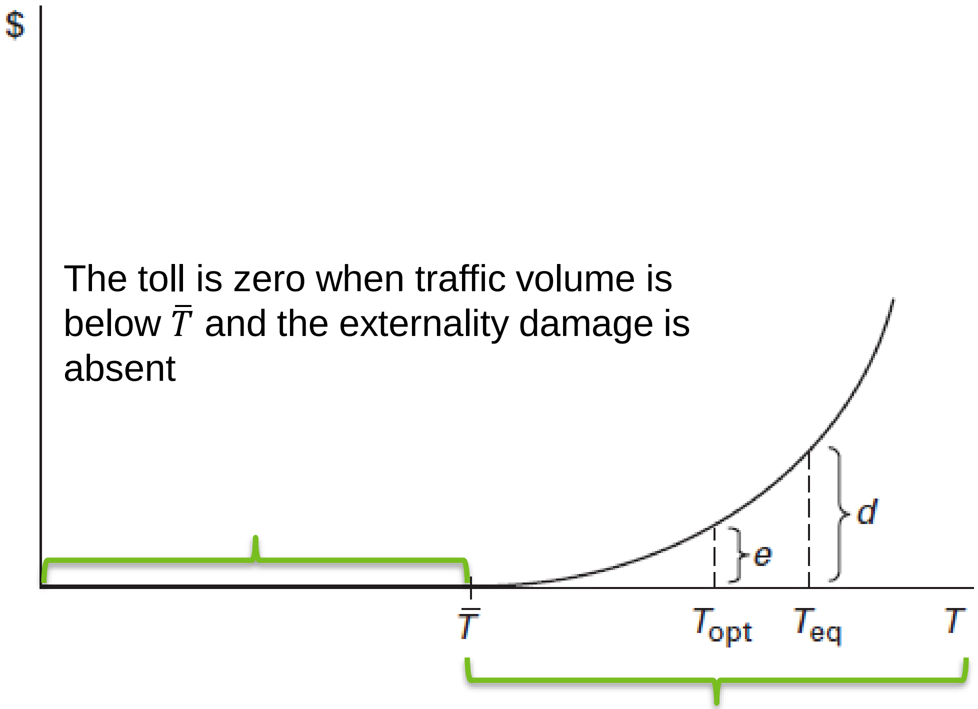
Congestion tolls

- **The equilibrium has too many freeway commuters**
  - No commuter has an incentive to consider the social cost of using the freeway, but focus instead on the smaller private cost
  - The freeway thus appears artificially cheap to commuters, with the result that some commuters use it when society would prefer that they took an alternate route instead
- **Society should ensure that their decisions mimic those of the social planner**
  - The commuters who should be diverted are those with the lowest alternate costs among the equilibrium group of freeway users

Congestion tolls

- **This outcome can be achieved by charging congestion tolls, which will raise the private cost of using the freeway until it coincides with the *MC* curve**
  - The toll must equal the vertical difference between the *MC* and *AC* curves, so that the new private-cost curve (given by the *AC* curve plus the toll) is the same as the *MC* curve
  - Since the vertical distance between the *MC* and *AC* curves is just the externality damage, the toll charges each commuter for this damage

Toll schedule



The toll is zero when traffic volume is below $\bar{T}$ and the externality damage is absent

The toll is positive when T is above $\bar{T}$

The social planner's toll schedule gives the toll per car as a function of traffic volume

The height of the schedule equals the vertical distance between the *MC* and *AC* curves

Optimal magnitude of congestion toll

- **The optimal magnitude for the toll is the one that results in the optimal level of traffic T_{opt}**
  - From the figure, we see that the optimal magnitude is equal to *e*
- **Importantly, the toll is the same for all freeway users regardless of the cost of their alternate route**
  - This is because freeway users impose the same externality cost on other users and must be charged symmetrically for that cost

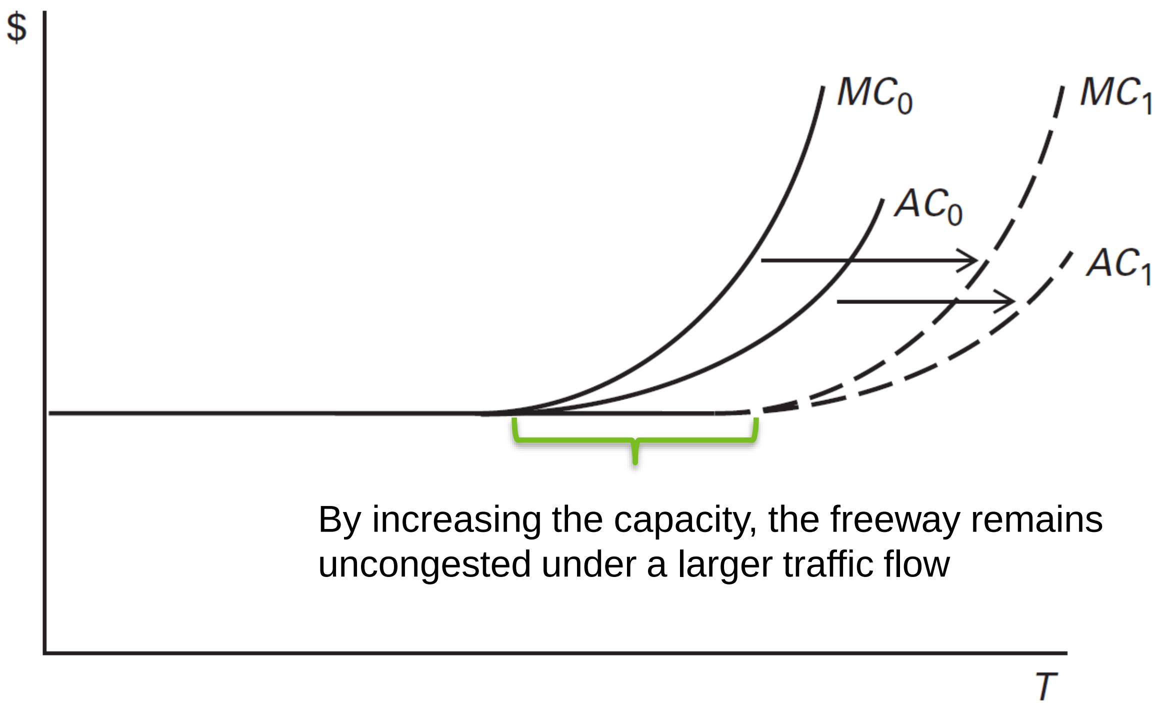
Time of day considerations

- **The freeway is less congested during off-peak hours**
- **In this case, the demand curve may intersect the *AC* and *MC* curves on their flat portion**
- **No congestion damage is present, and the congestion toll is unnecessary**
- **Ideally, the congestion-toll system would have tolls that vary by time of day**
- **Some freeway users may not be commuters and for them the alternate use might be the freeway at different hour**

Alternate price mechanisms

- **One often heard argument against tolls is that the gasoline tax already taxes car usage and raising gasoline would have the same effect as a congestion toll**
  - This is wrong because the gasoline tax is not targeted at congested freeways or other congested areas or congested times
- **Parking charges may have a similar effect on commuting as congestion tolls**
  - Workers may get free parking from their employer
  - If instead they would have to pay for parking and would get a raise instead, some would switch to public transit

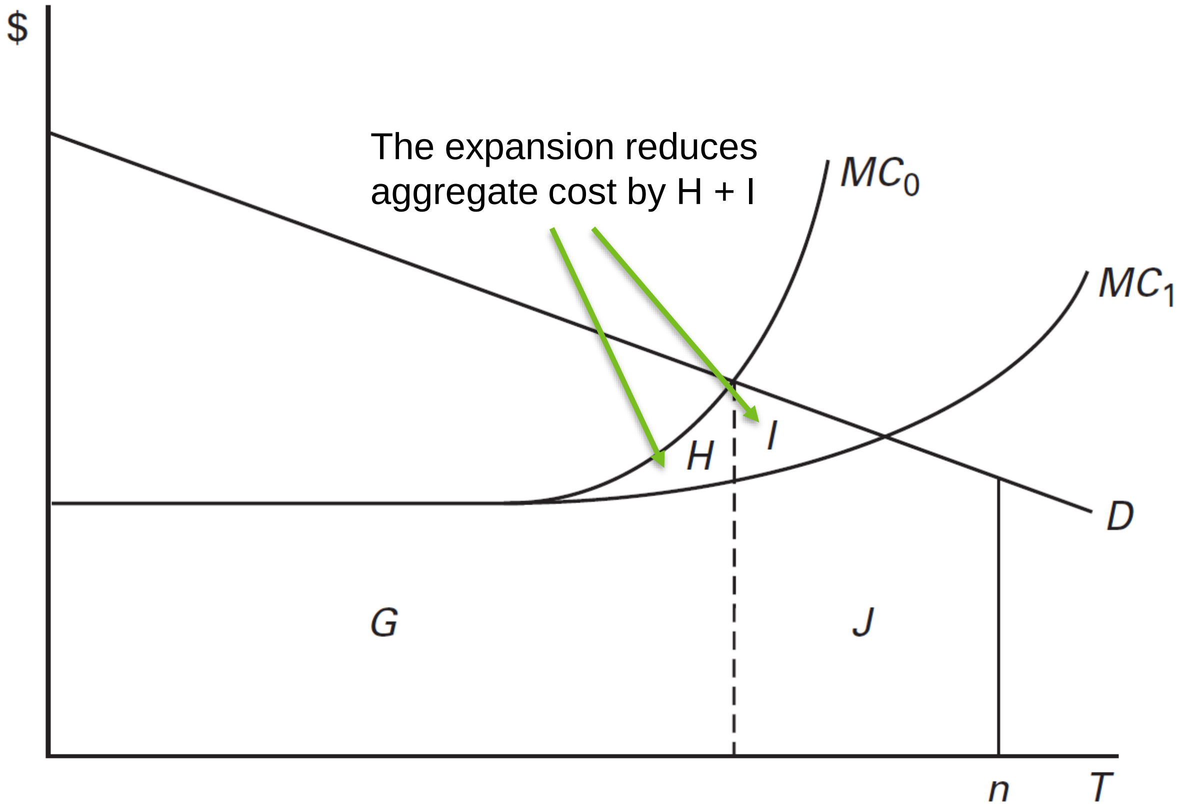
Choice of freeway capacity



The analysis so far has been conditional on the capacity of the freeway

Should we increase the capacity so that there is no congestion?

Choice of freeway capacity



The MC_0 curve refers to the smaller freeway and the MC_1 to the expanded freeway

If the cost of expansion is lower than $H + I$, the expansion is beneficial

At some point, the benefit will equal the cost and the freeway should not be expanded beyond this point

Choice of freeway capacity

- **This answer is that the optimal freeway should be congested**
- **This is because expanding the freeway, by adding lanes, is expensive**
  - Construction costs and the opportunity cost of land
- **The benefit from expanding the freeway is the reduction in total commuting costs**
- **At the optimum, the costs and benefits of expansion should be equal**
- **But this means that at the optimum there must be a positive benefit, i.e. there must be congestion!**

Evidence on real-world congestion tolls

- **Congestion tolls have been introduced in a number of cities in the 2000's**
  - London, Stockholm, Göteborg, Milan, Singapore
  - There is also a discussion whether Helsinki should introduce tolls, although this requires a law change
- **The effects of the tolls have been studied on several outcomes**
  - Traffic volume, traffic accidents, air quality, health outcomes, house prices

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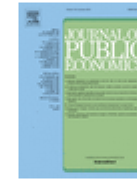
Journal of Public Economics

Volume 133, January 2016, Pages 11-22



Traffic accidents and the London congestion charge

Colin P. Green [a], John S. Heywood [b, a], María Navarro [a]

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https://doi.org/10.1016/j.jpubeco.2015.10.005

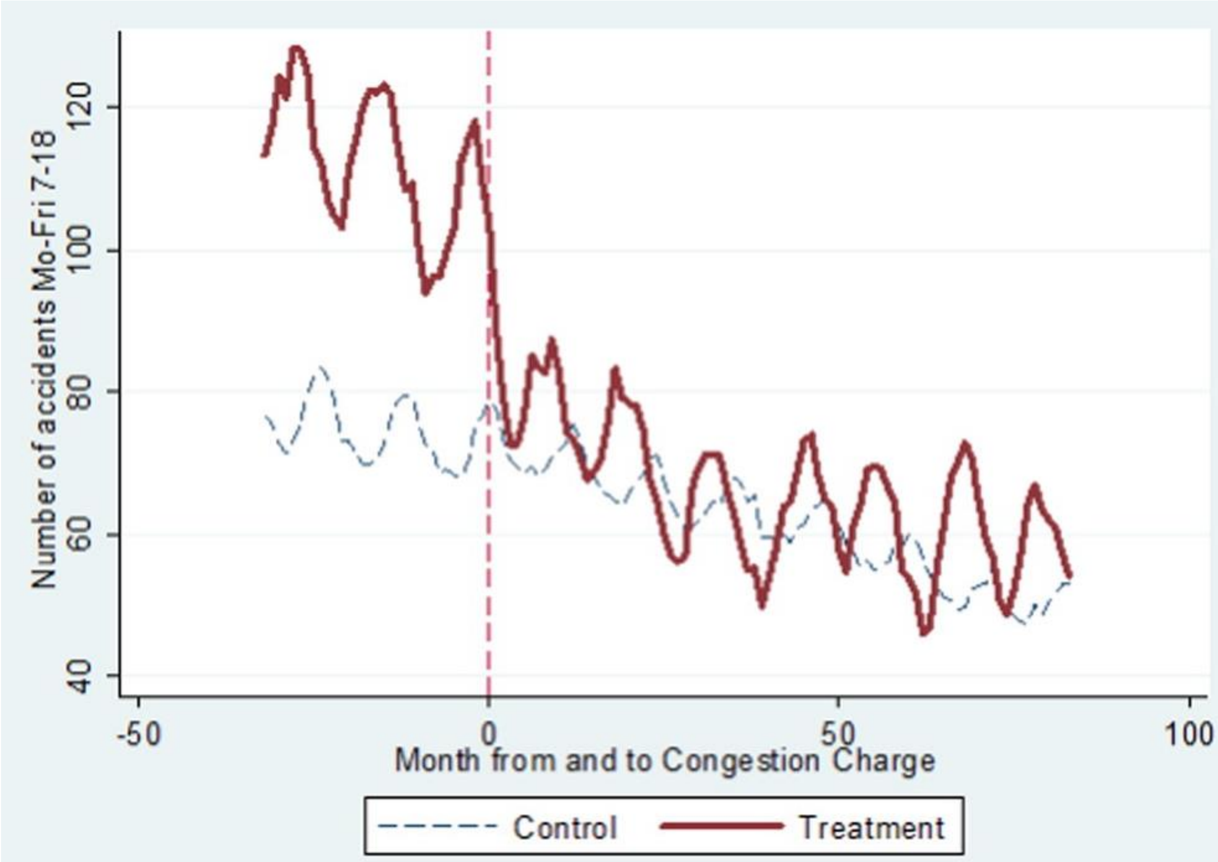
Highlights

- Estimate effect of London congestion charge on accidents and accident rates
- Theoretical effect is ambiguous, less traffic but higher speeds.
- Show robust, large reductions in number and rate of accidents and fatalities
- These reductions spill over to proximate areas, times and uncharged vehicles.

https://www.sciencedirect.com/science/article/pii/S0047272715001929

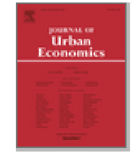

Regent's Park
King's Cross
St. Pancras
Euston
Angel
Marylebone
Russell Square
Oxford Circus
Marble Arch
Mayfair
Holborn
City Thameslink
Liverpool Street
Old Street
Bank
Aldgate
Blackfriars
Cannon Street
Fenchurch Street
Tower Bridge
Marble Arch
Piccadilly Circus
Hyde Park
Hyde Park Corner
Trafalgar Square
Charing Cross
Waterloo
London Bridge
Westminster
Knightsbridge
Victoria
Victoria
Elephant & Castle
Vauxhall Bridge
River Thames
HAMPSTEAD ROAD
EUSTON ROAD
PENTONVILLE ROAD
CITY ROAD
HACKNEY ROAD
MARYLEBONE ROAD
TOTTENHAM COURT ROAD
CLERKENWELL ROAD
OLD ST.
EDGWARE ROAD
HIGH HOLBORN
OXFORD STREET
CHEAPSIDE
BISHOPSGATE
COMMERCIAL STREET
WHITECHAPEL ROAD
BAYSWATER ROAD
PARK LANE
CHARING CROSS ROAD
FLEET STREET
LUDGATE HILL
STRAND
PICCADILLY
KENSINGTON ROAD
WATERLOO ROAD
BOROUGH HIGH ST.
TOWER BRIDGE ROAD
MILLBANK
NEW KENT ROAD
VAUXHALL BRIDGE ROAD
KENNINGTON LANE
KENNINGTON PARK RD
OLD KENT ROAD
GROSVENOR ROAD
Central London congestion charging zone

Accidents in London vs. 20 other major cities



Milan example

Journal of Urban Economics
Volume 89, September 2015, Pages 62-73



The effects of road pricing on driver behavior and air pollution

Matthew Gibson [a], Maria Carnovale [b]

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https://doi.org/10.1016/j.jue.2015.06.005

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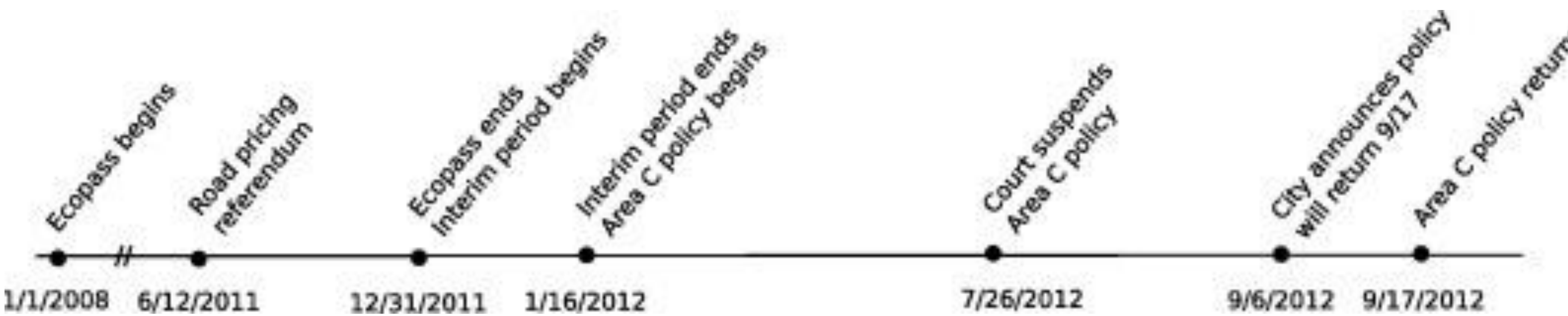
Abstract

Exploiting the natural experiment created by an unanticipated court injunction, we evaluate driver responses to road pricing. We find evidence of intertemporal substitution toward unpriced times and spatial substitution toward unpriced roads. The effect on traffic volume varies with public transit availability. Net of these responses, Milan's pricing policy reduces air pollution substantially, generating large welfare gains. In addition, we use long-run policy changes to estimate price elasticities.

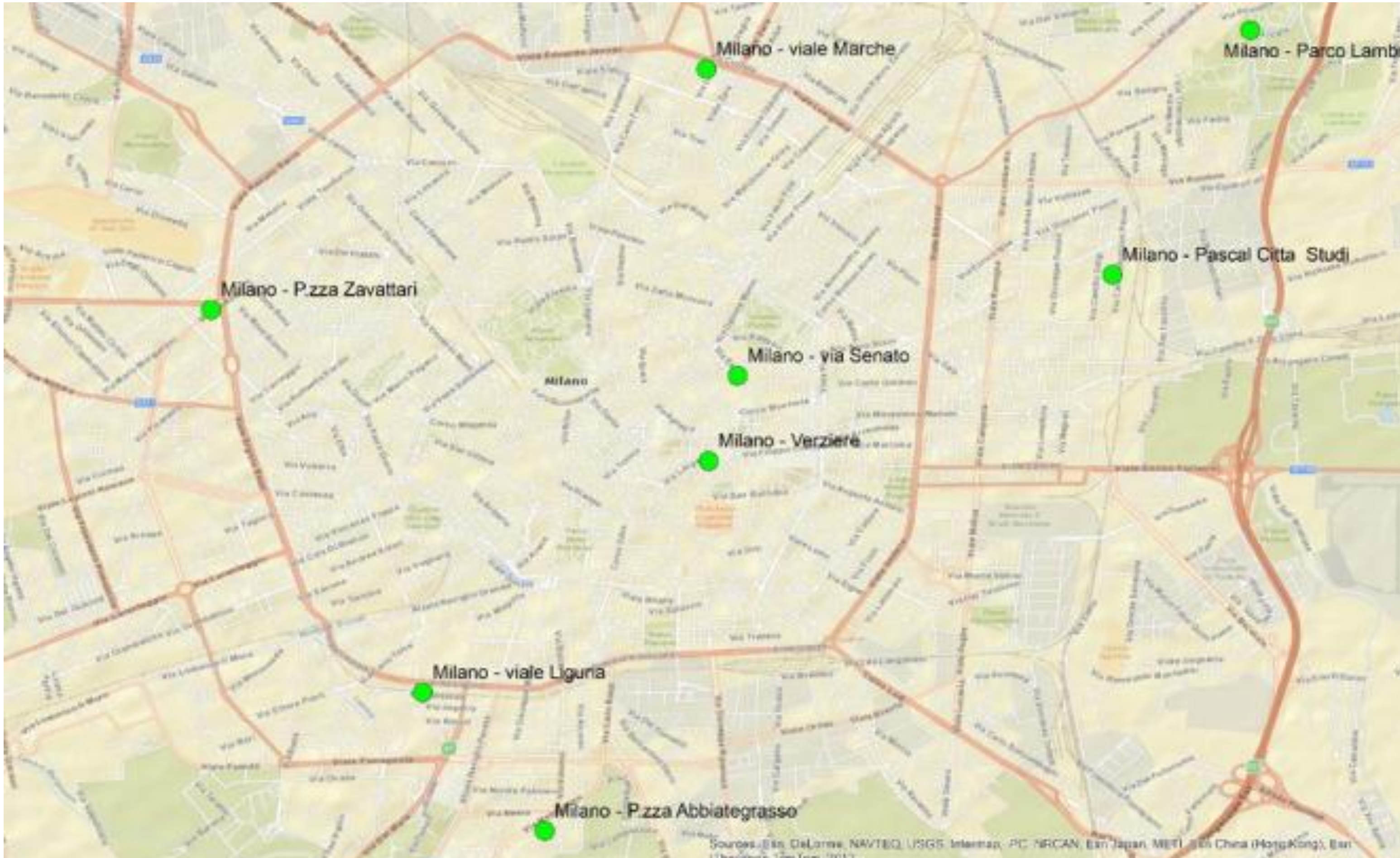
https://www.sciencedirect.com/science/article/pii/S0094119015000467

Milan’s quasi-experiment

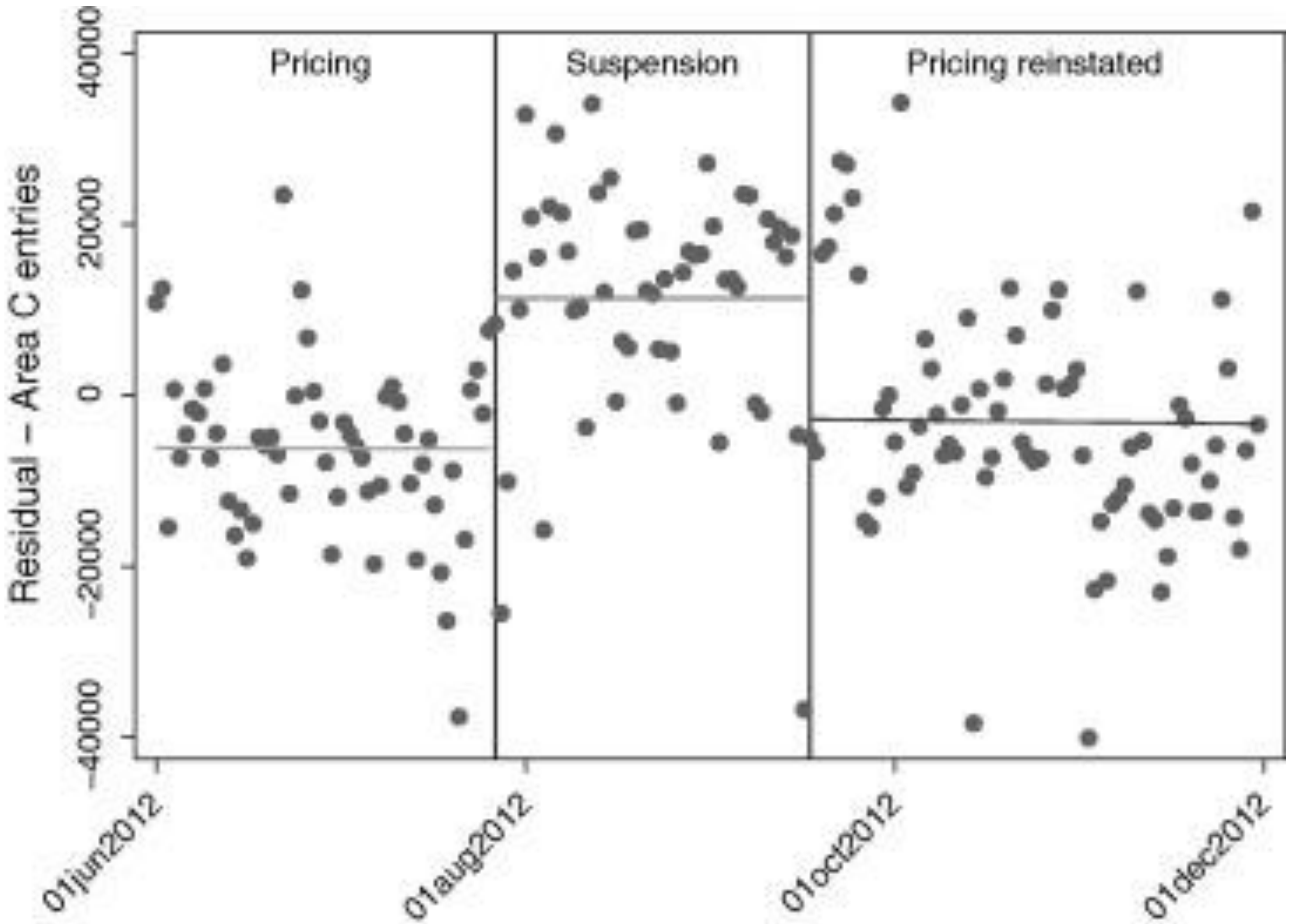
- **In late July 2012, an Italian court unexpectedly suspended Milan’s road pricing policy, called “Area C”**
- **The city reinstated pricing eight weeks later**
- **Using unique traffic data at 15-min resolution, our study examines behavioral responses to Milan’s policy, which requires drivers entering the city center to pay €5 on weekdays 7:30AM–7:30PM**



Milan’s quasi-experiment



Results – driving



Results – pollution

Table 6. Weekday pollution effect of Area C charge suspension, by location.

	ln(CO)	ln(PM10)	ln(PM2.5)
Area C	0.0606**	0.0404	
	(0.0248)	(0.0407)	
Ring roads	0.0182		
	0.0205		
Outside		0.1696**	0.2139*
		(0.0676)	(0.1210)
Lagged pollution	Yes	Yes	Yes
Weather controls	Yes	Yes	Yes
Year, month, week, DoW FEs	Yes	Yes	Yes
7th-deg. trend in date	Yes	Yes	Yes

Stockholm example

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Congestion charges and children’s health

Emilia Simeonova, Janet Currie, J Peter Nilsson, Reed Walker 08 July 2018

Traffic congestion is a major problem for urban centres. Among various negative externalities, traffic creates substantial pollution which can impact the health of residents. This column explores how the implementation of a congestion pricing zone affected the health of children in Stockholm. The programme saw short-term reductions in common traffic pollutants and an accompanying decrease in children’s hospital visits for acute asthma. This decrease grew larger the longer the tax was in place.

https://voxeu.org/article/congestion-charges-and-children-s-health

Recap

- **Freeway congestion involves an externality and as a result, freeways are overused**
- **Congestion tolls can be used to decrease traffic to a socially optimal level**
- **Tolls should depend on the time of day**
- **Increasing freeway capacity can also relief congestion, but at optimal capacity congestion is not zero**
- **Empirical evidence from different cities suggests that congestion tolls have been successful in increasing traffic speed, reducing accidents and improving air quality**