Markets for Transport: Eliminating Congestion through Scheduling, Routing, and Real-time Pricing

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In Gratitude

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Based on joint work with Peter Cramton and Axel Ockenfels

"Bringing the Efficiency of Electricity Market Mechanisms to Multimodal Mobility across Congested Transportation Systems," (Peter Cramton, Arash Beheshtian, R. Richard Geddes, Omid M. Rouhani, Kara M. Kockelman, Axel Ockenfels, Wooseok Do) *Transportation Research Part A: Policy and Practice*, 131, 58-69, 2020.

"Using Technology to Eliminate Traffic Congestion," (Peter Cramton, R. Richard Geddes and Axel Ockenfels) *Journal of Institutional and Theoretical Economics*, 175:1, 126-139, 2019.

"Set Road Charges in Real Time to Ease Traffic," (Peter Cramton, R. Richard Geddes and Axel Ockenfels) *Nature*, 23-25, 2 August 2018.

"Markets for Road Use: Eliminating Congestion through Scheduling, Routing, and Real-time Road Pricing," (Peter Cramton, R. Richard Geddes and Axel Ockenfels) Working Paper, University of Cologne, April 2019 [Presentation, German press, Wall Street Journal, New York Times].

Outline

I. Some History
II. Costs of Traffic Congestion
III. Disruptive Automotive Developments
IV. A Vision for the Future of Transportation
V. Applying Coasian Analysis to Traffic Congestion
VI. William Vickrey and Traffic Congestion
VII. The Role of the Independent System Operator
VIII. The Role of Service Providers
IX. Equity Considerations/Duranton and Turner
X. Directions for Future Research

Some History

- **Karl Benz** patents first mass-production car in Mannheim in **1885**
- **Benz Patent-Motorwagen** considered the first practical modern automobile
- First car put into **series production**
- Steered by driver via **line-of-sight**
- Internal combustion engine
- Developments over **past 140 years** mostly extensions of this technology!

- Surface transport ripe for disruption!

Benz’ Invention has Created Unprecedented Mobility!

Growing Costs of Automotive Technology

Traffic Congestion

* INRIX recently released its "2024 INRIX Global Traffic Scorecard"

* The average annual amount of travel delay was 43 hours in the U.S., 43 hours in Germany, and 62 hours in the U.K.

Other negative effects of traffic congestion:

- Worsens air pollution
- Harms health
- Increases obesity
- Increases divorce rates
- Growing over time with increases in wealth and densification globally

Health and Traffic Congestion

"Air pollution from traffic congestion in 83 of the nation's largest urban areas contributes to more than 2,200 premature deaths annually, costing the health system at least $18 billion, according to a study by Harvard School of Public Health (HSPH) researchers featured May 25, 2011, in USA Today."

Total annual 2024 congestion cost in the top 10 U.S. metro areas (INRIX 2024)

New York	**$9.5 billion**
Los Angeles	$8.5 billion
Chicago	$6.6 billion
Houston	$3.5 billion
Miami	$3.4 billion
Philadelphia	$3.3 billion
Atlanta	$2.9 billion
Washington, D.C.	$2.8 billion
Boston	$2.7 billion
Dallas	$2.4 billion

Growing Costs of Automotive Technology: **Traffic Accidents** (1)

The Six Leading Causes of Death caused by unintentional injury in 2023 (National Safety Council)

#3: Motor-vehicle crashes: 44,762 deaths

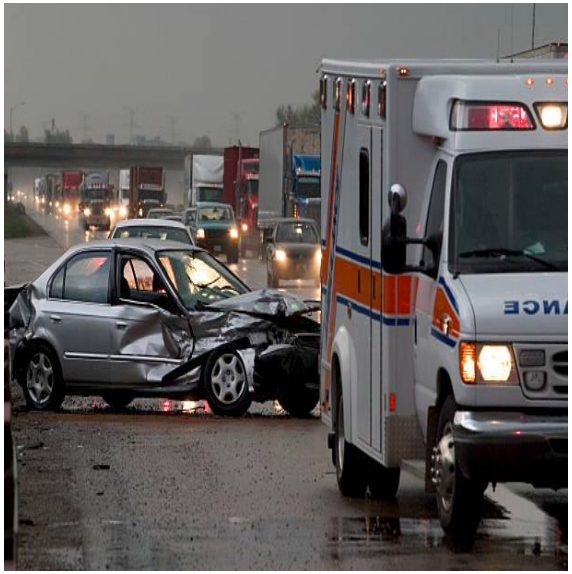
- Average rate of 13.4 deaths per 100,000 population
- **Death rate peaks at 20.2 for 21-year-olds** and again at 23.2 for 91-year-olds
- **Leading cause of preventable death** for every age from 5 to 22
- **Second leading cause of preventable death** for every age from 23 to 67

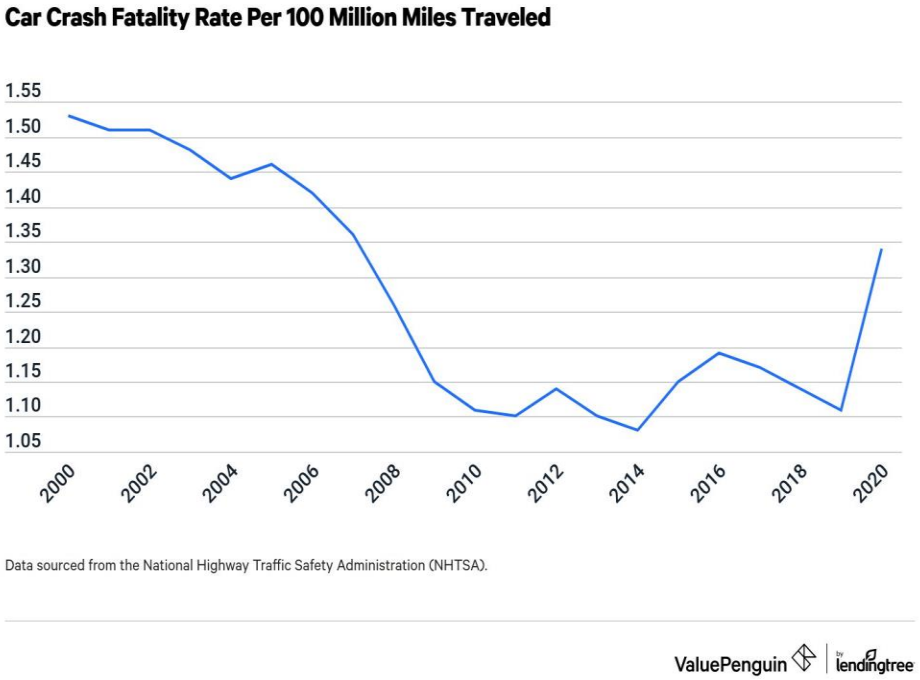
High Costs of Automotive Technology: **Traffic Accidents** (2)

U.S. highway deaths in perspective:

- U.S. traffic accidents killing the same number of (mostly) young people in about **16 months** as all U.S. soldiers who died in the Vietnam War (57,939)
- Traffic accidents killing the same number who died on September 11th in about **24 days**
- Should promote economic policies that reduce those numbers

High Costs of Automotive Technology: **Traffic Accidents** (3)





Recent Disruptive Automotive Developments (1)

- Developments in **autonomous/driverless vehicles**
- Developments in **location technology/kinematics**
- Developments in **alternative fuels** (including hydrogen)
- Developments in **market design**

- implement transparent and efficient pricing in transportation is certain. The platform is built and is available open access and open source. The team that did the development is here: https://forwardmarketdesign.com/. Any country in any sector can reach out for help in how to customize the platform for the needs of their country and sector.

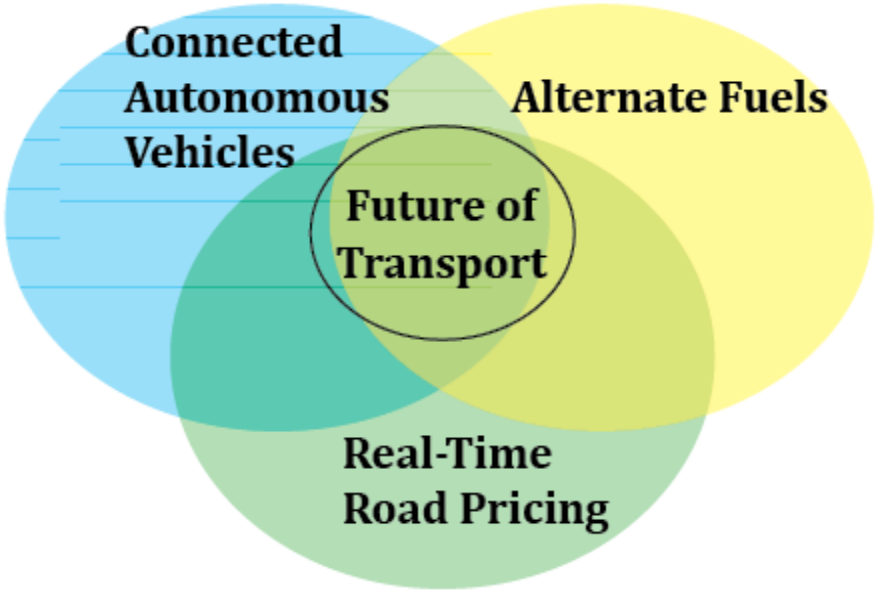
Recent Disruptive Automotive Developments (2)

- Policy Developments: Now have the ability to implement transparent and efficient pricing in transportation!
- Platform is built and is available open access and open source
- See: https://forwardmarketdesign.com/
- Any country in any sector can customize the platform for the needs of their country and sector

Examples of Disruption: Cavnue in Michigan

- Cavnue is a **40-mile driverless vehicle corridor** between Downtown Detroit and Ann Arbor
- **Dedicated lanes** along a segment of **Interstate 94**
- Cavnue opened to traffic in July 2024
- All traffic could be guided by road prices
- See Cavnue video

An Inspirational Vision: The Future of Transportation



Key Insights

- Technological progress being made on **CAVs and alternate fuels**
- Value of that progress **is limited** if those vehicles are struck in traffic!
- Progress needs to be made on **real-time, network-wide road pricing**
- With these three elements, transport would be a **safe, reliable, and efficient service!**
- **Free-flow traffic** and **autonomy** are likely to be **complements**

Simple analysis of traffic congestion

- A shortage of road space during peak times
- The unit price of road use cannot adjust in real time

Figure 1. Market for Road Services: New Jersey Turnpike at 4 AM.

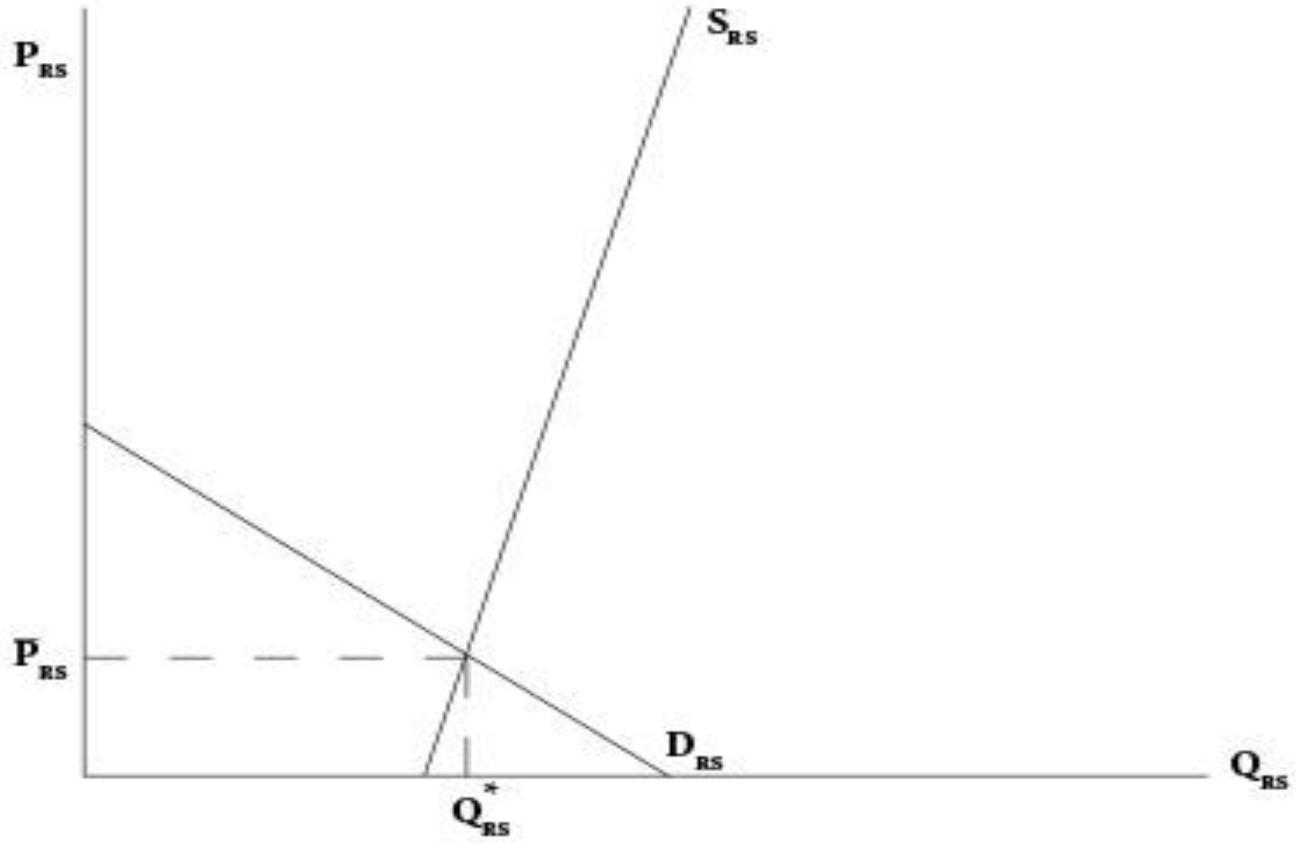
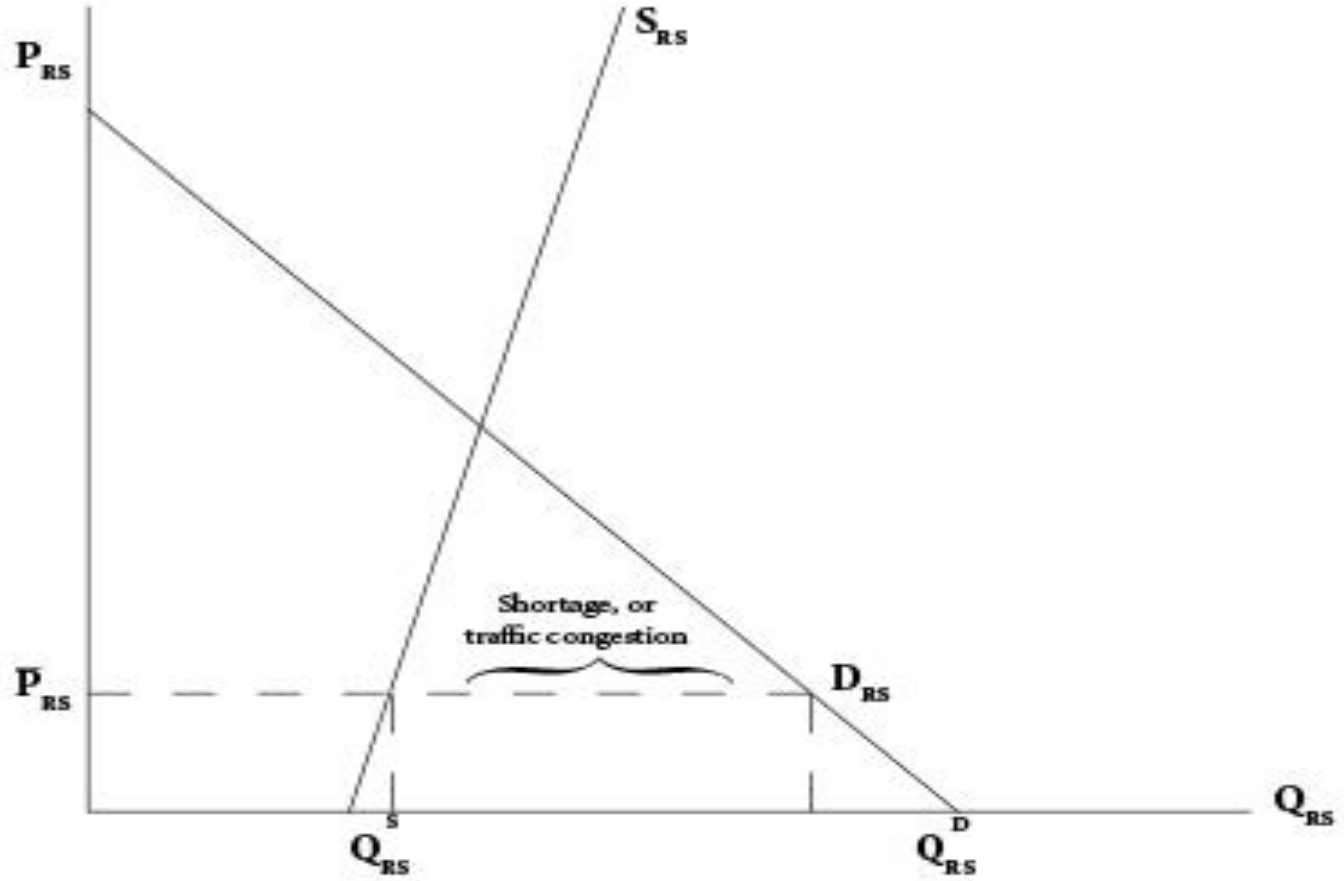


Figure 2. Market for Road Services: New Jersey Turnpike at 8 AM.



Traffic congestion has an added complexity:

The users of road and other transportation networks not only experience congestion, they create it. In deciding how and when to travel, most travelers take into account the congestion they expect to experience; few consider the costs their trips impose on others by adding to congestion.

-- Herbert Mohring (2001)

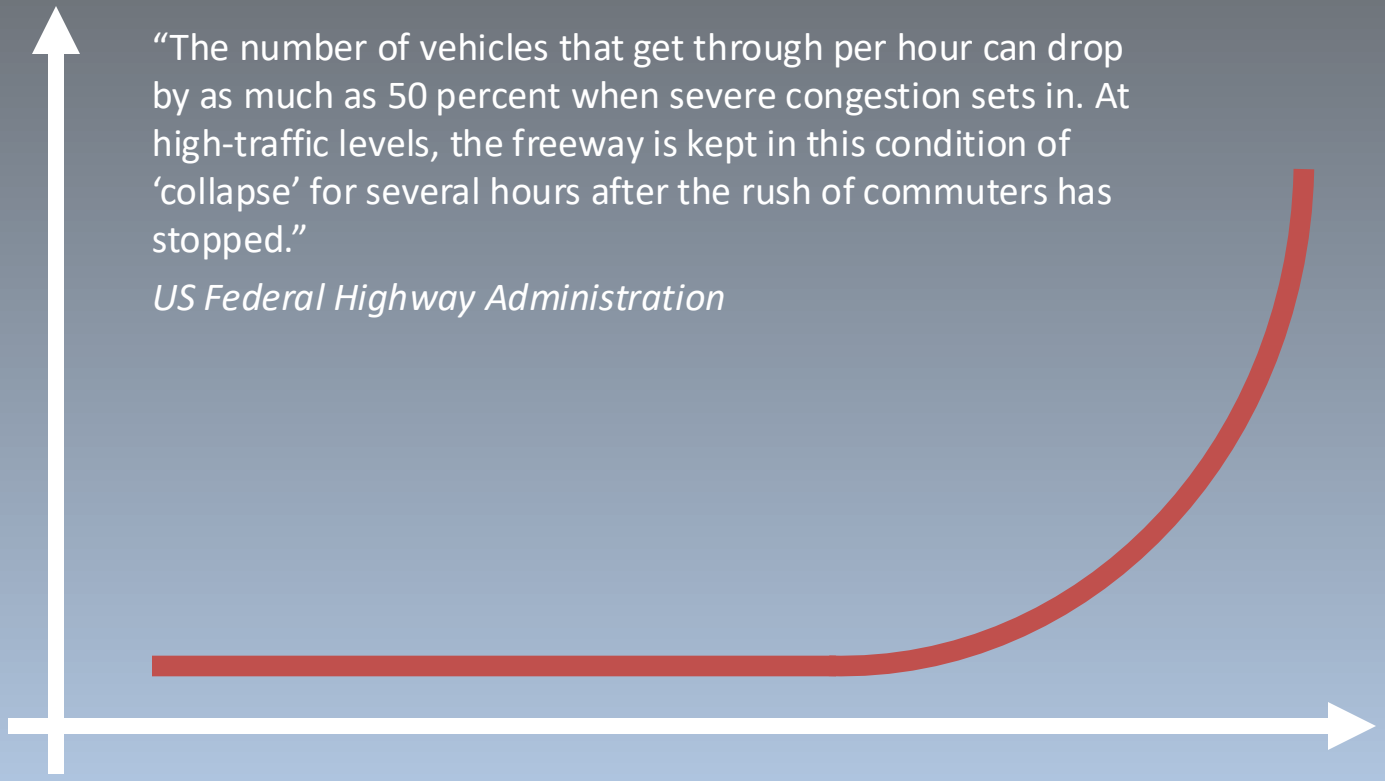
Non-linearity of social cost (i.e., congestion) in traffic volume

- As the number of vehicles per hour increases, the **social costs** in terms of congestion imposed on the facility **increase exponentially**
- Once traffic volume hits a certain point, facility **through-put collapses** (i.e., “gridlock”)
- This effect **works in both directions**!

Travel time

"The number of vehicles that get through per hour can drop by as much as 50 percent when severe congestion sets in. At high-traffic levels, the freeway is kept in this condition of 'collapse' for several hours after the rush of commuters has stopped."

US Federal Highway Administration



Traffic
(vehicles per hour)

William S. Vickrey and Congestion Pricing

William Vickrey, "Pricing and Resource Allocation in Transportation and Public Utilities," *American Economic Review*, May **1963**:

> *I will begin with the proposition that in no other major area are pricing practices so irrational, so out of date, and so conducive to waste as in urban transportation. Two aspects are particularly deficient: the absence of peak-off differentials and the gross underpricing of some modes relative to others.*

Benefits of Congestion Pricing: Demand Side

- Addresses congestion externality (Vickrey 1963; Nobel Prize 1996)
- Addresses environmental externality
- Encourages drivers to explore travel alternatives during peak times
- Simplifies consumer decision-making
- Improves safety
- Allows joint optimization of all transport modes (roads and transit)

Benefits of Congestion Pricing: Supply Side

- Provides essential information to direct scarce investment resources
- Generates the funds that underlie that investment with non-distortionary taxes
- Allows scarce road space to be allocated to the highest valued use (not politically)
- Incentivizes technological innovations that reduce demands on scarce capacity

Applying **Coasian Analysis** to Externality/Commons Problems

Three key steps to apply a **Coasian solution** an externality/commons problem:

1. Cleary define **excludable use rights** to the resource (*ius utendi*)
2. Make those rights **tradable** (i.e., create a market for the rights, *ius proprietatis transferri,* which generates prices)
3. Work to **reduce transaction costs** in the market for those rights to increase price accuracy

Extant Applications of Coasian Analysis

- **Tradable permits for sulfur dioxide** and **nitrogen oxide emissions** creating "cap and trade" market (Schmalensee and Stevins 2013, JEP)
- **Individual Transferable Quotas (ITQs)** to address overfishing, i.e., the commons problem (Hoshino et al, 2020)
- **Radio spectrum auctions** to address negative externality of interference (Myers 2023)
- **Auctions of airport takeoff-landing slots** to address congestion (Liu et al 2022)
- **Auction/price mechanism for immigration slots** (Becker and Lazear 2013, Orrenius and Zavodny 2020, Lazear and Ray 2021)

The Independent System Operator (ISO) in Energy

- An Independent System Operator (ISO) in energy is an **independent organization that manages the electric grid,** including the flow of electricity, transmission planning, and energy markets
- ISOs ensure **the safety and reliability** of the electric system by managing the flow of electricity across power lines

ISOs in North American Today

Apply Coase to **Road Use:** Key Policies

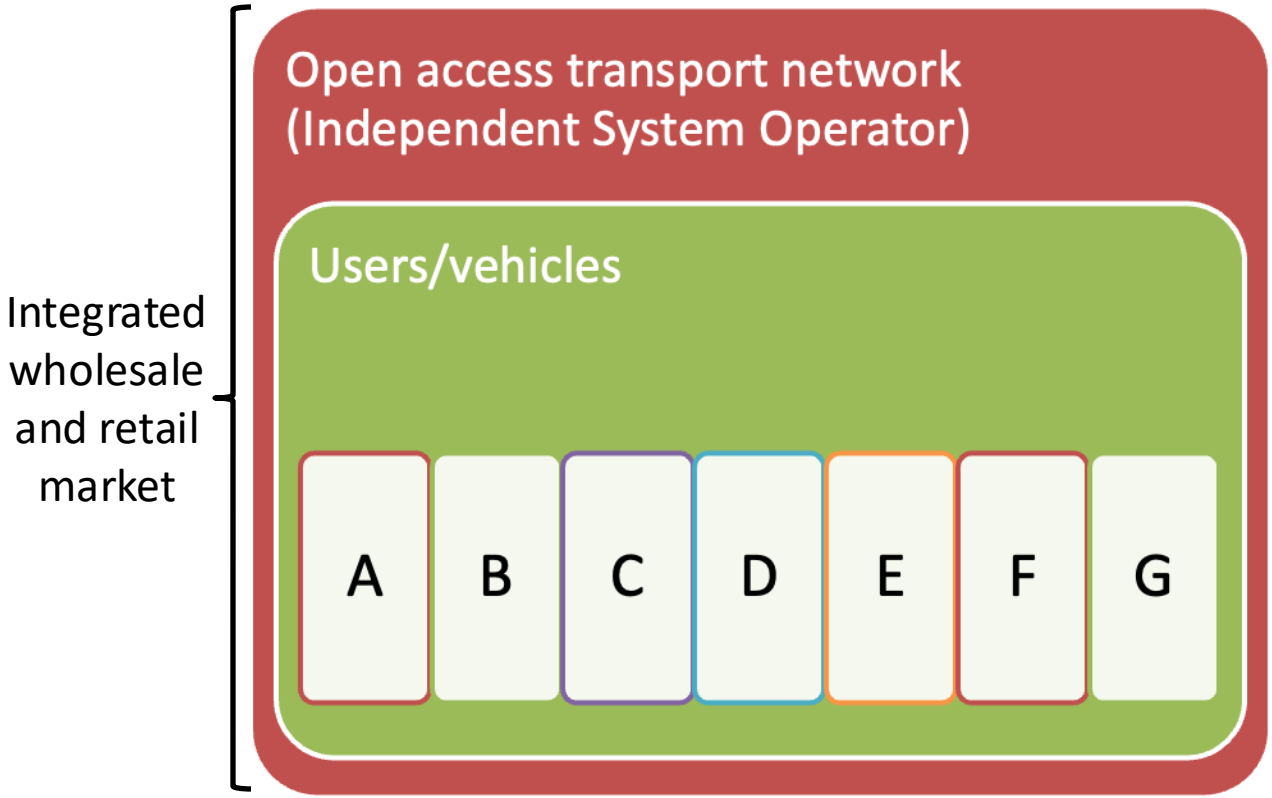
- Create **road "slots"** which are rights to use a particular section of road at a particular time (*ius utendi*)
- **Make slots tradable** in a "slot market," which generates **real-time, road-use prices**
- This prices ***all road usage network-wide in real time***
- Create ***both spot and forward markets*** in road-use slots to reveal price direction

Extension of current U.S. road policy

- Oregon launched its **network-wide Road Usage Charge (RUC) program**, OReGO, on July 1, 2015
- OReGO was the first RUC program in the world
- OReGo road prices are flat
- As of December 2023, there were over **60 priced managed lane corridors** in the United States
- CGO would **combine these extant approaches** to price entire road network in real time

The Independent System Operator (ISO) in Transport

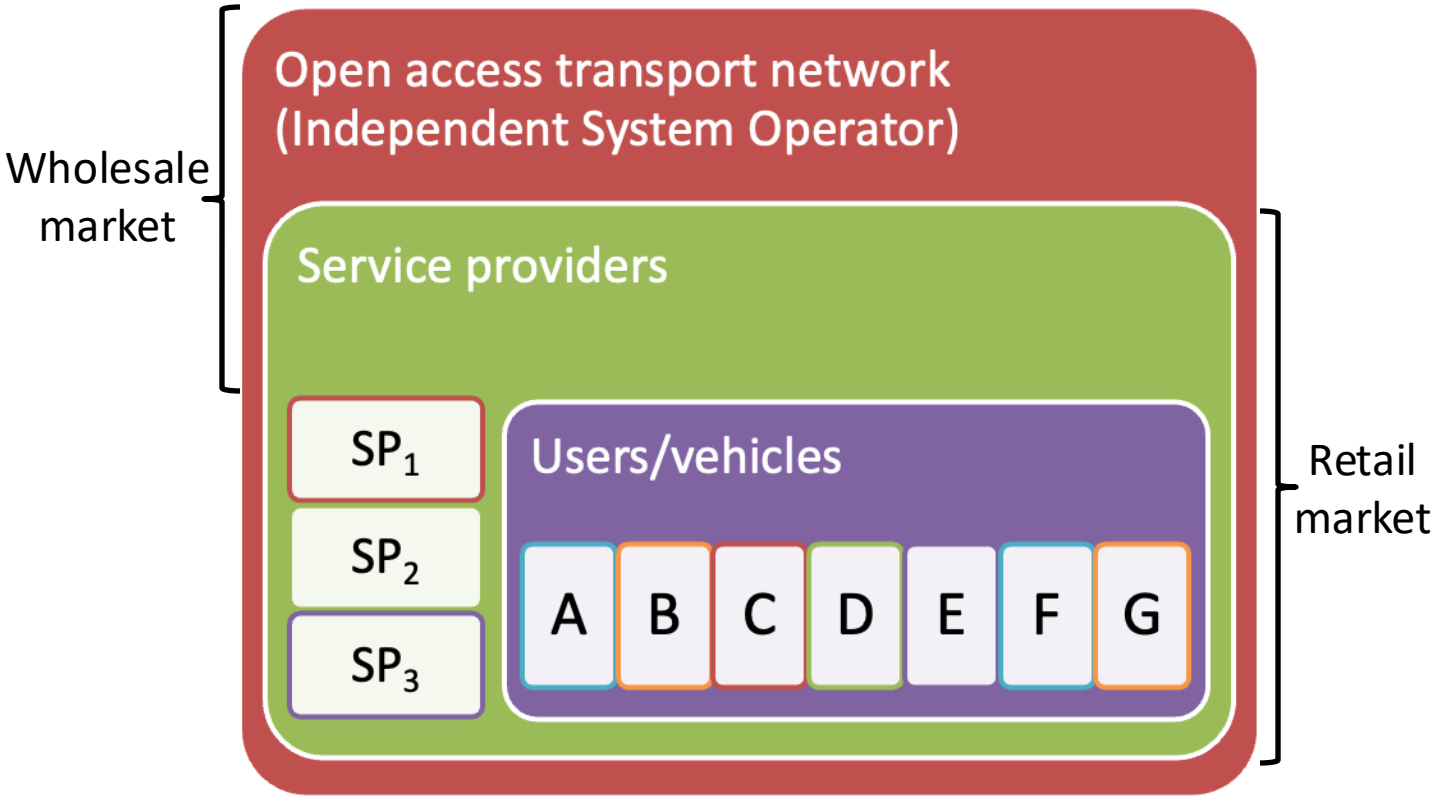
- Regional ISOs would **create spot and forward markets** in road slots
- Regional ISO **creates prices that ensure maximum flow** through the system (like "water through a funnel")
- Regional ISOs would **coordinate with public-sector road owners** (i.e., suppliers) and buyers of road-use rights (e.g., large users such as Amazon, UPS, FedEx, trucking companies, service providers)
- Key market principle: **ISO must ensure open access**; transport network is open to all
- Network capacity **cannot be withheld**
- Open on **non-discriminatory terms**
- ISO's operations would be **highly transparent**



Simple market model

Wholesale Market with Service Providers

- Forward trading **mitigates risks** (as in other commodities)
- **Service providers** compete for road use in forward markets as well as in real time
- Service providers **develop user apps** that allow easy **expression of demand** (i.e., via prices)



Wholesale market model as electricity successfully operating for two decades

ForwardTransport, Inc. … *lock in prices and drive with confidence!*

Type	Mon	Tue	Wed	Thu	Fri	Sat	Sun
Daily trip	●	●	●	●	●		

Round trip	One way	Multi-stop	Vehicle
Home		Work	MD 0123

Begin	End
Wed, 1 Nov 2017	Thu, 30 Nov 2017

	Depart	Arrive
Home to Work	8:00am	8:28am
Work to Home	5:00pm	5:28pm

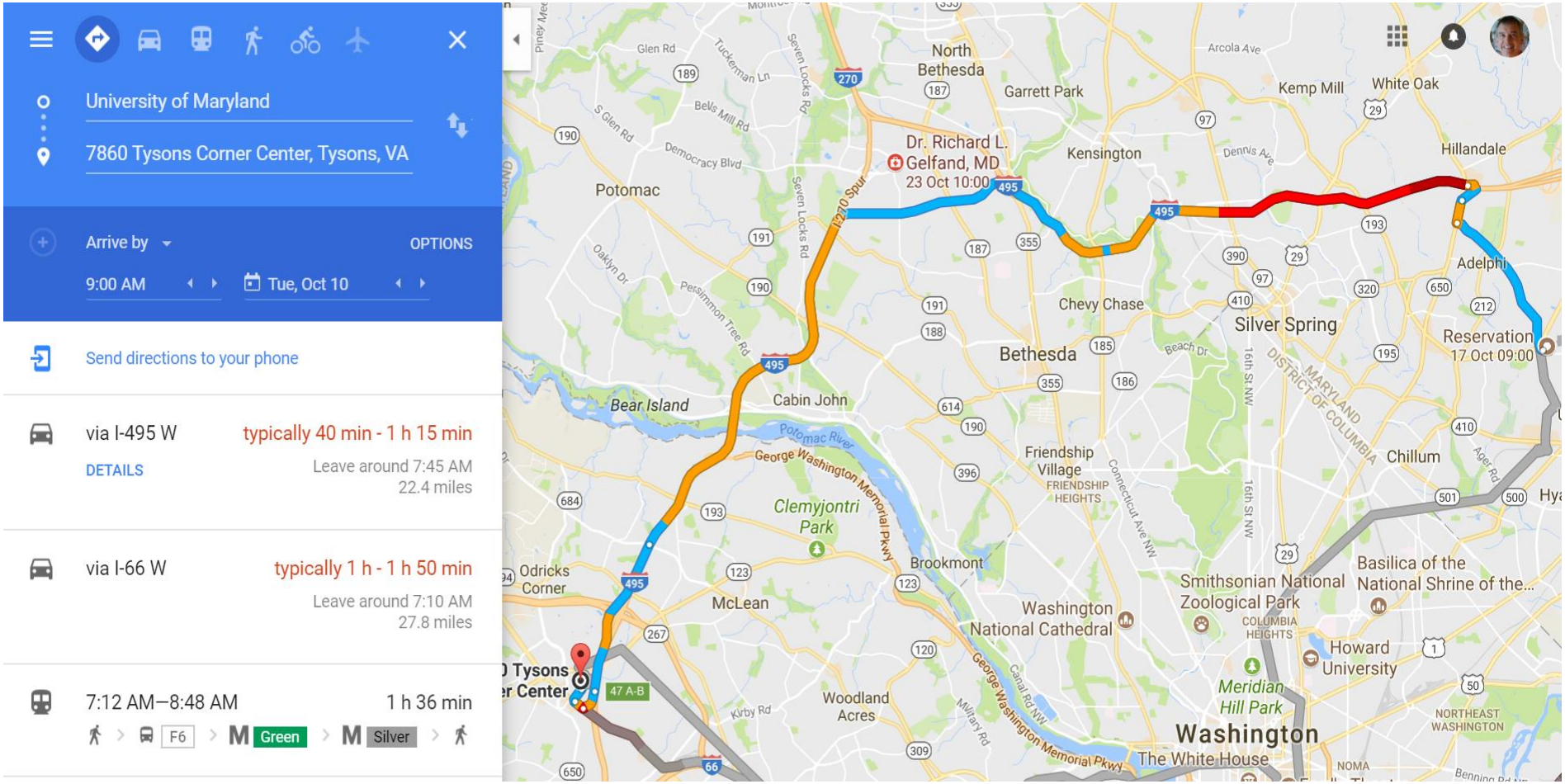
Cost per trip

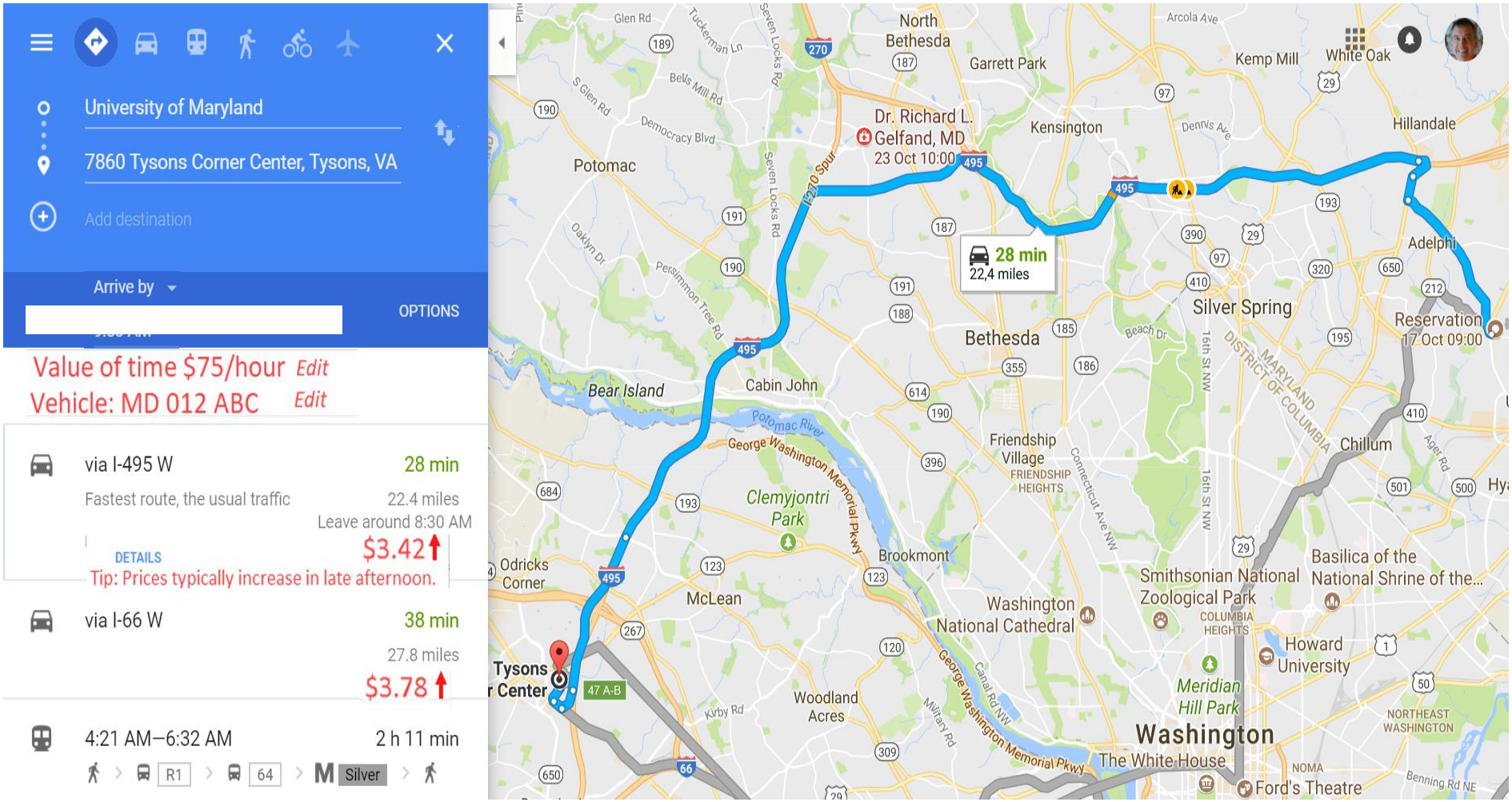
$ 3.76

Add to Cart

Alternatives and Price Change

Later		Earlier	
+10 min	$ 0.45	-10 min	$ 0.32
+20 min	$ (0.20)	-20 min	$ (0.33)
+30 min	$ (0.46)	-30 min	$ (0.59)
+40 min	$ (1.11)	-40 min	$ (1.24)
+50 min	$ (1.21)	-50 min	$ (1.34)
+60 min	$ (1.40)	-60 min	$ (1.53)
+70 min	$ (1.56)	-70 min	$ (1.69)
+80 min	$ (1.82)	-80 min	$ (1.95)
+90 min	$ (2.01)	-90 min	$ (2.14)


University of Maryland
7860 Tysons Corner Center, Tysons, VA
Arrive by
OPTIONS
9:00 AM
Tue, Oct 10
Send directions to your phone
via I-495 W
typically 40 min - 1 h 15 min
DETAILS
Leave around 7:45 AM
22.4 miles
via I-66 W
typically 1 h - 1 h 50 min
Leave around 7:10 AM
27.8 miles
7:12 AM—8:48 AM
1 h 36 min
F6
Green
Silver
Dr. Richard L.
Gelfand, MD
23 Oct 10:00
Reservation
17 Oct 09:00
North Bethesda
Garrett Park
Kemp Mill
White Oak
Hillandale
Kensington
Potomac
Chevy Chase
Silver Spring
Adelphi
Bethesda
Bear Island
Cabin John
Friendship Village
Chillum
Clemyjontri Park
Brookmont
McLean
Odricks Corner
Tysons Corner Center
Washington National Cathedral
Smithsonian National Zoological Park
Basilica of the National Shrine of the...
Howard University
Meridian Hill Park
Woodland Acres
Washington
The White House
NORTHEAST WASHINGTON
NOMA
Glen Rd
Tuckerman Ln
Seven Locks Rd
S Glen Rd
Bells Mill Rd
Democracy Blvd
I-270 Spur
Oaklyn Dr
Persimmon Tree Rd
Potomac River
George Washington Memorial Pkwy
Connecticut Ave NW
16th St NW
Arcola Ave
Dennis Ave
Beach Dr
Kirby Rd
Military Rd
Canal Rd NW
47 A-B


University of Maryland
7860 Tysons Corner Center, Tysons, VA
Add destination
Arrive by
OPTIONS
Value of time $75/hour Edit
Vehicle: MD 012 ABC Edit
via I-495 W
28 min
Fastest route, the usual traffic
22.4 miles
Leave around 8:30 AM
$3.42
DETAILS
Tip: Prices typically increase in late afternoon.
via I-66 W
38 min
27.8 miles
$3.78
4:21 AM–6:32 AM
2 h 11 min
R1
64
Silver
28 min
22,4 miles
Dr. Richard L. Gelfand, MD
23 Oct 10:00
Reservation
17 Oct 09:00
North Bethesda
Garrett Park
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Potomac
Bethesda
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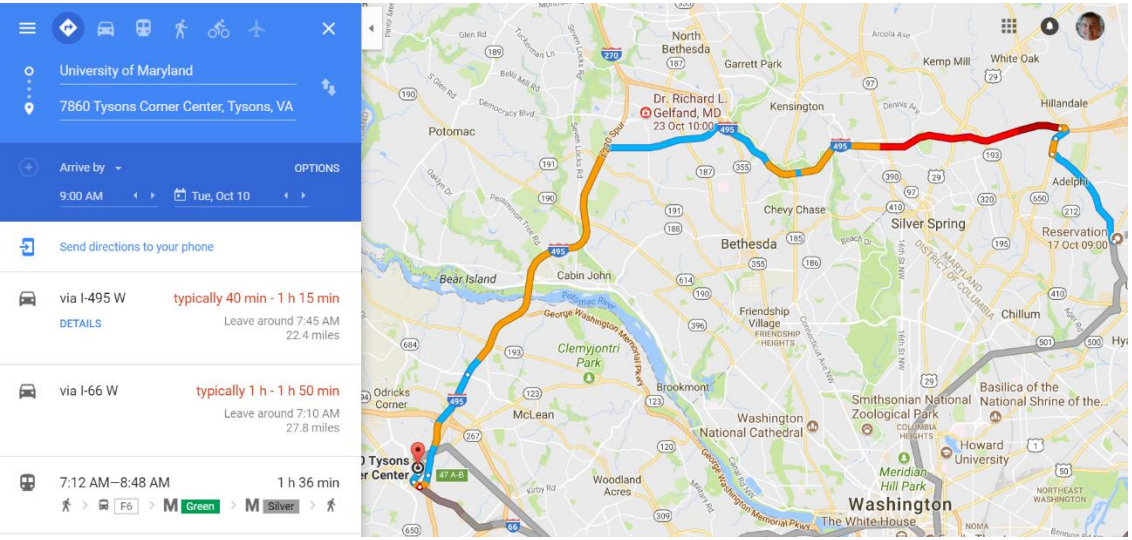
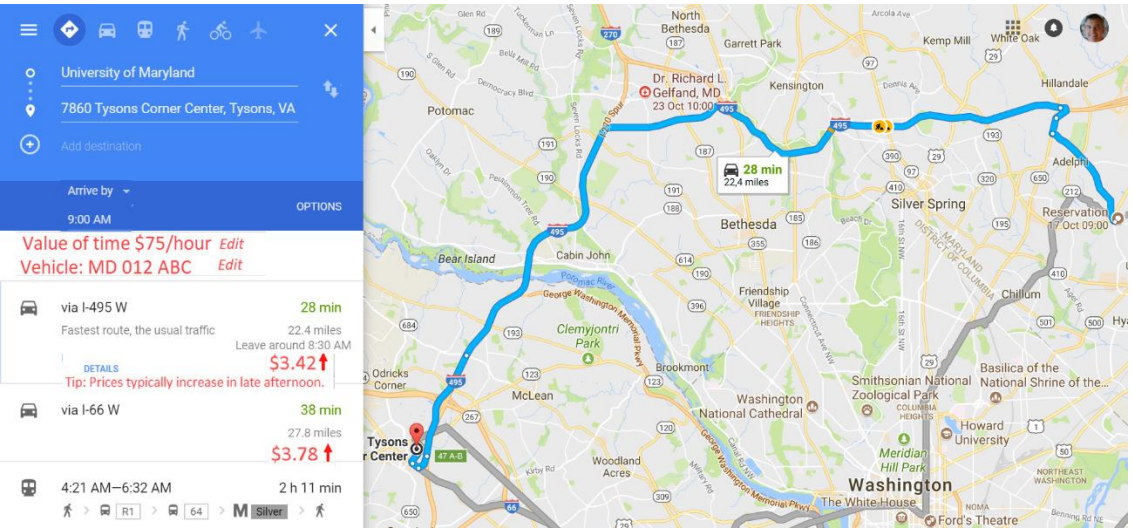
Washington
The White House
Ford's Theatre
Woodland Acres
Potomac River
George Washington Memorial Pkwy
I-270 Spur
Seven Locks Rd
Democracy Blvd
Persimmon Tree Rd
Oakyn Dr
Beach Dr
16th St NW
Connecticut Ave NW
Canal Rd NW
Kirby Rd
Milvan Rd
Dennis Ave
Arcola Ave
Glen Rd
S Glen Rd
Tuckerman Ln
Bells Mill Rd
Ager Rd
Benning Rd NE
NOMA
NORTHEAST WASHINGTON
COLUMBIA HEIGHTS
FRIENDSHIP HEIGHTS
MARYLAND
DISTRICT OF COLUMBIA





Today's transport is mostly "free," but **comes at the (high) cost of uncertain congestion delays**

Our market **puts a price on road use**, but avoids delays (and improves throughput)

Both regimes cause some drivers to leave early, late, or not at all, or to switch roads …

Equity Considerations (1)

- Real-time, network-wide road pricing creates max-flow conditions that **benefit both rich and poor**
- **Traffic congestion** is likely to be **regressive!**
- **All users benefit** from improved certainty of travel time (standard deviation of travel time reduced); more accurate trade offs
- **Poor can switch to less expensive** travel times (since road prices now revealed)

Equity Considerations (2)

- Lower income drivers tend to travel on **less expensive** roads
- Allowing road-use prices to vary complicates equity effects in a network
- CGO is consistent with **horizontal equity** where everyone pays the same for more (or less) valuable roads in real time

Equity Considerations (3)

- No examples of full network-wide dynamic pricing (yet!)
- Evidence from **dynamic tolling projects** that sit alongside GPLs
- Latest evidence suggests such tolling is *progressive*
- Cook and Li (2024) study the distributional effects of **dynamically priced highway toll lanes**. They state:

  > Relative to a world in which the same number of highway lanes are all free, status-quo tolling increases aggregate welfare and benefits drivers in all income quartiles, driven in large part by the option value. Moreover, we find that drivers in the bottom income quartile gain the most under status-quo tolling. These heterogeneous welfare effects by income stem primarily from the special distribution of lower- and higher-income drivers, rather than from preference heterogeneity.

- **Lower income groups** value **market information and tradeoffs** too!

Cannot "Build Our Way" Out of Congestion

"The Fundamental Law of Road Congestion" Duranton and Turner (AER 2011)

Supply-side policies (i.e., "build more roads") **typically not effective**

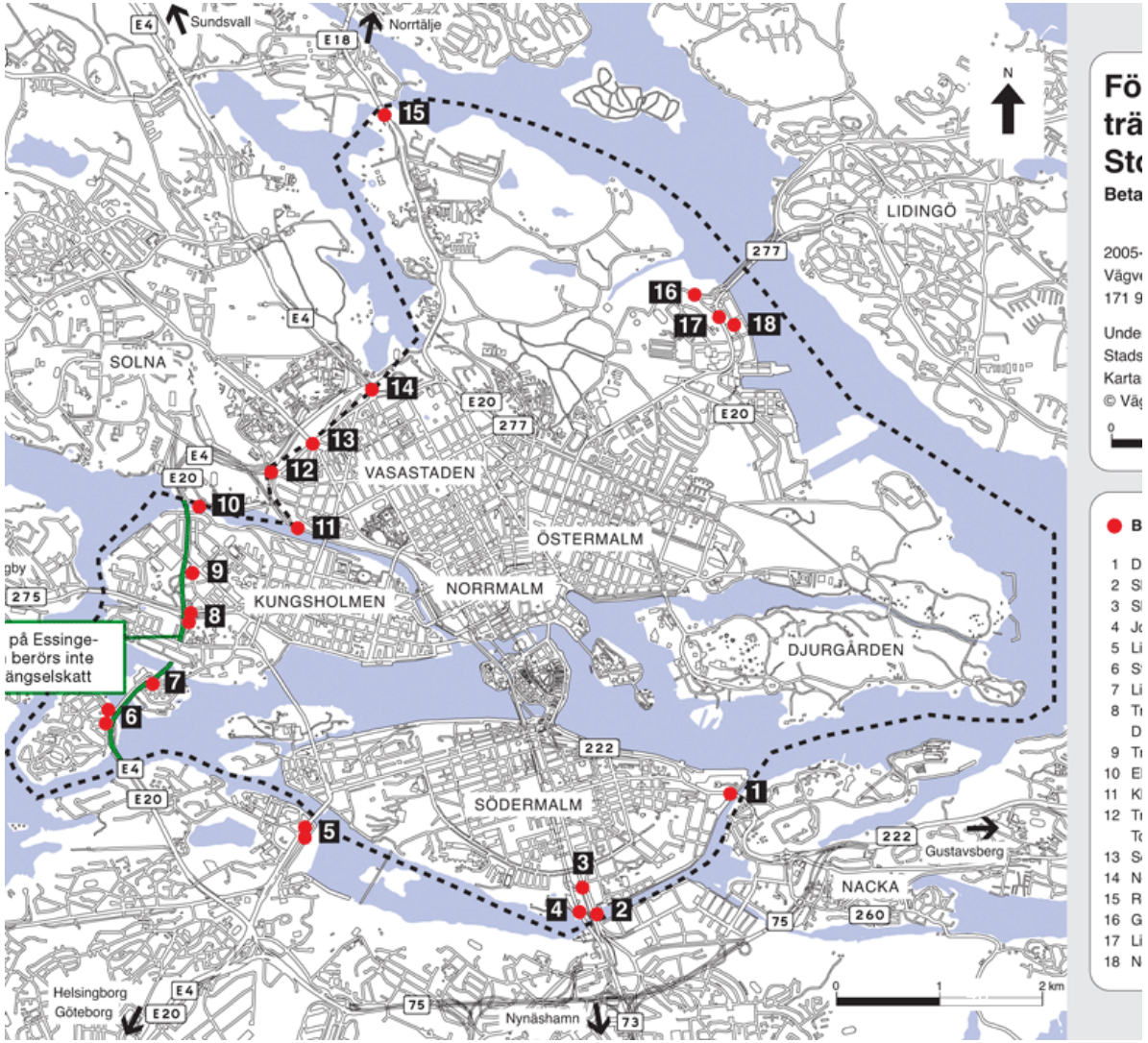
- If **unpriced capacity** is added, the road will often become **just as congested** as it was before
- Scarcity and cost of urban land
- Public-sector financial constraints

Ride-hailing services or self-driving cars **unlikely to cure congestion**

- Uber supports road pricing as "*the most effective way to manage vehicles on the road*"
- Lyft suggests that "*congestion pricing . . . has not caught on in a big enough way*"

Example: Cordon in Stockholm

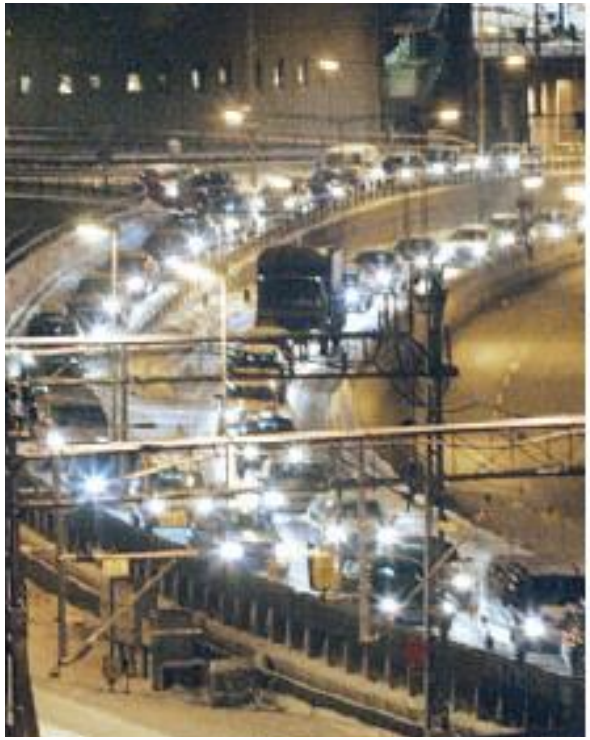
- Since 2006, cordon around the city, 2€ in peak and 1€ off-peak times
- Traffic volumes reduced by 20%, leading to reductions of queuing times of 30-50% (Eliasson, Hultkrantz, Nerhagen & Rosqvist 2009)
- Public support increased from around 30% in 2005 to almost 70% in 2007, and increased thereafter



The effect of a 2€ charge in Stockholm

Monday,
2 Jan 2006

(last day without charges)



Stockholm before and after the 2€ charge

Monday,
2 Jan 2006

(last day without charges)

Tuesday,
3 Jan 2006

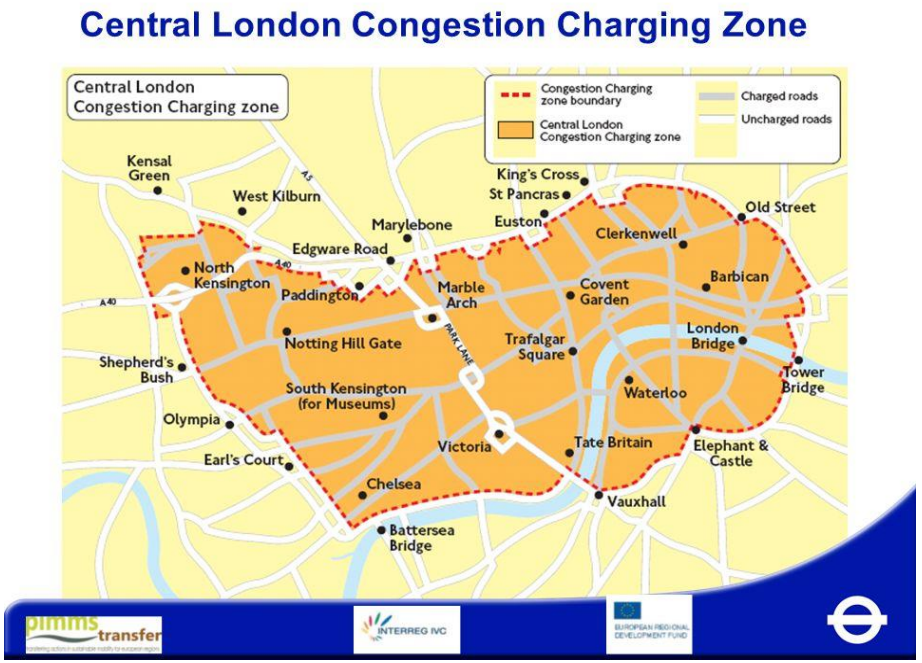
(first day with charges)

Source: Eliasson (2015)

Example: Cordon Pricing in London

Since 2013

- Today, vehicles are charged £11,50 per day if they drive in charging zone (exemptions and discounts)
- *Transport for London* concluded in 2014 that the charges were:
- "continuing to deliver congestion relief that [is] broadly in line with the 30 percent reduction achieved in the first year of operation"



Thank you!!