Step on It: Approaches to Improving Existing Vehicles' Fuel Economy

Ashley Langer and Shaun McRae

University of Arizona and University of Michigan

October 30, 2015

Connected and automated vehicle technology will transform personal transportation

- Lower accident risk
- Improve utilization of vehicles and infrastructure
- Reduce fuel consumption

We study the potential use of connected vehicle technology as an environmental policy

- Traditional economist prescription: gasoline tax
- Alternative policy: infrastructure upgrades and connected vehicles
  - These can reduce gasoline consumption by smoothing traffic flows and reducing stops
- Unlike a gasoline tax, these policies can make drivers better off by both saving money and reducing trip times

We use data on real-world driving behavior to describe the existing variation in fuel economy

- How does fuel economy vary across drivers?
- How do drivers optimally choose between faster trips and lower fuel consumption?
- What policies would be effective to reduce fuel consumption (holding vehicles and trips constant)?

Outline of the talk

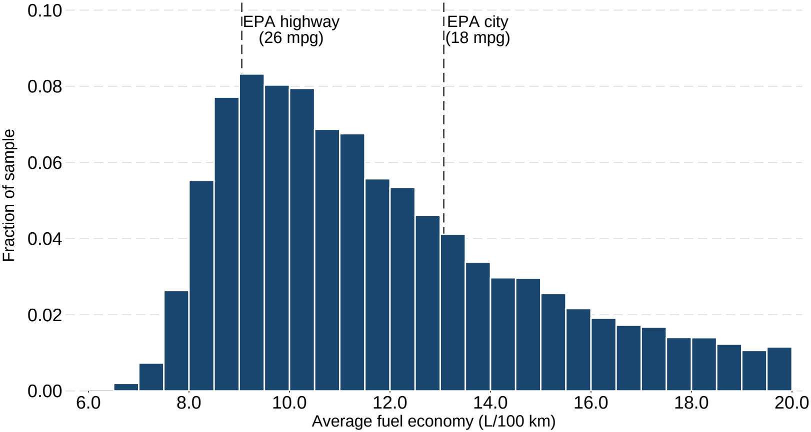
We use data from the IVBSS (Integrated Vehicle-Based Safety System) experiment

- Field test of advanced crash-warning technology by the DOT, industry partners, and the UM Transportation Research Institute (UMTRI)
- Sixteen identical passenger cars were fitted with the technology

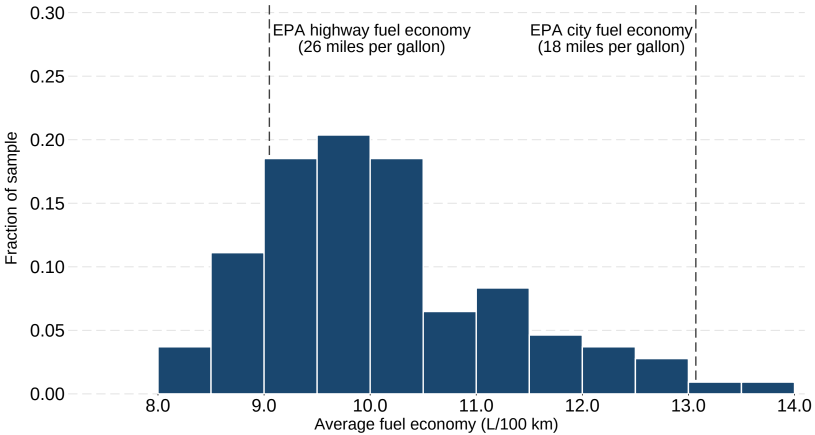
Observe how ordinary drivers behave in normal driving situations on real roads

- 108 drivers from southeast Michigan were given the vehicles to use for approximately six weeks
- Experiment ran from April 2009 to May 2010
  - Observe 220,000 miles of driving in 23,000 trips
- Each car had a computer installed that recorded several hundred variables at a high frequency
  - Vehicle location, speed, acceleration, fuel use, etc

Variation in fuel economy across trips



Variation in fuel economy across drivers

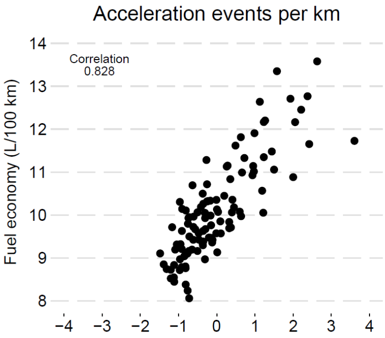


We decompose the sources of the large variation in observed fuel economy

Calculate standardized measures to summarize driving patterns

- Average speed
- Average acceleration and deceleration rates
- Number of acceleration events
- Time spent idling

  ...



Route characteristics (rather than driver behavior) explain most of the variation in fuel economy

Acceleration events per km	0.71***
	(0.10)
Idle time	0.35***
	(0.10)
Average speed (km/h)	-0.05
	(0.21)
Time above 100 km/h	-0.06
	(0.11)
Acceleration (m/s^2)	0.17***
	(0.05)
Deceleration (m/s^2)	0.03
	(0.048)
Speed given Speed $>$ 100km/h	0.20***
	(0.05)
Adjusted R^2	0.897

Outline of the talk

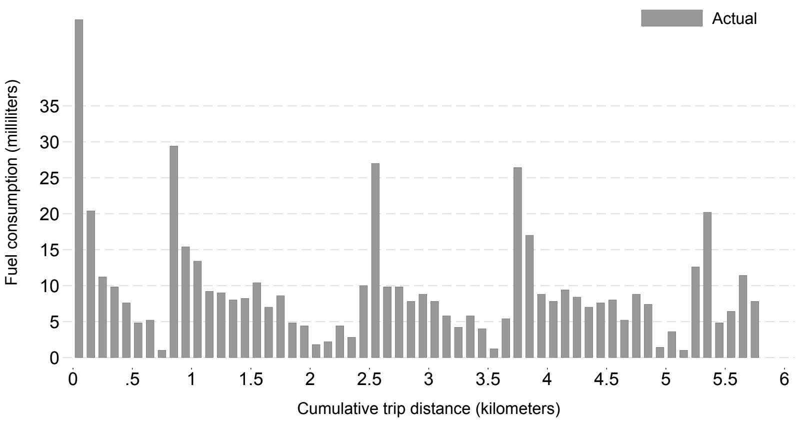
We develop an empirical model to connect driver choices to fuel consumption

- Drivers minimize the total cost of travel on each trip between (fixed) start and end locations
  - Choose the optimal route (e.g. city or highway)
  - Choose the optimal speed and acceleration along chosen route
  - Total cost = fuel cost plus value of time

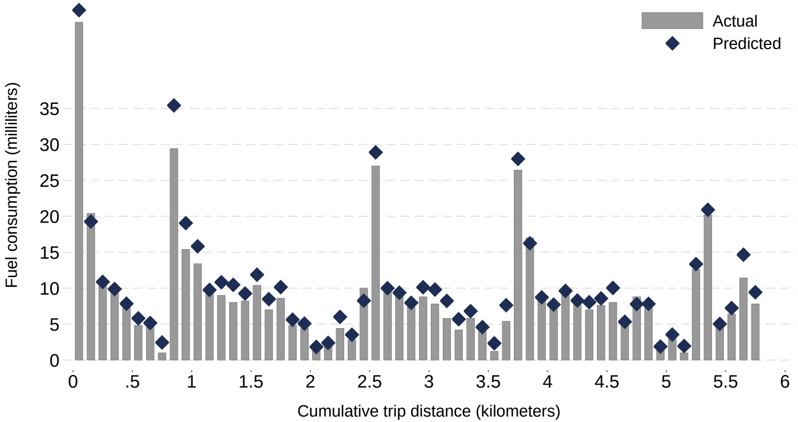
We develop an empirical model to connect driver choices to fuel consumption

- Drivers minimize the total cost of travel on each trip between (fixed) start and end locations
  - Choose the optimal route (e.g. city or highway)
  - Choose the optimal speed and acceleration along chosen route
  - Total cost = fuel cost plus value of time
- Trip time and vehicle fuel consumption both depend on driver behavior (speed and acceleration)
  - We use the second-by-second driver data from the IVBSS experiment to econometrically estimate a physical model of fuel consumption
  - Include interactions of higher-order polynomials in speed and acceleration, as well as road characteristics such as grade

Fuel consumption per 100 meters for one trip in the data



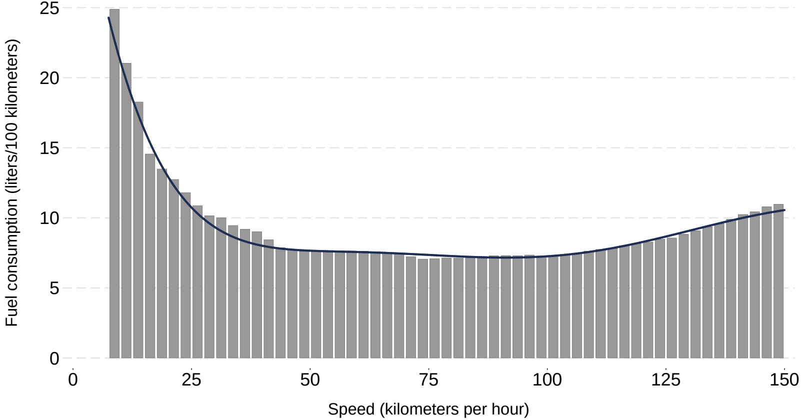
Estimated model of fuel consumption fits the observed data very well



Use this model to analyze optimal choices of speed and acceleration

- EPA provides tips for driving more efficiently in order to save money
  - Drive more slowly on the freeway
  - Accelerate less aggressively
- But for what values of time would these behaviors be worthwhile?

Relationship between speed and fuel consumption is almost flat for a large range of speeds



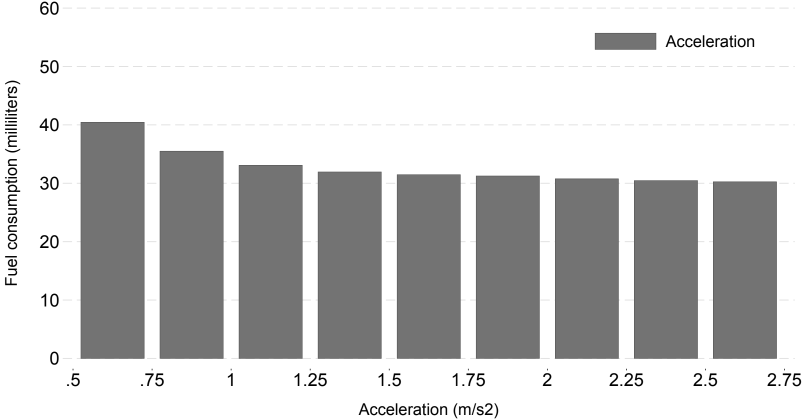
For most people, driving faster on the freeway is optimal (ignoring safety)

Over 100 kilometers

	Constant speed (km/h)				
	90	100	110	120	130
Fuel consumption (L)	7.16	7.25	7.63	8.27	9.08
Fuel cost ($)	6.62	6.71	7.05	7.65	8.40
Time (minutes)	66.7	60.0	54.5	50.0	46.2
Effect of increasing speed					
Δ Fuel cost ($)	.	0.09	0.34	0.60	0.75
Δ Time (minutes)	.	-6.7	-5.5	-4.5	-3.8
Cost of time ($/hour)	.	0.77	3.78	7.86	11.76

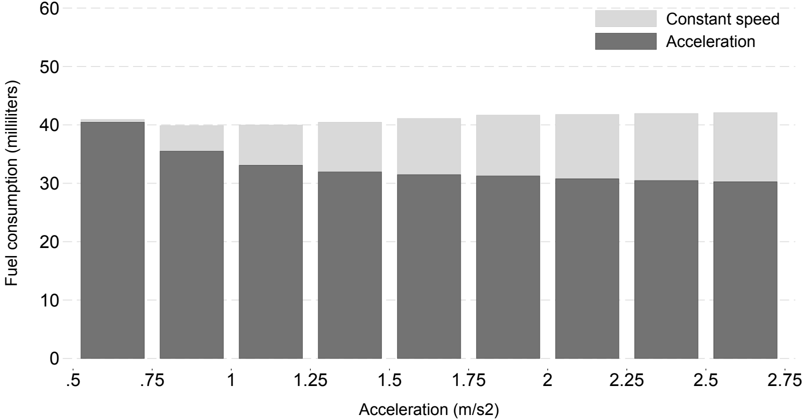
Higher rates of acceleration will get to a given speed using less fuel...

Accelerating from 2-15 m/s



... but over a fixed distance, there is little effect of acceleration on fuel usage

Accelerating from 2-15 m/s over 250 meters



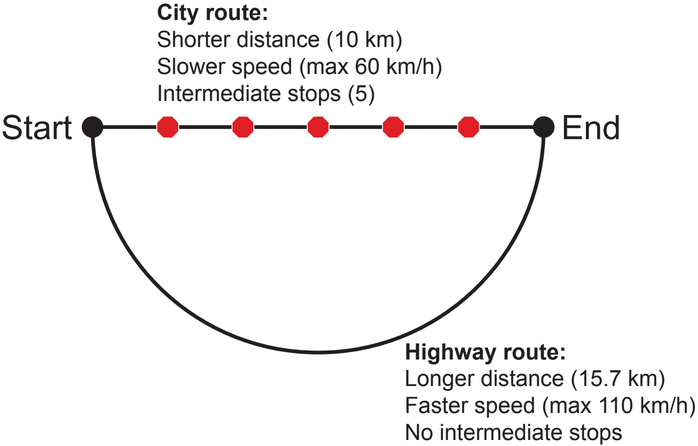
This implies that higher rates of acceleration are optimal (ignoring safety)

Accelerating from 2-15 m/s over 250m

	Acceleration (m/s^2)				
	1.0	1.5	2.0	2.5	3.0
2–15 m/s over 250 m					
Fuel consumption (mL)	45.26	45.16	45.66	46.20	46.74
Fuel cost (cents)	4.18	4.18	4.22	4.27	4.32
Time (seconds)	22.3	20.4	19.5	18.9	18.5
Cost of time ($/hour)	.	-0.18	1.77	3.18	4.76

Outline of the talk

Highly stylized model of gasoline consumption with optimal route choice and driving style



Slightly less than half of Michigan drivers would choose the city route

	Base
% city route	40.2
Fuel consumption (L)	1.22
City	1.065
Highway	1.330
Time (minutes)	9.58
Fuel economy (L/100km)	9.34
Total cost to driver	$2.92
Social cost	$3.03

Reduction in fuel consumption from higher gasoline prices more than offset by the increase in trip times

	Base	+$0.10	+$0.50
% city route	40.2	45.6	61.9
Fuel consumption (L)	1.22	1.21	1.16
City	1.065	1.065	1.064
Highway	1.330	1.330	1.330
Time (minutes)	9.58	9.69	10.07
Fuel economy (L/100km)	9.34	9.46	9.81
Total cost to driver	$2.92	$3.03	$3.52
Social cost	$3.035	$3.034	$3.043

Eliminating stops along city routes reduces fuel consumption and improves welfare

	Base	3 stops	Circles
% city route	40.2	61.9	56.5
Fuel consumption (L)	1.22	1.11	1.11
City	1.065	0.970	0.942
Highway	1.330	1.330	1.330
Time (minutes)	9.58	9.82	9.95
Fuel economy (L/100km)	9.34	9.23	9.00
Total cost to driver	$2.92	$2.86	$2.86
Social cost	$3.03	$2.97	$2.97

Outline of the talk

Smoothing traffic flow provides a win-win as an environmental policy

- \$0.10 per gallon increase in gas tax reduces fuel consumption by 1.86% (Bento et al 2005)
- From our data, the same saving could be achieved by reducing acceleration events by 0.085 events per kilometer (12% reduction)
  - Vehicle-to-infrastructure technology to improve traffic signal timing
  - Vehicle-to-vehicle technology to smooth driving patterns
  - Changes to road design (e.g. replace stop signs with traffic circles)
- Unlike a gas tax, these technologies may leave consumers better off by reducing gasoline consumption and reducing trip times

Conclusion

- There is substantial variation in fuel economy across drivers in identical vehicles
- Most variation in fuel use comes from frequency of acceleration events, not the rate of acceleration or highway speed
- This suggests that gasoline taxes will be fairly ineffective at improving fuel economy for vehicles on the road
- Measures to reduce variation in speed (such as vehicle-infrastructure communication) could lead to substantial reductions in fuel use