To Drive or Not to Drive?
A field experiment in road pricing

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12 January 2017

Road congestion costs HH $1400/year wasted time and fuel

1 in 5 UK drivers will spend over a year of their lives sitting in traffic

Road use/congestion charges

Proposed: per kilometer, for entering zone, for traveling at peak times, that adjust dynamically to guarantee free-flow

- Technology is almost ready
- Is the public?

Road use/congestion charges

Proposed: per kilometer, for entering zone, for traveling at peak times, that adjust dynamically to guarantee free-flow

- Technology is almost ready
- Is the public?

"Under mobility pricing, some struggling mom or dad with kids of modest income living in the Fraser Valley, because that's the only place they can barely afford to buy a home, would be hit with high tolls of one kind or another while a single lawyer or other professional with a high income and wealthy enough to live in Vancouver near their work would pay almost nothing." – Gordon Clark, The Province Op-Ed, Vancouver, February 2018

Road use/congestion charges

Proposed: per kilometer, for entering zone, for traveling at peak times, that adjust dynamically to guarantee free-flow

- Technology is almost ready
- Is the public?

"Sadiq Khan knows that if you're taking a pre-06 car into central London, you're probably not doing so for fun, and have already explored the options available to you. He knows that of the estimated 10,000 cars subject to the £10 fee, most will just have to chalk it up as another penalty for being poor in London." – Ed Wiseman, The Telegraph Op-Ed, London, October 2017

Road use/congestion charges

Proposed: per kilometer, for entering zone, for traveling at peak times, that adjust dynamically to guarantee free-flow

- Technology is almost ready
- Is the public?

"I've never been in favor of those proposals because I haven't seen one that I thought was fair particularly to folks in the outer boroughs." New York Mayor Bill de Blasio, August 2017

Our research

- Document who wins/loses in how we currently pay for roads
- Identify margins of adjustment if we price differently: who, on what trips

Frontier: large field experiment with real drivers and high-frequency data

- Kreindler 2018, but wealthy country and all types of trips

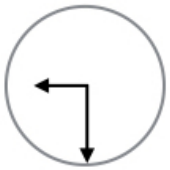
Hypotheses to test

1. Type of road charge adopted needs to closely target congestion, else drivers won't reduce trips that contribute to congestion
2. Low income, particularly low income living far from public transport, will be most hurt by congestion charges
3. Congestion charges could lead to increased social isolation amongst elderly

EXPERIMENT

- Independent govt advisory agency Infrastructure Victoria asked us to analyze raw data from 2015-2016 experiment implemented by Transurban (road & toll company)
- GPS in 1400 cars for 8-10 months
- Control group and several treatment arms facing road use charges
- Real money in credit accounts

TREATMENTS

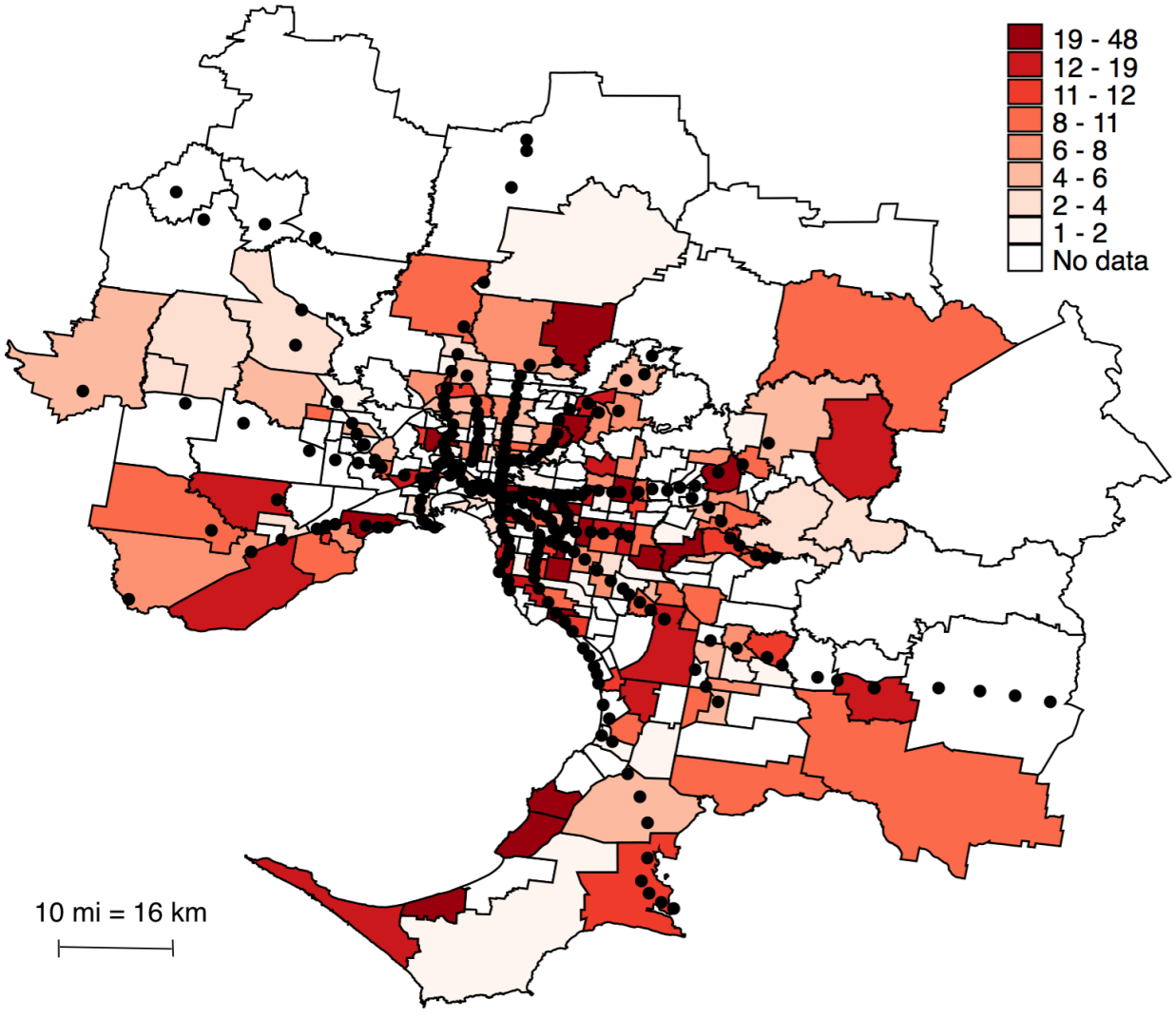


Control	**distance** 10 c/km	**time of day** 15 or 8 c/km	**location** 8 c/km + $8/day zone
30-40 weeks	12 weeks	8 weeks	8 weeks
N=356	N=340	N=344	N=329

Some challenges with experimental design

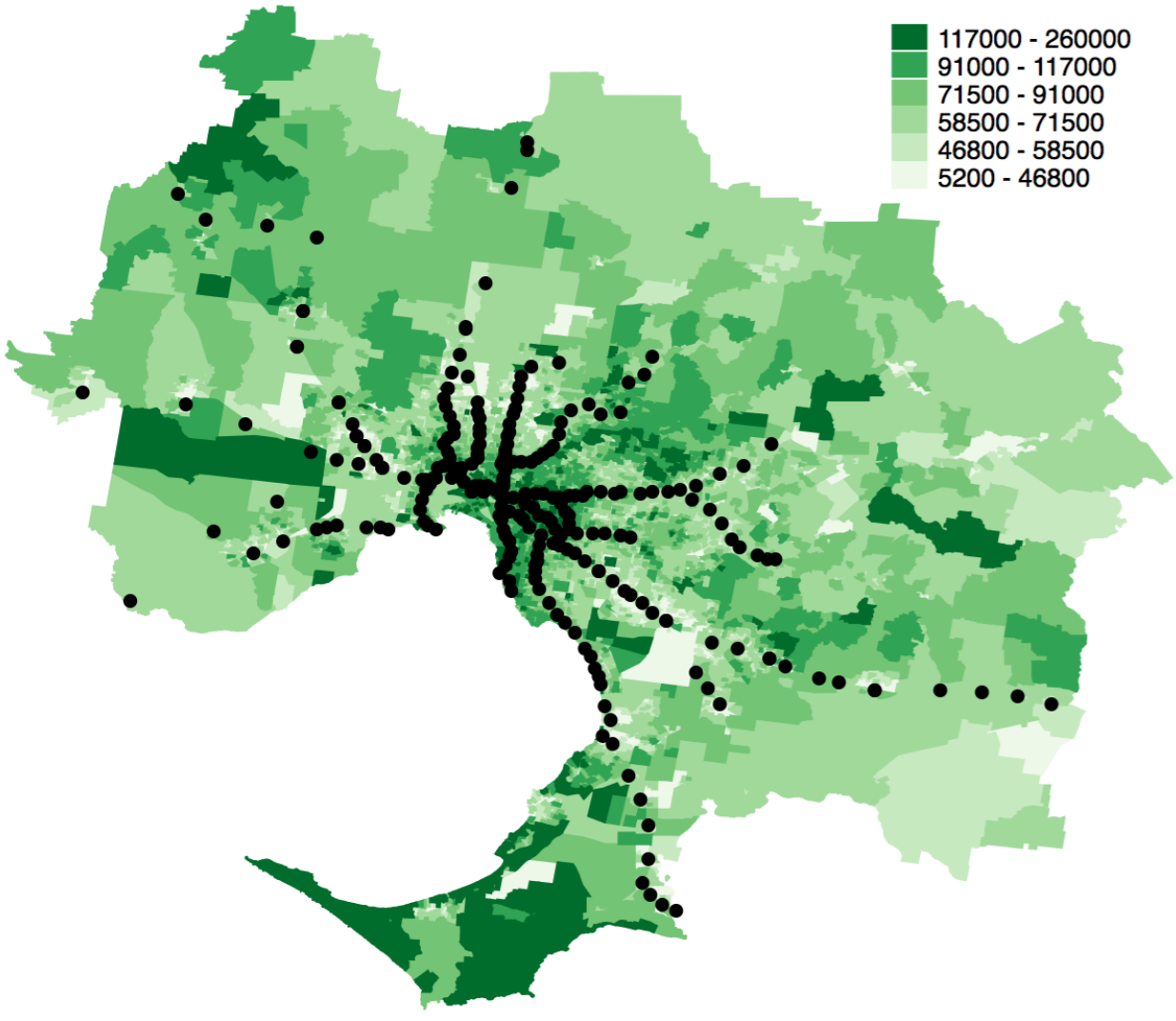
Lessons

Representative sample of Melbourne drivers



Variation in proximity to public transport

Representative sample of Melbourne drivers



And income $\times$ access to public transport

Our sample

Melbourne 4.8 million people (Metro Boston 4.6 million)
1173 people/mi^2 (Metro LA 1046 people/mi^2)

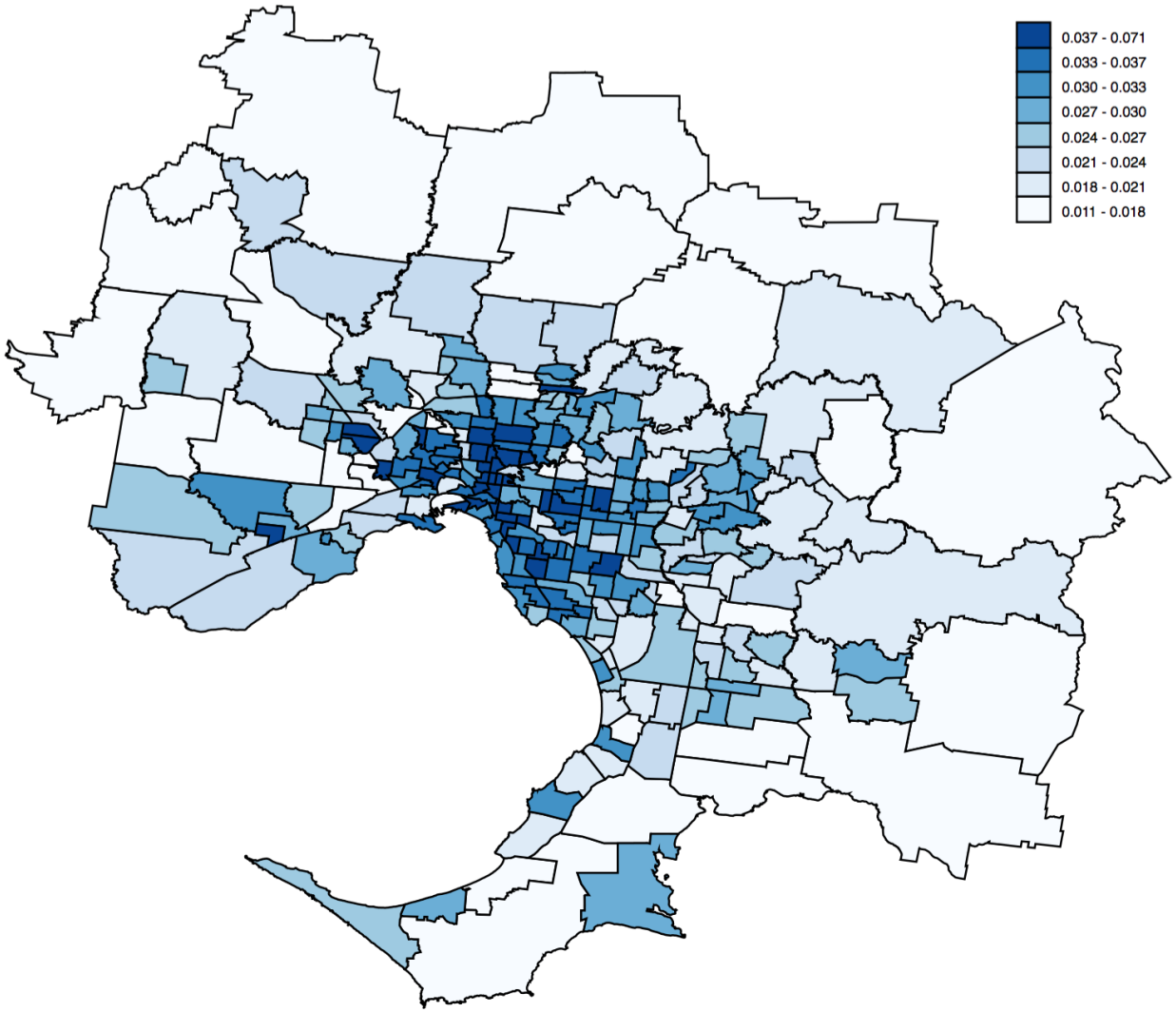
Gasoline US \$4/gallon (Boston \$2.60, SF \$3, London \$5.80)

Compared to 100 largest MSAs in US (2008):

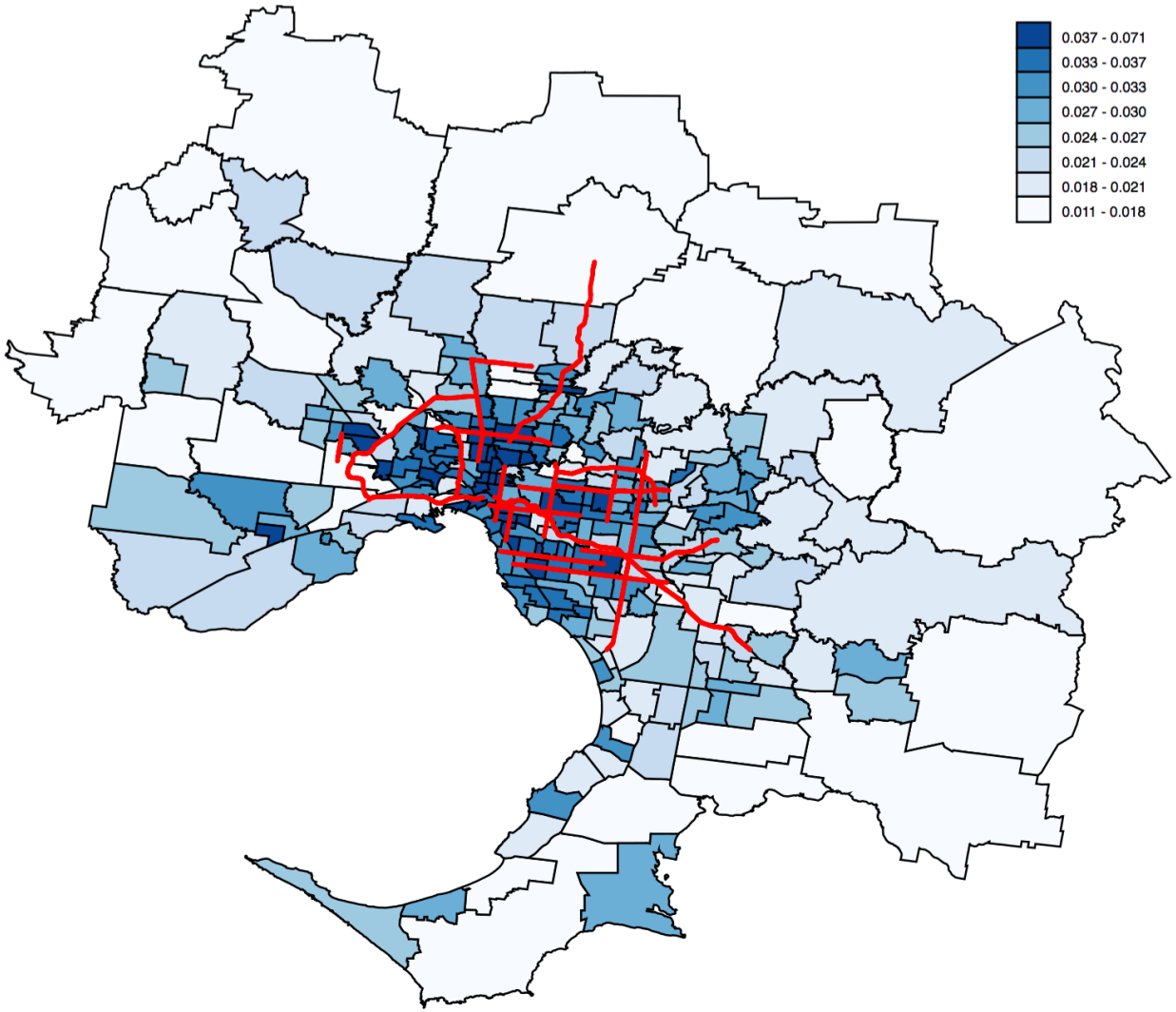
- fewer trips per day: 3.3 (4.1)
- trips are shorter: 10.2 km per trip (12.8)
- but slower: 22.2 minutes per trip (17.5)

46% live within walking distance train/tram (1km = 0.6mi)
22% within 10 minutes (500m)

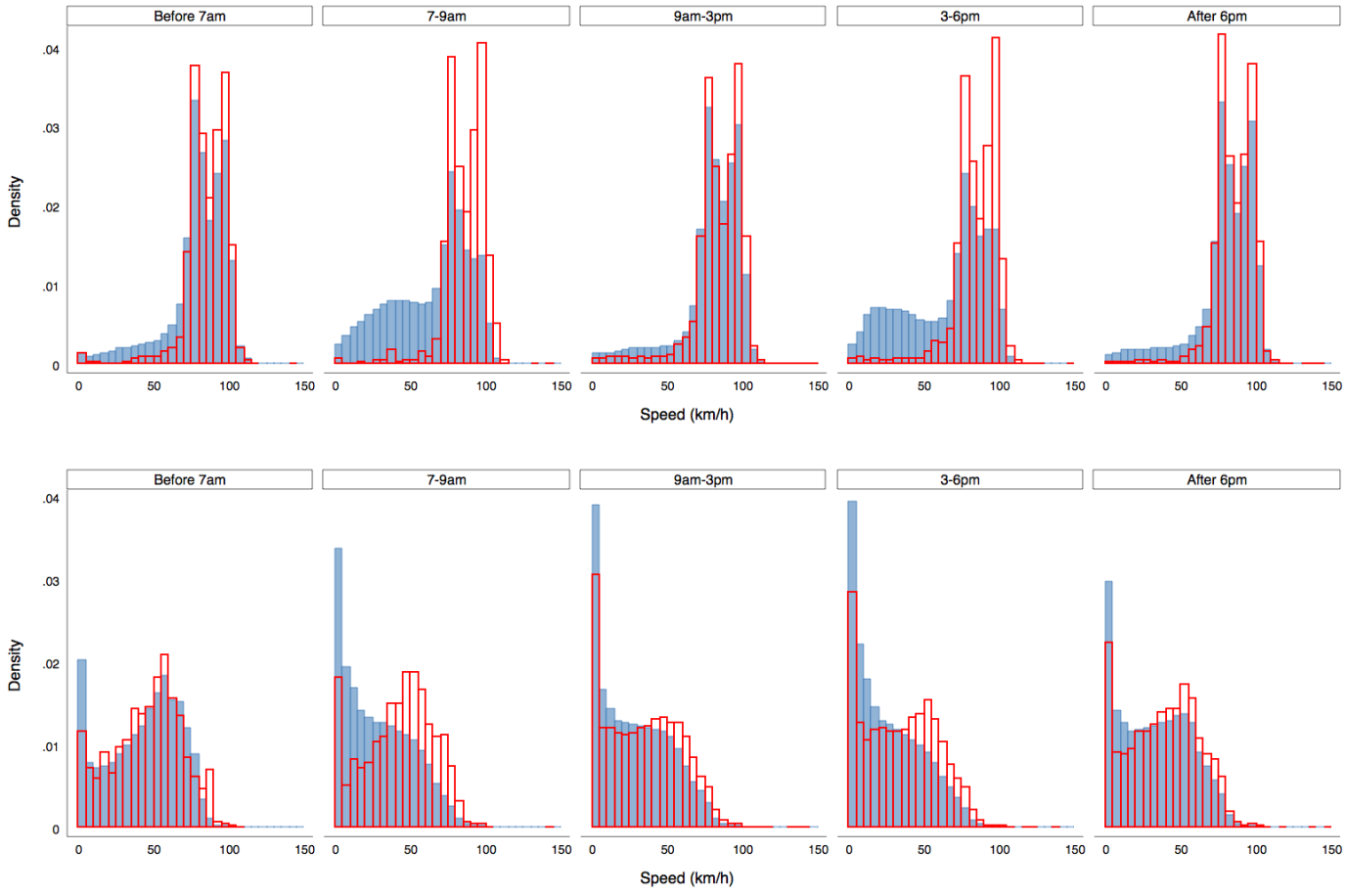
CONGESTION NOT JUST IN CENTER OF CITY



TOP 25 MOST CONGESTED ROADS (AUSROADS 2016)



FREEWAY CONGESTED AT PEAK TIMES CONGESTION ON ARTERIALS DIFFICULT TO PREDICT



blue = Monday-Friday, red=public holiday

Data

- GPS
  - 43 million location coordinates and time stamps
  - Map to road network, railway stations, tram stops, schools, zoning codes
  - Google Places to identify nearby shops
- HH surveys
  - Income, age, employed, children, vehicle
- Fuel economy: Green Vehicle Guide
- Petrol prices: AAA

Our contributions to the literature

- Do congestion charges work? event studies using aggregate traffic flows (Gibson and Carnovale 2015, Foreman 2016) or self-reported travel diaries/recall (Karlstrom and Franklin 2009), (Small et al. 2005);
- How targeted should charges be? Perry and Small 2005 and Langer et al. 2017 recommend VMT
- Road travel is relatively price inelastic (Hughes, Knittel, Sperling 2008, Levin, Lewis Wolak 2017) difficult to find instruments
- Gasoline taxes are regressive: CES data (West 2004), odometer data for new vehicles (Gillingham 2014)

Related literature with neat data: people value being on time

Kreindler 2017 and Bento et al. 2017

1. How targeted do road use charges likely need to be in order to reduce congestion?

Short-run partial equilibrium effect

Micro-behaviors: To what extent do discretionary trips take place under congested road conditions?

Daily treatment effects

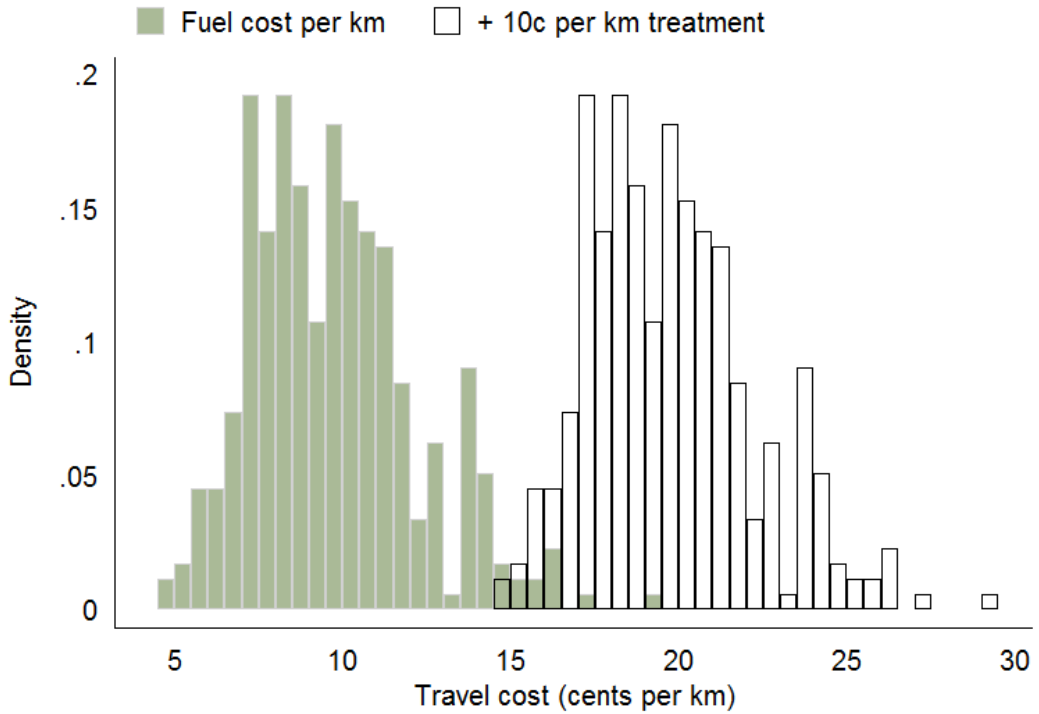
$$\begin{aligned} y_{it} =& \alpha + \beta \text{Treatment}_{it} + \left(\mathbf{X}_i - \overline{\mathbf{X}}\right) \gamma \\ &+ \left(\mathbf{X}_i - \overline{\mathbf{X}}\right) \times \text{Treatment}_{it}\ \delta + \epsilon_{it} \end{aligned}$$

y_{it}: distance, time spent traveling, destinations
$\mathbf{X}_i$: baseline y_i, low income, near public transport, senior, has children

Cluster standard errors at the household level

To express as price elasticity, need base MC

Let MC travel = cost of fuel



10 c/km VKT charge doubles cost of driving

ELASTICITIES: TWO-STAGE LEAST SQUARES

Let p_{it} be cost of driving: fuel cost + MRUS charge

$$\ln q_{it} = \beta \ln p_{it} + \alpha_i + \gamma_t + \epsilon_{it}$$

$$\beta = \frac{\partial \ln q}{\partial \ln p} = \frac{\Delta Q/Q}{\Delta P/P} = \text{price elasticity}$$

Price is endogenous (households chose fuel economy) so instrument for price using experimental allocation to treatment

Uniform distance-traveled charge

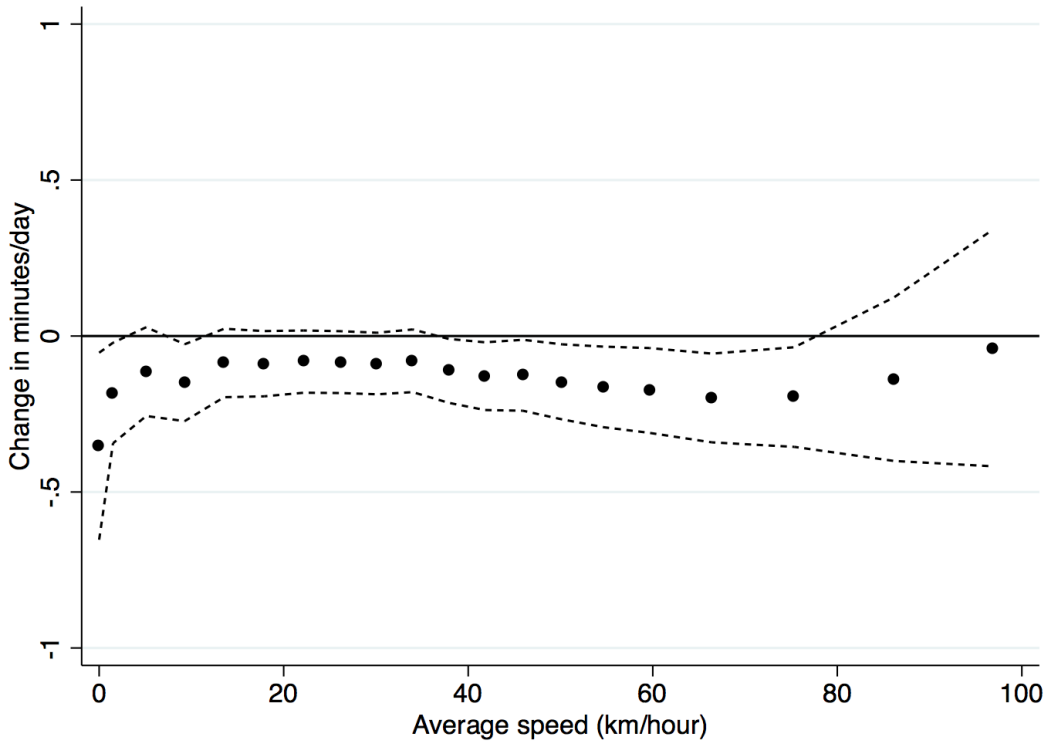
10c/km reduces distance traveled -8%, time on road -6% Table
Price elasticity: 13% reduction in km traveled for 100% increase in cost per km
Table

Most driving and reductions:

- off-peak times
- far from city center
- not on most congested roads

Table

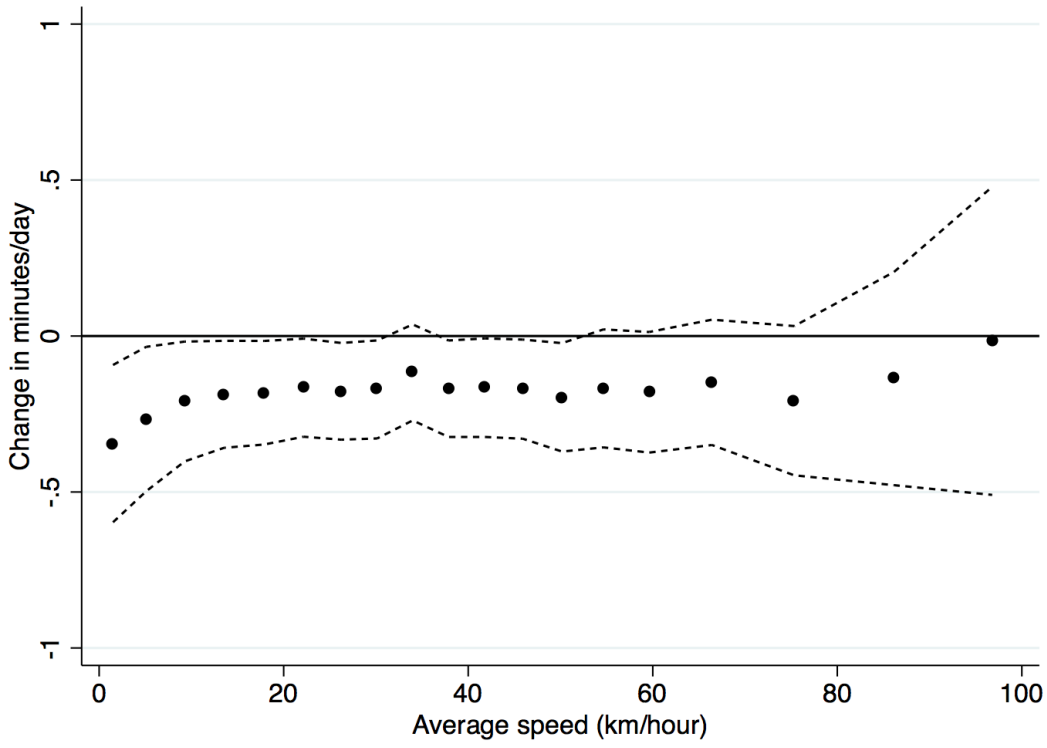
REDUCTIONS PRIMARILY IN TIME SPENT AT SPEEDS REPRESENTING UNCONGESTED ROAD CONDITIONS



ATE: change in daily distribution of micro-speeds for each driver

To what extent does dropped driving represent time that would have been spent in what looks like traffic?

CONTRAST: DISTANCE CHARGE THAT VARIES BY TIME-OF-DAY REDUCES TIME SPENT AT LOWER SPEEDS



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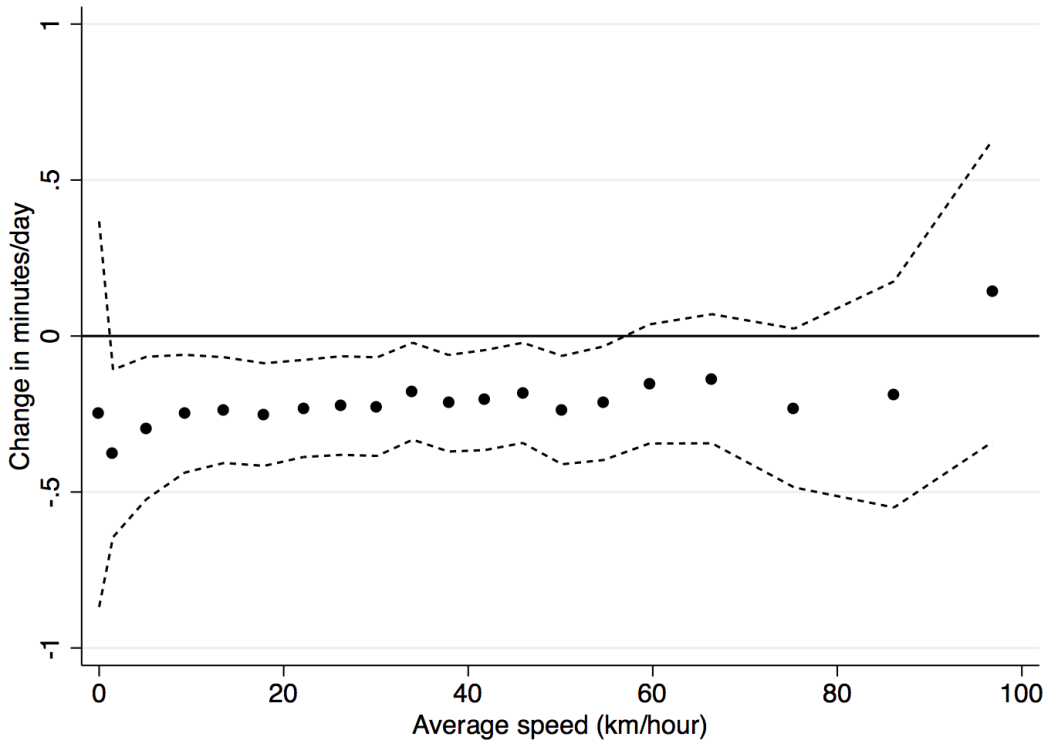
To what extent does dropped driving represent time that would have been spent in what looks like traffic?

Even more so under distance + location charge



ATE: change in daily distribution of micro-speeds for each driver

To what extent does dropped driving represent time that would have been spent in what looks like traffic?

Charges better targeting congestion?

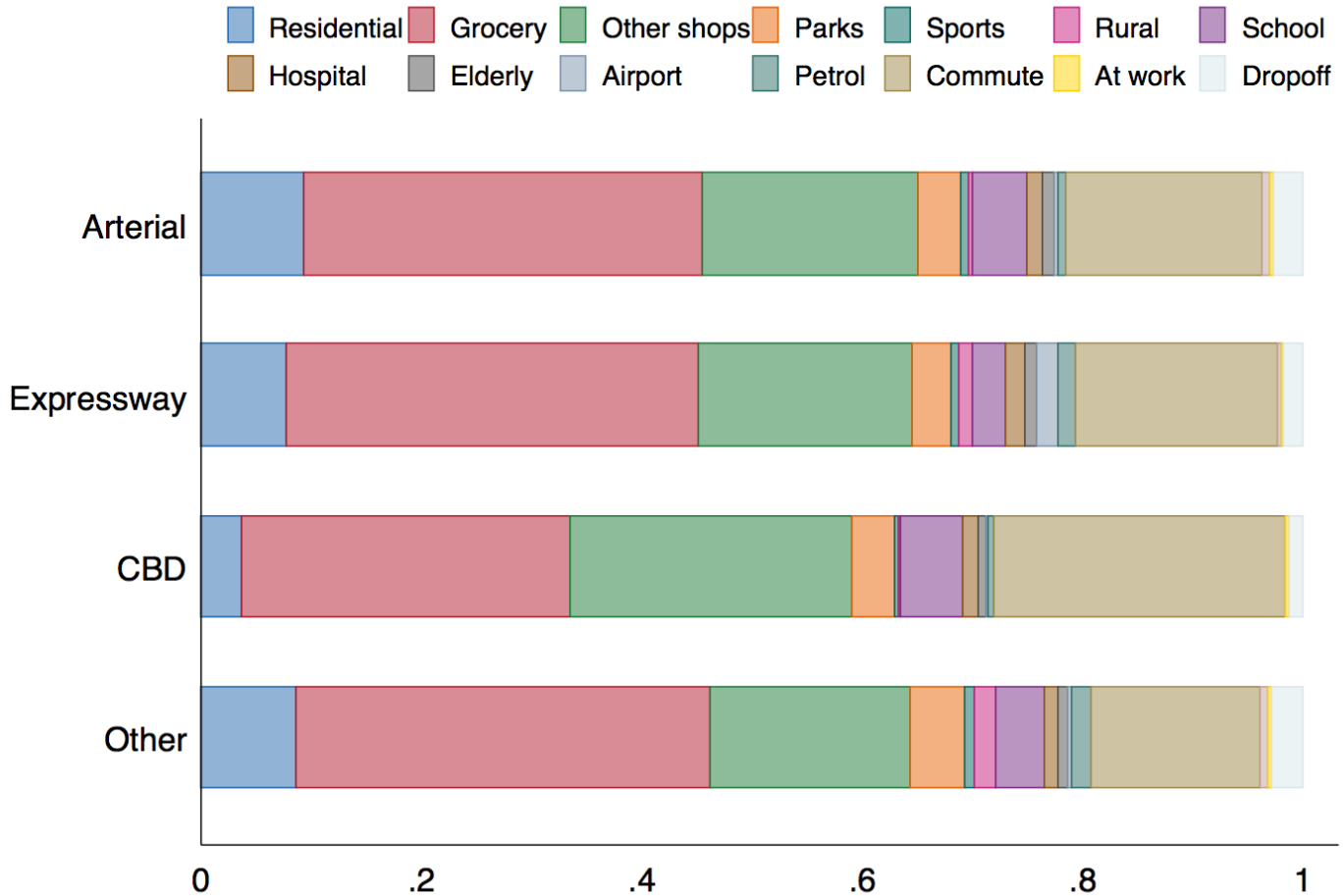
Time of day -based charge reduces peak driving Table

- Peak response small relative to increase in price
- Elasticity -0.11, noisy Table
- Limited evidence of time-shifting to mid-day and weekends

Location-based charge reduces driving into inner city on weekends

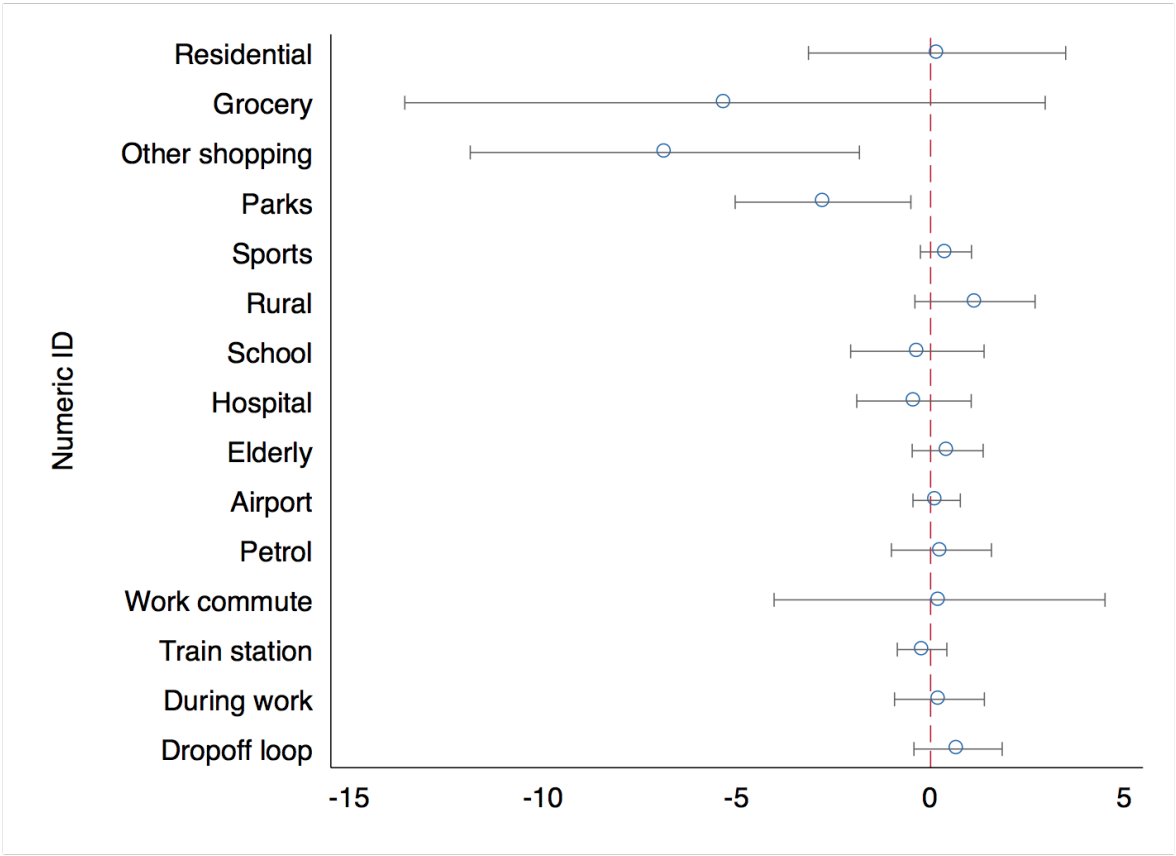
- Technically not priced then
- No evidence of increased driving around inner city
- No evidence of increased parking at rail stations

WHICH TRIPS? BASELINE DRIVING BY ROAD, DESTINATION



Reductions (km/week) by types of trip

Less shopping, also fewer park trips



No change in school trips and work commutes
Effect similar across types of road use charge

Implications of shopping result

- Relatively easy to stock up (average 10, 4 trips/week for grocery, other)
- Could be evidence of leakage

2. WHO WINS/LOSES UNDER ROAD USE CHARGES?

1. Estimate treatment effects and elasticities
   - by income and proximity to public transport
2. Estimate change in expenditure from switching to road user charges from fuel tax
   - assuming no price response
   - using estimated price elasticities

   Revenue-neutral: reduce gasoline taxes and, as needed, registration fees

Lower income households drive less

Some live further away from CBD and PT

- 41% live within 1km of PT (18% within 500m)
- 49% of higher incomes live that close (25% within 500m)

HH living far from CBD drive longer distances

But low income much more likely to be over the age of 65

- 56% of low-income are seniors
- 25% of higher income households are seniors

Seniors drive much less, especially at peak and into CBD

Inner city: 50% trips by $< 5\%$ of drivers (85% by HH not poor)

Low income households better off under more congestion-targeted revenue scheme

Table: Changes in weekly bill **assuming no price responsiveness**

Annual income	Households	Weekly fuel tax (AUD)	Change in weekly expenditures under Distance charge	TOD charge	Location charge
Less than $20,800	83	5.92	-4.18 (75%)	-4.51 (76%)	-3.32 (77%)
$20,800 to $41,600	162	7.39	-3.05 (67%)	-3.45 (68%)	-3.21 (71%)
$41,600 to $65,000	185	9.34	0.43 (60%)	0.13 (61%)	-0.47 (63%)
$65,000 to $104,000	260	8.96	1.40 (53%)	1.43 (54%)	1.25 (55%)
$104,000 to $156,000	203	9.56	2.36 (49%)	2.57 (49%)	2.18 (49%)
$156,000 or more	167	8.09	0.16 (58%)	0.65 (54%)	1.29 (52%)
Did not say	319	8.20	-0.55 (58%)	-0.52 (60%)	-0.50 (62%)

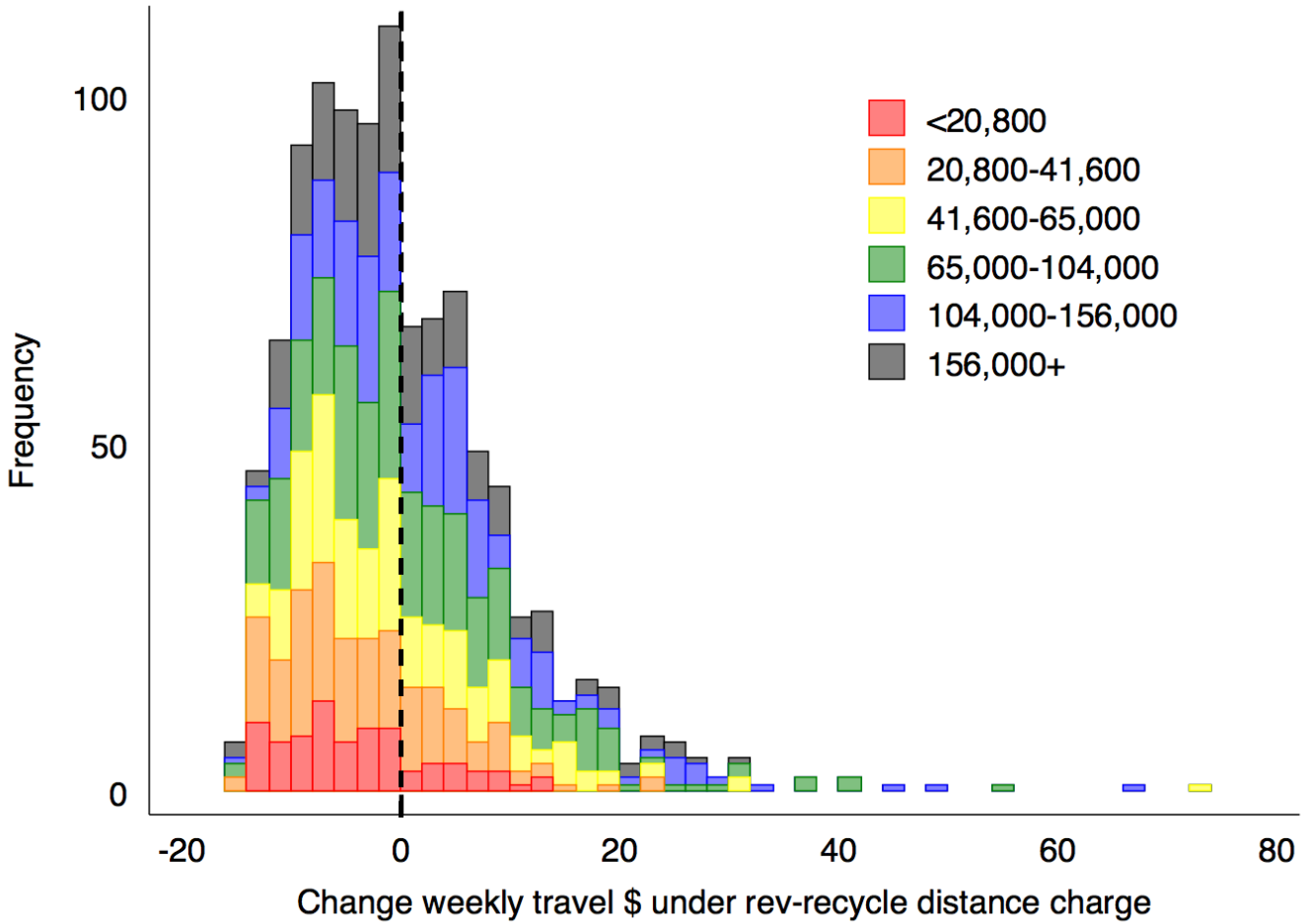
Δ travel expenditures under VMT charge

Losses for higher incomes far from public transit

	Distance to public transit			
Income	0 to 500m	500m - 1km	1 - 2.5km	More 2.5 km
Less than $20,800	-6.66	-5.01	-3.31	-1.10
$20,800 to 41,600	-6.20	-4.03	-2.10	-1.77
$41,600 to 65,000	-4.59	-1.10	2.01	1.66
$65,000 to 104,000	-2.51	0.97	2.11	4.90
$104,000 to 156,000	0.80	-1.33	2.29	7.75
Greater $156,000	-1.79	0.40	-0.21	5.89

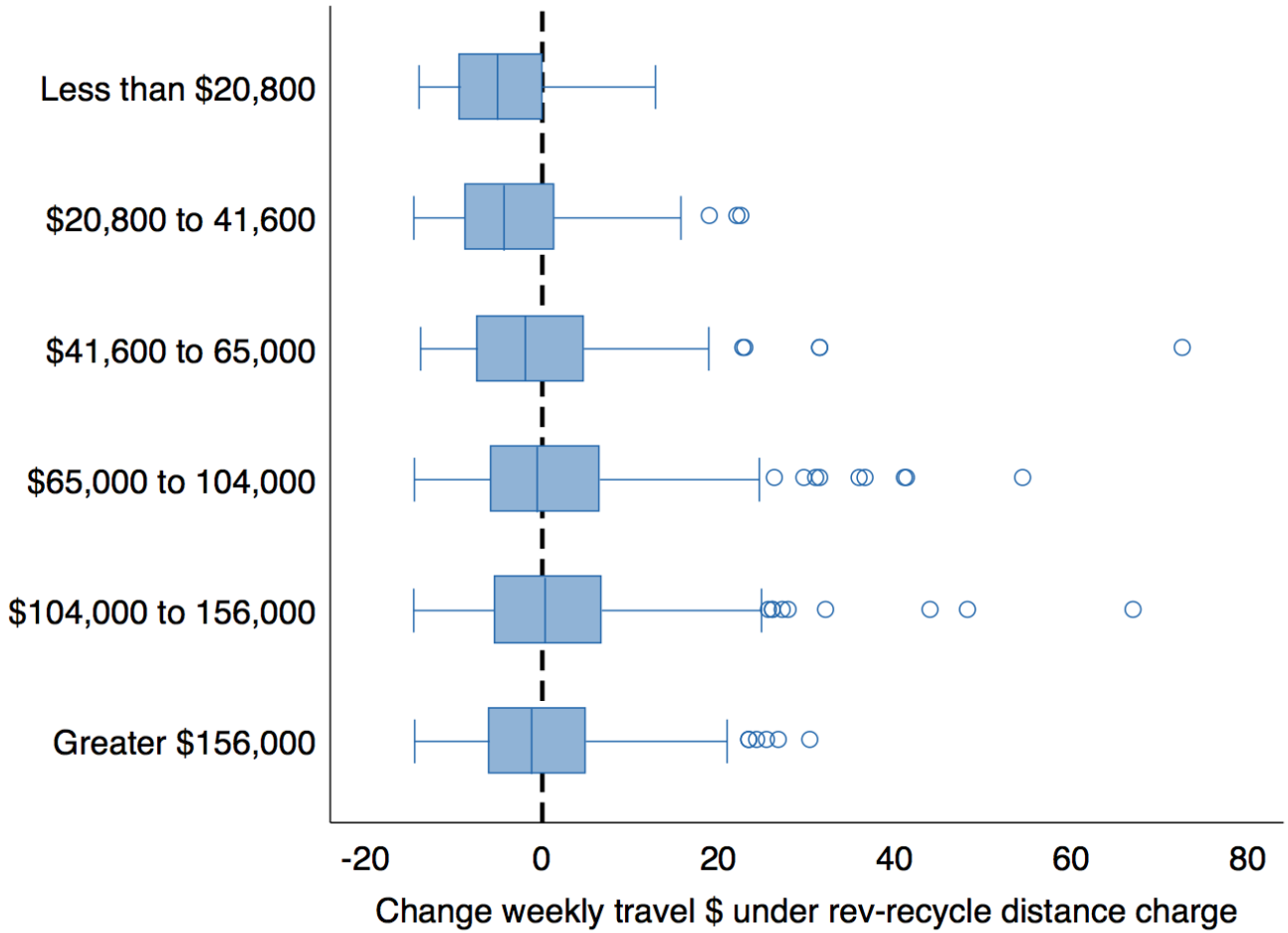
Δ travel expenditures under VMT charge

More poor households win than lose, some med-income large losses



Δ TRAVEL EXPENDITURES UNDER VMT CHARGE

MEAN AND QUANTILES



WHO LOSES MORE THAN $20/WEEK?

WEALTHIER, EMPLOYED, NEWER CARS

			Loses under distance charge		Loses under TOD charge		Loses under cordon charge	
	mean/sd	obs	diff/se	obs	diff/se	obs	diff/se	obs
Household								
Annual Income	90,276	980	21,677**	47	24,821***	60	17,644*	43
			(8821.2)		(7843.3)		(9214.5)	
Age $\geq$ 65	0.28	1245	-0.13**	54	-0.21***	71	-0.18***	51
			(0.062)		(0.054)		(0.063)	
Employed	0.68	1270	0.19***	58	0.25***	77	0.24***	56
			(0.061)		(0.053)		(0.062)	
Distance home SA1 to CBD (km)	22.7	1271	12.8***	59	16.4***	78	4.41**	57
			(2.06)		(1.78)		(2.12)	
Distance home SA1 to rail (km)	3.15	1271	2.74***	59	3.53***	78	1.07	57
			(0.74)		(0.65)		(0.76)	
Vehicle								
Average litres fuel per 100km	8.81	1273	-0.75**	49	-0.51*	68	-1.34***	47
			(0.34)		(0.29)		(0.34)	
Model year	2008.2	1273	3.08***	49	2.40***	68	2.95***	47
			(0.75)		(0.64)		(0.77)	
Multiple Cars (=1)	0.49	1269	0.15**	55	0.15**	74	0.14**	53
			(0.069)		(0.060)		(0.070)	

WHO LOSES MORE THAN $20/WEEK?

TRAVEL FURTHER, MORE OFTEN, TWICE AS MUCH IN CBD

			Loses under distance charge		Loses under TOD charge		Loses under cordon charge	
	mean/sd	obs	diff/se	obs	diff/se	obs	diff/se	obs
Trip								
Distance traveled (km/day)	29.1	1273	54.5***	60	49.6***	79	41.4***	58
			(2.43)		(2.10)		(2.66)	
Trips taken (/day)	3.25	1273	1.67***	60	1.56***	79	1.22***	58
			(0.21)		(0.19)		(0.22)	
Distance per trip (km/trip)	9.48	1273	7.69***	60	7.32***	79	6.39***	58
			(0.61)		(0.53)		(0.63)	
Share of time spent driving at peak (%)	33.9	1273	-2.85	60	6.99***	79	1.79	58
			(1.94)		(1.69)		(1.97)	
Share of households ever commuting (%)	40.1	1273	3.35	60	25.5***	79	17.6***	58
			(6.51)		(5.68)		(6.61)	
Share of hh-days entering CBD cordon (%)	2.92	1273	2.93**	60	4.48***	79	21.6***	58
			(1.21)		(1.06)		(1.09)	
Distance inside cordon (km/day)	0.25	1273	0.36***	60	0.29***	79	1.27***	58
			(0.086)		(0.076)		(0.081)	
Fraction km on Top 25 congested roads	0.10	1273	0.0050	60	0.0023	79	0.046***	58
			(0.011)		(0.010)		(0.012)	

Commuters under time-of-day and location

Estimating consumer surplus

Under constant elasticity of demand, $q = \alpha p^{\eta}$, ΔCS can be expressed as:

$$\Delta CS = \int_{p_1}^{p_0} p(x)dx = \frac{\alpha}{1+\eta}\left(p_0^{1+\eta} - p_1^{1+\eta}\right)$$

We estimate household-level α_i and income group level η_j using experimental variation in price

Low income HH respond more so save more

Distance-based charge

Annual income	Households	Elasticity	% Δ CS		Elasticity	% Δ CS	
			(1)	(2)		(1)	(2)
Less than 20,800	83	-0.13	-12.44	2.74	-0.60	-10.34	3.90
20,800 to 41,600	162	-0.13	-13.81	1.93	-0.19	-13.47	2.18
41,600 to 65,000	185	-0.13	-16.53	-0.26	-0.18	-16.21	-0.02
65,000 to 104,000	260	-0.13	-17.26	-1.10	0.10	-18.97	-1.85
104,000 to 156,000	203	-0.13	-18.19	-1.84	-0.22	-17.55	-1.43
Greater than 156,000	167	-0.13	-16.24	-0.37	0.05	-17.46	-0.89

Even more so under time-of-day Table

In summary

- Uniform VMT charges are likely to reduce driving under uncongested conditions
- More targeted charges could make moderate improvements at right times/speeds/places
- Households place relatively low value on frequent shopping trips
- Evidence that low income are more price-responsive
- Low income households could benefit from a revenue-neutral shift to from fuel tax to road user charges

Thank you

So you're running an RCT? Lessons learned

1. GPS in all HH vehicles, not just primary
2. Ok to collect ranked preferences for sub-treatments, not ok to use them (affects uniform distance charge only)
3. Make sure credit accounts will have enough balance that no one ever runs out

More Back

Potential RCT concerns addressed

- Adjusted for sub-treatment selection into 1st round by predicting control ranked preferences
- No substitution to unmonitored vehicles
- No differential attrition
- No end-cycle increase in use as account balances run out

SELECTION INTO SUB-TREATMENT IN FIRST ROUND

	Control		A - per trip		B - per km		C - Flat Rate	
	mean/sd	obs	diff/se	obs	diff/se	obs	diff/se	obs
Distance traveled (km/day)	30.6	384	4.91**	338	1.34	351	-1.44	331
	[24.2]		(1.73)		(1.60)		(1.62)	
Trips taken (/day)	3.23	384	0.11	338	0.33*	351	0.20	331
	[1.87]		(0.13)		(0.13)		(0.13)	
Distance per trip (km/trip)	9.59	384	1.58***	338	-0.37	351	-0.95**	331
	[4.84]		(0.38)		(0.32)		(0.33)	
Household-days entering CBD	2.11	384	0.83	338	-0.28	351	0.16	331
	[6.57]		(0.59)		(0.45)		(0.49)	
Average litres fuel per 100km	8.82	373	-0.17	337	0.074	351	-0.11	330
	[2.36]		(0.18)		(0.18)		(0.17)	

IPWs to adjust for phase 1 sub-treatment selection

- Multinomial logit for which sub-treatment ranked highest
- Re-weight phase one sub-treatments using IPWs. Effectively matches treatment and control based on preferences, with more weight on closer matches

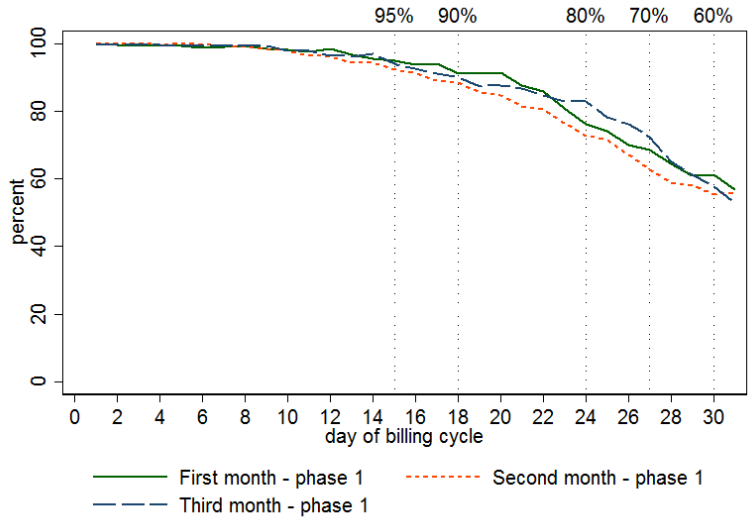
- Results very similar
- HH ranked sub-treatments thinking tax, i.e. benefit relative to average baseline
- But received subsidy with individual baseline

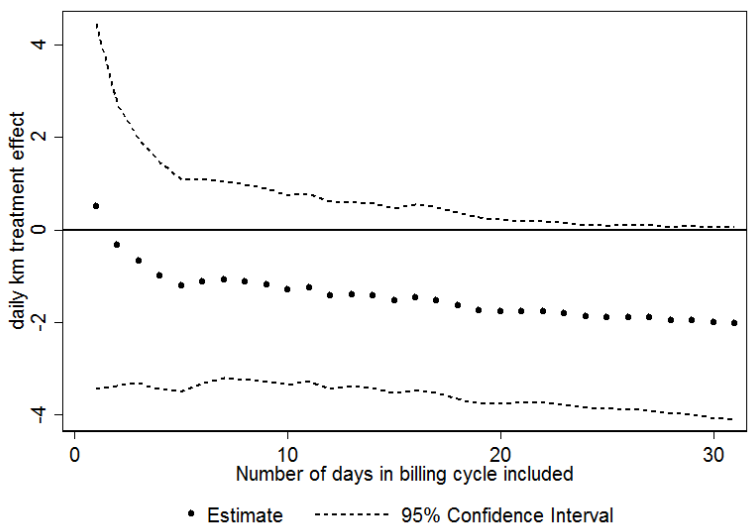
No evidence of substitution towards unmonitored vehicles

	(1) Distance	(2)	(3) Time of Day	(4)
VARIABLES	Multicars	One car	Multicars	One car
log price	-0.0659	-0.1785**	0.0021	-0.1768**
	(0.064)	(0.072)	(0.086)	(0.090)
Observations	10,007	9,588	9,388	8,853
R-squared	0.0226	0.0351	0.0284	0.0366
Treated hh	178	174	176	168
Control hh	170	172	170	172
CDW F-test	4854	5858	4396	4440

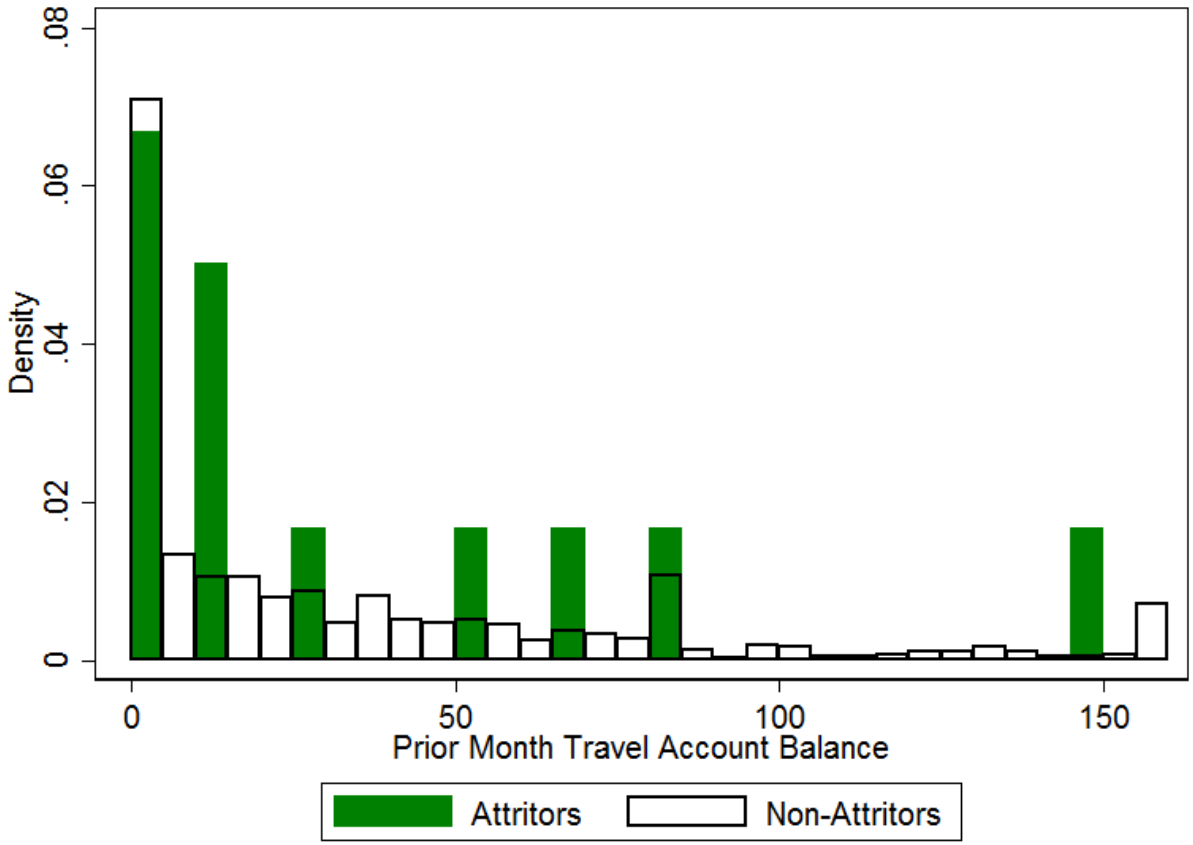
Positive balance most HH-days

TE robust to including maxed out balances





ATTRITION LOW, NOT F(REMAINING BALANCE)



Back

VKT CHARGE REDUCES DISTANCE -8%, TIME -6%

VARIABLES	(1) Trips (/day)	(2) Distance (km/day)	(3) Duration (min/day)
Treatment = 10c per km	-0.0965	-2.055*	-2.951**
	(0.0748)	(1.060)	(1.304)
Observations	147,831	147,831	147,831
R-squared	0.0308	0.00541	0.0142
Treated hh	353	353	353
Control hh	356	356	356
Mean dep var	3.375	32.23	51.61

Back

Most driving and reductions off-peak, not commutes

VARIABLES	(1) Peak	(2) Off-peak	(3) Mon-Fri	(4) Weekend	(5) Commute	(6) Not commute	(7) CBD	(8) CBD ring	(9) Far CBD
Treatment = 10c per km	-0.891	-2.061**	-3.489**	-2.096	0.543	-3.609***	-0.295**	-0.260	-2.510**
	(0.562)	(0.817)	(1.426)	(1.442)	(0.544)	(1.171)	(0.116)	(0.204)	(1.158)
Observations	148,160	148,160	100,691	47,469	148,160	148,160	148,160	148,160	148,160
R-squared	0.205	0.00792	0.00862	0.0128	0.0698	0.00904	0.00316	0.00607	0.0121
Treated hh	354	354	354	354	354	354	354	354	354
Control hh	358	358	358	358	358	358	358	358	358
Mean dep var	18.68	28.01	54.06	46.27	8.436	43.13	1.349	3.594	46.63

Dep var: minutes/day. Peak = Monday-Friday 7-9am and 3-6pm

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13% REDUCTION IN KM TRAVELED FOR 100% INCREASE IN PRICE PER KM

VARIABLES	(1) Overall	(2) Peak	(3) Off-peak
log per kilometer cost of travel	-0.1213**	0.0112	-0.1024**
	(0.048)	(0.052)	(0.047)
Observations	19,692	17,940	19,420
R-squared	0.0252	0.0136	0.0192
Treated hh	353	353	353
Control hh	344	344	344
CDW F-test	10510	10144	10522

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Daily treatment effects: fixed effects

$$y_{it} = \beta \text{ Treated}_{it} + \alpha_i + \gamma_t + \epsilon_{it}$$

y_{it}: distance, time spent travelling, destinations
α_i, γ_t: household, date fixed effects

Cluster standard errors at the household level

TIME OF DAY CHARGE REDUCES PEAK DRIVING

VARIABLES	(1) Peak	(2) Off-peak	(3) Mon-Fri	(4) Weekend
Treatment = 15c peak 8c off-peak	-1.902**	-1.280	-0.517	0.969
	(0.797)	(2.417)	(2.466)	(3.566)
Observations	139,396	139,396	71,875	43,952
R-squared	0.199	0.00568	0.00761	0.00938
Treated hh	344	344	344	344
Control hh	359	359	359	359
Mean dep var	19.17	44.41	96.12	60.59

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Peak response small relative to increase in price

VARIABLES	(1) Overall	(2) Peak	(3) Off-peak
log per kilometer cost of travel	-0.0813	-0.1059*	0.0078
	(0.062)	(0.055)	(0.076)
Observations	18,320	16,697	18,069
R-squared	0.0286	0.0146	0.0220
Treated hh	344	344	344
Control hh	344	344	344
CDW F-test	8800	11675	9185

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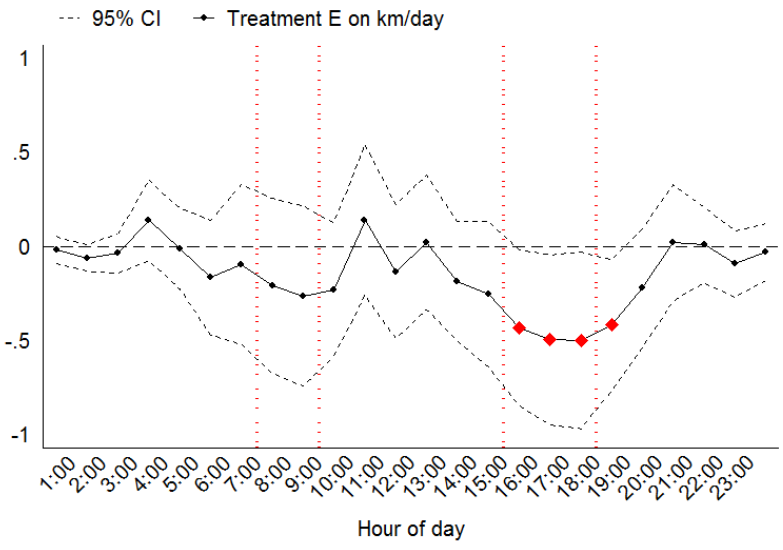
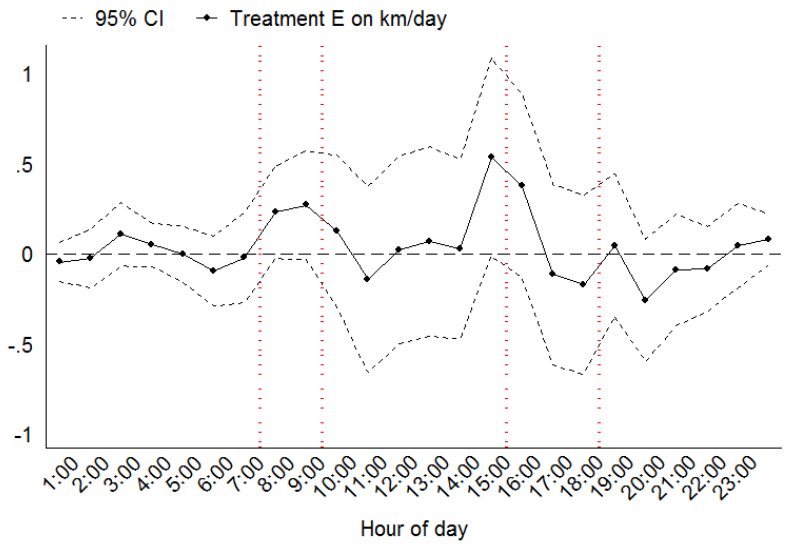
Weak evidence of time-shifting

(a) Monday-Friday



(b) Saturday-Sunday



LOW INCOME HH RESPOND MORE UNDER TOD SO SAVE MORE

Time-of-day charge

Annual income	Households	Elasticity		% Δ CS		Elasticity		% Δ CS	
		peak	off-peak	(1)	(2)	peak	off-peak	(1)	(2)
Less than 20,800	83	-0.09	-0.03	-12.22	3.44	-0.32	-0.47	-10.62	4.26
20,800 to 41,600	162	-0.09	-0.03	-13.58	2.66	-0.17	-0.02	-13.41	2.84
41,600 to 65,000	185	-0.09	-0.03	-16.52	0.29	-0.31	0.03	-16.02	0.72
65,000 to 104,000	260	-0.09	-0.03	-17.46	-0.76	-0.04	0.08	-18.05	-0.98
104,000 to 156,000	203	-0.09	-0.03	-18.51	-1.62	-0.05	-0.22	-17.96	-1.37
Greater than 156,000	167	-0.09	-0.03	-16.68	-0.30	0.02	0.32	-18.34	-0.99

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Responsive low income are young, employed, near public transport

Table: Low income

VARIABLES	(1) Age<65	(2) Age≥ 65	(3) Employed	(4) Unemployed	(5) Close train	(6) Far train
log price, Distance charge	-0.3307**	-0.1133	-0.3232***	-0.1259	-0.3153**	-0.2006
	(0.146)	(0.120)	(0.112)	(0.142)	(0.129)	(0.127)
Observations	3,073	2,987	3,166	2,930	2,157	3,906
R-squared	0.0695	0.0386	0.0842	0.0388	0.0724	0.0424
Treated hh	48	59	54	55	45	64
Control hh	60	48	56	52	37	70
CDW F-test	1617	1717	1878	1543	1395	1996