Effects of Pavement Roughness on Traffic Outcomes: Evidence from California

Margaret Bock
Alexander Cardazzi
Brad R. Humphreys
West Virginia University

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Presentation Outline

Motivation

- Substantial government highway maintenance spending - 2017 total government highway maintenance spending \$51 bil., capital outlay \$105 bil.
- Maintenance improves road smoothness (resurfacing, pot hole filling, etc.)
- Road roughness affects highway safety, vehicle maintenance costs
- Road smoothness represents key quality signal for government provided goods, likely affects political economy of public transportation infrastructure supply (Glaeser & Ponzetto, 2018)
- Despite large spending and economic importance, little research focuses on the consequences of road roughness
- Duranton, Nagpal & Turner (2020): "understudied, but central to any formulation of an optimal maintenance policy"

Context: Road Roughness

- Smooth new roads deteriorate with use and weathering (capital depreciation)
- Heavier use speeds up rate of depreciation, generates a negative externality
- Roughness can be reduced by maintenance (overlay, milling/repaving)
- New road durability also influenced by design decisions like surface type/quantity, surface thickness, drainage, construction techniques
- Theoretical literature on road pricing and optimal road durability (Small and Winston, 1986), and optimal maintenance (Newbery, 1988)
- A few papers in the highway engineering literature analyze road roughness and accidents, 2 analyze roughness and speed. All use simple measures of association.
- No research in economics on road roughness

Project Overview

- Analyze impact of road roughness for Federal-Aid Highways in California
  - 158,000 lane miles in state
  - State spent $576 mil on road maintenance, $994 mil on rehabilitation in 2018
  - Wide variation in geography, climate, urban cover
  - Access to large amount of high quality highway and traffic data
- Assembled spatially and temporally disaggregated data on road roughness, traffic speed/volume, accidents from multiple data sources
- Empirical investigation of impact of road roughness at specific points in time (proxied by International Roughness Index) on traffic speed and accident rates in month of IRI scan from 2011 to 2018

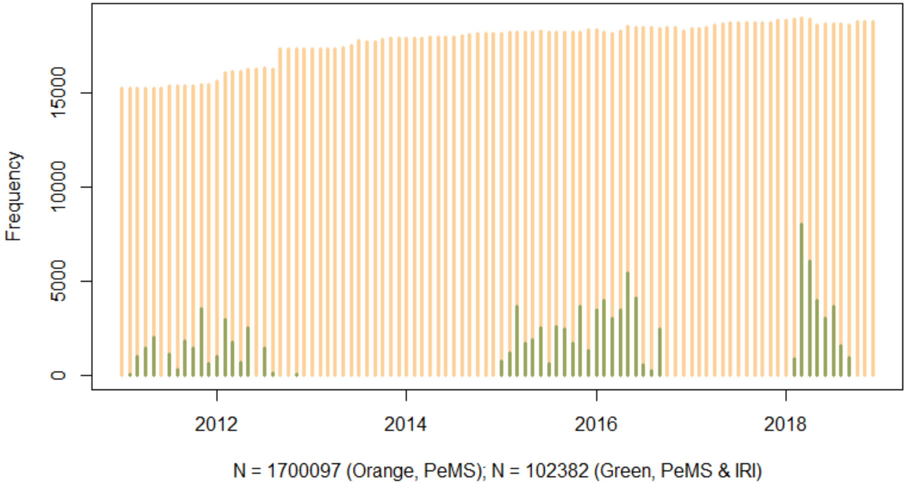
Data Sources

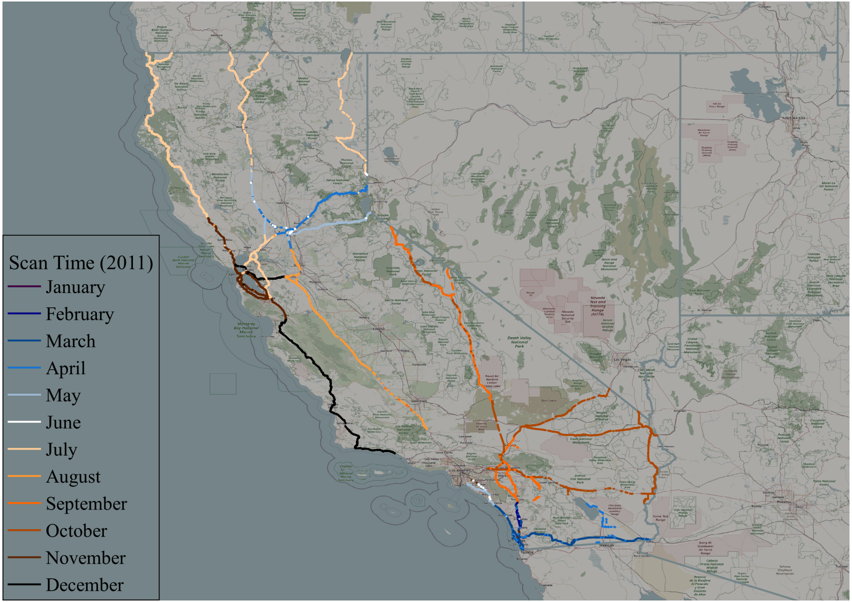
1. **Road Roughness**: Annual Pavement Condition Survey (APCS)
   - Unit of observation: 0.1 mile segments by lane
   - Road scans for 3 separate "waves": 2011-12, 2015-16, 2018
   - International Roughness Index (IRI), pavement type, geographic characteristics for each segment
   - IRI estimates for most segments in each wave, multiple estimates for segments in some waves
2. **Accidents**: California Highway Patrol (CHP) Incidents
   - Database containing all highway incidents including location (lat/long), occurrence time, incident type
   - Focus on incidents identified as collision or hit-and-run
3. **Traffic Conditions**: California Performance Monitoring System (PeMS)
   - Based on data from induction loop monitors
   - Vehicle Miles Traveled, Vehicle Hours Traveled, Vehicle Flow (Speed in MPH)
   - Available at different spatial/temporal levels; involves spatial interpolation

Analysis Data Set Construction

- Periodically observe 0.1 mile segment IRI, scan waves roughly 3-5 years apart
- Continuously observe PeMS VMT/VHT/speed for any segment length/time
- Universe of accidents identified by occurrence time & location
- Key issue: spatial & temporal matching of IRI and PeMS volume/speed data
- IRI changes over time with vehicle use, weathering, and noise across scans
- Longer time intervals likely to introduce more systematic bias to IRI measures
- **Current approach**: Match PeMS 1 mile/month traffic data to IRI by 0.1 mile segment, average to uniform 1 mile/month segments for calendar month scan occurred
- If IRI scan month and location randomly assigned, then IRI exogenous to time varying unobservable factors affecting accidents and traffic speed

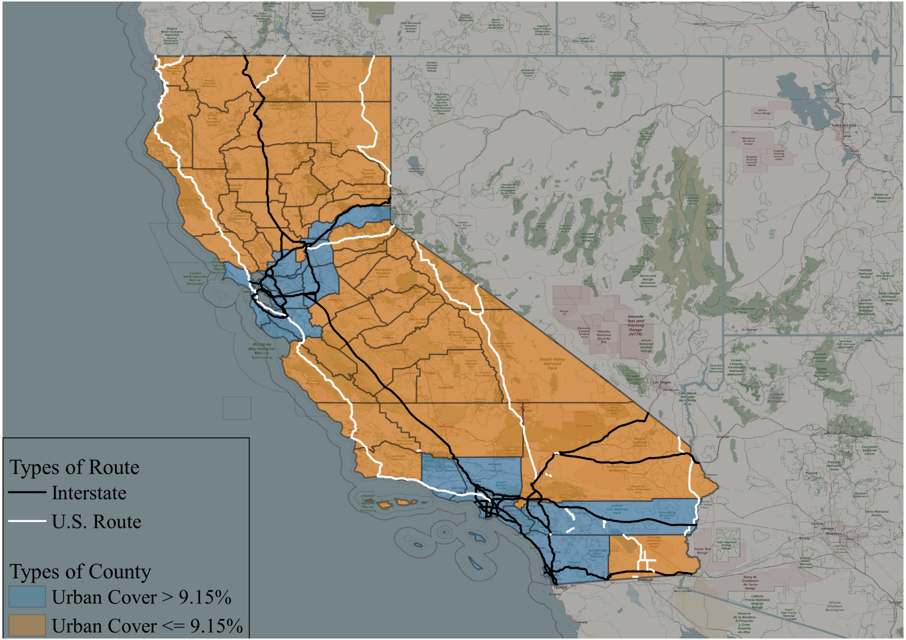
IRI Scans & PeMS Traffic Conditions, .1 mile/month segment



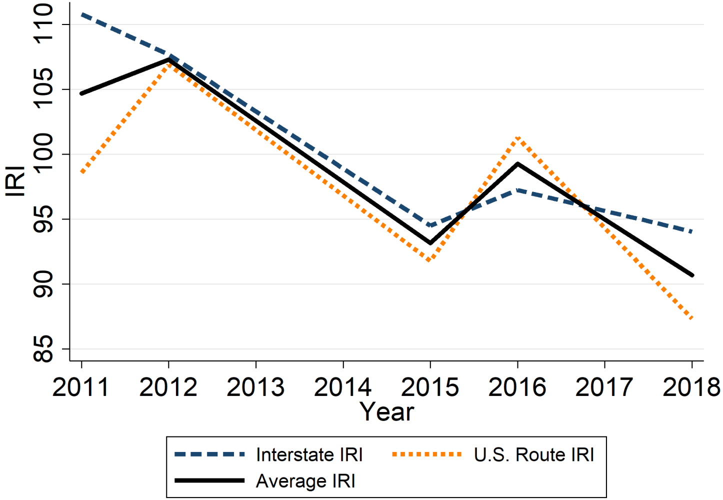

Scan Time (2011)
January
February
March
April
May
June
July
August
September
October
November
December

Analysis Data Set Characteristics

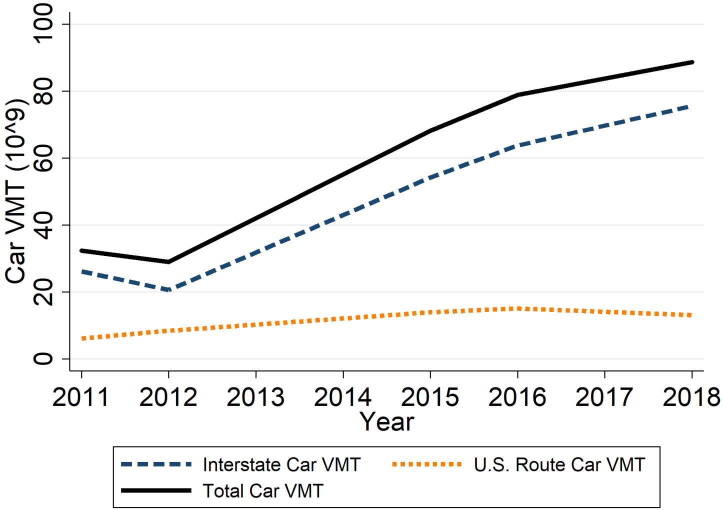
- California Federal Aid Highways
- 23 Interstate Highway System roads: I10, I110, I15, I205, I210, I215, I280, I380, I40, I405, I5, I505, I580, I605, I680, I710, I780, I8, I80, I805, I880, I905, and I980
- 8 US Numbered Highway System roads: US101, US199, US395, US50, US6, US75, US95, and US97
- About 35,000 highway lane month/miles, 6,500 unique 1 mile-lane road segments
- substantial heterogeneity in terms of urban cover, pavement type, climate
- IRI, accident rate, average speed data for about 13,000 1 month/mile segments in the month IRI scan occurred


Types of Route
Interstate
U.S. Route
Types of County
Urban Cover > 9.15%
Urban Cover <= 9.15%

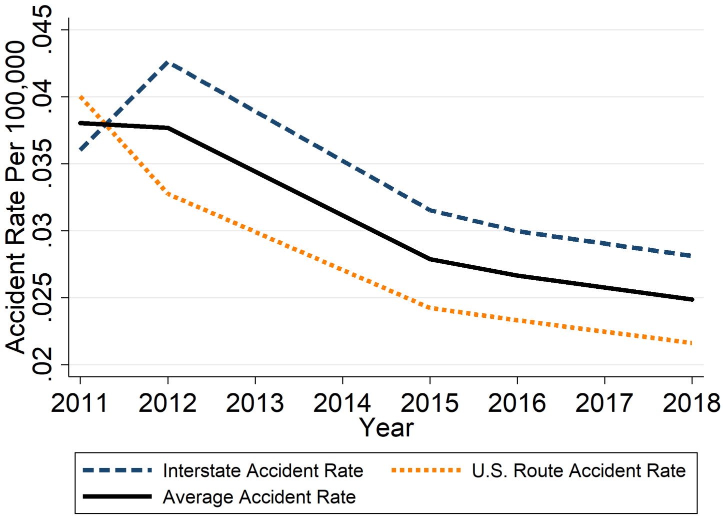
International Roughness Index



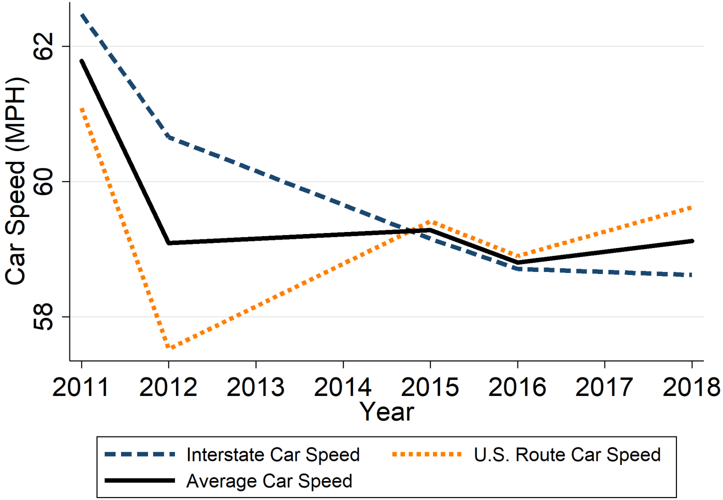
Vehicle Miles Traveled



Accident Rate



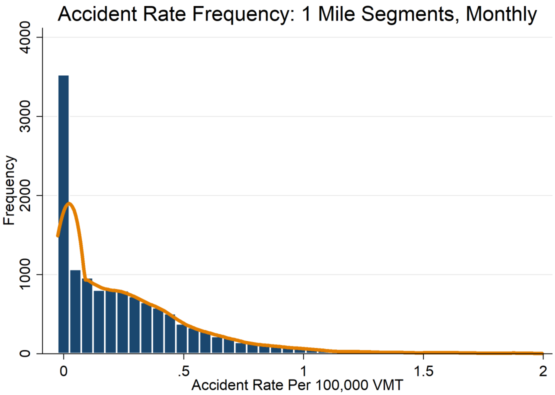
Average Speed

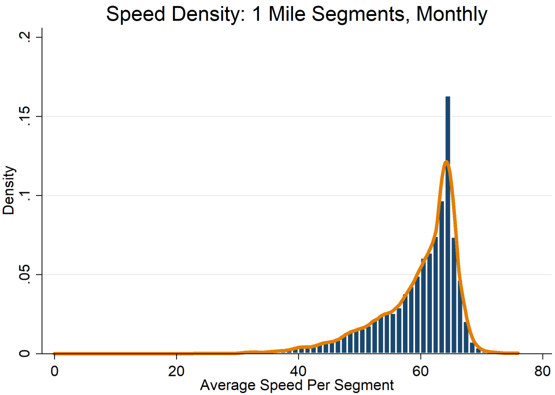


Summary Statistics, 1 month/mile segments ($N = 12,779$)

Statistic	Mean	St. Dev.	Min	Max
IRI	96.9	37.0	29	276
Accidents	7.39	8.66	0	103
Accident Rate per 100,000 VMT	0.263	0.332	0	9.35
VMT (100,000s)	29.5	14.9	0.32	194
VHT (100,000s)	0.531	0.292	0.005	3.187
Average Speed (MPH)	59.7	6.6	23.9	75.7
Elevation (ft.)	655	997	−268	7,381
Interstate Highway segment	0.80	0.40	0	1

Accident Rate and Speed Distribution





- 26% of Accident Rate observations $(N = 3,372) = 0$

Naïve OLS Models

$$TrafficOutcome_{srcmy} = \phi_r + \phi_c + \phi_m + \phi_y + \gamma_o IRI_{srcmy} + \epsilon_{srcmy}$$

- Model explains observed variation in traffic outcomes on one mile road segment s, on route r, in county c in month m and year y
- Traffic Outcomes: Monthly accident rate per 100,000 vehicle miles, average speed
- Contains Route (ϕ_r), County (ϕ_c), month (ϕ_m), year (ϕ_y), fixed effects to control for unobserved, time invariant heterogeneity in mile/month segments
- Error term ϵ_{srcmy} captures other unobserved factors affecting traffic outcomes. Assumed mean zero and heteroskedastic.
- Parameter estimate of interest ($\widehat{\gamma_o}$) causal if IRI scans randomly assigned to segments

Naïve OLS Model Results

	(1) Accident Rate	(2) Speed
IRI	0.001***	-0.023***
	(0.0001)	(0.001)
Observations	12,779	12,779
R^2	0.15	0.34
Year FE	Y	Y
Month FE	Y	Y
Route FE	Y	Y
County FE	Y	Y

*** $p<0.01$. Robust standard errors.

Empirical Strategy: Instrumental Variables

$$IRI_{srcmy} = \phi_r + \phi_c + \phi_m + \phi_y + \psi_1 Z_{srcmy} + \varepsilon_{srcmy}$$

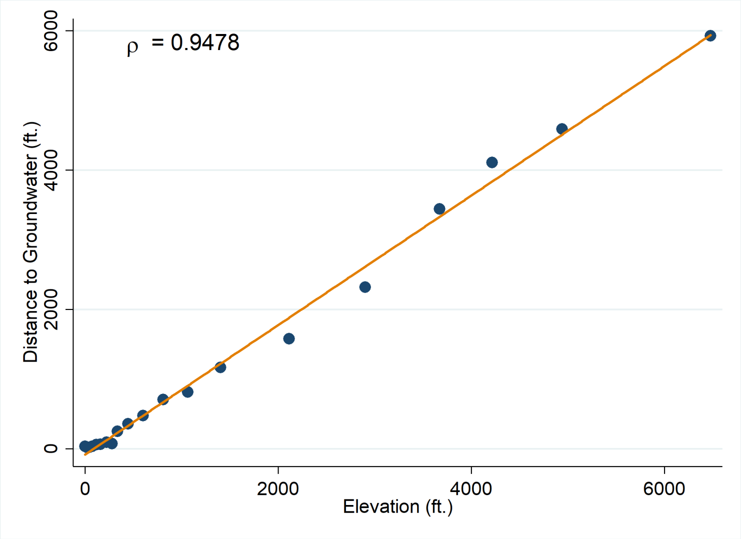
$$TrafficOutcome_{srcmy} = \phi_r + \phi_c + \phi_m + \phi_y + \beta_1 \widehat{IRI_s} + \eta_{srcmy}$$

- Identification problem: IRI scans not random, correlated with unobservable time varying factors affecting traffic outcomes contained in ϵ_{srcmy} from Naïve OLS Model
- IV uses an instrument Z_{srcmy} to identify causal effect of road roughness on traffic outcomes
- Model explaining variation in accident rates does not control for speed, since speed is endogenous.
- Year, month, route, county fixed effects

Identification

- Identification requires an instrument Z_{srcmy} correlated with road roughness and uncorrelated with unobservable time varying factors affecting traffic outcomes contained in ϵ_{srcmy}
- **Candidate Instrument**: *Depth to groundwater* under road segment
- 2019 FHA report: depth to groundwater associated with significant pavement deterioration for shallow depths
- California groundwater data exist, but only 5% of the road segments in sample located within 0.5 miles of a groundwater measurement well
- **Instrument**: *Elevation* of road segment. Geology literature identifies strong correlation between elevation and depth to groundwater
- Other papers in economics use elevation as an instrument: Dinkleman *AER* 2011, Faber *REStud* 2014

Elevation and Distance to Groundwater



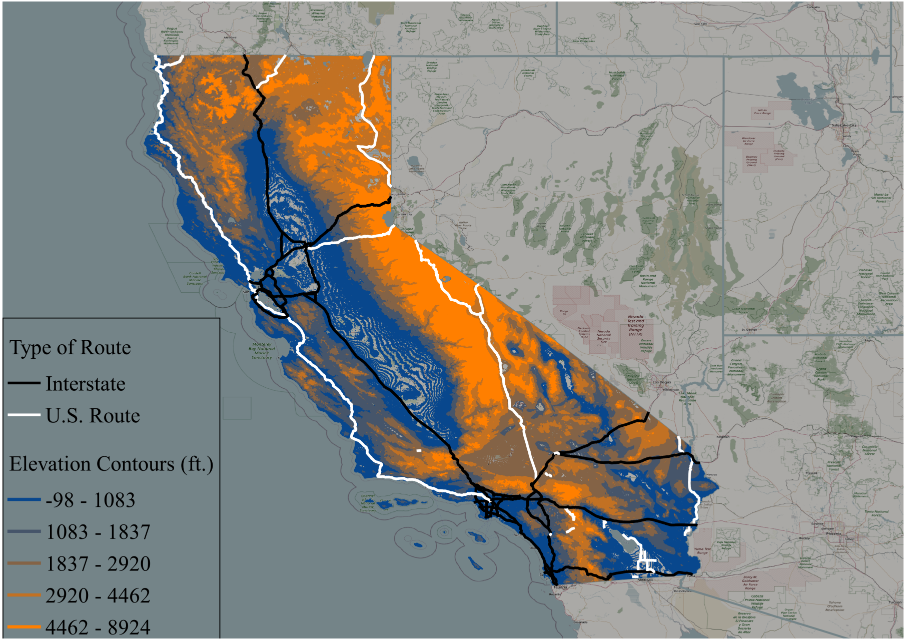

Type of Route
Interstate
U.S. Route
Elevation Contours (ft.)
-98 - 1083
1083 - 1837
1837 - 2920
2920 - 4462
4462 - 8924

Table: IV Estimates of IRI on Traffic Outcomes

	(1) Reduced Form	(2) 1st Stage	(3) 2nd Stage
Dependent Variable: Accident Rate			
Elevation	-0.0001***	-0.003***	
	(0.00001)	(0.001)	
$\widehat{IRI}$			0.023***
			(0.004)
Observations	12,779	12,779	12,779
Kleibergen-Paap F			30.4
Dependent Variable: Speed			
Elevation	0.0001***	-0.003***	
	(0.00001)	(0.001)	
$\widehat{IRI}$			-0.241***
			(0.045)
Observations	12,779	12,779	12,779
Kleibergen-Paap F			30.4

*** $p<0.01$. Robust standard errors.

Table: IV Estimates of IRI on Traffic Outcomes: Interstate vs. U.S. Route

	(1) Interstate 1st Stage	(2) Interstate 2nd Stage	(3) U.S. Rt. 1st Stage	(4) U.S. Rt. 2nd Stage
Dependent Variable: Accident Rate				
Elevation	-0.008***		0.006***	
	(0.0007)		(0.0008)	
$\widehat{IRI}$		0.0115***		-0.008***
		(0.0012)		(0.001)
Observations	10,240	10,240	2,592	2,592
Kleibergen-Paap F		18.8		63.6
Dependent Variable: Speed				
Elevation	-0.008***		0.006***	
	(0.0007)		(0.0008)	
$\widehat{IRI}$		-0.224***		-0.187***
		(0.022)		(0.036)
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Summary

- Rougher roads cause reductions in average speed on highways in CA
- Rougher roads cause increases in accident rates overall, and on interstate highways
- Rougher roads cause reductions in accident rates on US Numbered Highways in CA, likely reflects impact of speed on accidents
- Road roughness has important impacts on traffic outcomes - highway planners should recognize this when making maintenance decisions

Future Work

- Explore heterogenity in Asphalt vs Concrete surfaces
- Explore heterogenity in Urban vs Rural highways
- Address endogeneity between speed and accidents when analyzing the impact of roughness
- Getting access to detailed information on construction/maintenance project contracts (location, date, cost) - exploit this to understand changes in IRI for specific road segments over sample
- Deal with zeros (25% of observations) in accident rate variable - accident counts & count data model?