Distributional Effects of Air Pollution from Electric Vehicle Adoption

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Electric Cars

- Modern revival
- Tesla Model S, Nissan Leaf, BMW i3, Renault Zoe, etc.

Electric Car Market Share (October 2016)

Country	Market Share	Purchase Subsidies
US	0.8	\$7500 Federal + some states
UK	1.3	£4500
Germany	1.0	€4000
France	1.1	€6300
Norway	30.4	$\approx$ €12,000 (no purchase taxes)

Electric Cars and Air Pollution

- Environmental benefits of driving are equal to the reduced air pollution damages from the forgone gasoline car, *less* the resulting damages from an electric car
  - Tailpipe vs. smokestacks
- Literature finds EVs reduce CO_2 in US on average
  - Graff Zivin et al. (2014)
  - Michalek et al. (2011)
- Holland et al. (2016)
  - On average, damages from local pollutants (PM, ozone, etc.) roughly offset the benefits of CO_2 reductions
  - Significant heterogeneity in environmental benefits
    - Los Angeles ($4743 per vehicle driving 150k miles)
    - New York (-$32)
    - Fargo, North Dakota (-$4605)

This Paper

- Analyzes entire fleet of electric cars in US
- Compares created and received environmental benefits
  - Created benefits are appropriate for efficiency
  - Received benefits are appropriate for distributional effects (equity)
- Considers efficiency of purchase subsidies

Caveats

- Local air pollution only (not CO_2)
- Driving only (not life-cycle)
- Model electricity grid circa 2011
- Distributional effects due to combination of consumer preferences and a suite of policies
  - Purchase subsidies, carpool access, discounted electricity, free parking, tax breaks for charging infrastructure, etc.
  - We do not attribute distributional effects to individual policies

Outline

Summary of Holland et al. (2016)

An Overview of Calculating Damages from Driving

- Driving gasoline car in county i causes damages in many counties
- Charging electric car in county i increases electricity consumption (load) which causes damages in many counties
- For electric car
  - Damage matrix $\mathbf{E}$
  - $e_{i,j}$ damages per mile in county j due to driving electric car in county i
- For gasoline car
  - Damage matrix $\mathbf{G}$
  - $g_{i,j}$ damages per mile in county j due to driving gasoline car in county i

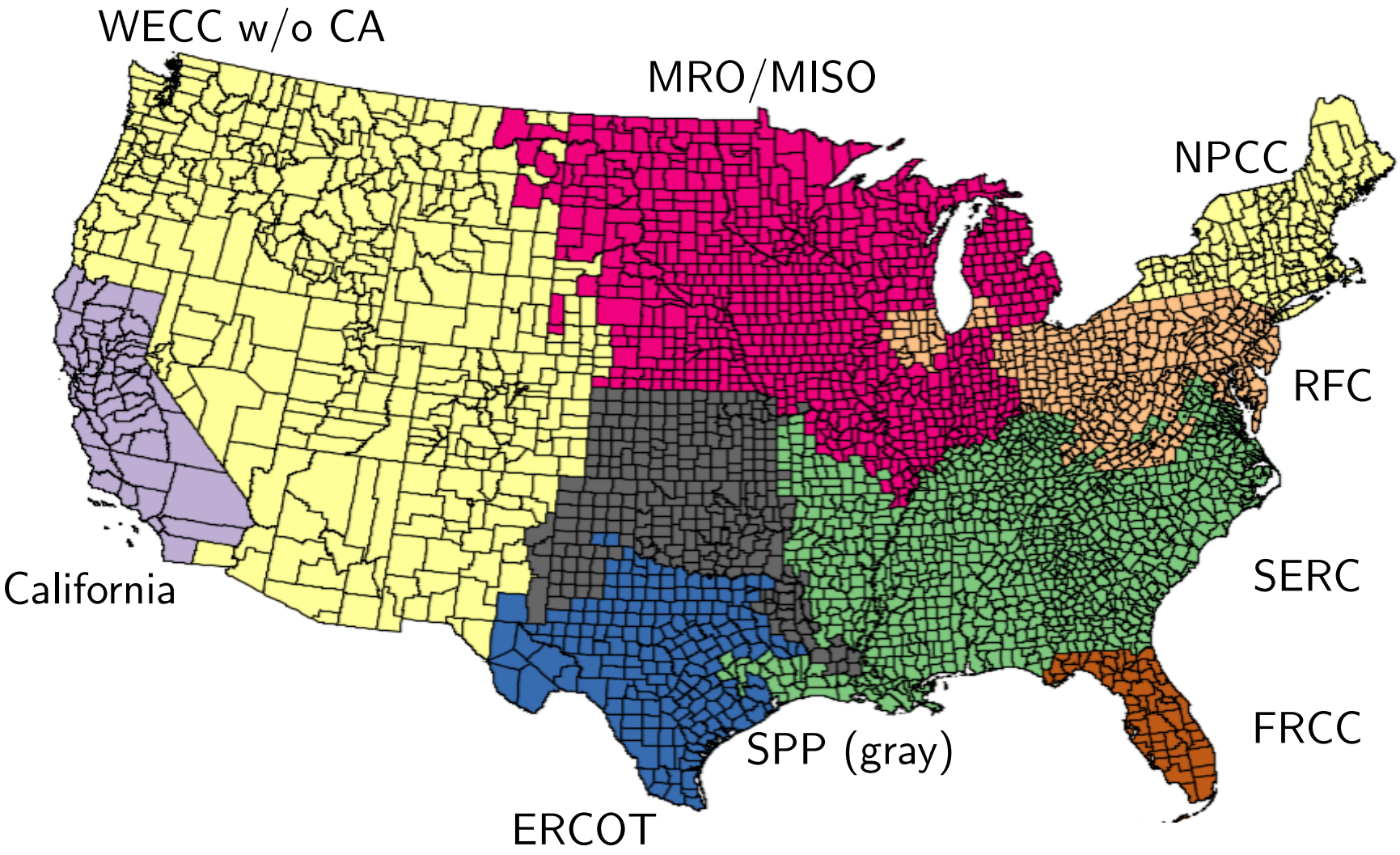
Details of Holland et al. (2016)

- Emissions per mile × damages per unit emissions
- Emissions per mile
  - Gasoline car
    - Emissions per mile (sources: GREET & EPA)
    - Urban/ rural adjustment
  - Electric car
    - kWh per mile (EPA)
    - Cold weather adjustment
    - **Electricity generation and air emissions model**
- Damages per unit emissions
  - Global CO_2 at SCC (EPA)
  - Local pollutants SO_2, NO_X, $PM_{2.5}$, and VOC:
  - Where pollution goes and who it hurts
  - **Air pollution integrated assessment model** (AP2)

Electricity Generation and Air Emissions Model

- Model the US electricity grid
- Consumption (NERC) regions (9) are the spatial unit for electricity load shocks due to charging electric car
- Load shock in one region may affect plants in other regions
- Plant-level regressions to estimate effects of change in load in a given region on emissions
- Time of day when charged matters
- Data sources for emissions (EPA), load (FERC), & charging profile (EPRI)

Map of Electricity Load Regions



Plant-Level Regressions

$$y_{it} = \sum_{h=1}^{24} \sum_{j=1}^{J(i)} \beta_{ijh} HOUR_h LOAD_{jt} + \sum_{h=1}^{24} \sum_{m=1}^{12} \alpha_{ihm} HOUR_h MONTH_m + \varepsilon_{it},$$

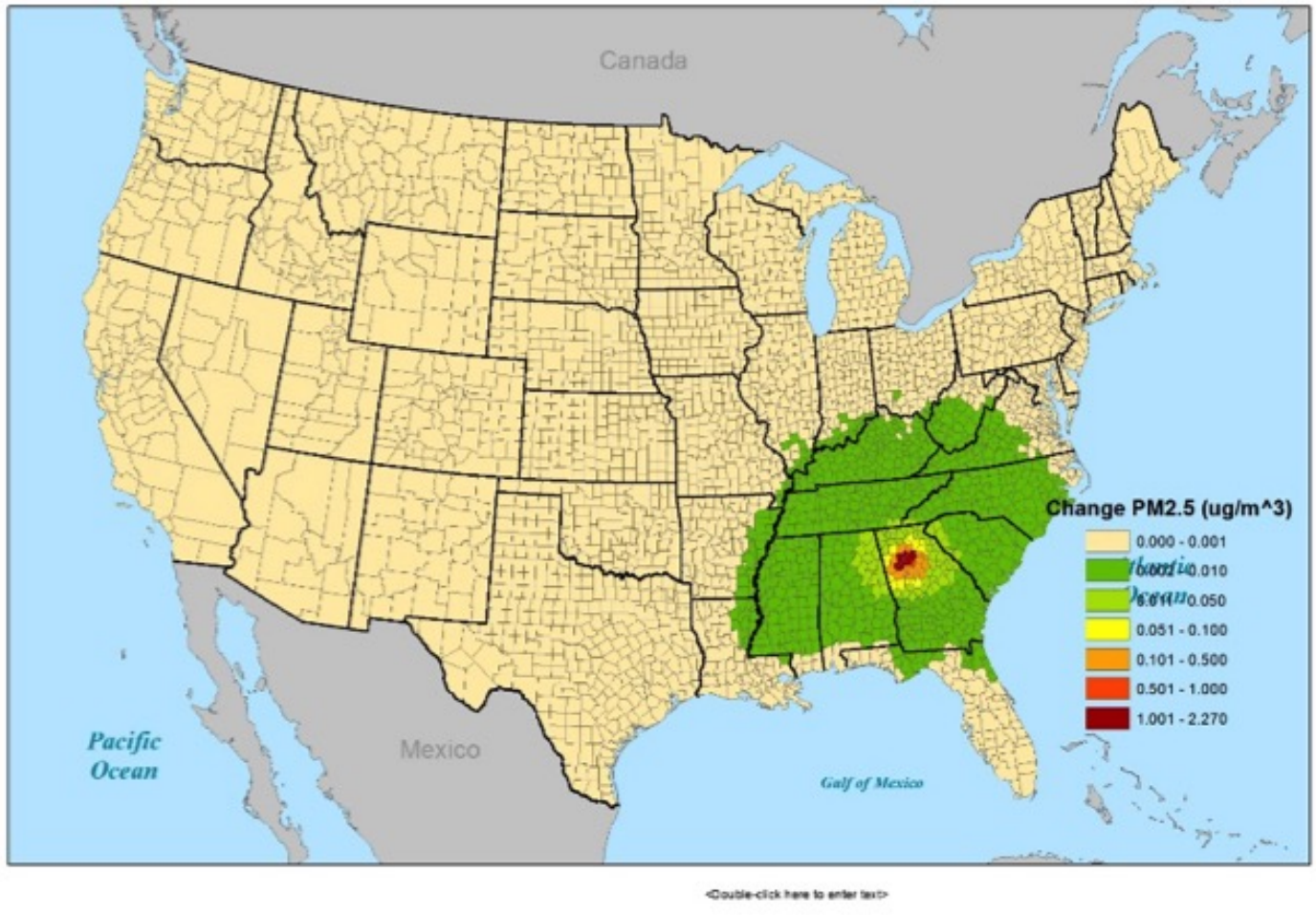
- y_{it}: emissions of plant i and time t
- $J(i)$: number of regions in i's interconnection
- $HOUR_h$: hour of the day h
- $MONTH_m$: month
- $LOAD_{jt}$: electricity consumed in region j at time t.

Emission factors β_{ijh}: marginal change in emissions t plant i from an increase in electricity usage in region j in hour h.

Air Pollution Integrated Assessment Model

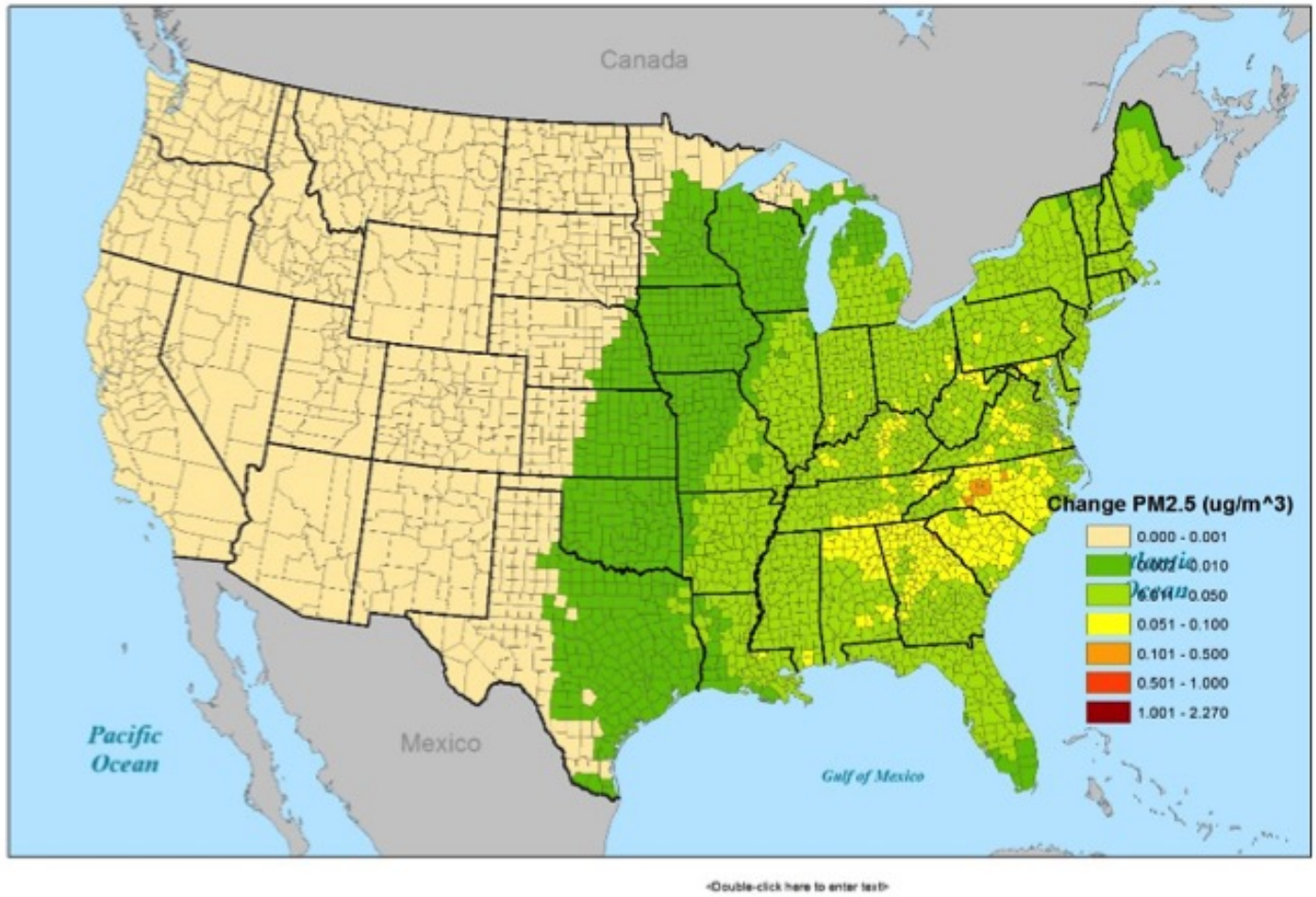
- AP2 model (Muller 2014)
- Maps emissions → ambient concentrations → damages
- Counties are spatial unit
- Chemical and physical processes
  $PM_{2.5} = F(PM_{2.5}, SO_2, NO_X, VOC)$
  $SO_2 = G(SO_2)$
  $O_3 = H(NO_X, VOC)$
- Ambient concentrations of SO_2, O_3, and $PM_{2.5}$ cause a myriad of health and environmental damages
  - Human health (mortality, morbidity; value of a statistical life estimates) due to $PM_{2.5}$ and O_3
  - Crop and timber losses due to O_3
  - Building and material degradation due to SO_2
  - Reduced visibility and recreation due to $PM_{2.5}$

Gasoline Car Driven in Georgia (Fulton Co.): $g_{i,j}$



Ford Focus Gasoline

Electric Car Driven in Georgia (Fulton Co.): $e_{i,j}$



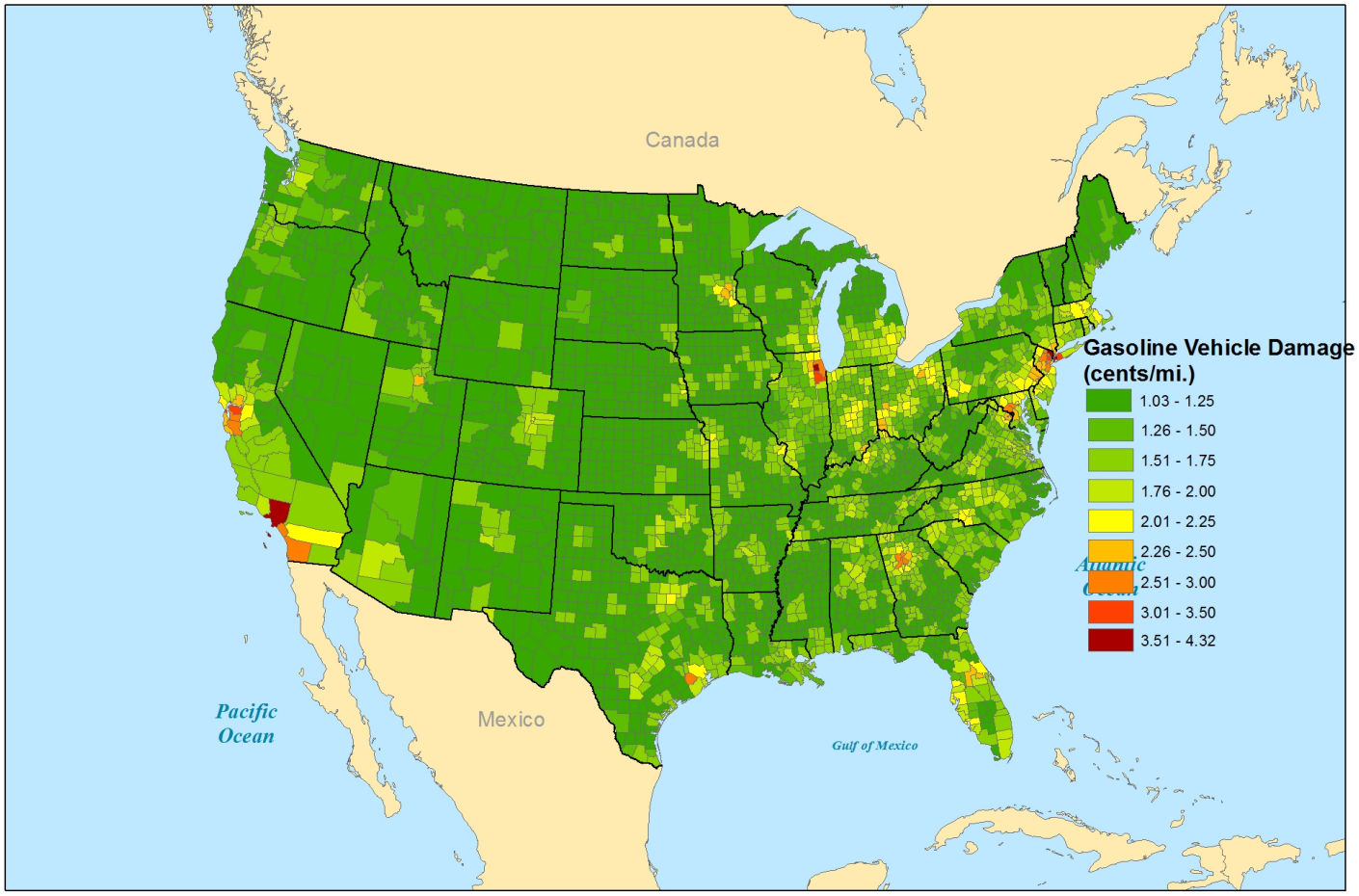
Ford Focus Electric

Results of Holland et al. (2016)

Environmental benefits of a Ford Focus electric vs. Ford Focus gasoline

- For county i, add up all damages over all counties from driving gasoline car, $\sum_j g_{i,j}$
- For county i add up all damages over all counties from driving electric car, $\sum_j e_{i,j}$.
- Difference gives environmental benefits in county i

Damages for Gasoline Car by County



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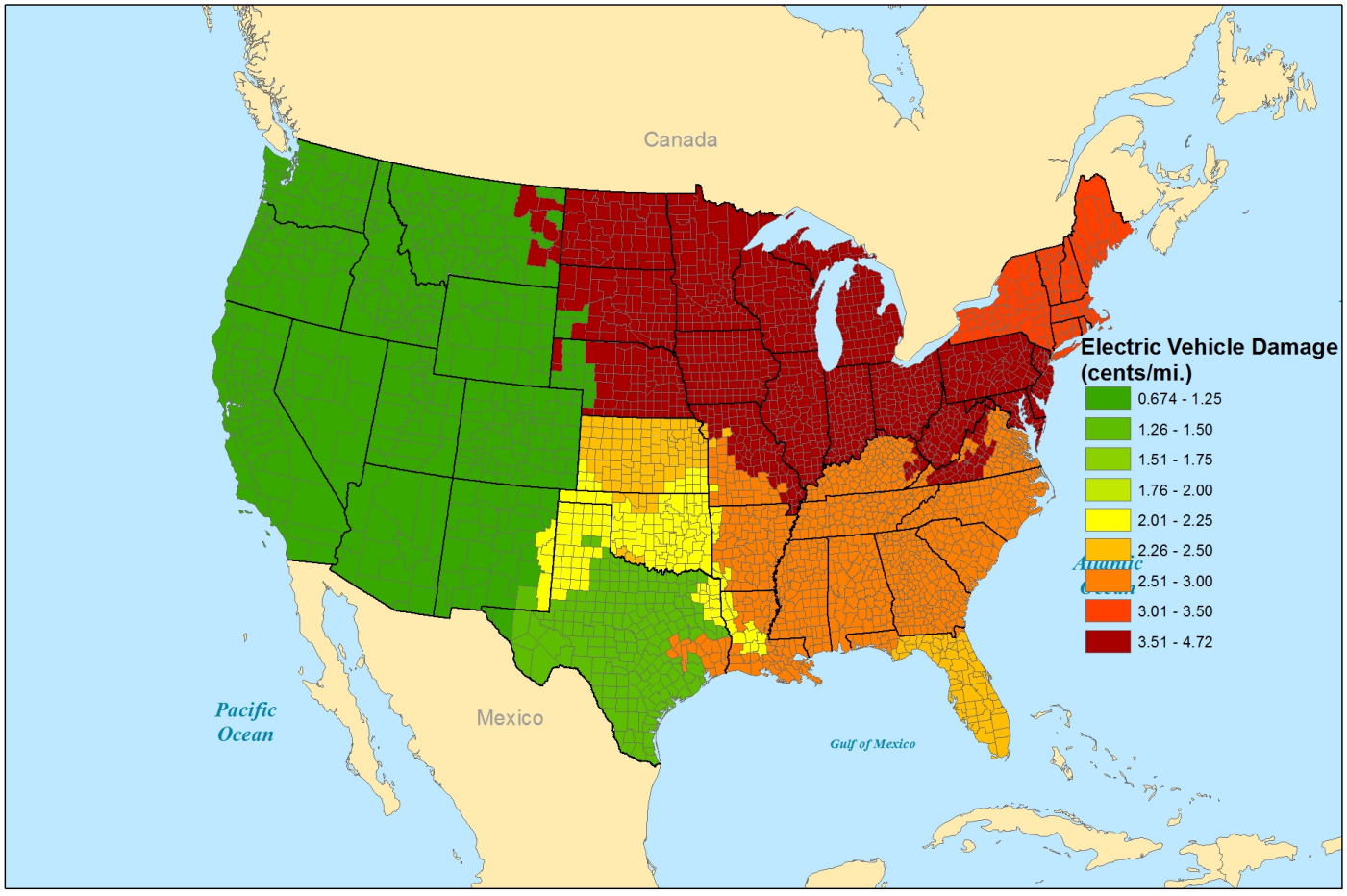
Ford Focus Gasoline, cents per mile

Damages for Electric Car by County



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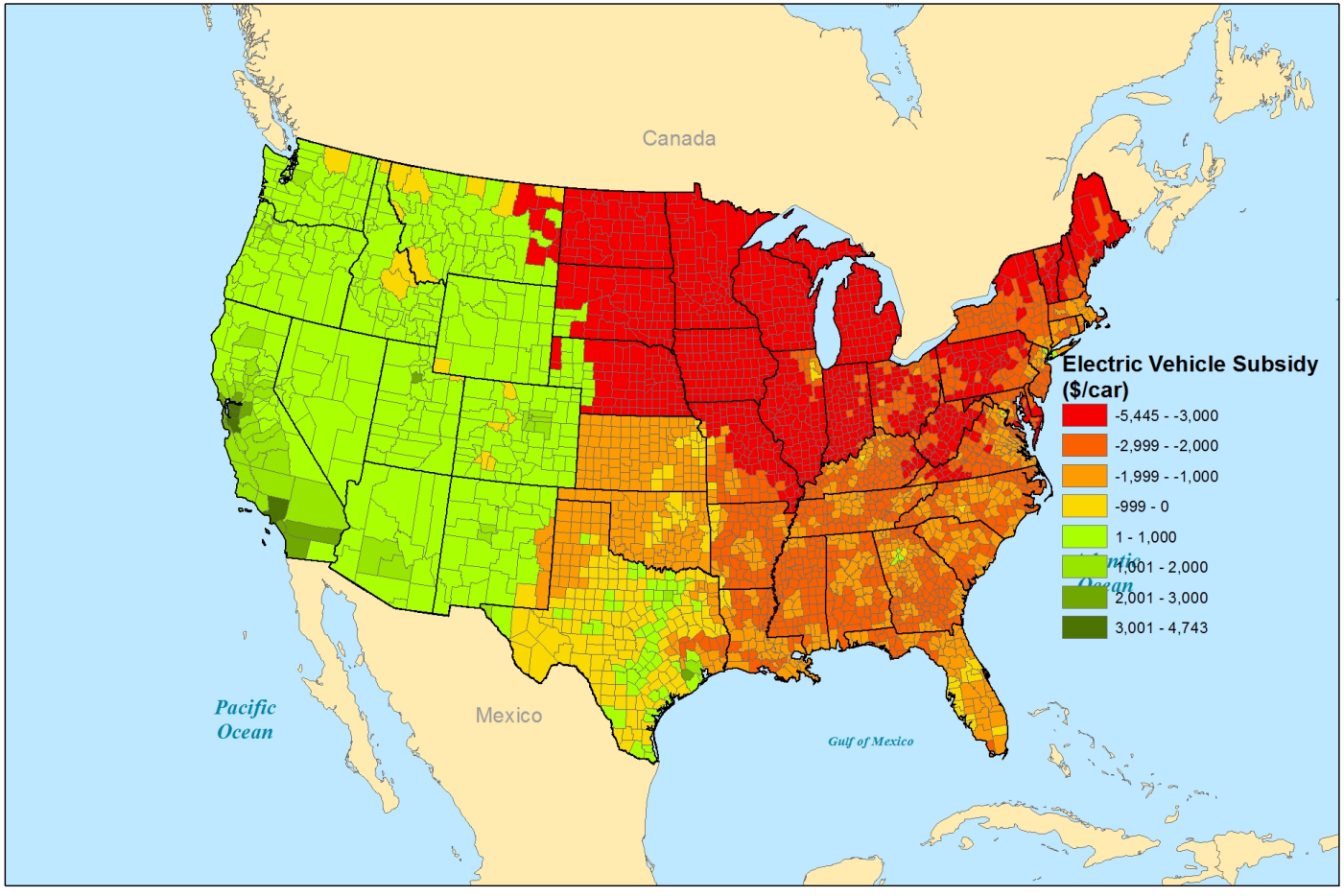
Ford Focus Electric, cents per mile

Environmental Benefits by County



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Dollars per vehicle switched from gasoline to electric

Environmental Benefits Summary Statistics

	Mean	Min	Max
Damages Focus Electric	2.59	0.67	4.72
Damages Focus Gas	1.86	1.03	4.32
Environmental Benefits (EB)	-0.73	-3.63	3.16
Global EB	0.44	-0.21	0.89
Local EB	-1.17	-3.43	2.28

Notes: Damages and benefits are in cents per mile. This is the distribution across all counties in contiguous US, regardless of whether there are electric cars (weight by total vehicle miles travelled).

Outline

Data

- Electric car registrations by county and model, as of June 2014 (source: IHS Automotive)
- Market survey data on forgone, or second choice, gasoline vehicles (source: MaritzCX)
- Demographic data on income, race, and population by block group level (US Census)
- Local air pollution damages (extension of method of Holland et al. (2016))

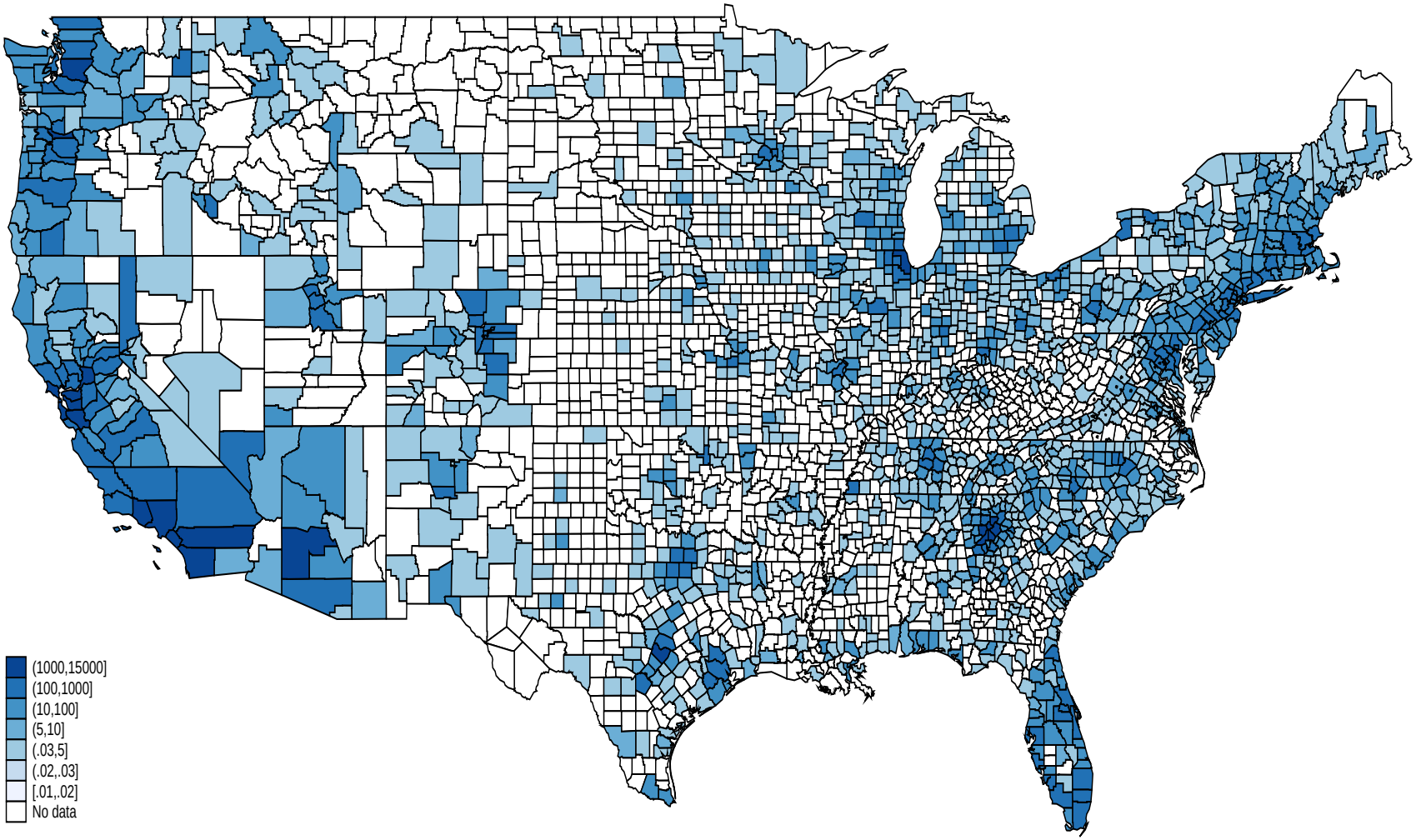
What types of electric cars?

US Fleet of Electric Cars

Model	Registrations
Chevy Spark	1,899
Fiat 500	8,555
Ford Focus	4,436
Honda Fit	1,055
Mitsubishi i-Miev	1,721
Nissan Leaf	69,860
Smart EV	4,077
Tesla S	38,235
Toyota Rav4	2,456
Total	132,294

Source: IHS Automotive registration data

Where are the electric cars?



Source: IHS

.. mostly in urban centers (98%)

City (MSA)	Number of Vehicles
Atlanta, GA	14,496
Los Angeles, CA	13,854
San Jose, CA	11,170
Oakland, CA	8,131
San Francisco, CA	6,437
Seattle, WA	6,352
Santa Ana, CA	5,734
San Diego, CA	5,722
Portland, OR	3,105
Sacramento, CA	2,838

Source: IHS

Forgone Gasoline Cars

Nissan Leaf : Model most seriously considered

Response	Frequency	Share
No Other Considered	31,081	61%
Chevrolet Volt *	3372	7%
Toyota Prius	2166	4%
Ford Focus Electric *	1889	4%
Toyota Prius Plug-in *	1073	2%
Tesla Model S *	903	2%
Honda Fit EV *	590	1%
BMW i3 *	502	1%
Ford C-Max Energi *	459	1%
Fiat 500 Electric *	448	1%
Kia Soul	344	1%
Mitsubishi i-MiEV *	332	1%
Ford Fusion	301	1%

Notes: * indicates plug-in vehicles. Source: MaritzCX Data

Defining Composite Gasoline Cars

- For each electric car model, select top 10 *non*-plug-in cars from most seriously considered list
- Composite car emissions equal to weighted average of emissions from these cars
- Use Holland et al. (2016) methodology to determine **G** for composite car and **E** for electric car model
- Compare electric car model to forgone composite gas car

Environmental Benefits Created and Received

- Accounts for entire fleet of electric cars and forgone composite gas cars
- Intuition: row sum (created) vs. column sum (received)
- Given specific model car (e.g. Nissan Leaf), there are n_i vehicles for this model registered in county i.
- Environmental benefits created by county i

$$n_i \sum_j (g_{i,j} - e_{i,j})$$

- Environmental benefits received by county j

$$\sum_i n_i (g_{i,j} - e_{i,j})$$

- Repeat for all models (different n, $\mathbf{E}$ & $\mathbf{G}$) and aggregate

Results of Environmental Benefits

Benefits Created and Received by Region ($1000)

Region	Benefits Created	Benefits Received
Midwest	-2,709	-2,329
Northeast	-2,437	-4,083
South	-5,174	-4178
West	10,276	10,545
Total	-44	-44

Results of Environmental Benefits

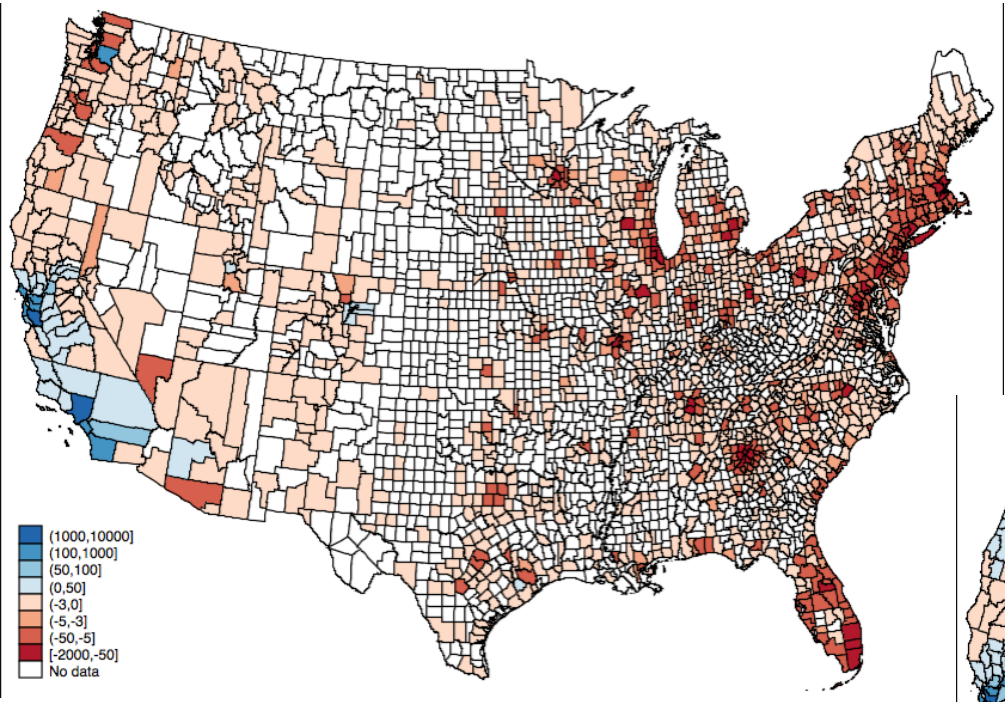
Benefits Created and Received by Metropolitan Statistical Area ($1000)

MSA	Benefits Created	Benefits Received
Atlanta, GA	-2,032	1,237
Los Angeles, CA	4,615	3,382
San Jose, CA	1,647	941
Oakland, CA	1,241	1,573
San Francisco, CA	797	1,012
Seattle, WA	97	336
Santa Ana, CA	910	1,387
San Diego, CA	664	677
Portland, OR	-34	82
Sacramento, CA	112	138

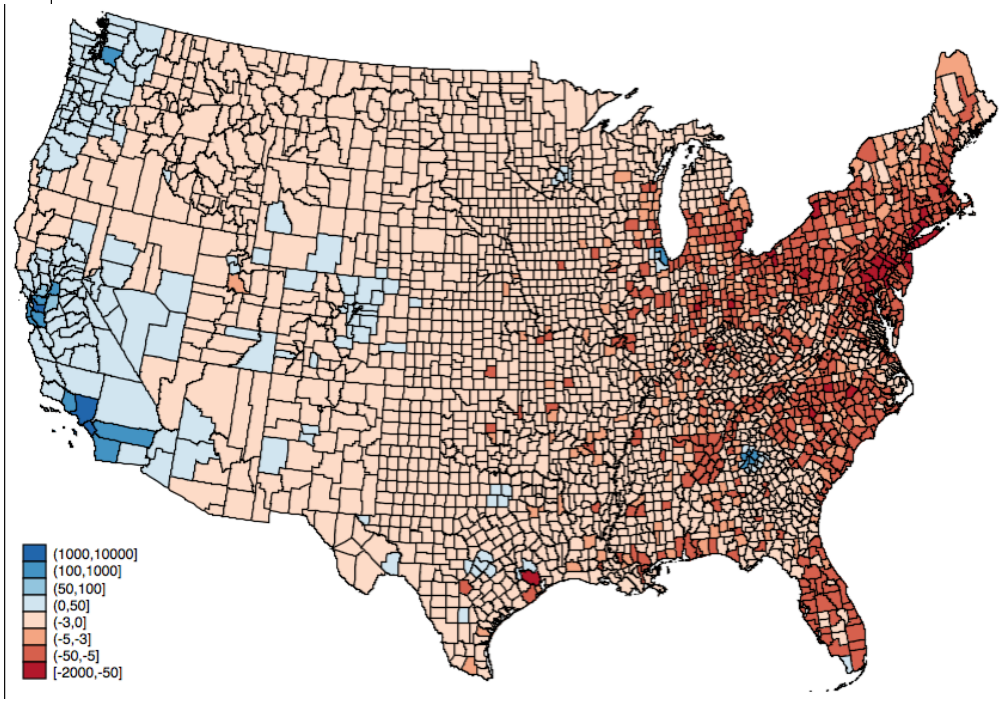
Results of Environmental Benefits

Benefits Created and Received by County

Created



Received



Summary Statistics

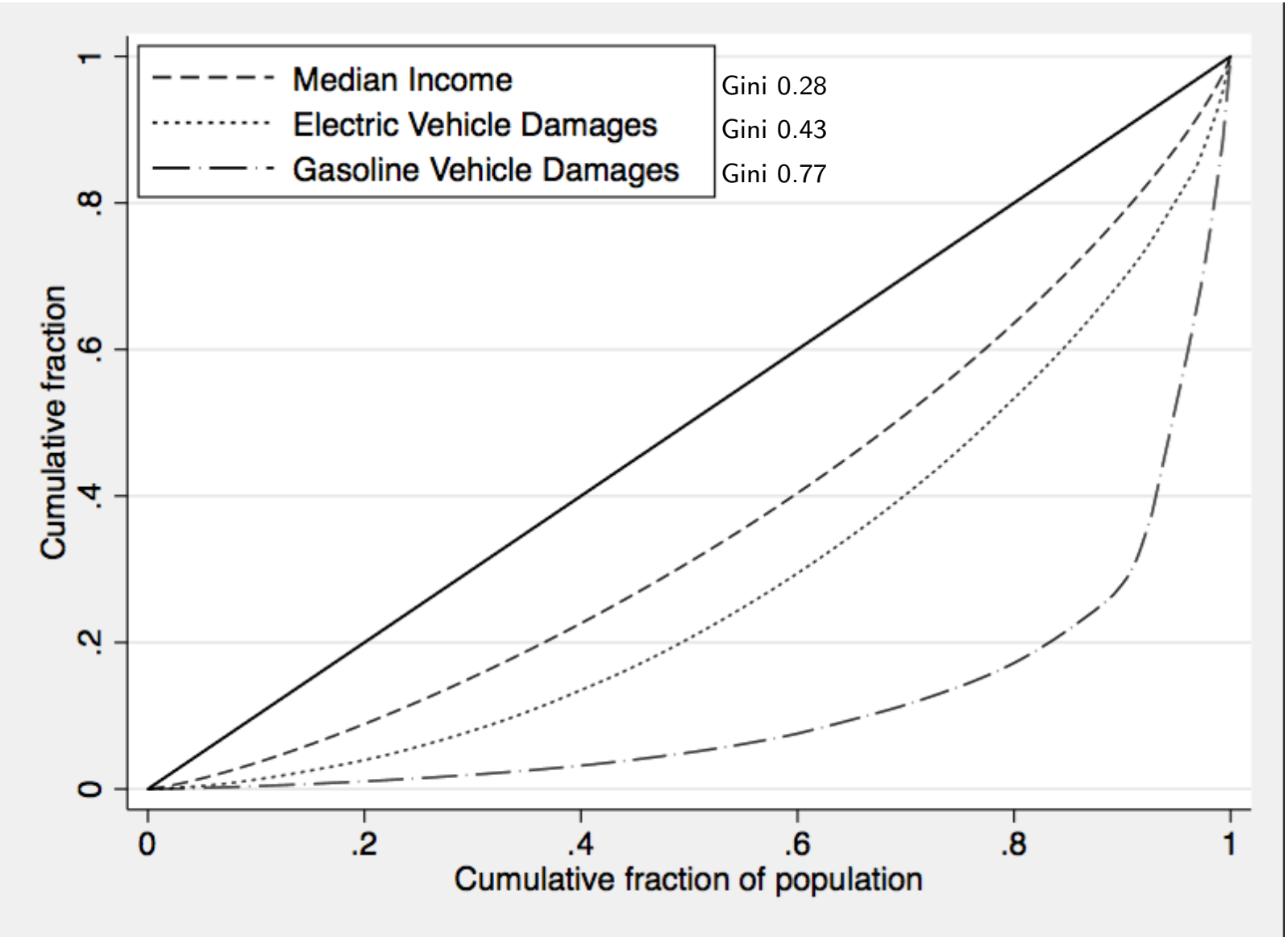
County-Level Benefits Received **per Capita** and Census Block Group-Level Demographic Variables

Variable	Mean	Std. Dev.	Min	Max
Gas vehicle damages p.c.	0.081	0.19	0.001	1.335
Elec vehicle damages p.c.	0.081	0.075	-0.002	0.546
EV net benefits p.c.	0	0.139	-0.297	0.813
Income (10k)	6	3.143	0.25	25
Share Black	0.126	0.217	0	1
Share Hispanic	0.161	0.229	0	1
Share Asian	0.046	0.093	0	1
Share White	0.643	0.311	0	1
Urban Indicator	0.836	0.37	0	1
Share Poverty	0.136	0.129	0	1

Notes: There are 215,328 block groups; total population of 305 million.

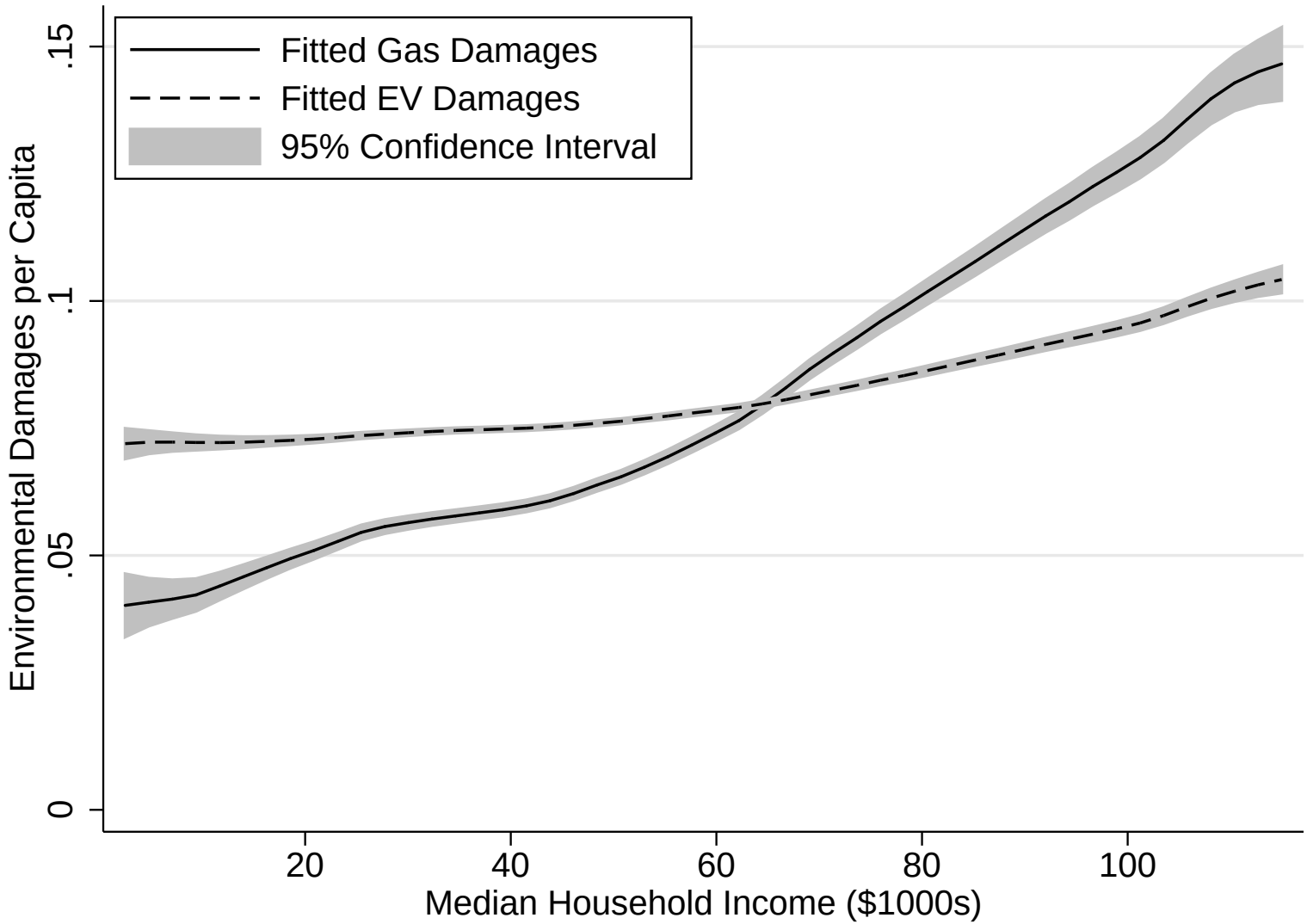
Lorenz Curves

Separate Curves for Income and for Each Type of Damages Received



Relationship between Damages and Income

Kernel-Weighted Local Polynomial Regressions



Who Receives Environmental Benefits from EVs?

Benefits per Capita, Income, and Race

	Demographic Group				
Income Decile	Black	Hispanic	Asian	White	All
1	-0.032	0.019	0.064	-0.047	-0.023
2	-0.021	0.043	0.069	-0.045	-0.016
3	-0.020	0.051	0.071	-0.044	-0.018
4	-0.009	0.057	0.081	-0.040	-0.014
5	-0.007	0.063	0.091	-0.035	-0.011
6	-0.001	0.068	0.101	-0.031	-0.007
7	0.007	0.076	0.107	-0.022	0.001
8	0.011	0.084	0.133	-0.011	0.012
9	0.011	0.094	0.138	0.003	0.025
10	0.016	0.097	0.164	0.032	0.050
Total	-0.013	0.058	0.116	-0.021	-0.000

Correlations

Correlates of Environmental Benefits Received per Capita

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income (10k)	0.007***							
	(0.002)							
Share Poverty		-0.035						
		(0.024)						
Urban Indicator			0.071***					
			(0.016)					
Population Density				0.002*				
				(0.001)				
Share Black					-0.034			
					(0.021)			
Share Hispanic						0.179***		
						(0.051)		
Share Asian							0.616***	
							(0.118)	
Share White								-0.140***
								(0.038)

*** p<0.01, ** p<0.05, * p<0.10

Notes: Dependent variable is environmental benefits per capita. These WLS regressions weight by total population and cluster standard errors by county.

Descriptive Regressions

Descriptive Regressions of Environmental Benefits Received per Capita

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Income (10k)	0.007***	0.005***	0.010***	0.009***	0.003**	0.002	0.011***	0.011***
	(0.002)	(0.002)	(0.002)	(0.002)	(0.001)	(0.001)	(0.003)	(0.003)
Urban Indicator		0.064***		0.034***		0.041***		0.019***
		(0.016)		(0.007)		(0.011)		(0.005)
Share Black	-0.009	-0.025						
	(0.019)	(0.021)						
Share Hispanic			0.206***	0.194***				
			(0.055)	(0.053)				
Share Asian					0.595***	0.572***		
					(0.116)	(0.115)		
Share White							-0.171***	-0.164***
							(0.042)	(0.042)

*** p<0.01, ** p<0.05, * p<0.10

Notes: These WLS regressions weight by total population and cluster standard errors by county.

Additional Regressions

Summary of Distributional Results

- Environmental benefits per capita as a function of income and race
- Environmental benefits positively correlated with
  - Income
  - Urban
  - Hispanic and Asian population shares
- Environmental benefits negatively correlated with
  - White population shares

Sensitivity Analysis

Environmental Benefits Received Per Capita, All Households by Income Decile

Income					Forgone Vehicle		
Decile	Baseline	MSA	$PM_{2.5}$	Road	Subst	Prius	Benz
1	-0.023	-0.023	-0.024	-0.006	-0.024	-0.032	-0.009
2	-0.016	-0.017	-0.018	-0.006	-0.018	-0.027	-0.000
3	-0.018	-0.018	-0.020	-0.016	-0.020	-0.028	-0.002
4	-0.014	-0.015	-0.016	-0.008	-0.016	-0.026	0.002
5	-0.011	-0.012	-0.013	-0.007	-0.013	-0.023	0.007
6	-0.007	-0.008	-0.010	-0.004	-0.010	-0.021	0.012
7	0.001	0.000	-0.002	0.000	-0.002	-0.014	0.023
8	0.012	0.010	0.008	0.011	0.008	-0.006	0.038
9	0.025	0.023	0.020	0.016	0.021	0.003	0.056
10	0.050	0.047	0.045	0.018	0.045	0.021	0.093
Total	-0.000	-0.001	-0.003	-0.000	-0.003	-0.015	0.022

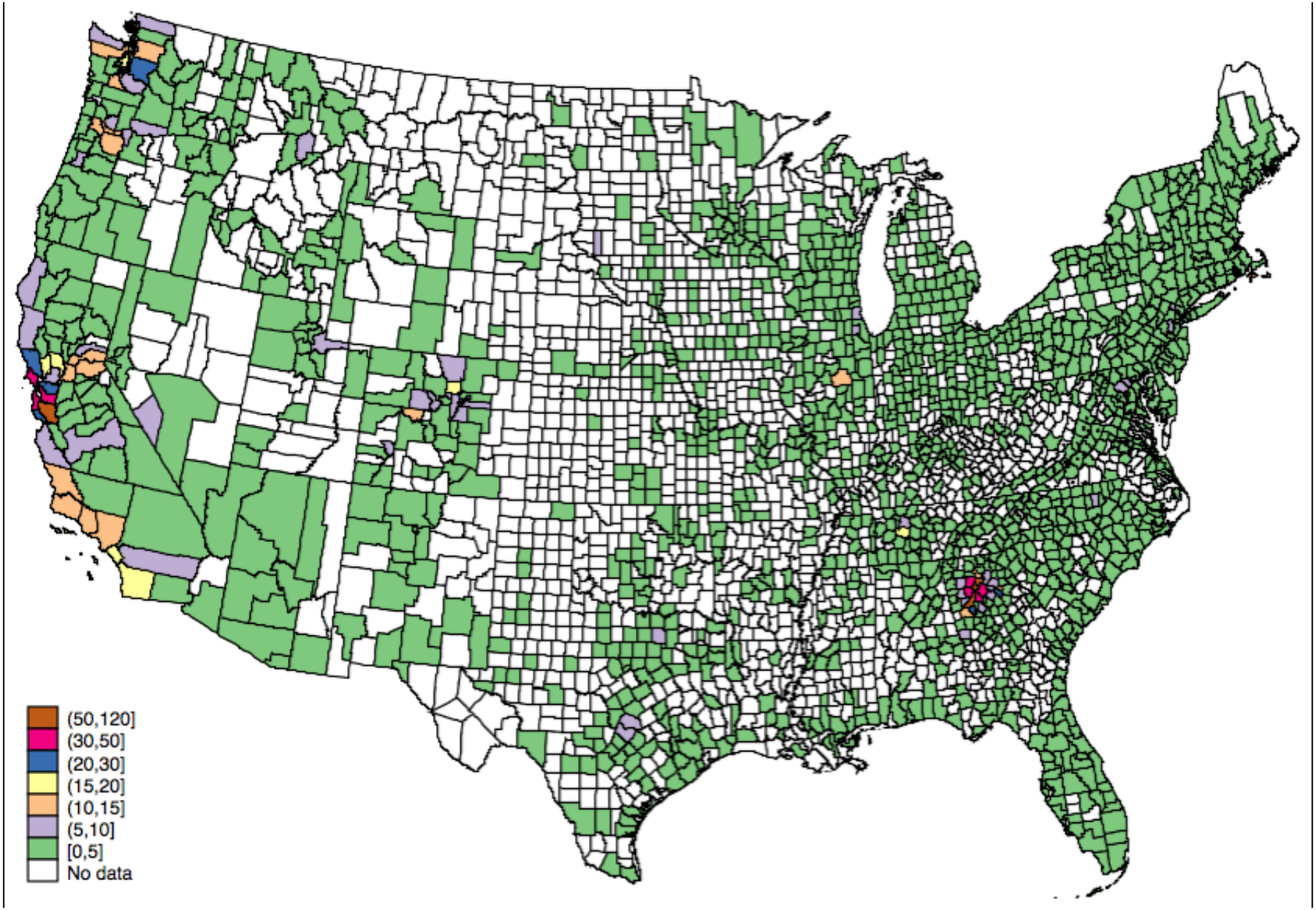
Notes: "MSA" assumes vehicles in urban areas are driven throughout MSA. "PM" includes damages from re-suspended particles. "Road" apportions own-county emissions to census block groups that are near major roads. "Subst" uses alternative forgone gasoline vehicles that are close engineering substitutes for each electric vehicle (e.g. Ford Focus for Focus EV). "Prius" uses the Toyota Prius as the forgone substitute for all electric vehicles. "Benz" uses the Mercedes S550 as the forgone substitute for all electric vehicles.

Outline

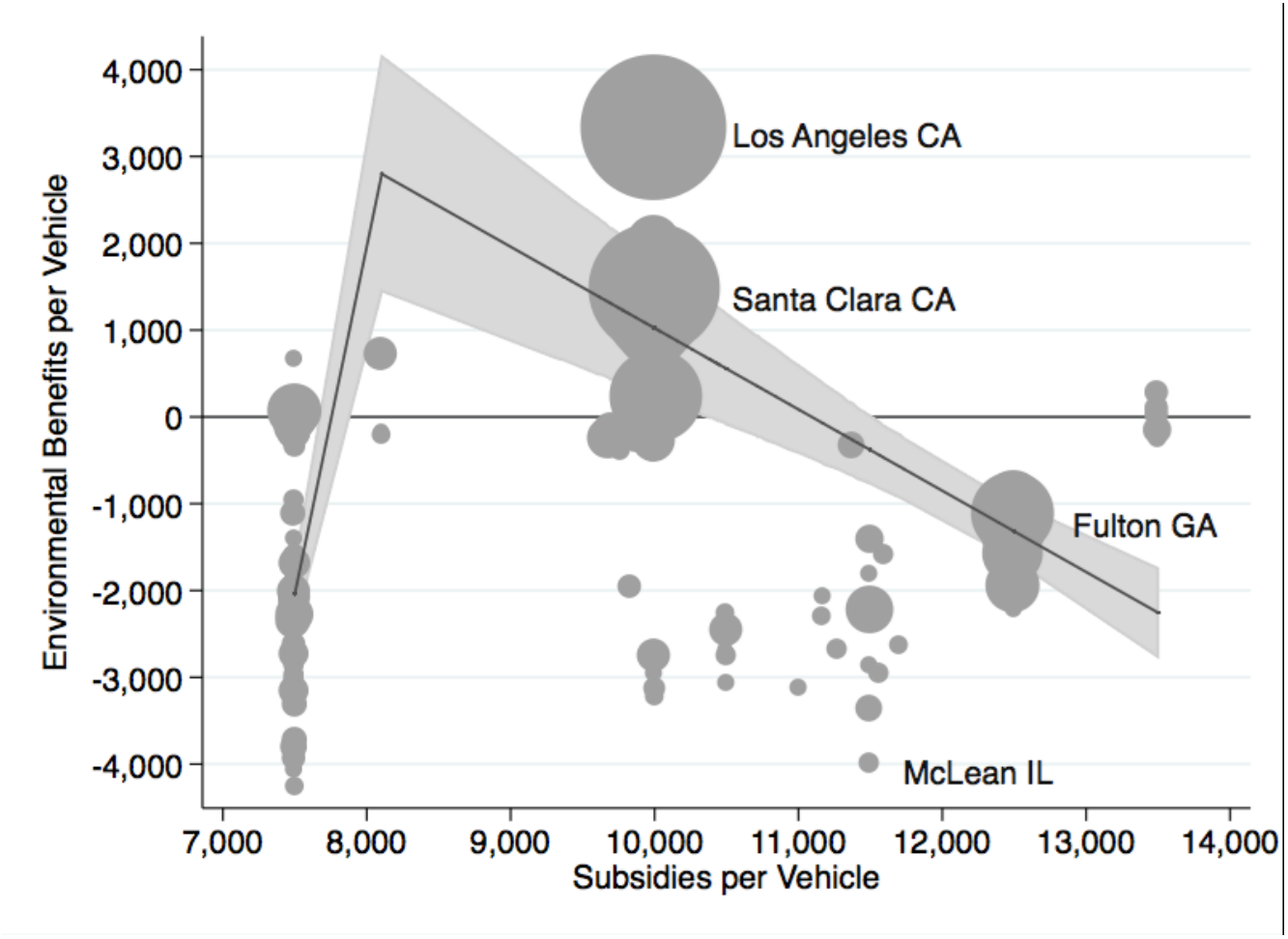
Purchase Subsidies

- Federal $7500 tax credit per vehicle purchased
- 11 States offer additional purchase subsidies
  - Colorado $6000
  - Georgia $5000
  - Illinois $4000
  - Louisiana & Maryland $3000
  - California, Massachusetts & Texas $2500
  - New Jersey $2461
  - Washington $2321
  - Utah $605
- Additional benefits excluded here

Subsidy (state and federal) per capita by county



Purchase Subsidies and Created Env. Benefits



Regression : $EB = \alpha \text{Indicator} + \beta \text{Subsidy} + \varepsilon$

Conclusion

- Distribution of received damages
  - Gas damages have high Gini and positive income correlation
  - Electric damages have low Gini and low income correlation
- Environmental benefits received correlated with
  - Income (+), Urban (+)
  - Hispanic (+), Asian (+), White (-)
- Conditional on a state offering subsidies, increase in subsidy is associated with a decrease in created environmental benefits

Descriptive Regressions

Additional Descriptive Regressions of Benefits Received per Capita

	(1)	(2)	(3)	(4)	(5)	(6)
Income (10k)	0.006***	0.004***	0.009***	0.006***	0.006***	0.004***
	(0.002)	(0.001)	(0.002)	(0.001)	(0.002)	(0.001)
Share Poverty	-0.017	-0.013*	-0.064***	-0.022***		
	(0.013)	(0.007)	(0.020)	(0.008)		
Urban Indicator	0.014***	0.013***	0.016***	0.014***	0.014***	0.017***
	(0.004)	(0.003)	(0.005)	(0.003)	(0.004)	(0.003)
Population Density	-0.000	0.001***	0.001	0.001***		
	(0.001)	(0.000)	(0.001)	(0.000)		
Share Black	0.028	0.042***			0.023	0.050***
	(0.017)	(0.009)			(0.017)	(0.009)
Share Hispanic	0.191***	0.017			0.186***	0.034**
	(0.048)	(0.015)			(0.050)	(0.015)
Share Asian	0.559***	0.241***			0.551***	0.271***
	(0.103)	(0.055)			(0.111)	(0.057)
Share White			-0.163***	-0.048***		
			(0.038)	(0.008)		
State FE	No	Yes	No	Yes	No	Yes

*** p<0.01, ** p<0.05, * p<0.10

Notes: These WLS regressions weight by total population and cluster standard errors by county.

Back