

# Quantifying Plug-in Electric Vehicle Mileage

**John Paul Helveston**, George Washington University

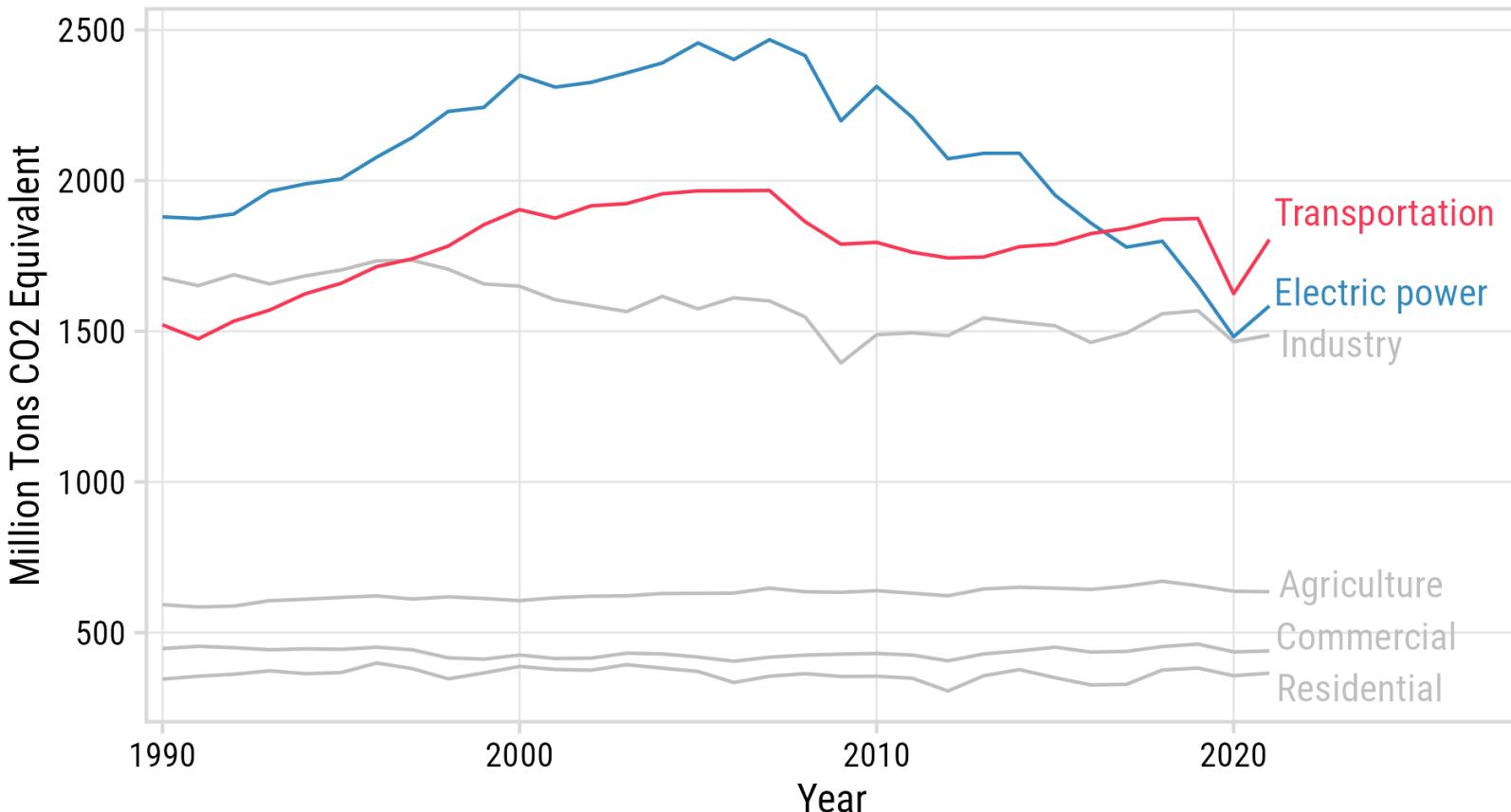
Eliese Ottinger, George Washington University

Lujin Zhao, George Washington University

January 11, 2024

# Electrifying the passenger vehicle fleet is a critical climate goal

## GHG Emissions by U.S. Sector



Data from US EPA: <https://cfpub.epa.gov/ghgdata/inventoryexplorer>

# Two Studies, One Dataset

## Measuring Electric Vehicle **Mileage** in the United States

Lujin Zhao (Ph.D. Student)  
Eliese Ottinger (Undergraduate RA)

**Status:** Published in *Joule*

## Measuring Electric Vehicle **Resale Value** in the United States

Laura Roberson (Ph.D. Student)  
Saurav Pantha (Former Graduate RA)

**Status:** Submitting soon

# Data: ~13M used vehicle listings from 60k dealerships (2016 - 2022)

	Conventional	Hybrid	PHEV	BEV (Non-Tesla)	BEV (Tesla)
# of Listings	12,604,702	610,946	130,889	118,580	57,193
Miles (1,000)					
mean	52	57	43	27	36
sd	32	35	26	15	21
Age (years)					
mean	4.5	4.7	4.1	4.2	4.2
sd	1.8	1.8	1.4	1.4	1.5
Price (\$USD)					
mean	15,928	15,448	19,263	14,658	50,181
sd	6,852	5,096	12,748	6,053	12,380
Electric Range (miles)					
mean		33	104	251	
sd		14	48	50	
min		11	58	139	
max		53	259	402	

# Going the Distance: Quantifying Electric Vehicle Mileage in the United States

Lujin Zhao (Ph.D. Student)

Eliese Ottinger (Undergraduate RA)

John Paul Helveston, Ph.D.

The George Washington University

# We really need to understand PEV usage

- PEV emissions reduction benefit **depends on vehicle usage**  
[Jenn \(2020\)](#)
- Modelers typically assume **BEV miles = CV miles**
- Revenue from proposed mileage tax **depends on vehicle usage**  
[Metcalf et al. \(2022\); Zhao and Mattauch \(2022\); Davis and Sallee \(2020\)](#)
- PEV adoption depends on **how well PEVs substitute for CVs**  
[Xing et al. \(2021\)](#)

# Conflicting prior results on BEV mileage

Study	Estimated Annual VMT	Sample Location	Sample Size*	Data Year(s)	Data Source
Davis (2019)	6,300	U.S.	436	2017	NHTS <sup>†</sup>
Burlig et al. (2021)	6,700	California	57,290	2014 - 2017	Household electricity meter readings
Rush et al. (2022)	8,838	U.S.	Unknown	2013 - 2021	Edmunds vehicle listings
Jia and Chen (2022)	10,000	California	184	2019	2019 California Vehicle Survey
Tal et al. (2020)	12,522	California	100	2015 - 2018	On-board vehicle sensors
This Study (2023)	7,165 (cars) 10,587 (SUVs)	U.S.	175,773 (cars) 12,623 (SUVs)	2016 - 2022	Used vehicle listings

\*BEV sedans only.

<sup>†</sup>National Household Travel Survey (FHWA, 2017).

# Conflicting prior results on BEV mileage

BEV < CV

Study	Estimated Annual VMT	Sample Location	Sample Size*	Data Year(s)	Data Source
Davis (2019)	6,300	U.S.	436	2017	NHTS <sup>†</sup>
Burlig et al. (2021)	6,700		57,290	2014 - 2017	Household electricity meter readings
Rush et al. (2022)	8,838		Unknown	2013 - 2021	Edmunds vehicle listings
Jia and Chen (2022)	10,000	California	184	2019	2019 California Vehicle Survey
Tal et al. (2020)	12,522		100	2015 - 2018	
This Study (2023)	7,165 (cars) 10,587 (SUVs)	U.S.	175,773 (cars) 12,623 (SUVs)	2016 - 2022	Used vehicle listings

\*BEV sedans only.

<sup>†</sup>National Household Travel Survey (FHWA, 2017).

# Inconsistent data quality in prior studies

BEV < CV

BEV ~= CV

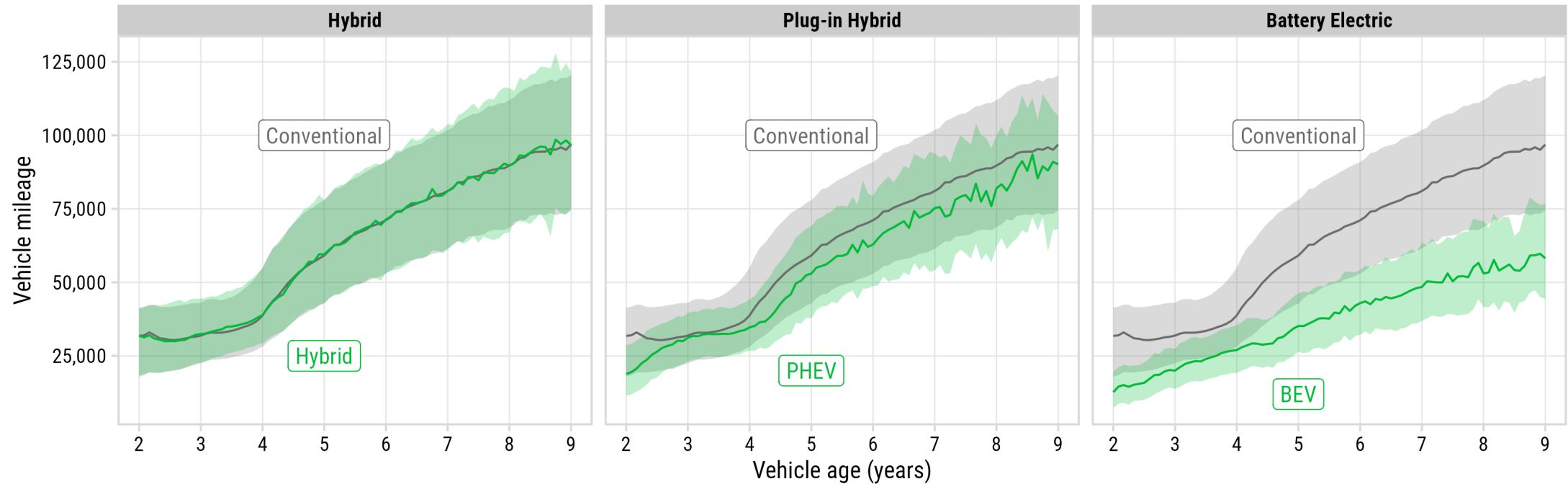
BEV < CV

Study	Estimated Annual VMT	Sample Location	Sample Size*	Data Year(s)	Data Source	Large N	Nationally Representative	Direct VMT Measurement
Davis (2019)	6,300	U.S.	436	2017	NHTS <sup>†</sup>		X	
Burlig et al. (2021)	6,700		57,290	2014 - 2017	Household electricity meter readings	X		
Rush et al. (2022)	8,838		Unknown	2013 - 2021	Edmunds vehicle listings		X	X
Jia and Chen (2022)	10,000	California	184	2019	2019 California Vehicle Survey			X
Tal et al. (2020)	12,522		100	2015 - 2018	On-board vehicle sensors			X
This Study (2023)	7,165 (cars) 10,587 (SUVs)	U.S.	175,773 (cars) 12,623 (SUVs)	2016 - 2022	Used vehicle listings	X	X	X

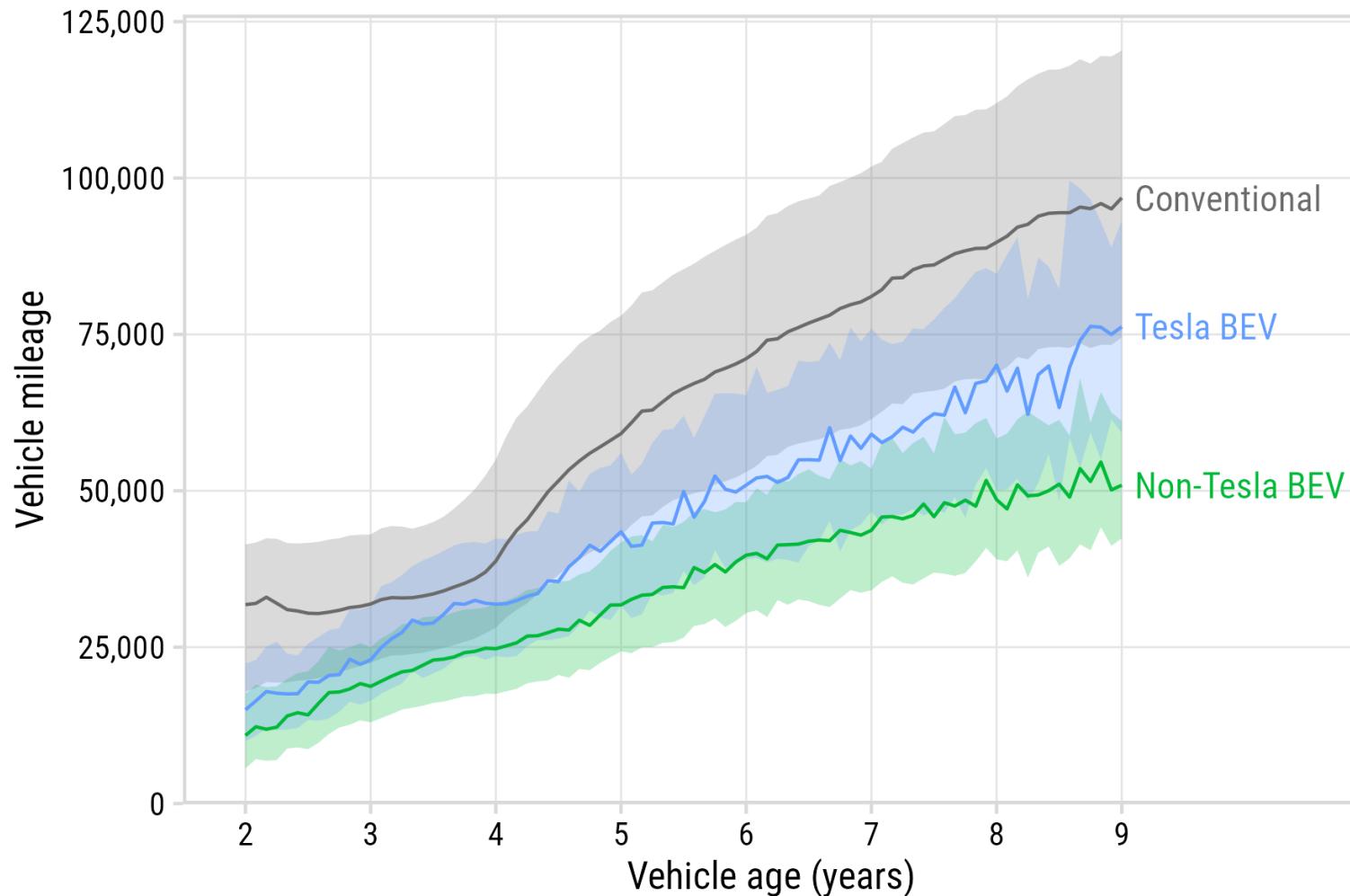
\*BEV sedans only.

<sup>†</sup>National Household Travel Survey (FHWA, 2017).

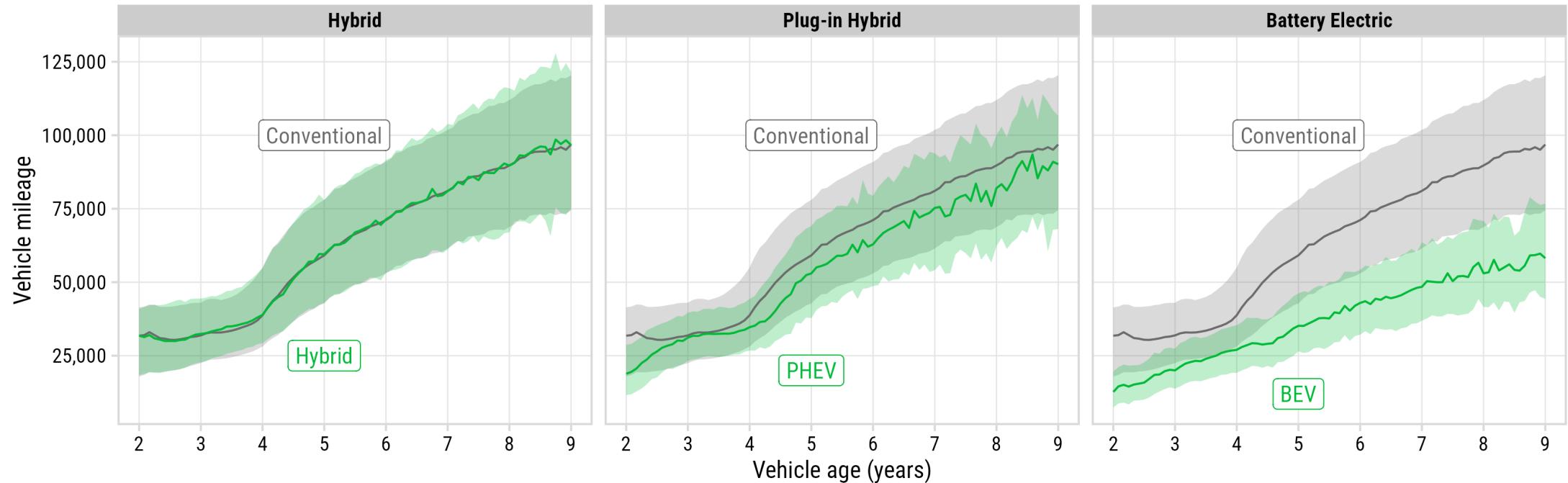
# BEVs are driven significantly less than other powertrains



# Teslas driven more than non-Tesla BEVs (but not as much as CVs)



# BEVs are driven significantly less than other powertrains



$$mileage = \beta_0 + \beta_1 age + \beta_2 age * powertrain + \beta_3 age * cents\_p\_mile + \epsilon_i$$

	Cars		SUVs	
	Model 1a	Model 1b	Model 2a	Model 2b
age_years	11.642*** (0.004)	11.642*** (0.004)	12.945*** (0.004)	12.945*** (0.004)
<i>Interactions with age_years</i>				
powertrain_hybrid	0.299*** (0.019)	0.299*** (0.019)	-0.853*** (0.068)	-0.853*** (0.068)
powertrain_phev	-0.529*** (0.046)	-0.529*** (0.046)		
powertrain_bev	-4.492*** (0.040)		-2.358*** (0.196)	
powertrain_bev_non_tesla		-5.428*** (0.050)		-4.482*** (1.317)
powertrain_bev_tesla		-2.856*** (0.068)		-3.809*** (0.220)
Num. obs.	12,927,779	12,927,779	11,926,367	11,926,367
R <sup>2</sup>	0.406	0.406	0.477	0.477

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

	Cars		SUVs	
	Model 1a	Model 1b	Model 2a	Model 2b
age_years	11.642*** (0.004)	11.642*** (0.004)	12.945*** (0.004)	12.945*** (0.004)
<i>Interactions with age_years</i>				
powertrain_hybrid	0.299*** (0.019)	0.299*** (0.019)	-0.853*** (0.068)	-0.853*** (0.068)
powertrain_phev	-0.529*** (0.046)	-0.529*** (0.046)		
powertrain_bevev	-4.492*** (0.040)		-2.358*** (0.196)	
powertrain_bevev_non_tesla		-5.428*** (0.050)		-4.482*** (1.317)
powertrain_bevev_tesla		-2.856*** (0.068)		-3.809*** (0.220)
Num. obs.	12,927,779	12,927,779	11,926,367	11,926,367
R <sup>2</sup>	0.406	0.406	0.477	0.477

BEVs driven  
4,500 miles  
less than CVs  
on average

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

	Cars		SUVs	
	Model 1a	Model 1b	Model 2a	Model 2b
age_years	11.642*** (0.004)	11.642*** (0.004)	12.945*** (0.004)	12.945*** (0.004)
<i>Interactions with age_years</i>				
powertrain_hybrid	0.299*** (0.019)	0.299*** (0.019)	-0.853*** (0.068)	-0.853*** (0.068)
powertrain_phev	-0.529*** (0.046)	-0.529*** (0.046)		
powertrain_bev	-4.492*** (0.040)		-2.358*** (0.196)	
powertrain_bev_non_tesla		-5.428*** (0.050)		-4.482*** (1.317)
powertrain_bev_tesla		-2.856*** (0.068)		-3.809*** (0.220)
Num. obs.	12,927,779	12,927,779	11,926,367	11,926,367
R <sup>2</sup>	0.406	0.406	0.477	0.477

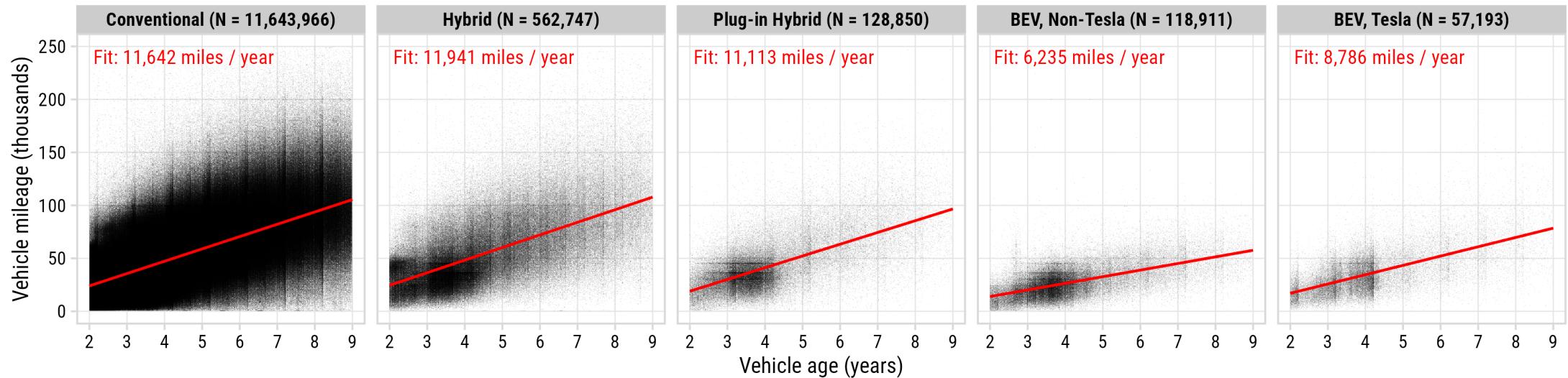
\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

BEVs driven  
4,500 miles  
less than CVs  
on average

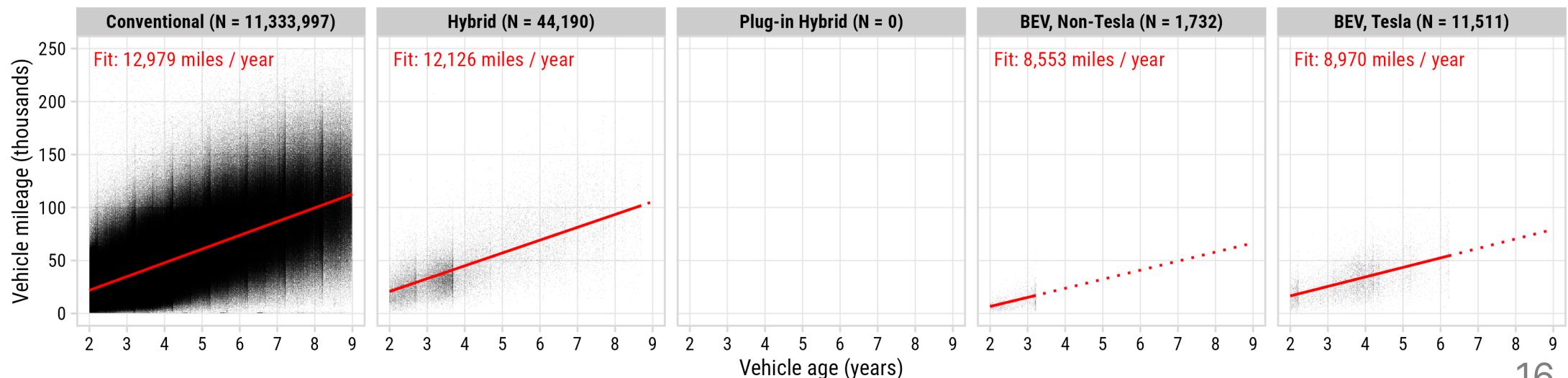
Non-Tesla  
BEVs:  
-5,400 miles

Tesla:  
-2,800 miles

## Cars



## SUVs



Powertrain:	Model 3a BEV	Model 3b PHEV	Model 3c Hybrid	Model 3d Conventional
age_years	5.835*** (0.422)	12.925*** (0.398)	14.028*** (0.359)	11.448*** (0.032)
<i>Operating cost and range interactions with age_years</i>				
cents_per_mile	-0.059** (0.020)	0.524*** (0.039)	-0.044 (0.028)	-0.136*** (0.002)
range	0.009*** (0.001)	-0.183*** (0.011)		
range*range_low (<100mi)	0.055*** (0.010)			
range*range_mid (100 - 200mi)	0.033*** (0.009)			
<i>Select model interactions with age_years</i>				
Reference level:	<i>Nissan Leaf</i>	<i>Toyota Prius Prime</i>	<i>Honda Accord</i>	<i>BMW 3 Series</i>
bolt ev	-5.672*** (0.293)			
model 3	1.056*** (0.292)			
model s	0.538* (0.244)			
Num. obs.	175,773	130,025	562,747	12,059,234
R <sup>2</sup>	0.412	0.459	0.403	0.450

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

Powertrain:	Model 3a BEV	Model 3b PHEV	Model 3c Hybrid	Model 3d Conventional
age_years	5.835*** (0.422)	12.925*** (0.398)	14.028*** (0.359)	11.448*** (0.032)
<i>Operating cost and range interactions with age_years</i>				
cents_per_mile	-0.059** (0.020)	0.524*** (0.039)	-0.044 (0.028)	-0.136*** (0.002)
range	0.009*** (0.001)	-0.183*** (0.011)		
range*range_low (<100mi)	0.055*** (0.010)			
range*range_mid (100 - 200mi)	0.033*** (0.009)			
<i>Select model interactions with age_years</i>				
Reference level:	Nissan Leaf	Toyota Prius Prime	Honda Accord	BMW 3 Series
bolt ev	-5.672*** (0.293)			
model 3	1.056*** (0.292)			
model s	0.538* (0.244)			
Num. obs.	175,773	130,025	562,747	12,059,234
R <sup>2</sup>	0.412	0.459	0.403	0.450

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

## Non-linear range effect:

+10 mi range:

Low range (<100 mi):  
+640 mi/yr

Mid range (100-200 mi):  
+420 mi/yr

High range (>200 mi):  
+90 mi/yr

Powertrain:	Model 3a BEV	Model 3b PHEV	Model 3c Hybrid	Model 3d Conventional
age_years	5.835*** (0.422)	12.925*** (0.398)	14.028*** (0.359)	11.448*** (0.032)
<i>Operating cost and range interactions with age_years</i>				
cents_per_mile	-0.059** (0.020)	0.524*** (0.039)	-0.044 (0.028)	-0.136*** (0.002)
range	0.009*** (0.001)	-0.183*** (0.011)		
range*range_low (<100mi)	0.055*** (0.010)			
range*range_mid (100 - 200mi)	0.033*** (0.009)			
<i>Select model interactions with age_years</i>				
Reference level:	Nissan Leaf	Toyota Prius Prime	Honda Accord	BMW 3 Series
bolt ev	-5.672*** (0.293)			
model 3	1.056*** (0.292)			
model s	0.538* (0.244)			
Num. obs.	175,773	130,025	562,747	12,059,234
R <sup>2</sup>	0.412	0.459	0.403	0.450

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

## Non-linear range effect:

+10 mi range:

Low range (<100 mi):  
+640 mi/yr

Mid range (100-200 mi):  
+420 mi/yr

High range (>200 mi):  
+90 mi/yr

Tesla effect isn't just from range

# BEV mileage less sensitive to operating cost than CV mileage

Powertrain:	Model 3a BEV	Model 3b PHEV	Model 3c Hybrid	Model 3d Conventional
age_years	5.835*** (0.422)	12.925*** (0.398)	14.028*** (0.359)	11.448*** (0.032)
<i>Operating cost and range interactions with age_years</i>				
cents_per_mile	-0.059** (0.020)	0.524*** (0.039)	-0.044 (0.028)	-0.136*** (0.002)

1 cent increase in operating cost:

BEV: -69 mi/yr

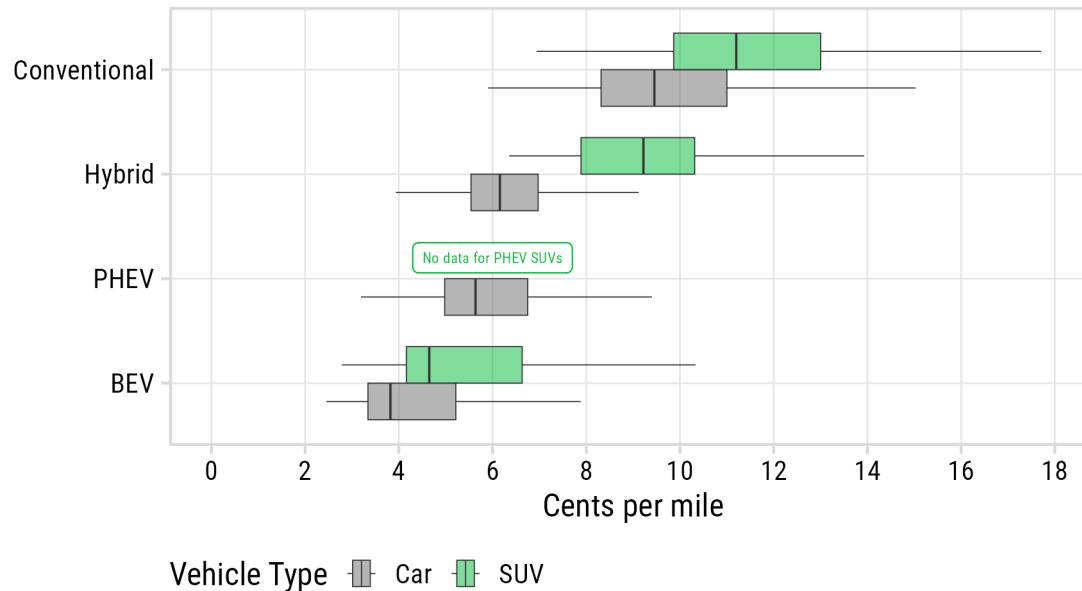
CV: -136 mi/yr

# BEV mileage less sensitive to operating cost than CV mileage

Powertrain:	Model 3a BEV	Model 3b PHEV	Model 3c Hybrid	Model 3d Conventional
age_years	5.835*** (0.422)	12.925*** (0.398)	14.028*** (0.359)	11.448*** (0.032)

*Operating cost and range interactions with age\_years*

cents_per_mile	-0.059** (0.020)	0.524*** (0.039)	-0.044 (0.028)	-0.136*** (0.002)
----------------	---------------------	---------------------	-------------------	----------------------



1 cent increase in  
operating cost:

BEV: -69 mi/yr  
CV: -136 mi/yr

BEVs have much lower  
operating costs

# Why low BEV mileage?

# Why low BEV mileage?

## Intra-household substitution?

Maybe current adopters have multiple cars?

Perhaps, but NHTS data suggests **secondary cars are only driven 1,000 - 2,000 miles less per year.**

Powertrain:	Model 6a Conventional	Model 6b Hybrid	Model 6c Conventional
age_years	12.839*** (0.875)	15.157*** (3.964)	12.332*** (0.880)
<i>Interactions with age_years</i>			
cents_per_mile	-0.243*** (0.040)	-0.378 (0.346)	-0.239*** (0.040)
secondary vehicle	-1.063*** (0.180)	-2.169* (0.849)	-1.586*** (0.309)
HHSIZE 3	1.419*** (0.230)	1.096 (1.035)	1.501*** (0.232)
HHSIZE 4	1.541*** (0.265)	1.356 (1.195)	1.627*** (0.268)
HHSIZE 5	2.644*** (0.447)	2.019 (2.248)	2.676*** (0.451)
HHSIZE 6+	0.340 (0.703)	0.661 (4.386)	0.446 (0.711)
Num. obs.	32,169	2,139	32,169
R <sup>2</sup>	0.368	0.409	0.358

\*\*\* $p < 0.001$ ; \*\* $p < 0.01$ ; \* $p < 0.05$

# Why low BEV mileage?

**Maybe newer models  
are driven more?**

Some (limited) evidence this may  
be the case

(MY 2019: only 10,484 listings,  
max age of 3.2 years old)

Powertrain:	Model 5a	Model 5b	Model 5c	Model 5d
age_years	5.835*** (0.422)	6.639*** (0.449)	1.813** (0.573)	3.746*** (0.632)
age_years <sup>2</sup>		-0.093*** (0.018)		-0.156*** (0.022)
<i>Model year interactions with age_years (reference level: my2012)</i>				
my2013		1.431*** (0.158)	1.311*** (0.159)	
my2014		1.852*** (0.195)	1.580*** (0.199)	
my2015		1.626*** (0.194)	1.175*** (0.204)	
my2016		1.097*** (0.200)	0.473* (0.218)	
my2017		0.184 (0.237)	-0.616* (0.261)	
my2018		1.531*** (0.296)	0.597 (0.323)	
my2019		4.146*** (0.469)	3.021*** (0.494)	
Num. obs.	175,773	175,773	171,701	171,701
R <sup>2</sup>	0.412	0.413	0.412	0.412

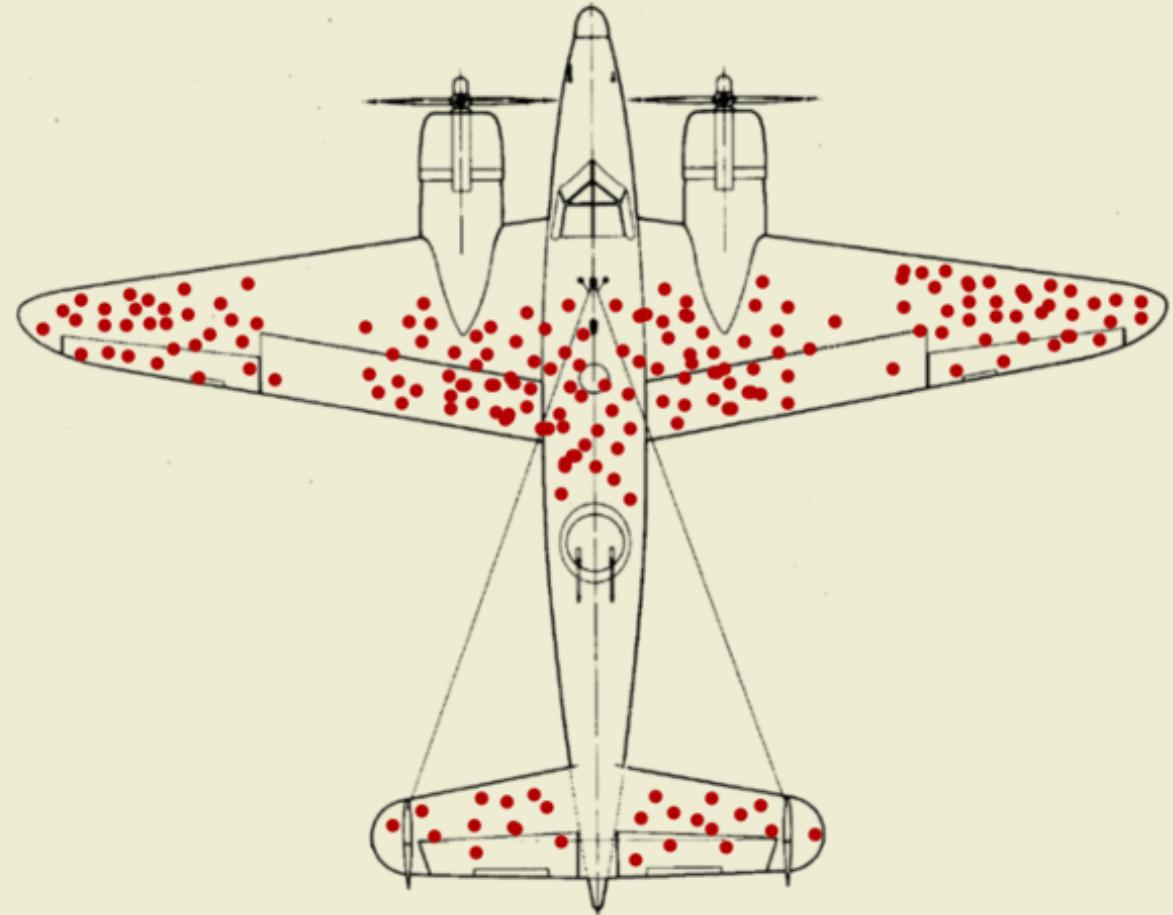
\*\*\*p < 0.001; \*\*p < 0.01; \*p < 0.05

# Why low BEV mileage?

## Selection bias?

Maybe current adopters just have lower driving needs?

No way for us to measure this, but it seems very plausible



# Key takeaways

- BEVs are driven significantly less than other powertrains:  
**Non-Tesla BEVs: -5,400 miles; Tesla: -2,800 miles**
- Far less variability in BEV mileage than CV mileage  
(BEVs only substituting for lower-mileage CV usage)
- BEV mileage less sensitive to operating cost than CV mileage
- Can't say **why** low BEV mileage, but still relevant for policy

# Thanks!

Slides:

<https://slides.jhelvy.com/2024-ev-policy-council-vmt/>

@jhelvy@fediscience.org   
@JohnHelveston   
@jhelvy   
jhelvy.com   
jph@gwu.edu 