Quantifying Plug-in Electric Vehicle Mileage and Resale Value

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Two Studies, One Dataset

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

Zhao, L., Ottinger, E., Yip, A., & Helveston, J.P. (2023) "Quantifying electric vehicle mileage in the United States00404-X)" *Joule*. 7, 1–15.

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

Roberson, Laura A., Pantha, S., & Helveston, J.P. (2024) "Battery-Powered Bargains? Assessing Electric Vehicle Resale Value in the United States" *Environmental Research Letters*.

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

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†
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.

†National Household Travel Survey (FHWA, 2017).

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Inconsistent data quality in prior studies

	Study	Estimated Annual VMT	Sample Location	Sample Size[*]	Data Year(s)	Data Source	Large N	Nationally Representative	Direct VMT Measurement
BEV < CV	Davis (2019)	6,300	U.S.	436	2017	NHTS[†]		X	
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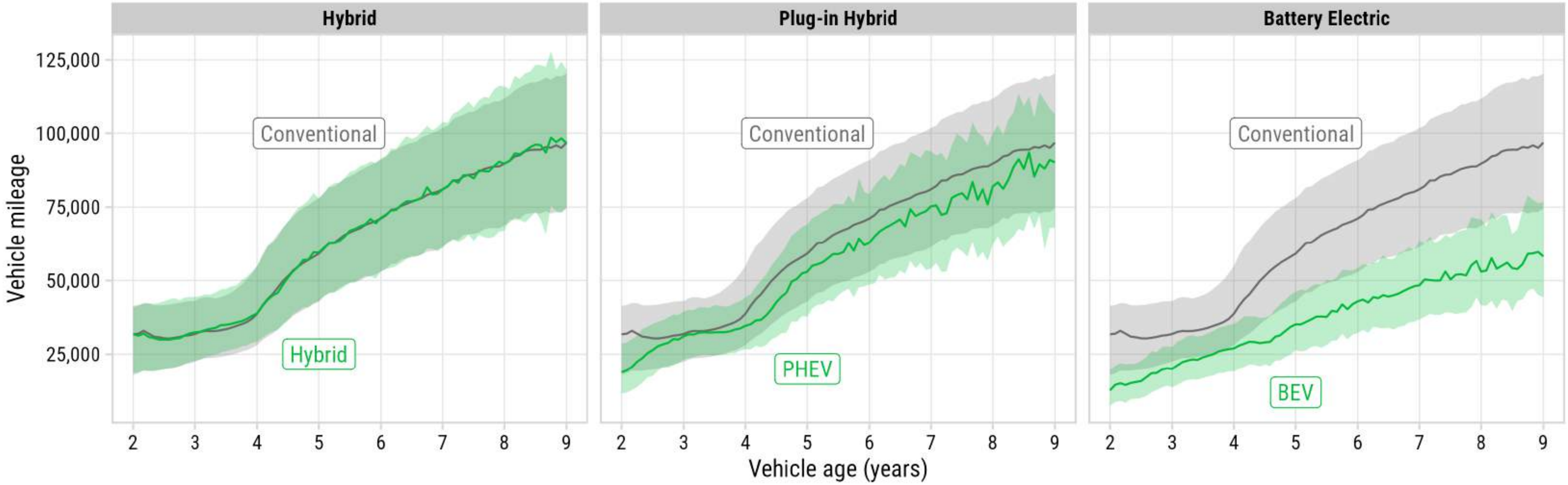
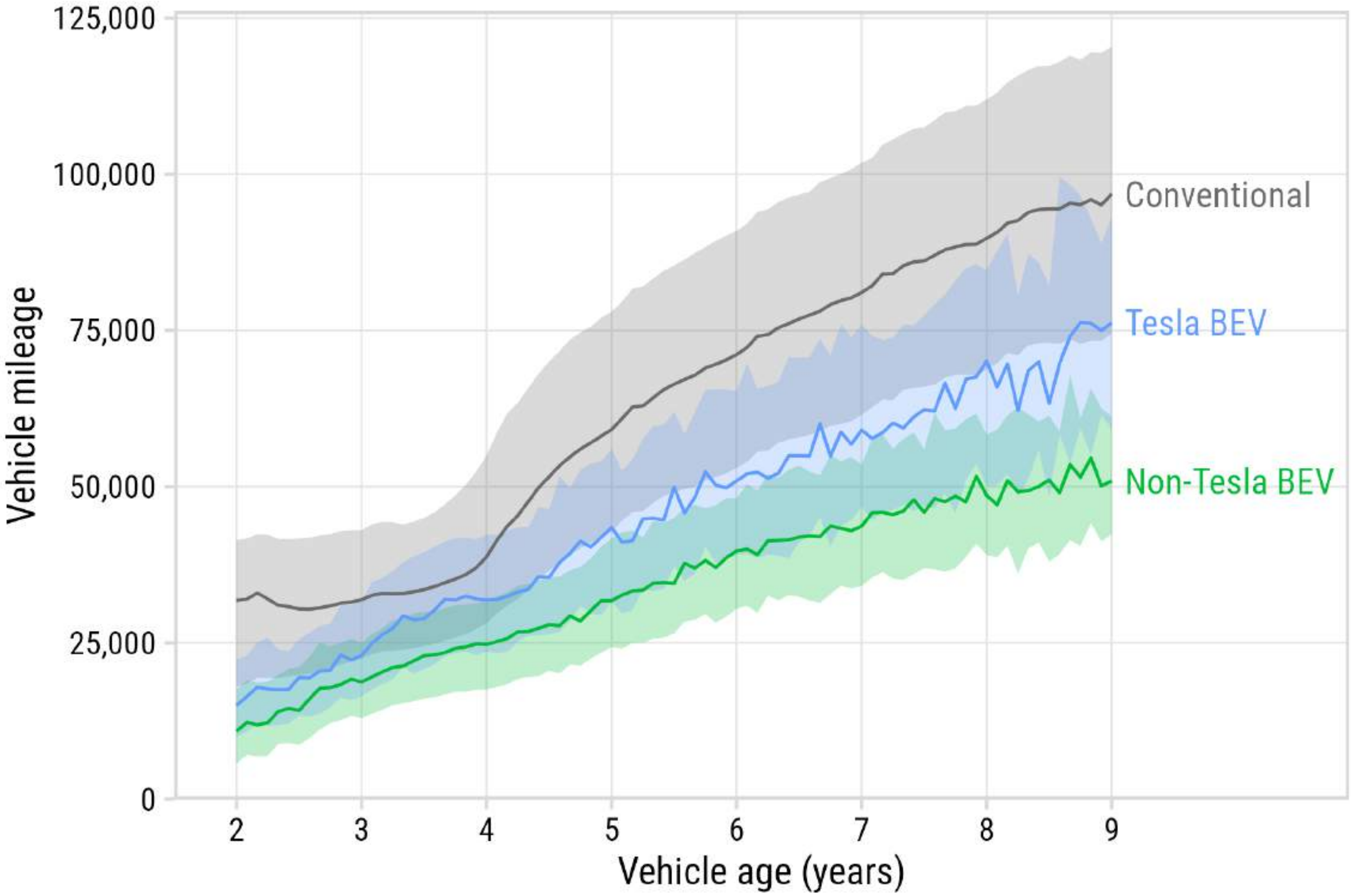
BEVs are driven significantly less than other powertrains



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



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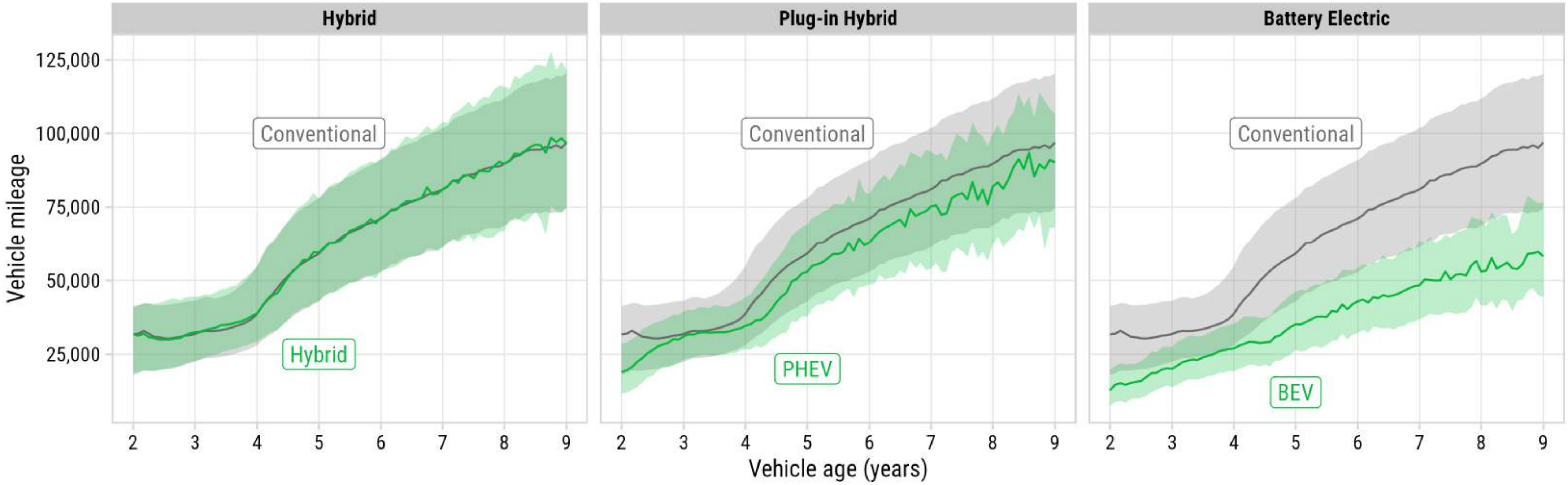

$$mileage = \beta_0 + \beta_1 age + \beta_2 age * powertrain + \beta_3 age * cents\_p\_mile + \epsilon_i$$

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

$^{***}p < 0.001$; $^{**}p < 0.01$; $^{*}p < 0.05$

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BEVs driven 4,500 miles less than CVs on average

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BEVs driven 4,500 miles less than CVs on average

Non-Tesla BEVs: -5,400 miles

Tesla: -2,800 miles

Powertrain:	Model 3a BEV	Model 3b PHEV	Model 3c Hybrid	Model 3d Conventional
age_years	5.835***	12.925***	14.028***	11.448***
	(0.422)	(0.398)	(0.359)	(0.032)
Operating cost and range interactions with age_years				
cents_per_mile	−0.059**	0.524***	−0.044	−0.136***
	(0.020)	(0.039)	(0.028)	(0.002)
range	0.009***	−0.183***		
	(0.001)	(0.011)		
range*range_low	0.055***			
(<100mi)	(0.010)			
range*range_mid	0.033***			
(100 - 200mi)	(0.009)			
Select model interactions with age_years				
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^2	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

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

Tesla effect isn't just from range

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)

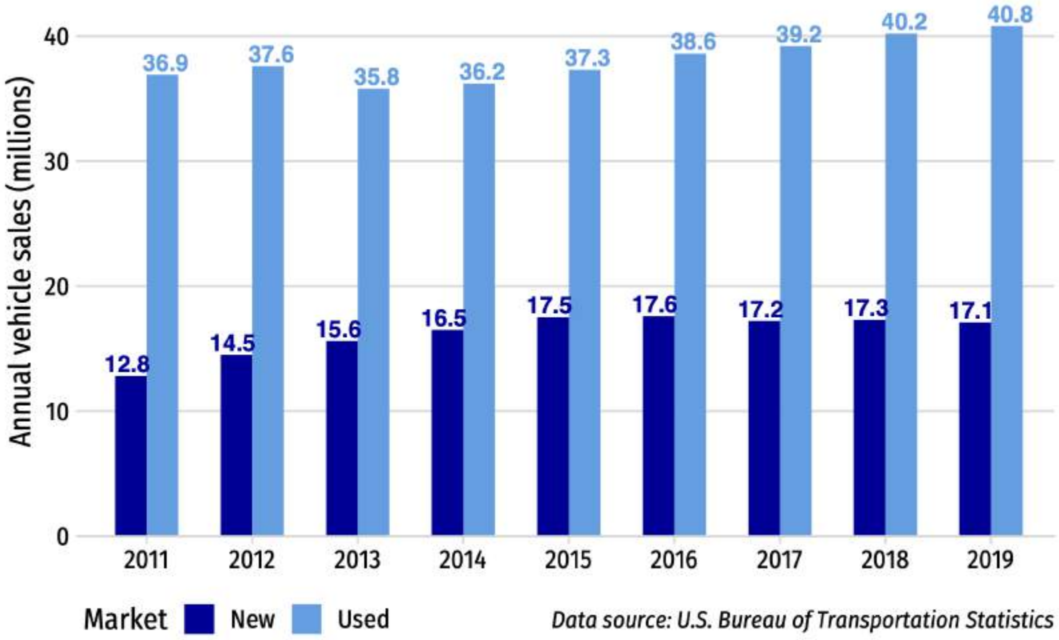
- BEV mileage less sensitive to operating cost than CV mileage

Battery-Powered Bargains?
Measuring Electric Vehicle Resale Value in the United States

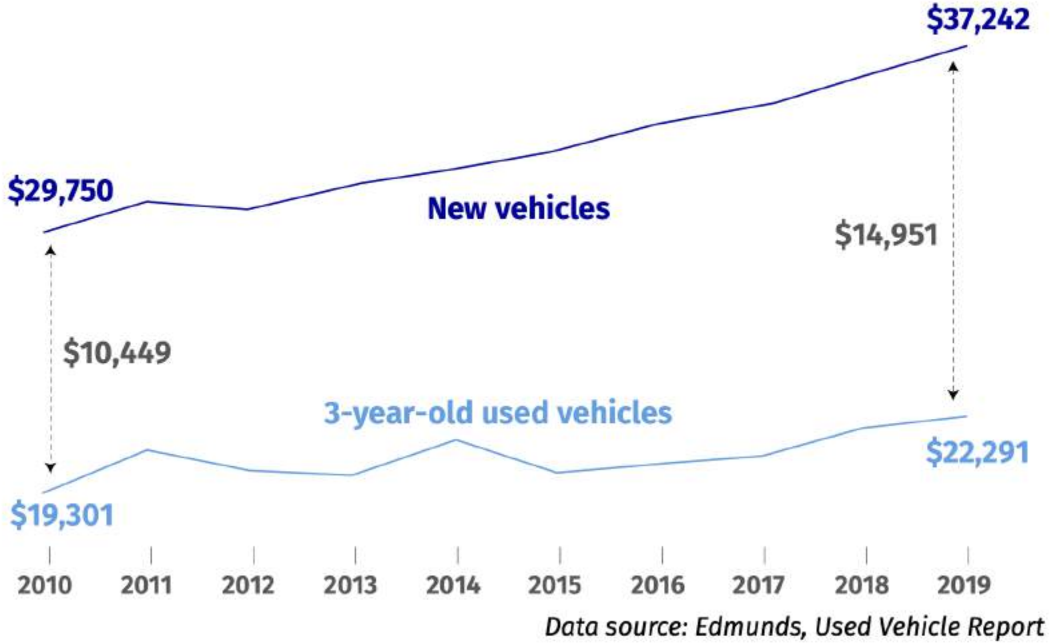
Laura Roberson (Ph.D. Student)
John Paul Helveston, Ph.D.

The vehicle resale market is critically important

70% of sales are used vehicles



Used vehicles are more affordable (pre-covid)



We really need to understand PEV resale value

- Depreciation is a key component in "Total Cost of Ownership" (TCO) models, e.g. ANL's TCO Study

- "Resale anxiety" a potential obstacle to electric vehicle adoption Brückmann et al. (2021)

- BEV buyers nervous about depreciation tend to lease rather than buy Dua et al. (2019)

Prior research suggests PEVs depreciate faster than CVs

Study	Model Years	MSRP Data	Resale Value Data	Resolution	Sample Size	Main Results PEVs vs. ICEs
This study	2012-2018	EPA; carsheet.io	marketcheck	Daily listings	9,015,324	BEVs and PHEVs depreciate quicker than CV/HEV but is improving with more recent model years and higher ranges.
Rush et al. (2022)	2012-2019	Edmunds	Edmunds TMV	Monthly time series	582,000*	CVs and HEVs consistent 3-yr retention; PHEVs and BEVs initially lower but increasing in retained value
Burnham et al. (2021)	2013-2019	EPA	Edmunds TMV	1 TMV snapshot (July 2020)	686*	BEVs and PHEVs depreciate more quickly than HEVs and CVs
Hamza et al. (2020)	2014-2019	KBB	KBB	Snapshot (2019)	72*	PHEVs and CVs hold value similarly; BEVs 11% lower retention over 5 years
Guo et al. (2019)	2010-2016	Wards	Edmunds TMV	Snapshot (Q4 2016)	1,400*	PEV retention lower than gasolines equivalents. Tesla major exception with highest retained value over time.
Schoettle et al. (2018)	2011-2015	EPA	KBB	Snapshot (Jan. 2018)	200*	PHEVs retained resale value equally as well as CVs (i.e., 0% average difference), and BEVs improved to an average of -5.7% difference in resale value compared to CVs
Tal et al. (2017)	2011-2015	New car buyers survey / OEM website	Self-reported used car buyers survey	Snapshot (2016)	160*	PEVs models held 34% (2011 Nissan Leaf) to 80% (2014 Toyota Prius plug-in) of value in 2015 compared to MSRP.
Zhou et al. (2016)	Unknown	NADA guides	NADA guides	Unknown	Unknown	Comparing the adjusted retention rates of PHEVs and BEVs with those of CVs indicates 2-3 year retention rate is lower for PEVs.

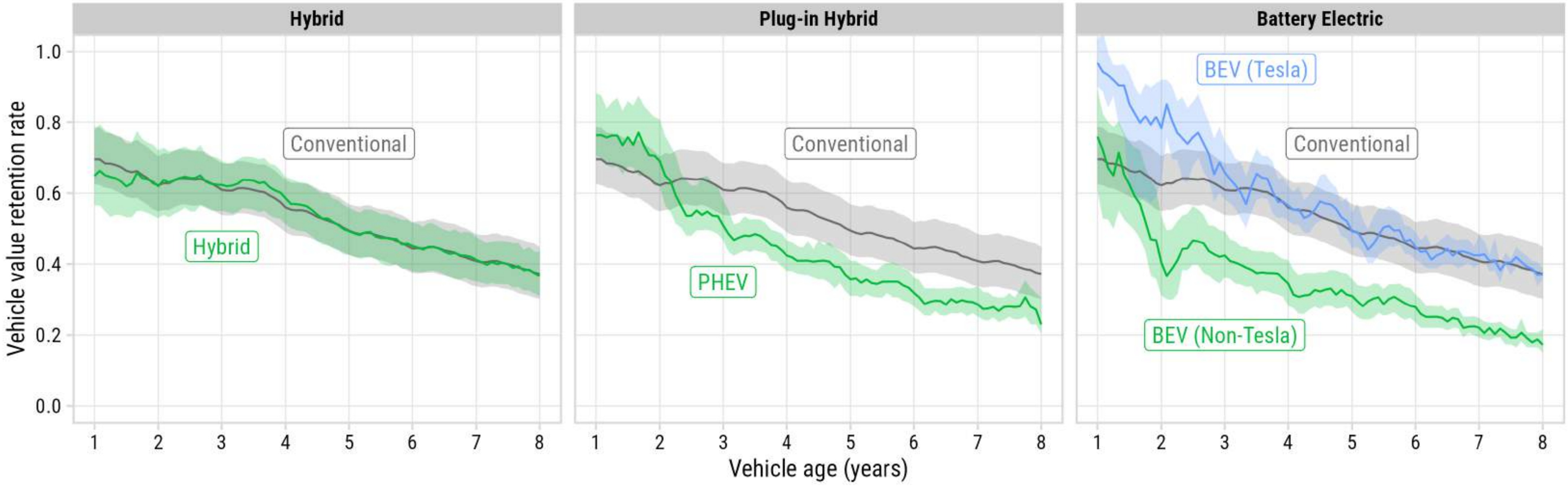
Abbreviations:
EPA = Environmental Protection Agency (fueleconomy.gov)
TMV = True Market Value (private party data)
KBB = Kelly Blue Book (private party data)
NADA = National Automobile Dealers Association

**Sample sizes estimated based on descriptions of data in papers.*

Value Retention Rate: $r = \frac{ListingPrice}{MSRP}$

BEVs & PHEVs are depreciating worse than CVs and HEVs

(Except Tesla)



Data: All listings between 2016 - 2019 (inclusive)

Modeling retention rate as exponential decay

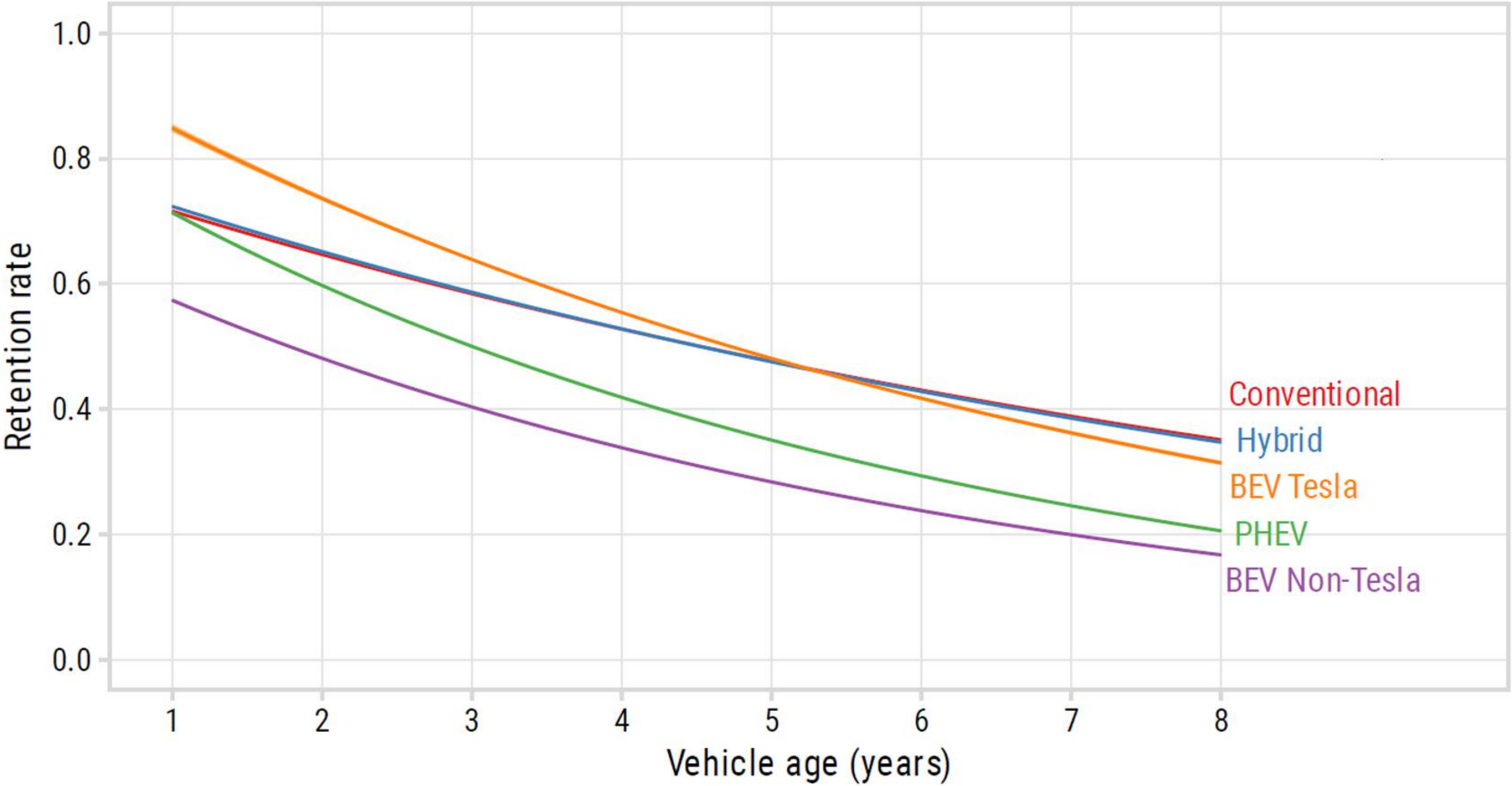
$$r = \alpha \exp(\boldsymbol{\beta}\mathbf{x})$$

$$\log(r) = \alpha + \boldsymbol{\beta}\mathbf{x}$$

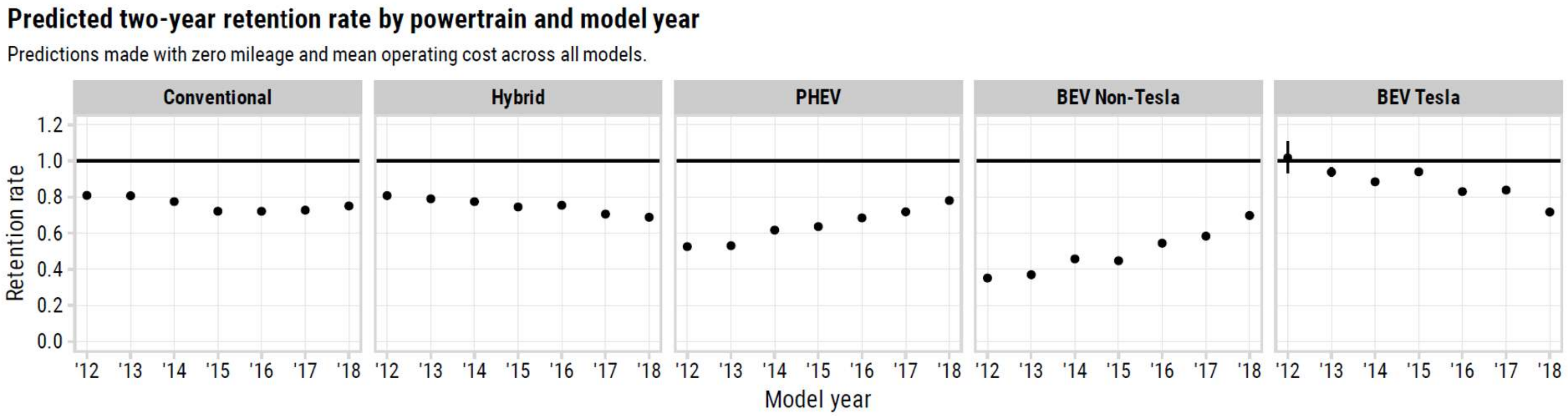
Interpretation:

$$\Delta r = \exp(\hat{\beta}) - 1$$

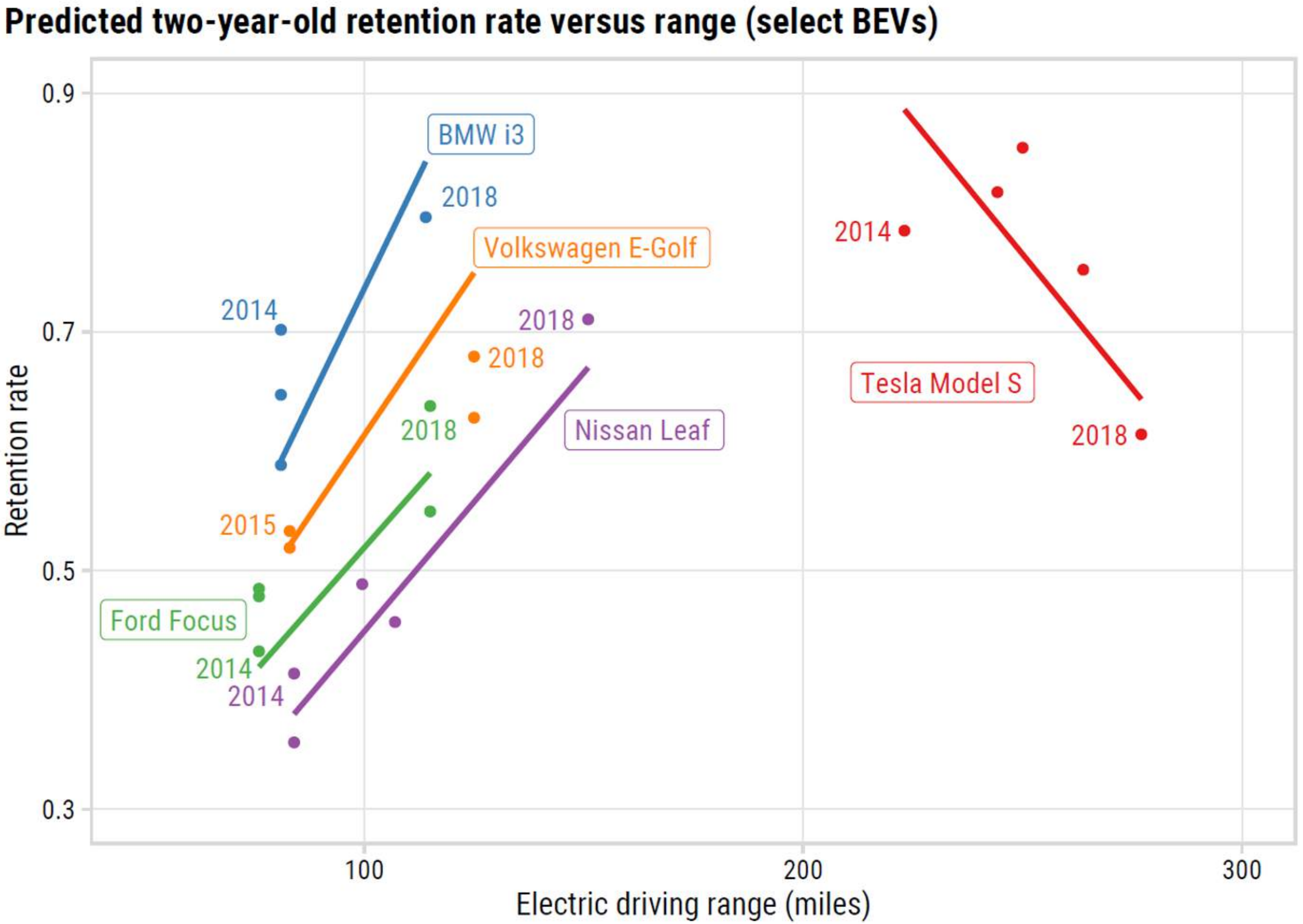
Effect of age on predicted retention rate by powertrain



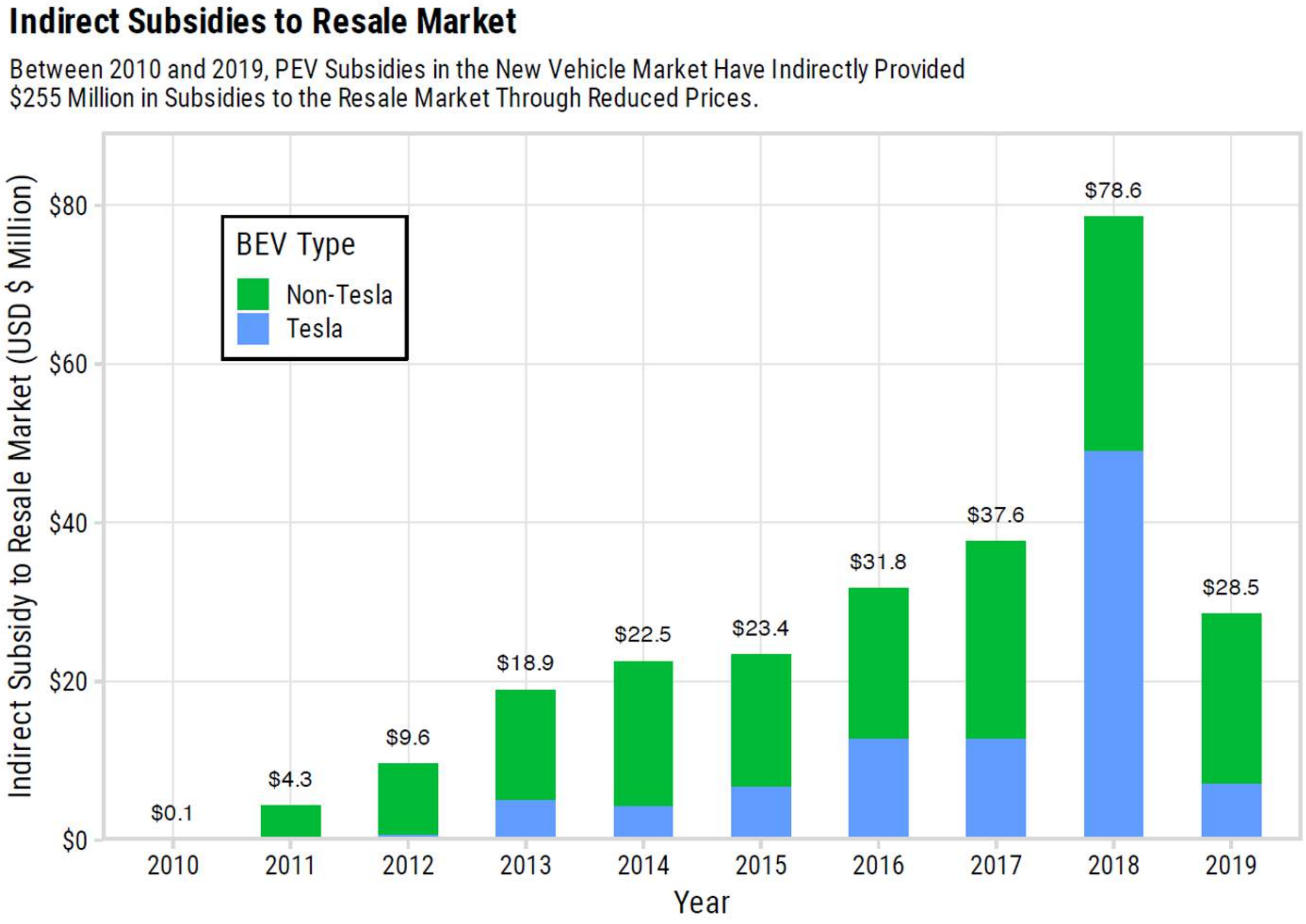
Newer PEVs are holding value better than older PEVs



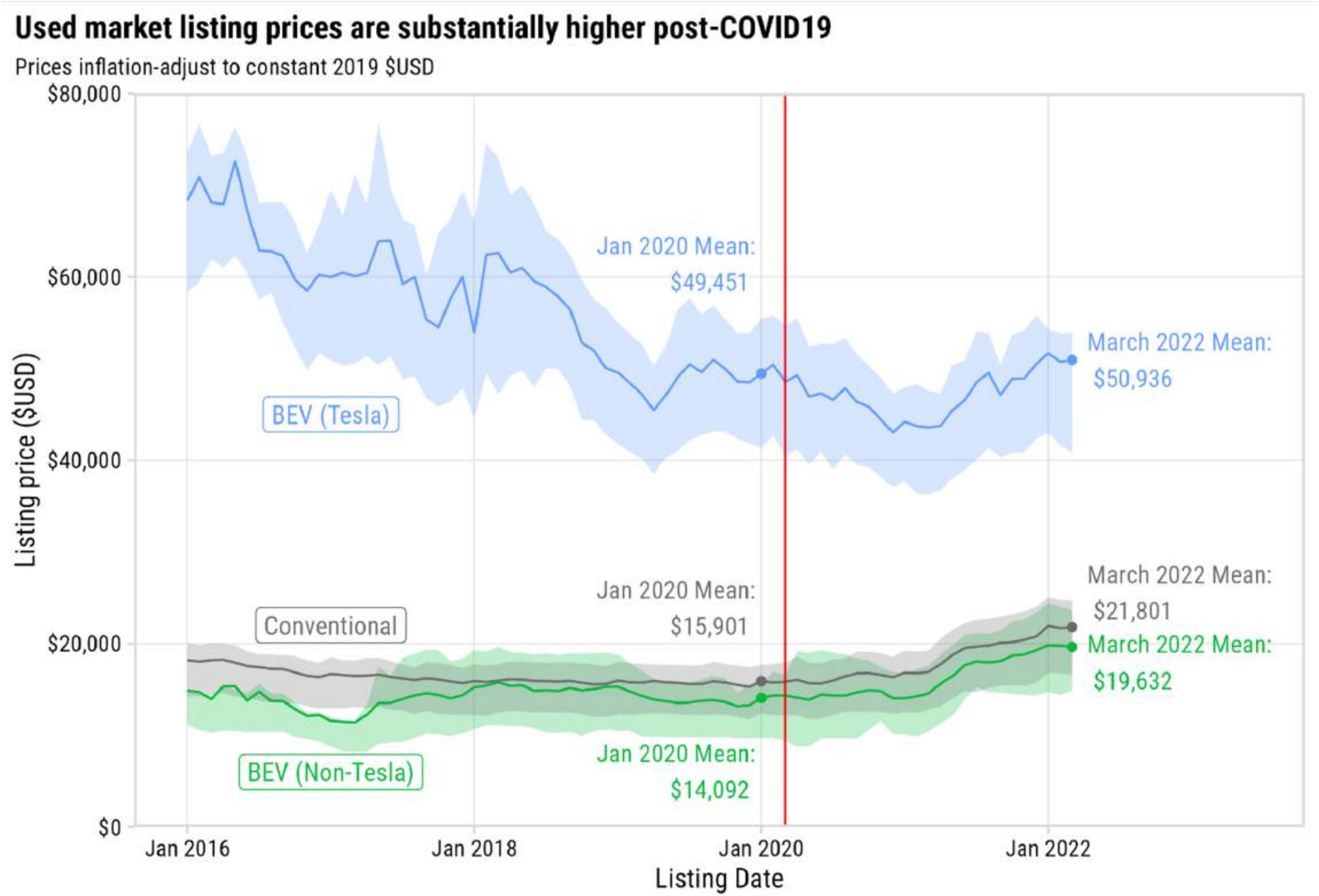
Longer-range BEVs hold value better, w/diminishing returns at 200+ miles



Used EVs gain additional benefit from new vehicle subsidies with no additional cost to gov't



COVID-19 had substantial impact on used vehicle pricing



Key takeaways

- BEVs have depreciated faster than CVs, but this is changing!

- Newer model BEVs with higher ranges are holding their value more similarly to CVs.

- Subsidies for new BEVs pass ~3% lower prices in used market

- Post COVID19 pandemic used prices are up ~40%

Thanks!

Slides:

https://slides.jhelvy.com/2024-issst-conf/

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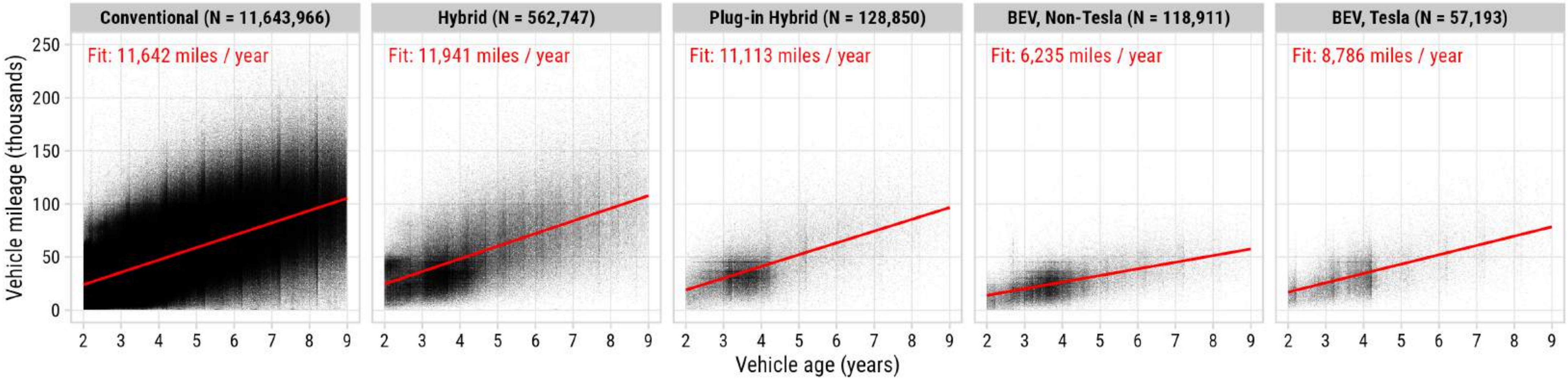
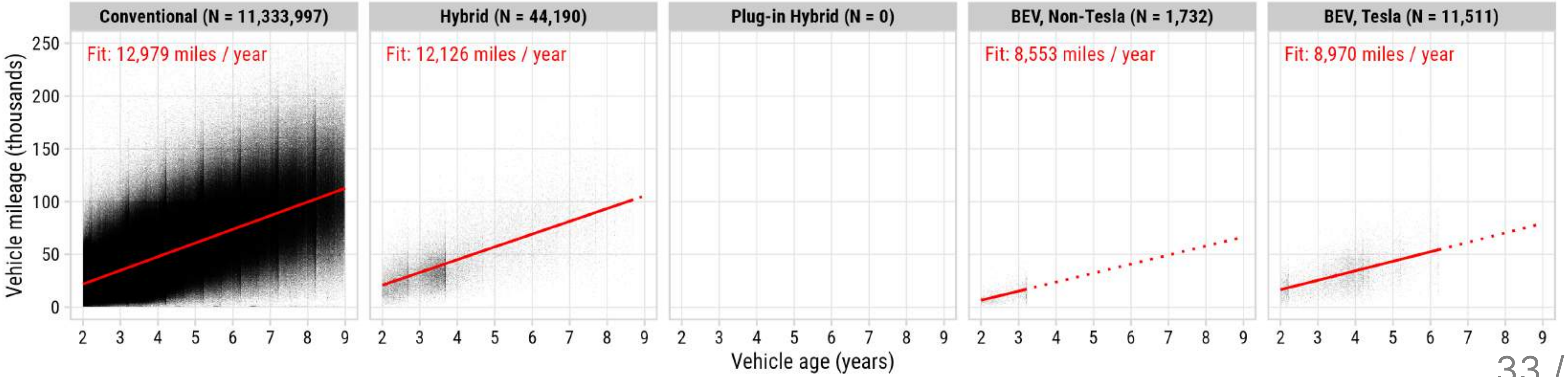
Extra slides

Cars



Conventional (N = 11,643,966)
Fit: 11,642 miles / year
Hybrid (N = 562,747)
Fit: 11,941 miles / year
Plug-in Hybrid (N = 128,850)
Fit: 11,113 miles / year
BEV, Non-Tesla (N = 118,911)
Fit: 6,235 miles / year
BEV, Tesla (N = 57,193)
Fit: 8,786 miles / year
Vehicle mileage (thousands)
Vehicle age (years)

SUVs



Conventional (N = 11,333,997)
Fit: 12,979 miles / year
Hybrid (N = 44,190)
Fit: 12,126 miles / year
Plug-in Hybrid (N = 0)
BEV, Non-Tesla (N = 1,732)
Fit: 8,553 miles / year
BEV, Tesla (N = 11,511)
Fit: 8,970 miles / year
Vehicle mileage (thousands)
Vehicle age (years)

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***	12.925***	14.028***	11.448***
	(0.422)	(0.398)	(0.359)	(0.032)
Operating cost and range interactions with age_years				
cents_per_mile	−0.059**	0.524***	−0.044	−0.136***
	(0.020)	(0.039)	(0.028)	(0.002)

1 cent increase in operating cost:

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

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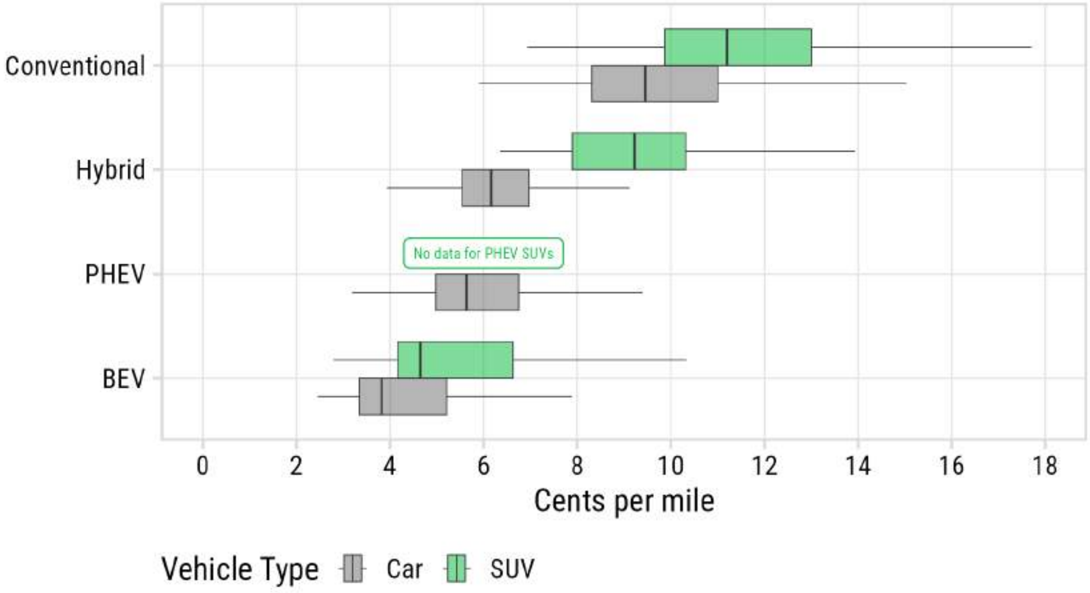


1 cent increase in operating cost:

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***	15.157***	12.332***
	(0.875)	(3.964)	(0.880)
Interactions with age_years			
cents_per_mile	−0.243***	−0.378	−0.239***
	(0.040)	(0.346)	(0.040)
secondary vehicle	−1.063***	−2.169*	−1.586***
	(0.180)	(0.849)	(0.309)
HHSIZE 3	1.419***	1.096	1.501***
	(0.230)	(1.035)	(0.232)
HHSIZE 4	1.541***	1.356	1.627***
	(0.265)	(1.195)	(0.268)
HHSIZE 5	2.644***	2.019	2.676***
	(0.447)	(2.248)	(0.451)
HHSIZE 6+	0.340	0.661	0.446
	(0.703)	(4.386)	(0.711)
Num. obs.	32,169	2,139	32,169
R^2	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***	6.639***	1.813**	3.746***
	(0.422)	(0.449)	(0.573)	(0.632)
age_years^2		−0.093***		−0.156***
		(0.018)		(0.022)
Model year interactions with age_years (reference level: my2012)				
my2013			1.431***	1.311***
			(0.158)	(0.159)
my2014			1.852***	1.580***
			(0.195)	(0.199)
my2015			1.626***	1.175***
			(0.194)	(0.204)
my2016			1.097***	0.473*
			(0.200)	(0.218)
my2017			0.184	−0.616*
			(0.237)	(0.261)
my2018			1.531***	0.597
			(0.296)	(0.323)
my2019			4.146***	3.021***
			(0.469)	(0.494)
Num. obs.	175,773	175,773	171,701	171,701
R^2	0.412	0.413	0.412	0.413

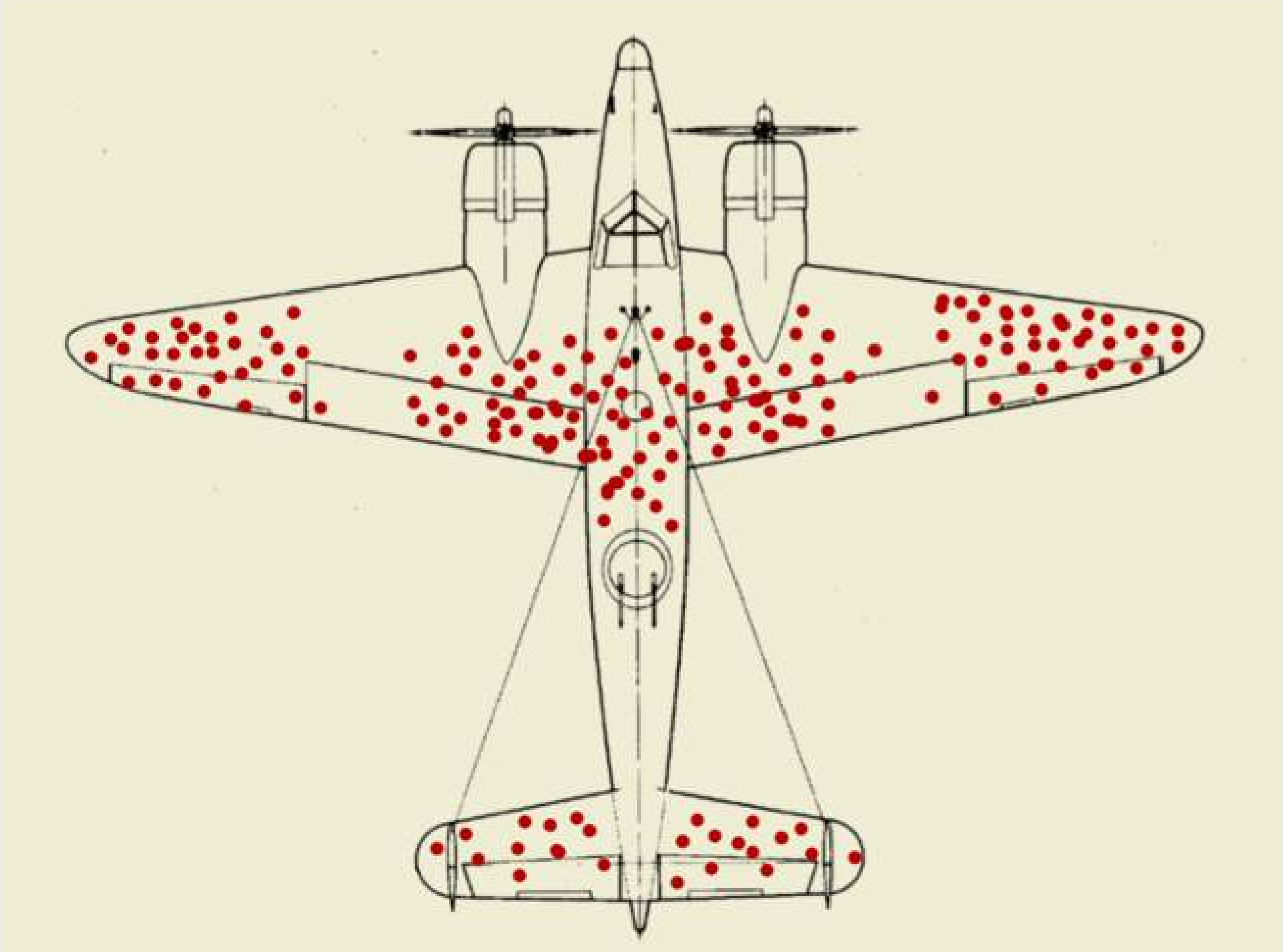
***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Why low BEV mileage?

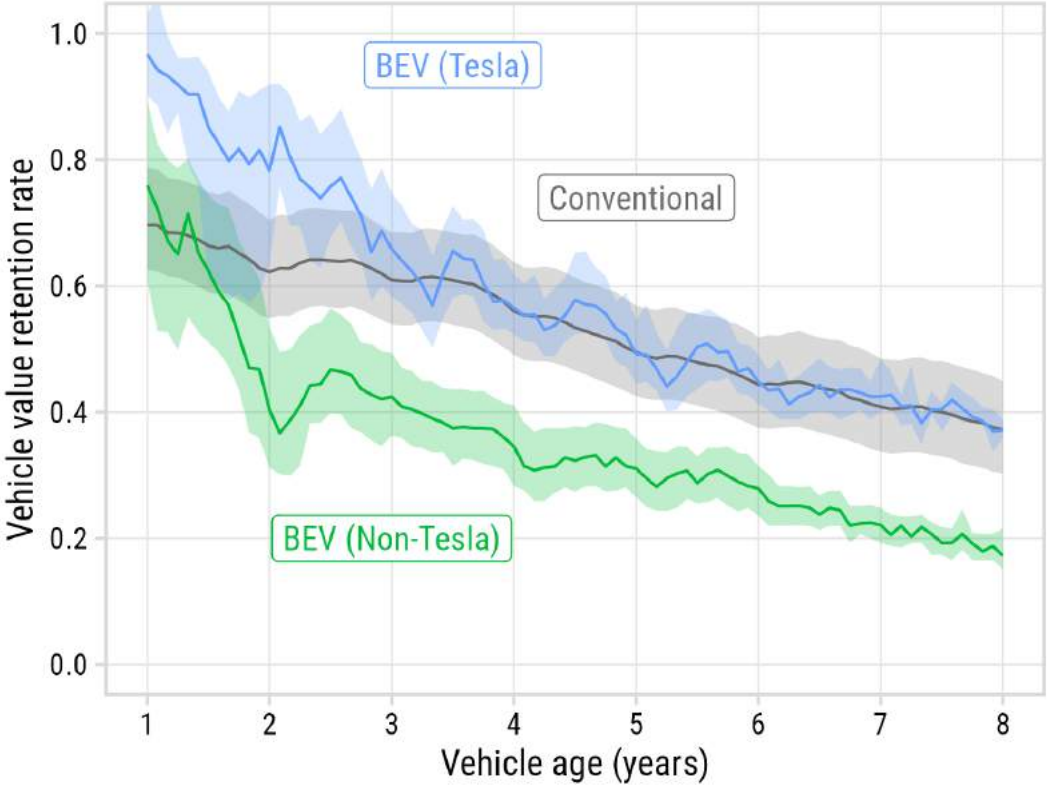
Selection bias?

Maybe current adopters just have lower driving needs?

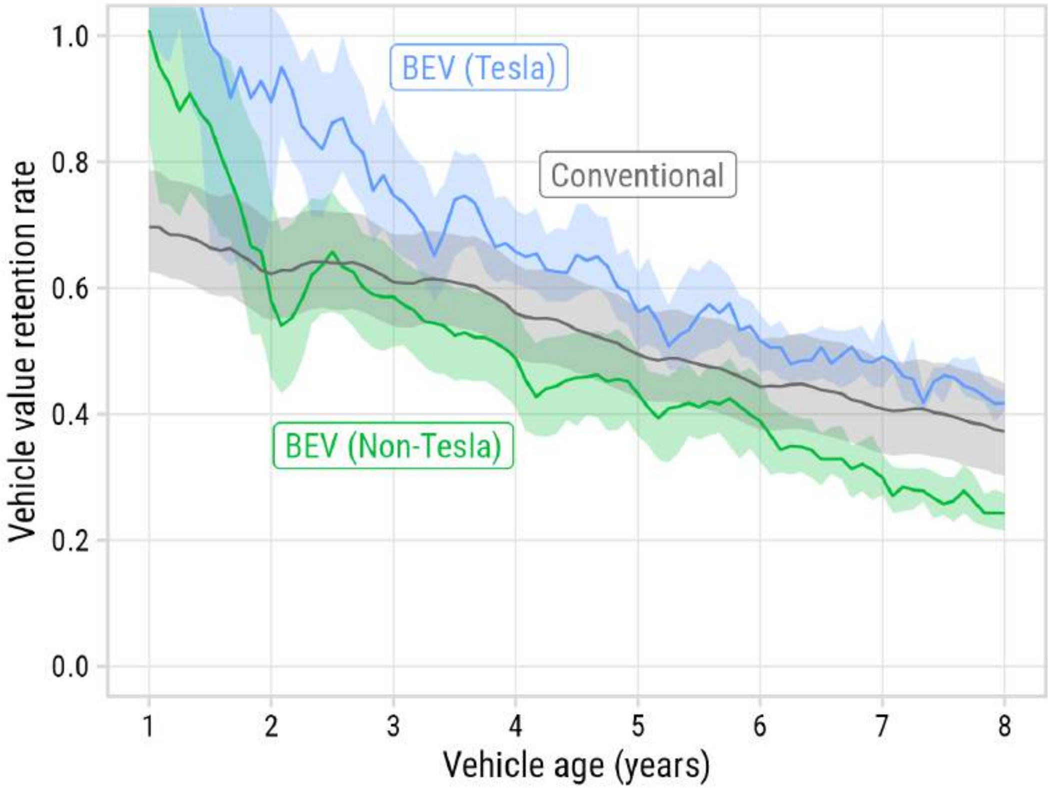
No way for us to measure this, but it seems very plausible



$$\frac{Price}{MSRP}$$



$$\frac{Price}{MSRP - Subsidy}$$



PEV subsidies for new cars (should) impact used car pricing

New Market

(MSRP - Subsidy = Price)
$30,000 - $7,500 = **$22,500**

Used Market

(Assuming adequate supply)
Max Price = **$22,500**

Two year r by model shows huge gains in newer BEVs