Has Consumer Acceptance of Electric Vehicles Been Increasing?

Evidence from Microdata on Every New Vehicle Sale in the United States

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Abstract

Electric-vehicle sales have been rapidly growing around the world, spurred by technology advances and policy actions. This study leverages rich data on all individual new light-duty vehicles sold in the United States from 2014-2020. We examine how electric vehicle attributes, prices, and sales have evolved, exploring substantial heterogeneity across geography, vehicle class, price range, and demographics. We use a matching analysis to compare electric vehicles to similar conventional vehicles to find that electric vehicles have been surprisingly competitive in very recent years. This suggests that constrained supply is an important determinant of the low overall EV market share.

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The light-duty vehicle fleet appears to be at the beginning of a fundamental transformation. For over a century, light-duty vehicles have been powered directly by fossil fuels—gasoline and diesel. Yet in the past decade, battery electric vehicles (EVs) have become a viable alternative, with EVs making up 15% of global new vehicle sales in Q3 2022. EVs have been heavily promoted by policymakers around the world, with both vehicle subsidies and subsidies for charging stations. With this policy tailwind, many automakers have committed to fully phasing out fossil fuel-powered internal combustion engine vehicles by 2035 and have invested billions of dollars toward EV development and production facilities.

This study examines how EV attributes, prices, and quantities sold have changed in recent years, with a focus on comparisons between EV and the most similar conventional (internal combustion engine) vehicles. We also explore heterogeneity across geography, demographics, vehicle classes, and price ranges to underscore that the United States cannot be seen as a monolithic vehicle market with respect to EVs. We leverage data on all new light-duty vehicles sold in the United States from 2014 to 2020, where an observation in the data is an individual vehicle in a zip code. Using these data, we perform a matching analysis and explore a set of descriptive results to glean new insights into how EV sales stack up against the sales of similar conventional vehicles.

Our matching analysis compares EVs with similar conventional vehicles and shows that EVs are becoming increasingly competitive where they are competing, but EV sales shares are still well below 50% in nearly all vehicle and price segments. Many market segments (e.g., vehicle classes) remain deeply untapped, with minimal market penetration of EVs so far. In contrast, EVs are overrepresented in the luxury market segments. Interestingly, while the attributes of EVs have been dramatically improving, the average price of the vehicles—and the price of each vehicle relative to the closest competitors—has remained relatively constant. These findings suggest that there is a taste penalty for EVs—the fraction of vehicle buyers that prefers an EV over a similar gasoline vehicle is small—and/or that EV model availability is limited. Our matching analysis indicates that when EVs are available, they tend to do well relative to similar conventional vehicles.

This paper relates to several recent literatures on EVs. One recent group of papers studies how EV demand responds to public charging infrastructure (Li et al. 2017; Li 2019; Ou et al. 2020; Sinyashin 2021; Springel 2021) or home charging availability (Davis 2022). Another object of study is the effect of financial incentives on EV adoption (Muehlegger and Rapson 2020; Armitage and Pinter 2022; Xing et al. 2021; Remmy 2022; Barwick et al. 2022). Demand for EVs may also be determined by peer effects (Tebbe 2022). Finally, several papers have studied how tastes for EVs are heterogeneous across geography and demographics (Linn 2022; Archsmith et al. 2021), and how they change over time (Forsythe et al. 2022).

Data

Our primary data set was obtained from Experian and is sourced from automobile dealers and state agencies. The data consist of all new vehicles registered in the United States from 2014 to 2020. The data are at the level of the vehicle identification number (VIN), which is a 17-digit alphanumeric code that uniquely identifies an individual vehicle. The data also contain the zip code of each vehicle registration. The first 10 digits of the VIN contain information on the make, model, model year, and trim of the vehicle. We decode each VIN in the data set, which also provides additional vehicle attributes, such as the fuel type, wheelbase, horsepower, and manufacturer suggested retail price (MSRP) for each vehicle.

In a separate data set from Experian, we also observe all vehicles in the entire vehicle fleet, along with make, model, model year, trim, the year of registration, county, and a set of demographic variables. We use the model year to focus on new vehicles, and we leverage these data for an analysis of how demographics correlate with EV adoption. We further bring in data on fuel economy from the U.S. Environmental Protection Agency's fueleconomy.gov website. Finally, we merge in data from the U.S. Department of Energy on charging station availability and census data on population to develop a measure of charging station density. Appendix 1 presents summary statistics for both data sets.

In the primary data set, there are over 111 million observations. For a small fraction of the sample, we are missing key vehicle attributes, such as MSRP or wheelbase. Thus, our final sample contains approximately 106 million observations (the separate sample that contains the demographics has over 58 million observations). In the final full sample, we observe 913,619 dedicated battery EVs and 531,723 plug-in hybrid electric vehicles (PHEVs).[1]

Trends in the Vehicle Market

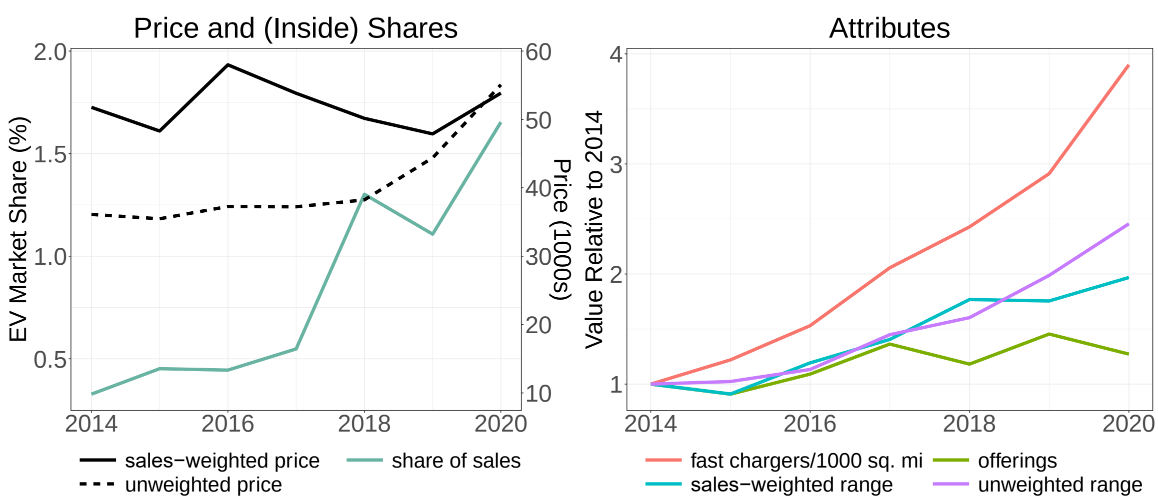
We begin our analysis by exploring key EV trends for the period 2014-2020 (Figure 1). On the left panel we observe the share of light-duty vehicle sales that are EVs. There is a clear trend upwards in the EV market share, with the market share in 2020 reaching just over 1.5%. The price (i.e., MSRP less federal subsidies) of EVs has been steadily increasing if we simply take the unweighted average across vehicle offerings. This reflects greater higher-priced luxury offerings in 2019 and 2020 and the expiration of incentives for several major EV manufacturers.

[1] In the remainder of the paper, the terms 'electric vehicles' or 'EVs' refer specifically to battery electric vehicles, not including PHEVs, unless otherwise noted.

However, the sales-weighted average price for EVs has stayed relatively constant since 2014 at around $50,000 because few of the high-priced luxury EVs vehicles are sold.

The right panel plots the trends in EV offerings, EV range (sales-weighted and unweighted), and Level 2 and DC fast charger density. All four of the time series are normalized to be 1 in 2014, and the panel plots the growth relative to 2014. The bottom line (green) presents the number of EV offerings on the market, defined as unique make-model-range combinations. We observe that they have increased by less than 1.5x between 2014 and 2020, which is not nearly as dramatic as the relative increase in range or the number of charging stations. In fact, we see automakers add and drop EV offerings, even if there is a general trend upwards. The average EV range (sales-weighted and unweighted) increased substantially over the time period, by 2x to 2.5x; the average density of fast chargers increased even faster, reaching nearly 4x 2014 levels by 2020.

Figure 1. EV trends for the period 2014-2020.



Heterogeneity in EV Sales

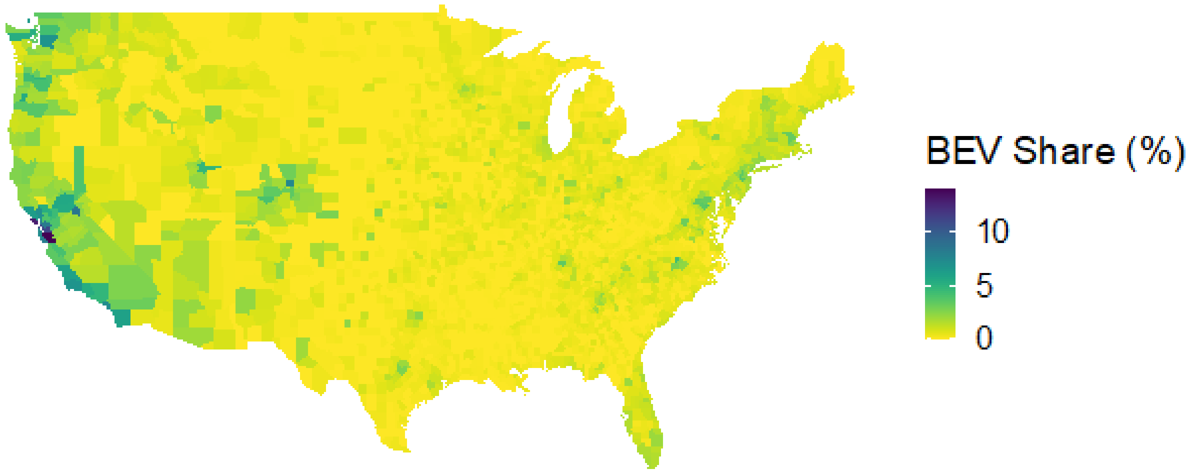
There is remarkable heterogeneity in EV sales, across geographies (e.g., within and between states, and in urban vs. rural areas), across demographics, and across vehicle classes or segments.

Figure 2 shows the county-level share of EVs in total new vehicle sales across the United States in the last year of our data, 2020. One of the most striking findings is that in most of the United States, the share of EVs is zero or near-zero. Only a few states have many counties with EV market shares above 5%. California is a prominent example, with the highest market shares in the counties in the Bay Area.

One driver of this geographic dispersion is that many of the states with higher market shares of EVs have "Zero-Emission Vehicle" (ZEV) policies that mandate that a certain percentage of the vehicles that each automaker sells are ZEVs (EVs count as ZEVs), or they must buy credits from other automakers to meet their target. Thus, automakers will provide more EVs to dealers in these states and in some cases may offer EVs for lower prices. Outside of these states, EVs are not as commonly offered to dealers.

But there could be other drivers as well. Most of the counties that have near-zero market shares for EVs are in rural areas. This is true even in many of the ZEV states, such as Washington and Oregon. Demand for EVs may be low in these rural areas, and as a result auto companies may not provide EVs to the dealerships in these areas. Demand may also be low due to limited charging stations in some of these rural countries, which would make owning an EV more difficult. There can also be supply-side explanations. Shipping EVs to rural dealerships may incur higher costs.

Figure 2. County-level market share of battery electric-vehicle sales in 2020.



We can further explore the urban/rural heterogeneity—along with additional aspects of demographic heterogeneity—with an ordinary least squares regression of adoption of an EV (or PHEV) using the second Experian data set that includes demographics. This descriptive regression is presented in Table 1. A time trend is included as well to capture the possibility demand for EVs and PHEVs improving over time due to unobserved factors. The results suggest that households are more likely to adopt an EV or PHEV if they reside in urban areas, have higher incomes, or are more highly educated. The time trend is significant and positive. The magnitudes of the coefficients may make the changes appear small but recall that the mean sales percentage of EVs and PHEVs is only 2.3% (higher towards the end of the sample), so an increase of one half of a percentage point, such as we see with the coefficient on urban, is a notable increase.

Table 1. Regression of EV/PHEV adoption on demographics.

	(1)	(2)	(3)
Time	0.006***	0.007***	0.007***
	(0.002)	(0.002)	(0.002)
Single-family home	-0.008**	0.001	-0.000
	(0.003)	(0.002)	(0.002)
Urban	0.024**	0.007**	0.005*

	(0.011)	(0.003)	(0.003)
Income $100k-$200k	0.019***	0.014***	0.011***
	(0.007)	(0.005)	(0.004)
Income $200k+	0.044***	0.039***	0.032***
	(0.013)	(0.011)	(0.009)
Single-family home x Urban	-0.018	-0.002	-0.002
	(0.012)	(0.005)	(0.005)
Graduate Degree			0.006***
			(0.001)
High School Diploma			-0.012***
			(0.004)
Less Than High School			-0.019**
			(0.008)
Some College			-0.010***
			(0.004)
State fixed effects	No	Yes	Yes
Mean	0.023	0.023	0.023
Observations	58,654,169	58,654,169	58,654,169

Dependent variable is a dummy for EV or PHEV. ***p < 0.01; ** p < 0.05; * p < 0.1

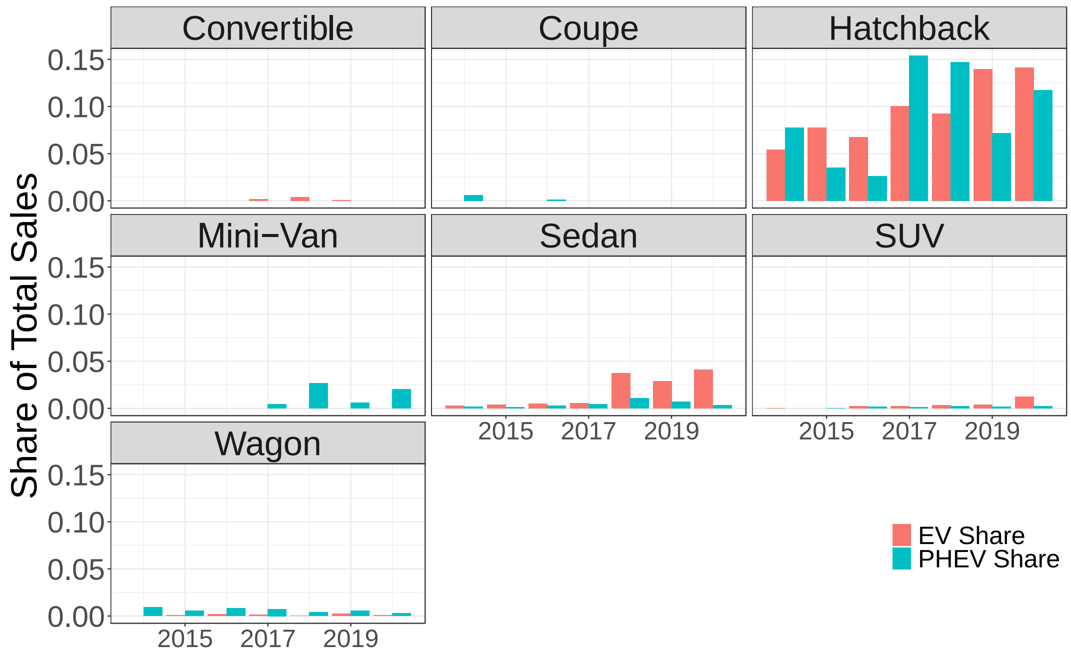
We also examine heterogeneity by the price of the vehicles sold. For this, we go back to our primary data set. Figure 3 shows the share of total sales by price range bracket that are EVs or PHEVs. The numbers next to each bar show the number of vehicles sold in that price category. A clear insight emerges: the market share of EVs and PHEVs is quite high in several price brackets at the high end, but the number of vehicles sold in these high price brackets is relatively small. Moreover, this pattern shows only a slight shift towards higher market shares in the lower price brackets by 2020. These results immediately indicate that EVs *can* make up a large market share in the U.S. new car market, but that there is a great deal of untapped product space for EVs in the lower price brackets. These untapped markets make up a much larger fraction of the total vehicle market than the luxury segments in which EVs thrive. It may have been much harder for EVs to penetrate the lower-price markets due to the high cost of batteries, but these markets hold substantial promise as the cost of batteries declines. As our analysis is only descriptive, we cannot conclude definitively if the untapped EV markets in the lower-price segments are caused by limited demand (e.g., a "taste penalty" relative to similar gasoline vehicles) or limited supply (e.g., supply chain constraints); decomposing this is a promising avenue to explore in future research.

Figure 3. EV and PHEV shares of total vehicle sales in price range bracket, 2014-2020.

Notes: Numbers over each bar contain total sales by price group (thousands).

To shed further light on the potential untapped markets for EVs, we next explore heterogeneity by vehicle class. Figure 4 presents the share of total sales in each of the major vehicle classes over time. The most striking finding is that in the hatchback category, sales of EVs and PHEVs are close to 15% of the market in some years. Hatchbacks are a small market segment with a relatively large number of EV offerings, including the Chevrolet Bolt and the Nissan Leaf. The market for sedans is much larger, and there we see the Tesla Model S capture 3-5% of the market after 2018. Yet in nearly all other vehicle classes, the market share of EVs and PHEVs is extremely small. This again points to the existence of untapped markets.

Figure 4. EV and PHEV shares of total vehicle sales by vehicle class, 2014-2020.



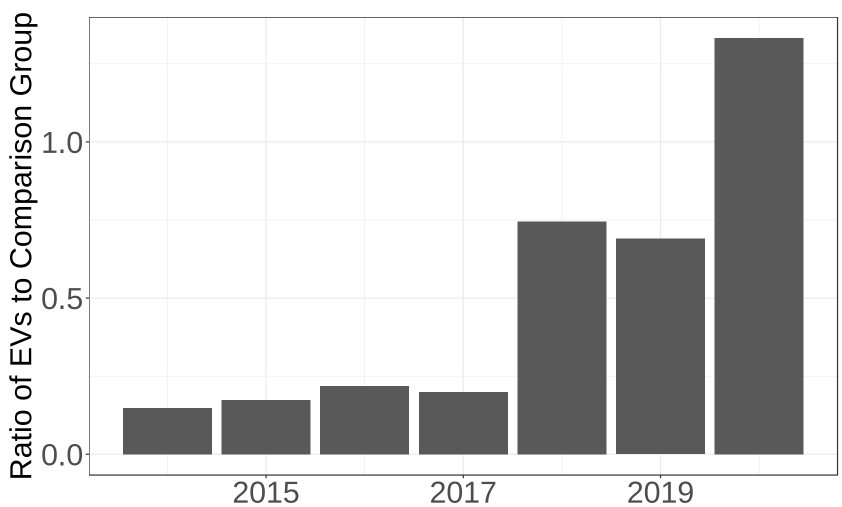
Matching Analysis

We explore the idea of untapped markets further by comparing the sales of EVs to similar conventional vehicles. For this analysis, we use a nearest-neighbor matching approach. We estimate a linear probability model where the dependent variable is an EV dummy. The included attributes are the price (net of incentives), vehicle class (i.e., body type, including SUV, coupe, hatchback, etc.), drive type (all-wheel drive or not), wheelbase, number of doors, and the log of the horsepower/weight ratio. We then obtain the propensity score for each conventional vehicle indicating its similarity to EVs. We estimate the model separately for each model year and for prices above and below the median. For each EV model, we select a set of the three most similar conventional vehicles based on the propensity score. We find very similar results using an alternative matching approach (see Appendix 2).

Figure 5 shows the ratio of sales of EVs to those in the comparison group of conventional vehicles most similar to the EVs. Not surprisingly, for most model years, the ratio is much less than one, indicating that EVs are sold less than comparable vehicles. However, beginning in

2018, the ratio exceeds 0.5, suggesting a market share larger than one-third when zooming in on higher-similar EV and conventional vehicles. In 2020, the ratio is greater than one, so the EV market share rises above 50%—vastly higher than the actual fleet-wide market share of less than 2% in those years. The main takeaway from this figure is that when we focus on only the conventional vehicles that are comparable to EVs, EVs are becoming increasingly competitive. The low overall market share stems from the (near-)absence of EV offerings in many segments of the vehicle market, suggesting that constrained offerings play an important role in explaining the untapped markets.

Figure 5. Ratio of sales of EVs to comparable gasoline vehicles.



Conclusions

The findings of this analysis show that EV sales have been on the rise from 2014 to 2020. The attributes of EVs and availability of fast charging infrastructure have been steadily improving even as the sales-weighted price of EVs has remained relatively flat, all contributing to greater sales of EVs. However, EVs have insignificant market share in vast swaths of the United States, likely due in part to ZEV standards and automaker decisions about where to sell their EVs. Similarly, EVs have very low market share across many price brackets and vehicle segments.

Yet there are regions and market segments where EVs are extremely competitive and increasingly so over time. Perhaps surprisingly, when compared to similar (matched) gasoline vehicles, EVs have seen relative sales shares exceeding 30% in recent years.

These results suggest that constrained supply of EVs is an important determinant of the near-absence of EV sales in large parts of the vehicle market, and more generally plays a key role in explaining the heterogeneity in EV sales, likely along with heterogeneity in the taste for EVs. This exploratory analysis sets the stage for formal demand estimation and structural modeling to disentangle the relative contribution of demand- and supply-side factors in explaining the increase in EV sales over the past decade, and to disentangle trends in demand caused by enhanced EV attributes vs. a reduction in the "taste penalty" for EVs. A richer understanding of EV demand is important for automakers and policymakers.

References

Archsmith, James, Erich Muehlegger, and David Rapson. 2021. "Future Paths of Electric Vehicle Adoption in the United States: Predictable Determinants, Obstacles and Opportunities," in M. Kotchen, T. Deryugina and J. Stock, eds., *Environmental and Energy Policy and the Economy*, NBER Volume 3, University of Chicago Press.

Armitage, Sarah, and Frank Pinter. 2022. "Regulatory Mandates and Electric Vehicle Product Variety." Working Paper.

Barwick, Panle Jia, Hyuk-soo Kwon, and Shanjun Li. 2022. "Attribute-Based Subsidies and Market Power: An Application to Electric Vehicles." Working Paper.

Davis, Lucas. 2022. "Electric Vehicles in Multi-Vehicle Households." *Applied Economics Letters*.

Forsythe, Connor, Kenneth Gillingham, Jeremy Michalek, and Kate Whitefoot. 2022. “What’s Driving Electric Vehicle Adoption? Evaluating Changes in Consumer Preferences and Vehicle Technology.” Working Paper.

Li, Jing. 2019. “Compatibility and Investment in the U.S. Electric Vehicle Market.” Working Paper.

Li, Shanjun, Lang Tong, Jianwei Xing, and Yiyi Zhou. 2017. “The Market for Electric Vehicles: Indirect Network Effects and Policy Design.” *Journal of the Association of Environmental and Resource Economists* 4(1): 89-133.

Linn, Joshua. 2022. “Balancing Equity and Effectiveness for Electric Vehicle Subsidies.” Working Paper.

Ou, Shiqi, Zhenhong Lin, Xin He, Steven Prezesmitzki, Jessey Bouchard. 2020. “Modeling Charging Infrastructure Impact on the Electric Vehicle Market in China.” *Transportation Research D: Transport and Environment* 81: 102248.

Remmy, Kevin. 2022. “Adjustable Product Attributes, Indirect Network Effects, and Subsidy Design: The Case of Electric Vehicles.” Working Paper.

Sinyashin, Alexey. 2021. “Optimal Policies for Differentiated Green Products: Characteristics and Usage of Electric Vehicles.” Working Paper.

Springel, Katalin. 2021. “Network Externality and Subsidy Structure in Two-Sided Markets: Evidence from Electric Vehicle Incentives.” *American Economic Journal: Economic Policy* 13(4): 393-432.

Tebbe, Sebastian. 2022. “Peer Effects in (Hybrid) Electric Vehicle Adoption.” Working Paper.

Xing, Jianwei, Benjamin Leard, and Shanjun Li. 2021. “What Does an Electric Vehicle Replace?” *Journal of Environmental Economics and Management* 107: 102432.