Project Title	**Role of Public Charging Infrastructure on Electric Vehicle Market Development**
Principal Investigators	**Joshua Linn**, Professor Department of Agricultural and Resource Economics 2210 Symons Hall College Park, Maryland 20742 linn@umd.edu https://sites.google.com/umd.edu/joshualinn **Cinzia Cirillo**, Professor Department of Civil and Environmental Engineering 3250 Jeong H. Kim Engineering Building College Park, Maryland 20742 ccirillo@umd.edu https://cinziacirillo.weebly.com/
Other project members	**Lavan Teja Burra**, PhD candidate Department of Civil and Environmental Engineering 3246 Jeong H. Kim Engineering Building College Park, Maryland 20740 ltburra@umd.edu
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Background and Project Objectives:

While the market for plug-in hybrid and all-electric vehicles in the United States has substantially increased in the last decade, they still make up a small market share of new passenger vehicles, around 7% in 2022 (Argonne National Laboratory). Range anxiety and lack of home charging access may hamper growth of the electric vehicle (EV) market, and convenient, reliable, and on-the-go access to public charging stations could play an essential role in the transition from gasoline to EVs.

To this end, the US government is making significant efforts to expand the public charging network and electrify the light-duty vehicle fleet. As part of the 2021 Infrastructure Investment and Jobs Act (IIJA), the government is investing $7.5 billion in building EV charging stations across major highway corridors and low-income locations[1]. The recent Inflation Reduction Act (IRA) also includes tax credits for public chargers installed in low-income communities, in addition to subsidies for EV purchases. Subject to federal oversight, local and state governments will decide how to allocate the available funds to new charging stations.

Besides representing a massive increase of public investment in charging stations, IIJA and IRA include two important changes from past public investment: a focus on DC fast-charging and directing investments to low-income and rural areas. Although recent research has characterized the effect of charging stations on EV sales (e.g., Li et al. 2017, Springel 2017, and Li et al. 2022), with the exception of Sommer and Vance (2021), existing research does not distinguish between level-2 charging and DC fast-charging. Because DC fast-charging dramatically reduces charge times (for example, from 6.5 hours to 30 minutes for an EV with 75 kWh of battery capacity), consumers may respond differently to DC fast-charging availability. Moreover, the literature has not examined how low-income or rural consumers respond to charging availability; their responses may differ from other EV consumers because of home charging availability and other factors.

This research project aims to investigate the role of public charging infrastructure on EV adoption, with focus on two main aspects. First, we will ask whether consumer demand for EVs responds differently to DC fast-chargers and level-2 chargers.

Second, we will consider the heterogeneity in access to public charging infrastructure across demographic groups. The existing charging network is predominantly spread across metropolitan and high-income areas, indicating regional and economic disparities (Brown et al. 2022). Communities with lower EV ownership would likely attract less infrastructure investment, making them less desirable travel designations for EV owners. In turn, the lack of charging infrastructure may further disincentivize residents in these communities from buying EVs. Because government funding guidance prioritizes the deployment of charging stations in rural and disadvantaged communities, it is important to examine how the demand for EVs varies across urban/rural areas and demographic groups, such as, income, education, and race. This will improve understanding of the specific groups that are likely to benefit from these provisions and help guide policymaker decisions about charging station placement.

We aim to answer the following questions:

[1] Detailed information about the deployment of EV charging infrastructure as part of this program can be found at https://www.fhwa.dot.gov/environment/alternative_fuel_corridors/nominations/90d_nevi_formula_program_guidance.pdf.

1. How does public charging infrastructure affect EV sales, distinguishing the effect of level-2 and DC fast-chargers?
2. How strongly do low-income and rural vehicle buyers respond to public charging stations?

We will answer these questions using parameter estimates from a two-sided structural model of the EV market. Comparing counterfactual policy designs will yield insights for local, state, and federal policy makers about how to allocate charging investments efficiently and equitably.

Data:

We will build a comprehensive data set of new car purchases and charging station entry in the US from 2010 to 2020. To do so, we will combine data from various sources.

Survey of new car buyers. Our primary data source is the household survey conducted by InMoment called the New Vehicle Customer Study, which collects responses from around 200,000 new car buyers each year. We have access to data from 2010 through 2020, which includes detailed information on the new vehicle purchased[2], vehicle transaction price, and socio-demographic information such as household income, age, education, and race. The survey also provides information about the previous vehicles that were replaced (if any) to buy the new one, and other household vehicles. Crucial for our analysis, the data includes the household's zip code.

Car attributes and registrations. To supplement the InMoment data, the study will merge vehicle characteristics data from Wards Automotive, which provide detailed attributes of each vehicle model in each model year, including horsepower, size, curb weight, wheelbase, and fuel economy. For EVs, the study will gather information on battery size, range covered on full charge. Because the survey response rates vary across households, we will weight observations using data from IHS Markit, which provides state-level vehicle registration data by model, trim, fuel type, body style, and year.

EV purchase incentives. We compile data on EV purchase rebates or tax credits at the federal and state levels. The Department of Energy's Alternative Fuel Data Center (AFDC) database provides information on the amount of subsidy, the qualification requirements, and eligible purchase dates for each program, at both the state and federal levels.

EV charging stations. The study will utilize public charging station database available on the AFDC, which is a national database of public charging stations that includes information about the number of charging ports by levels (level-2/DC fast charging), their opening dates, geographic coordinates, and other characteristics.

Additional data. We will use publicly available data from the US Census website to construct a measure of accessibility for the nation's interstate and major highway network. We will merge this with the currently approved EV corridors (available on US Department of Transportation website). We will use an aggregate measure of vehicle miles travelled (VMT) (from NHTS or a dataset from BTS) that reflects the travel patterns across regions. This will further enable us to construct a measure that reflects the consumer's dependence on public charging infrastructure based on their driving patterns.

[2] This include make, model, trim, drive type (such as front-wheel drive), and power train specifications (engine size, transmission type, and fuel type) information.

Overall, the resulting data set will include detailed information on consumer vehicle choice and public charging network, covering the entire nation and spanning over a decade.

Approach:

Given the presence of positive network externalities between electric vehicles and charging stations, commonly referred to as the "chicken and egg problem", we will adopt a two-sided market framework to model the EV market. A joint structural model will be developed that combines both consumer vehicle choices and the entry model of charging station supply. Our approach will build on empirical models of EV demand, such as Springel (2021), Cole et al. (2021), and Linn (2022).

Our consumer demand model augments standard discrete choice models by allowing for heterogeneous preferences over vehicle prices and public charging availability. There are Q_{gr} consumers of demographic *g* in region *r* who choose a vehicle from among *J* new models in the market. The indirect utility of consumer *i* from purchasing an EV can be specified as follows.

$$u_{ij} = \beta_{ig} p_{jr} + \alpha_2 ln(N_{gr}^{L2}) + \alpha_3 ln(N_{gr}^{L3}) + \sum_k x_{jk}\gamma_{gk} + \xi_{jr} + \varepsilon_{ij}$$

Where p_{jr} is the vehicle price divided by consumer income and β_{gr} describes the sensitivity of utility to price[3], x_{jk} is a vector of observed vehicle characteristics, N_{gr}^{L2} and N_{gr}^{L3} represents the measure of level 2 and DC fast charging station network. These variables are computed by weighting counts of charging points by a measure of local VMT, thereby reflecting the differences in dependence on charging stations based on region-specific travel patterns. ξ_{jr} is the unobserved vehicle characteristics, and ε_{ij} is the idiosyncratic preference shock. The effect of level 2 charging stations decreases with the EV stock to capture the waiting time at slow charging stations. Heterogeneity across consumers is captured via the demographic and region-specific parameters and the error term.

Making standard assumptions on the error term yields an expression for each vehicle's market share. Depending on how we introduce consumer heterogeneity, we can estimate parameters using linear regressions or simulated method of moments.

However, the demand model introduces two main identification problems. First, vehicle sales and prices are determined simultaneously. Second, to the extent that chargers are situated according to the prevalence of EVs, sales and charging stations are jointly determined. Several papers in the literature have addressed the endogeneity concerns using various instruments. For example, Springel (2021) instruments for prices using cost shifters and vehicle characteristics and for charging infrastructure using charging station subsidies. Li et al. (2022) constructs a set of instruments based on battery capacity to address price endogeneity and use the lagged cumulative stock of EVs purchased by government agencies and taxi fleets. Sommer and Vance (2021) use the count of transformers along the electric grid as an instrument for DC fast chargers and the count of gas stations as an instrument for level-2 chargers. We will consider using these instruments as well as using the DOT EV corridors to predict charging infrastructure.

[3] Note that the demand equation will include the effective purchase price of the vehicle model i.e., transaction price less the related subsidies (tax credits at both federal and state level).

We will build a charging station entry model following Springel (2021). By applying this structural model, we can evaluate the effectiveness of policies including the EV subsidy provisions and charging station investment through IRA and IIJA. Additionally, simulating counterfactual incentive structures and policy scenarios will help us provide insights on effective future directions for government intervention.

Policy Impact:

Over the next 5 years, the IIJA and IRA direct local, state, and federal policy makers to invest in public charging stations that allow for faster charging and that are more likely to be located in low-income or rural areas. There is little research on how these particular types of investments will affect EV demand. The proposed work aims to inform those choices. The study will evaluate how charging infrastructure affects EV demand, thereby evaluating the effectiveness of infrastructure investment across urban and rural areas. Additionally, the study will identify to what extent different demographic groups will benefit from equitable access to charging stations, thereby providing insights into the disparity of EV adoption. The study can shed light on how much these investments will boost EV adoption, and whether additional investments will be needed to achieve President Biden's goal that plug-in vehicles will account for 50% of new vehicle sales by 2030. Overall, the outcomes of the project will provide policymakers with data, methods, and findings that will support decisions related to investments in the transportation sector and climate change.

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