Modeling and analyzing near term transitions to alternative fueled vehicles using a spatial regional consumer choice and fueling infrastructure model

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Project Background and Motivation

• Consumer preferences, especially in the transportation sector are captured through discrete choice models
  – Has heterogeneous consumer segments
  – Captures consumer perception towards various technologies based on consumer characteristics and vehicle attributes
  – But, they typically operate on a spatially aggregated level
  – Spatial details are especially important while considering the effect of infrastructure availability in the neighborhood

• Implements consumer vehicle purchase behavior into a detailed spatial model with geographic specification of charging and refueling stations

• This research project illustrates the vehicle purchase behavior of consumers in California at zip code level
Consumer Choice Representation

MA³T model developed by Oak Ridge National Laboratory (Lin & Greene, 2010) is used to represent vehicle consumer choice (typically the choice representation is done in two stages):

First, demand is disaggregated into different consumer segments based on their characteristics (driving behavior, risk attitude, etc.).

Secondly, non-monetary costs (“disutility costs”) that capture consumer perception of different vehicle technologies are added to the model.

These costs go through a nested multinomial-logit module to determine purchase probability of each vehicle technology for each consumer group.

<table>
<thead>
<tr>
<th>Disutility Cost Component</th>
<th>Description</th>
<th>Dependent Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Refueling inconvenience cost (for non-electric vehicles—eg. FCVs)</td>
<td>The combined time and inconvenience cost to refuel a vehicle</td>
<td>Annual miles driven, fuel economy, vehicle storage, station availability, value of time</td>
</tr>
<tr>
<td>Range Limitation Cost (BEVs)</td>
<td>The estimated generalized cost incurred by a BEV owner due to limited range of battery electric vehicles in conjunction with the owners VMT pattern</td>
<td>Daily VMT, annual miles driven, infrastructure availability, anxiety cost (consumer-specific, based on their risk attitude)</td>
</tr>
<tr>
<td>Model availability cost</td>
<td>Estimated cost of consumer perception based on make and model diversity available in the market</td>
<td>Cumulative vehicle sales</td>
</tr>
<tr>
<td>Risk Premium</td>
<td>The risk premium perceived by the consumer based on their ability to take risk</td>
<td>Cumulative vehicle sales</td>
</tr>
</tbody>
</table>
Effect of Household Income on Vehicle Price

- Perception of incremental vehicle price (difference from gasoline vehicles) significantly depends on the household income.
- The income related disutility cost is estimated from the (incremental vehicle price / income) ratio.
- For lower income households, the ratio (incremental vehicle price/income) is higher than higher income households, indicating, as household income increases, the “disutility” associated with larger incremental vehicle prices decreases.
- Current work focuses on calibrating this method based on historic vehicle sales data for different income groups.
Purchase Probability Estimation

Monetary costs of the vehicle

Vehicle and Fuel cost

Disutility Costs

Disutility costs of the vehicle from the POV of the consumer

Choice Algorithm

Nested Multinomial Logit Choice Module

Purchase probability of the vehicle technology
Illustration of Cost Components

- Income-related cost
- Model availability cost
- Refueling cost
- Range Limitation cost
- Electricity cost
- Fuel cost
- Vehicle cost

High-income household
- Good Infrastructure availability
- Early Adopter
- Low VMT

Low-income household
- Poor infrastructure availability
- Late Majority
- Frequent driver

Bar charts comparing cost components for different vehicle types (Gasoline, Diesel, G. Hybrid, PHEV, BEV, FCV) under different income and infrastructure conditions.
Early adopter, low VMT, high income, good infrastructure availability

Late majority, high VMT, low income, poor infrastructure availability

Purchase Probability

- Gasoline
- Diesel
- G.Hybrid
- PHEV
- BEV
- FCV
1565 zip code regions * 5 income groups * 7 VMT categories * 3 Risk categories * Home charger Population share * Workplace charger population share = 657,300 consumer groups

Source

MA³T
MA³T
DOE¹
CHTS²
ACS³

Input Data

- Fueling data
  - Fuel prices
- Vehicle attributes
  - Cost, efficiency, range, storage
- Infrastructure data
  - Infrastructure locations
- Spatial Consumer data
  - Income, driving profile, housing type
  - Risk tolerance of consumers

US Sales
- National vehicle sales

Vehicle and fuel costs
Disutility costs*
Estimate density and proximity

Sensitivity and scenario analysis
Nested Multinomial-logit module

Vehicle Technology Market shares
Estimated at neighborhood level

Framework Complete
Ongoing work
Future work (2017)

*Refueling inconvenience cost, range limitation cost, risk premium, model availability cost, and income related utility

¹Department of Energy, ²California Household Travel Survey; ³American Community Survey
Income Distribution in CA regions

San Francisco Bay Area

Southern California

Central California

State Income Distribution

SF Bay area has greater high income population share than the state average.
Assumption: People working in the tech sector tend to be more interested in new technologies.

Place of employment from ACS micro census data is used to obtain early adopter population (e.g., people employed in technology, scientific professions).

These are 51 zip code regions (SF bay area & some parts of Southern California), constituting almost 60% of the early adopter population.
Infrastructure Availability Calculation for each Zip Code

• We currently use a simplified approach for calculating refueling availability
  – For each zip code, a 5-mile buffer radius is constructed around the region
  – The number of hydrogen stations / public charging stations inside the region is calculated.
  – This is divided by the number of gasoline stations in the neighborhood for hydrogen stations or divided by the number of public attractor locations in the neighborhood for charging stations
  – The resulting percentage is the “station availability” value for that region.

• This parameter will be further refined to include all the stations in the nearby region, and the availability parameter will be estimated based on both proximity and density.
Infrastructure Availability Distribution

Range limitation cost is a function of public charger availability
Refueling cost is a function of hydrogen station availability

57 zip code regions, 3% of population
27 zip code regions, 2.5% of population
This cost trajectory reflects the consumers who have no access to home or work chargers, and rely only on public chargers.

- Low annual VMT: 8,656 miles; Medium annual VMT: 16,068 miles, and high annual VMT: 28,288 miles

Station availability is typically the percentage of hydrogen stations to gasoline stations in the region.

Source: MA³T Model (Lin & Greene, 2010)
Bay area has 78% higher BEV purchase probability than the state average due to presence of high income population and better access to workplace charging.
• The number of households with vehicles is higher in Southern California than other regions in CA.
• Therefore, SoCal leads in actual vehicle purchase numbers in all categories.
• Total vehicle sales in SF bay area is 17.6% of the total sales in CA, but their BEV sales is about 31% in the state, and FCV sales is 27% of total.
12 out of 20 cities belong to SF Bay Area
11 out of 20 cities are located in Southern California.
• BEV adoption is more prevalent compared to FCV.
• SF Bay area leads in BEV adoption, Southern California leads in FCV adoption
Presence of hydrogen station in the neighborhood is very important for FCV adoption.

On the other hand, workplace charging plays a significant role in BEV adoption compared to the presence of public chargers.
Summary

• This research estimates spatial distribution of alternative-fueled vehicle purchases with a consumer choice model
  – Segmenting consumers using spatially sensitive attributes such as income, driving behavior and utility factors related to infrastructure proximity.

• Initial results:
  – Can match patterns of adoption in higher income, early adopter areas such as SF Bay Area
  – The AFV adoption numbers are higher than expected—better calibration to data needed

• Main challenge: insufficient data at the detailed spatial level
Future Work

• Continue calibrating the model, collect more data
• Constructing a feedback loop between the years to analyze vehicle transitions for the next 5-10 years
• Split the spatial resolution into 1-sq.mile grids to refine infrastructure analysis
• Analyzing different infrastructure investment patterns (eg. What are the optimal locations for the next 100 hydrogen stations? Which pattern would lead to maximum adoption of FCVs?)
• Cost and emissions estimation of the model scenarios
ADDITIONAL SLIDES
Vehicle Prices

Vehicle Prices in the year 2020

Vehicle prices are from the MA T model (based on DOE's Autonomie model). This does not include subsidies or tax credits.
## Input Module—Consumer Characteristics (data)

<table>
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<tr>
<th>Attribute</th>
<th>Description</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumer driving profile</td>
<td>Expressed in annual miles traveled (divided into seven categories—5000 to 35,000 miles)</td>
<td>California Household Travel Survey (VMT profile at zip code level)</td>
</tr>
<tr>
<td>Risk Attitude</td>
<td>Division of consumers based on their perception of risk towards new technologies: Early adopters, Early Majority and late majority.</td>
<td>Early adopter population is determined from employment type (tech sector) from ACS data.</td>
</tr>
<tr>
<td>Income</td>
<td>Average household income. Willingness to pay for a vehicle technology increases with increase in income (divided into 5 categories)</td>
<td>California Household Travel Survey (Annual household income)</td>
</tr>
<tr>
<td>Home Charger Access</td>
<td>Estimates consumers with dedicated garage access. This determines how much they rely on public chargers</td>
<td>American Community Survey 2015 (single detached household percentage at zip code level)</td>
</tr>
<tr>
<td>Workplace charger access</td>
<td>Estimates consumers with access to workplace chargers</td>
<td>Assumptions are made for each region (20% for SF bay area, 5% for SoCal, and 0.1% for the rest of CA)</td>
</tr>
</tbody>
</table>
Daily VMT Distribution for each VMT Category

VMT Distribution for each annual mile category

Probability Density

Daily eVMT availability (mile)
Map of Existing Hydrogen Station Locations

Source: California Fuel Cell Partnership
Map of Planned Hydrogen Station Locations in 2016

Source: California Fuel Cell Partnership
National Level—Hydrogen Stations (Existing)