The MA$^3$T model: Market Adoption of Advanced Automotive Technologies

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Outline

- Purpose of Model
- Framework, Theory and Implementation
- Calibration and Validation
- Features and Capabilities
- Selected Results
- Areas for Improvement
- Conclusions
MA3T was developed to allow DOE to analyze the transition of U.S. LDV powertrain mix and relevant policies.

- Functional objectives
  - Assessment of social benefits and costs
  - Identifying barriers and drivers
  - Analysis of a wide range of policies
  - Analysis of stakeholder behavior
MA3T simulates consumer choices and interactions between technologies, infrastructure, policies, and social impacts.
MA3T is implemented in Excel/VBA. Three files are involved. Multi-run is convenient.

Save
- Save the four input files "Scenario" "Segmentation" "EnergyPrices" and "Policy"

Load
- Load the above four input files

Single Run
- Run the model once with result files generated in the same folder; press ESC to abort the run

Multi Run
- Select and run multiple scenarios

Calibrate
- Calibrate to historical sales data

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The core NMNL consumer choice model assumes homogeneous preferences within each of the 1458 disaggregated market segments.

- Nested multinomial logit (NMNL) is commonly used for forecasting transportation demand.

- Conditional probability of choice $i$ in nest $j = \text{car/truck}$, $k = \text{Conv/H}_2/\text{EV}$ and $l = \text{technology type}$ is a function of a price sensitivity parameter $\beta_{jkl}$ and generalized cost $c_{ijkl}$

$$p_{i|jkl} = \frac{e^{\beta_{jkl}c_{ijkl}}}{\sum_h e^{\beta_{jkl}c_{hjkl}}}$$

$$\sum_i p_{i|jkl} = 1$$

- the generalized cost $c_{ijkl}$ is a function of technology attributes $x_{zijkl}$ and the attribute weight (or value) $w_{zijkl}$

$$c_{ijkl} = \sum_z w_{zijkl} f_z(x_{zijkl})$$
MA3T integrated NMNL with a wide range of knowledge. Some of the integrated theories are validated, but more need to be studied and learned:

- Nested multinomial logit (NMNL)
- Learning by doing (LBD) and co-learning
- Economy of scale
- Gamma distribution for random daily distance
- Fuel-travel-back: optimal station locations
- Path-dependant charging benefit
- Supply constraint for new technologies
- Conflict: infrastructure availability and utilization
- Policy design, e.g. feebate parameters
- Calibration—learning from history
- Dynamic product design (being implemented)
- Optimal transition (to be implemented)
Calibration of NMNL constants aims at reducing bias. Precision can be improved by discovering/including more relevant factors.

Calibration Constant for buying

Constant for buying SI LTK

Constant for buying SI HEV

SI HEV sales calibration
Extrapolation of GC constants based on weighted history learning seems to produce close estimates for year 2012.

Validation

![Bar chart showing historic versus predicted market acceptance]

- Car/LDV: 51.39% (Historic), 49.91% (Predicted)
- LTK/LDV: 48.61% (Historic), 50.09% (Predicted)
- HEV/Car: 4.08% (Historic), 4.20% (Predicted)
- PHEV/Car: 0.20% (Historic), 0.24% (Predicted)
MA3T simulates 1458 U.S. consumer segments choosing among 40 LDV choices

- U.S. LDV market divided into 1458 seg., 2005-50
- Buy or no buy decision is now endogenous
- 20 powertrain technologies, cars and light trucks, to be expanded into small cars, midsize cars, large cars, SUVs and pickup
- Vehicle attributes: retail price, fuel economies, acceleration, refueling hassle, range limitation cost, etc
- Infrastructure: hydrogen, natural gas, electricity, diesel; home, work, public charging
- Policies: fuel/carbon tax, feebate, parking or HOV incentives, tax credit or rebate
1,458 consumer market segments are characterized by a combination of data and assumptions.

- **Region**
  - 01_NewEngland  02_MiddleAtlantic  03_EastNorthCentral
  - 04_WestNorthCentral  05_SouthAtlantic  06_EastSouthCentral
  - 07_WestSouthCentral  08_Mountain  09_Pacific

- **Area**
  - 01_Urban  02_Suburban  03_Rural

- **Technology Attitude**
  - 01_Early-Adopter  02_Early-Majority  03_Late-Majority

- **Driver**
  - 01_Modest-Driver  02_Average-Driver  03_Frequent-Driver

- **Home Charging**
  - 01_Level-1  02_Level-1  03_Neither

- **Work Recharging**
  - 01_With Work Recharging  02_Without
The parameters of the NMNL model are calibrated based on consensus estimates from previous studies, theory, and assumptions.

- competition among lower level nests/choices is more price sensitive than among the upper level nests
- price elasticities in the model can be modified

20 Passenger Cars
- SI/CI/NG Conv: conventional powertrain powered by gasoline/diesel/natural gas
- SI/CI/NG HEV: hybrid vehicle by gasoline/diesel/natural gas
- SI PHEV10/20/40: gasoline PHEV with 10/20/40-mile e-range
- H2 ICE: conventional powertrain with hydrogen ICE
- H2 FC HEV: hybrid vehicle with fuel cell (FC)
- H2 FC PHEV10/20/40: FC PHEV with 10/20/40-mile e-mile
- BEV-100/150/200: battery electric vehicle with 100/150/200-mile range. EERV, in the EV nest

20 Light-duty Trucks
- Same nest structure as passenger cars
- Slightly less price elastic

The current 2 classes to be expanded into small cars, midsize cars, large cars, SUV and pickup trucks
Choice attributes included (or planned to) are intended to reflect factors that will influence choices relatively predictably in the long run.

- vehicle retail price
- fuel and electricity cost
  - affected by daily VMT distribution and driving behavior, varying by region, area and driver type
- battery replacement cost
- acceleration
- cargo space
- towing
- range
- home backup power
- refueling and recharging accessibility cost
- model availability
- technology risk
- vehicle-to-grid costs and revenues
- Maintenance cost
- greenness (placeholder)
- can be expanded to include more items
The validated ORNL Gamma method allows more accurate estimation of PHEV energy use/cost. Three types of drivers are represented in MA3T.
Gamma distribution can be specified by the mean and mode, i.e. average and typical daily distances

- **Expected daily fuel use (gge/day)**
  
  \[ E_g = C_{g,cd} \cdot \int_0^{R_{cd}} x \cdot p(x) \cdot dx + C_{g,cs} \cdot \int_{R_{cd}}^{M} x \cdot p(x) \cdot dx + (C_{g,cd} - C_{g,cs}) \cdot R_{cd} \cdot (1 - \int_0^{R_{cd}} p(x) \cdot dx) \]

- **Expected daily electricity use (kWh/day)**
  
  \[ E_e = C_{e,cd} \cdot \left( \int_0^{R_{cd}} x \cdot p(x) \cdot dx + R_{cd} \cdot (1 - \int_0^{R_{cd}} p(x) \cdot dx) \right) \]

- **Gamma distribution of daily distance**

  \[ p(x; k, \theta) = x^{k-1} e^{-x/\theta} \frac{\theta^k}{\Gamma(k)}, \quad k\theta = x_{avg}, \quad (k-1)\theta = x_{md} \]

References:
Base scenario: moderate technology progress; no expansion of charging or hydrogen refueling infrastructure
Program Goal: all vehicle components meeting DOE program goals on time; fast expansion of both charging and hydrogen infrastructure.
MA3T has been used to analyze the effect of DOE technical targets on hydrogen vehicle market.
Improved charging infrastructure increases fuel savings for PHEV and improve range assurance for BEV, but to what extent will it facilitate PEV adoption?
The contribution of infrastructure improvement to PEV market adoption can be amplified by battery cost reduction or prevented by high battery cost.

**Figure 5 Impact of Recharge Availability on PHEV Penetration, Conditional on Battery Cost**

Note: 1. Reference assumes existing policies, recharge availability and moderate technology progress. 2. Battery20 stands for 20 years earlier reduction of battery cost. 3. Deployment of each recharge option is assumed to be aggressive during 2017-2025. 4. Projections generated by ORNL MA³T model. 5. The temporary kinks are due to expiration of the ARRA PHEV subsidies.
Areas for future improvement

- Vehicle and energy data update
- Calibration and validation
- Parameterization
  - Price elasticity
  - Value of fuel savings; risk aversion
  - Value of refueling and recharging convenience
  - V2G
  - Charging behavior and services
- Market segment data
  - Early adopters
  - Driver and driving distributions
  - Home vehicle flexibility
  - Duty cycle
MA³T provides a flexible modeling framework that can be improved as we learn more about how markets respond to advanced automotive technologies.

- NMNL core plus logical structure that can be populated with best available information.
- Detailed market disaggregation important for representing early market penetration.
- Need better data in several areas, especially
  - Early adopters
  - Charging behavior
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