COCHIN-TIMES: Integration of Vehicle Consumer Choice in TIMES Model and its Implications for Climate Policy Analysis

*International BE₄ Workshop*
*University College London*
*April, 2015*

Kalai Ramea, David Bunch*, Sonia Yeh, Chris Yang, Joan Ogden

*Graduate School of Management, University of California, Davis*
*Institute of Transportation Studies, University of California, Davis*
Background

- Since 2007 California government has pursued public policy and regulations to mitigate GHG emissions

Motivation: There is a need for improved models for analyzing policies for addressing climate change goals

- Consumer choice is very important in light-duty vehicle adoption—59% of energy use comes from LDVs in the transportation sector
Overview of Model Approach

• Energy Systems Models
  – Technology rich on the supply side, but lack behavioral details

• Consumer Choice Models
  – Detail choices on the demand side but lack supply sector details

• Our focus: ‘Marrying’ these two types of models

\[ \text{Supply-rich} \rightarrow \text{Consumer Choice Model} \rightarrow \text{Demand-rich} \]
\[ \text{Supply rich} \rightarrow \text{TIMES model} \rightarrow \text{Minimal behavior rep.} \]
\[ \text{Supply-rich} \rightarrow \text{COCHIN-TIMES} \rightarrow \text{Demand-rich} \]

COCHIN: CO
sumer CH
oice IN
tegration
MA$^3$T (Market Allocation of Advanced Automotive Technologies), nested multinomial logit model developed by Oak Ridge National Laboratory.
Consumer Group Divisions in the MA$^3$T Model (for every census region)

- **Settlement Type**
  - Urban
  - Suburban
  - Rural

- **Risk Attitude**
  - Early Adopter (8%)
  - Early Majority (38%)
  - Late Majority (54%)

- **Driving Behavior**
  - Low Annual VMT (8656 miles)
  - Medium Annual VMT (16068 miles)
  - High Annual VMT (28288 miles)

- **Recharging Infrastructure**
  - Home + Work
  - Home + No Work
  - No Home + Work
  - No Home + No Work

(+ public recharging infrastructure common to all)
Vehicle Technologies

Conventional
- Internal Combustion
  - Gasoline
  - Diesel
- Hybrid
  - Gasoline
  - Diesel
- Gasoline Plugins
  - 10-mile
  - 20-mile
  - 40-mile

Hydrogen
- Hydrogen ICE
- Fuel Cell Vehicle
- Fuel Cell Plugin

EVs
- 100-mile
- 150-mile
- 250-mile
Vehicle Purchase Decision-Making

- **Monetary Costs**
  - Vehicle Price
  - Fuel Cost

- **Disutility Costs**
  - Perception
  - Infrastructure support

**Consumer Choice**

Vehicle Purchase
Disutility Cost Components

- Refueling Inconvenience Cost
  - Cost associated with the lack of access to refueling infrastructure (station availability)
  - Based on various spatial simulation and cluster analysis studies done on access time to find stations—multipliers are derived

- Range Anxiety Cost
  - Cost to capture the consumer’s perception of anxiety associated with the limited range of EVs and infrastructure availability.
  - Based on a daily VMT distribution, model checks whether it meets the range for the day. If not, a $/day penalty is given, which differs across risk groups

- New Technology Risk Premium
  - The consumers’ willingness to pay to avoid risk (or gain novelty) approaches zero as cumulative sales of the vehicle technologies increases over time

- Model Availability Cost
  - Make and model diversity is represented in the vehicle choice model as the log of the ratio of the actual number of makes and models available, to the “full diversity” number (conventional vehicles)

More details on formulation of these costs can be found in this National Research Council report: “Transitions to Alternative Vehicles and Fuels”: http://www.nap.edu/catalog.php?record_id=18264
MA³T Model

- **Nested Multinomial-Logit Module**
  - Increase in Vehicle Sales
  - Increase in Vehicle Stock

- **Learning Equation for Vehicle Prices**

**Model input**
- Recharging Infrastructure
- Fuel Prices
- Fuel Infrastructure
- Policies

- Range Anxiety Cost in EVs
- Electricity usage share in PHEVs**

**Model Output**
- Decrease in Risk Premium
- Increase in Model Availability*

**Direct Costs**
- Refueling Inconvenience Cost

**Disutility Costs**
- Subsidy/ HOV/ Parking

**Increase in Model Availability** leads to decrease in model availability cost.
* Decrease in Vehicle Price until it reaches the ‘Learned Out Cost’.
** Electricity usage share in PHEVs decrease when there is inadequate recharging infrastructure.
Steps to Introduce Consumer Choice in TIMES

Standard TIMES model

Step 1: Creating heterogeneity in demand

Step 2: Adding disutility costs

Step 3: Creating clones of each group and adding random error terms

Eg. Creating clones to include MNL structure for any consumer group (simpler than COCHIN, which has NMNL structure)

Logistic Regression Curve

Total Cost = Vehicle Cost + Fuel Cost + Disutility Costs + (Error term/scale)
COCHIN: US Reference Case

- Timeline: 2005 to 2050, nationwide model, annual investment
- Represents both light-duty cars and trucks
- 12 light-duty car technologies and 12 light-duty truck technologies
- Has 36 consumer groups (risk attitudes, driving profiles, recharging infrastructure)
- Vehicle costs and efficiencies are included from Argonne National Laboratory’s Autonomie model
- Fuel prices are taken from Annual Energy Outlook (2013)
- 52% of the population has access to home recharging infrastructure, 5% of the population reaches access to workplace recharging in 2050, about 15,000 public recharging station locations are installed by 2035.
**COCHIN: Annual Sales Share**

**COCHIN Model: One Consumer Group: LMAHNW**

*Vehicle and Fuel Costs*

- *LMAHNW: Late Majority, Average Driver, Home Recharging, No work recharging*
- Exhibits “winner-takes-all” or “knife edge” phenomenon
- All the vehicles in the mix are light-duty cars. Trucks do not get invested at this point.
Adding driver groups introduce variations in vehicle technology investments with high annual VMT drivers investing in more fuel efficient vehicles followed by lower VMT groups.
• Due to public recharging availability, high annual VMT drivers invest in plugins towards the end of the model time period.
• PHEV 10s are chosen by late majority frequent drivers, and PHEV 20s are chosen by early majority frequent drivers.
• Light-duty trucks enter the model results after adding the clones for every group.
Random runs of COCHIN Model (1 clone per group)
Random runs of COCHIN Model (5 clones per group)
Random runs of COCHIN Model (20 clones per group)
G.Hybrid: Gasoline Hybrid

PHEV 10: Plugin 10-mile range

PHEV 20: Plugin 20-mile range

EV 100: Battery electric vehicle 100 mile range

FCV: Fuel cell vehicle

FP: Fuel cell plugin
COCHIN Vs. MA³T: Annual Sales Numbers

Total LDV sales numbers are taken from AEO 2014 Sales Numbers

G.Hybrid: Gasoline Hybrid

PHEV 10: Plugin 10-mile range

PHEV 20: Plugin 20-mile range

EV 100: Battery electric vehicle 100 mile range

FCV: Fuel cell vehicle

FP: Fuel cell plugin
Summary and Work in Progress

• COCHIN 1.0
  – LDV-only model mimics consumer choice behavior similar to MA$^{3}$T model
  – Demand heterogeneity, disutility costs and random error distribution added as ‘costs’ to introduce nested-logit structure
  – Results can be reproduced for various scenarios
  – Model approach itself has a broad application—can be applied to any region, any sector (provided we have the data)

• COCHIN 2.0
  – Improves limitations of MA$^{3}$T—multiple levels of public recharging infrastructure (for example, co-existence of Level II and fast charging), better representation of spatiality
  – Incorporates endogeneity on station availability, risk premium and model diversity calculations
  – Need to perform sensitivity analysis and generate policy scenarios

• Currently COCHIN methodology is being integrated in the full CA-TIMES model
  – Policy analysis such as carbon cap, infrastructure investment, vehicle subsidies, etc.
Working paper on the economic theory behind COCHIN-TIMES can be found at this link: http://gsm.ucdavis.edu/faculty/david-s-bunch under “Research Articles”.

QUESTIONS?

Email: kramea@ucdavis.edu
ADDITIONAL SLIDES
Disutility Cost Components

- Model Availability Cost
- Risk Premium
- Refueling Inconvenience Cost
- Home Recharging Cost
- Towing Cost
- Range Anxiety Cost

Urban
Early Adopter
Moderate driver

Rural
Late Majority
Frequent driver

\( \text{$/vehicle} \)
Has access to both home and work recharging

Cost Components: Late Majority, High Annual VMT

![Graphs showing cost components over years for different vehicle types: Plugin 10-mile Range, Fuel Cell Vehicle, EV 100-mile Range, Gasoline, Diesel, Gasoline Hybrid. Each graph contains bars representing different cost components: Vehicle Cost, Fuel Cost, Range Anxiety Cost, Refueling Inconvenience Cost, Risk Premium, Electricity Cost, Model Availability Cost, Total Cost.]

UC Davis Institute of Transportation Studies
Consistency between TIMES and MA$^3$T

• Household VMT is essentially taken as a “given”, it is not part of the choice process
• The only thing that differentiates competing vehicle technologies from one another is the “negative utility” associated with their costs
• Both TIMES and MA$^3$T models view the consumer’s planning horizon “as if” the vehicle were purchased new and driven for the entire life of the vehicle (i.e., there is no explicit modeling of the used vehicle market)
• In both approaches, the vehicle is (generally) assumed to have a technical lifetime ($L$ years)
• Both models are “essentially” based on cost minimization
• The approaches recognize two basic types of costs: a fixed costs based on acquisition of the vehicle, and variable costs based on distance traveled
Share of Cars and Trucks: MA3T and COCHIN (20 clones)
Illustrative infrastructure scenario:

- Public recharging reaches 35,000 stations by 2025.
- Hydrogen infrastructure reaches 3000 stations by 2035
- Workplace recharging reaches 18% population in 2050 (ref. case: 5%)
National Reference Case Infrastructure Growth Curves

- All public and workplace recharging stations are LEVEL II stations (6kW power)
- Each public recharging station is assumed to have an average of 3 recharge points
Light-Duty Car Vehicle Prices

$/Vehicle

- Gasoline
- Diesel
- G.Hybrid
- D.Hybrid
- PHEV 10
- PHEV 20
- PHEV 40
- FC HEV Car
- FC P20 Car
- EV100 Car