**Household Vehicle Choice through an Adoption Perspective**

A Theoretical & Simulation-Based Examination

**Motivation**

- Why look at vehicle ownership, vehicle choice or usage behavior?
  - Forecast vehicle sales
  - Provide guidance for policy planning
    - Policy incentives
    - Taxing
    - Public transportation
  - Predict vehicle/gasoline usage
    - Environmental issues
    - Energy consumption

**Objectives**

- **Vehicle/Mode Choice**
  - Disaggregate ➔ Adoption
  - Aggregate ➔ Diffusion
- **Vehicle Usage**
  - Fuel consumption

**Recent reviews:**

- De Jong et al. (2007)
- Potoglou and Kanaroglou (2008)
- De Jong and Kitamura (2009)
  - Aggregate vs disaggregate
  - Dynamic vs static
  - Data requirements
**Past Research in Technology Adoption and Diffusion**

- **Aggregate Level**
  - Diffusion of technology
  - S-shaped diffusion curve (Rogers 1962, Griliches 1957)
    - Early adoption
    - Takeoff
    - Saturation
    - Decline

- **Imitation Model or Epidemic Model**
  - Innovators vs imitators
  - Role of communication
  - Limitations: homogeneity and lack of theoretical linkages
    - Mansfield (1961), Bass (1969 and 1980) and Mahajan et al. (1990)
    - Ingram and Liu (1999) and Darby and Gately (1999)
  - Threshold Model

- **Threshold Model**
  - Theoretical basis: micro-level behavior
  - Sources of heterogeneity
  - Technology diffusion through dynamic processes
  - Find critical threshold of adoption

- **Disaggregate Level**
  - Vehicle holding model
  - Vehicle transaction model
  - Mannerling and Winston (1985)
  - Train (1986) and Hensher et al. (1992)
  - indirect utility function
  - Limitations:
    - Reliance on revealed preference data
    - Problematic stated preference data
Our Approach – Theoretical Model

- Disaggregate Level (Adoption)
  - Microeconomic basis:
    - Indirect utility function
    - Household utility maximization
- Aggregate Level (Diffusion)
  - Heterogeneity in population:
    - Household income levels
    - Household structure
    - Comfort / quality levels
    - Environmental awareness factor

Household utility $U(x_j, z)$
- Miles traveled ($x_j$)
- Composite good ($z$)
- Utility-maximization choice:
  - Jointly optimize
    - Miles traveled on vehicle $j$ ($x_j$)
    - Vehicle type ($j$) where $j \in \{1, 2, \ldots, J\}$

Utility Maximization – Miles ($x_j$)

$$\max_{x_j} U(x_j, z)$$

**FOC:**
$$\frac{\partial U}{\partial (x_j)} + \frac{\partial U}{\partial (z)} [-e_j] = 0$$

**SOC:**
$$\frac{\partial^2 U}{\partial (x_j^2)} + \frac{\partial^2 U}{\partial (z) \partial (x_j)} [-e_j] < 0$$

Comparative statics:
$$\frac{dx_j}{de_j} < 0 \quad \frac{dx_j}{dI} > 0 \quad \frac{dx_j}{dF_j} < 0$$

Indirect Utility Function

$$V_j \equiv \max_{x_j} U(x_j, I - F_j - e_j x_j)$$

- $I$: household income
- $F_j$: annual fixed cost of owning vehicle type $j$
- $e_j$: variable cost per mile traveled

- $V_j$ is a function of income, household characteristics and vehicle specific characteristics

Indirect Utility Illustrated

![Utility Frontier](image)

Aggregation of vehicle demand

$$S_j(t) = T \int_{I^j_c}^{I^j_t+1} g_k(I) dI$$

$$= T[G_t(I^j_{c+1}) - G_t(I^j_c)]$$

where

- $S_j(t)$ is the desired stock of vehicle type $j$ at time $t$
- $g_k(I)$ is income distribution of population at time $t$
- $G_t(I) = \int_0^I g_k(I) dI$ is cumulative income distribution of population at time $t$
- $T$ is the total population size
Aggregate flow demand at time $t$:

$$Q_j(t) = \frac{\partial S(t)}{\partial t} = S(t)$$

- Actual demand is current desired stock minus previously accumulated stock
- $Q_j(t)$ represents the percentage of adopters of vehicle type $j$ relative to previous period

What determines how many vehicles of each type are demanded in each period?

- Population effect $\left( S(t)^{\frac{1}{2}} \right)$
- Income distribution effect $\left( \frac{\partial G_j(I_t^{t+1})}{\partial t} - \frac{\partial G_j(I_t^t)}{\partial t} \right)$
- Variable cost effect ($e_j$)
- Fixed cost effect ($F_j$)

Our Approach – Model Extensions

- Started with:
  $$V_j \equiv \max_{x_j} U(x_j, I - F_j - e_j x_j)$$
- Extensions:
  - Comfort / quality levels $q_j$
  - Household structures $q_{jh}$
  - Environmental awareness factor $\alpha_j$

  Final Specification
  $$V_j \equiv \max_{x_j} U(x_j, q_{jh} x_j, \alpha_j, I - F_j - e_j x_j)$$

Simulation Calibration Data
- Vehicle types
  - New Vehicles (compact, mid to full-size, SUV/minivan, hybrid)
  - Used Vehicles (small, large)
- Vehicle characteristics
  - Annual fixed cost (Edmunds.com)
  - Variable cost (gasoline price: EIA; fuel efficiency: EPA)
  - Comfort/quality parameter (Espey & Nair 2005)
- Household characteristics
  - Income distribution (Current Population Survey from U.S. Census Bureau)
  - Household types (with children, without children or senior households)
Our Approach – Simulation

Simulation Calibration Data

Environmental awareness
1. Without environmental awareness
2. Function of gas prices \( \alpha_j = \frac{\theta_j (1)}{\theta_j (T-1)} \)
3. Surveyed environmental awareness
   (“how much do you personally worry about the ‘greenhouse effect’ or global warming?” Gallup Annual Poll from Nisbet and Myers 2007)

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<th>Year</th>
<th>Very much (%)</th>
<th>Fair amount (%)</th>
<th>Only a little (%)</th>
<th>Not at all (%)</th>
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<td>2007</td>
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\[
y = 1.1123x - 0.0065 \\
R^2 = 0.949\]

Simulated Values vs. Observed Values

Our Approach – Simulation

No proxy for environmental awareness

Gas price proxy for environmental awareness

Survey proxy for environmental awareness
Our Approach – Simulation
Survey proxy for environmental awareness

Our Approach – Simulation
Sample Simulated Scenarios
- Energy price fluctuations
- Hybrid vehicle price decreases due to learning-by-doing
- Government policy changes
  - Tax incentives for hybrid vehicles
  - Gasoline tax
- Income distribution shifts
- Shape of income distribution changes

Our Approach – Simulation
Energy price change: 1% increase per period

Our Approach – Simulation
Energy price change: 3% increase per period

Our Approach – Simulation
Energy price change: 5% increase per period

Our Approach – Simulation
Energy price change: 10% increase per period
Some observations:
- Adoption of different vehicle technologies due to Variable Cost Effect
- Fewer SUV or large vehicle purchases with small energy price increases, but more with larger price increases
- Large energy price increase ➔ household optimize with less miles traveled
- Elasticity of demand for gas (miles traveled): -0.56 to -0.77
- Marginal utility of comfort/quality becomes more significant in adoption decision as variable cost increases beyond a certain level

Main determinants of adoption:
- Fixed cost of technology
  - Learning-by-doing
  - Policy incentives
- Income distribution shifts / shape changes
- Other determinants of adoption:
  - Variable cost
  - Changes in environmental awareness

Some characteristics:
- High economic growth ➔ income growth
- Rising income inequality ➔ change in shape of income distribution
- Low environmental awareness
- Population growth
- Infrastructure differences
- Public transportation

Energy price increase 5% per period
- Dramatic income distribution shifts (from last slide)
Concluding remarks

- What we've done so far...
  - Theoretical model of adoption & diffusion of vehicles
  - Simulation model based on micro theory
  - Case studies based on calibrated simulations

- Some future research directions...
  - Calibration of simulation model for developing economies taking into account non-motorized methods of travel (by foot ➔ two-wheeled ➔ four-wheeled)
  - Random variable of preferences for comfort or environmental awareness
  - Allocation of decision power within the household