Modeling a System of Feebates

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- Background on Electric Vehicles, Urban Air Pollution and Feebates
- Could We Control a Feebate Program?
Electric Cars: Are They The Future?

Cover Story from May 1994
Key Questions

Will they Work?

Who Will Buy Them?
Gas-sipping hybrids are joining the first-class set. The Lexus GS 450h uses both a gas engine and an electric motor like the Prius, its pioneering sibling from Toyota. But, unlike the Prius, the luxury sedan goes from zero to 60 mph in under six seconds. (Chip East/Reuters)
“It is handsome and elegant in its lines and conforms in design to the modern horse carriages ... Boiler is absolutely non-explosive and water-feed automatic.”
Ohio Electric Car Company
The Ohio Brougham “41”

Price: $2,900
Dodge Brothers Touring Car

Price: $785 includes windshield, electric self starter, speedometer …
Electric Cabs in New York

This millionaire’s sleek electric cab caused a stir in 1912, even among blasé New Yorkers.

This millionaire’s sleek electric cab caused a stir in 1912
Most Green

GM EV-1
Emissions: ZEV
Highway Efficiency: 4 miles/kwh
Top Score

Honda Civic GX CNG
Emissions: ULEV
Highway Efficiency: 43 mpg (equivalent)
Tied for Second
Urban Air Pollution

\[
\text{Hydro Carbons (HC)} + \\
\text{Nitrogen Oxides (NO}_x\text{)} + \\
\text{Sunshine} = \\
\text{Ozone (O}_3\text{) or Smog}
\]
Urban Air Pollution in the USA

• Highly publicized in the 1960s
• Clean Air Act of 1970 and 1975, set ambient standards to protect human health
• 1988: over 300 areas in the US earned “Non-Attainment” status for Ozone
• 1990: Roughly half of all Americans live in areas that exceed the Ozone Standard
Compare a CV with an EV
(Annual Emissions)

<table>
<thead>
<tr>
<th>CV</th>
<th>EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>115 lbs of HC</td>
<td>Zero</td>
</tr>
<tr>
<td>133 lbs of NO\textsubscript{x}</td>
<td>Zero</td>
</tr>
<tr>
<td>1,346 lbs of CO</td>
<td>Zero</td>
</tr>
</tbody>
</table>
How Valuable is the EV?

- Avoids 115 lbs of HC @ $8/lb = $920
- Avoids 133 lbs of NOx @$12/lb = $1,596
- Avoids 1,346 lbs of CO @$5/lb = $6,730
- Total Value to Air Basin around $9,000
You Forgot the Power Plant to Charge the EV Batteries!

- Assume gas-fired generator in the Basin
  - When is this used?
- Adds around 20 pounds of NO\textsubscript{x} to the EV
- Adds $300/vehicle in cost to the Basin

- Net Value of the EV = $9,000 - $300
What About the Infrastructure to Support a Conventional Vehicle?

• Refineries & Gas Stations
  – Extra HC and NOx adds $1,300 in cost
• Now, net value of an EV is
• $9,000 - $300 +$1,300 = $10,000
Let’s Try a $10K Feebate

- Fee Imposed on Sale of CV = $2K
- Rebate for Sale of an EV = $8K
- Suppose 8 out of 10 buy a CV:
  - Collect $16K
- The other 2 buy a EV:
  - Pay out $16K
- A Feebate program could be self-financing
Suppose We Were Wrong about 80% Market Share

• Suppose only 7 out of 10 buy a CV
• We would collect
  – 7 x $2K = $14K in fees
• And pay out:
  – 3 x $8K = $24K in rebates
• A Feebate program could be a Disaster!
Controllability of a Feebate Program: well suited for system dynamics

System Dynamics is that branch of control theory which deals with socio-economic systems and that branch of management science which deals with problems of controllability

Geoffrey Coyle
Management System Dynamics
Stella’s Array Editor
Use Stella’s Array Editor

• Name 5 Elements:
  – Conventional Vehicle (CV)
  – Electric vehicle (EV)
  – Hybrid electric (HEV)
  – Compressed Natural Gas (CNG)
  – Alcohol fueled (ethanol; AL)

• Dimension Name = V

• With Vensim (use “Subscripts” Control in the Professional Version)
Calculating Total Cars in Use:

Sum Across the Elements in the Array

\[
\text{total\_cars\_in\_use} = \text{ARRAYSUM}(\text{cars}[*])
\]

Equation for Sales[V]

INFLOWS:

\[
\text{sales[V]} = \text{total\_sales} * \text{market\_shares[V]}
\]
The Vensim PL version does not support subscripts, so we can create a separate set of stocks for each vehicle type.
Determining Market Share

• How would we determine market share of vehicles?
  – Go out and ask people!
    • Survey – ‘Stated Preference Survey’

• How do we analyze?

• An old friend…
  – MULTINOMIAL LOGISTIC REGRESSION!
  – Choice of a vehicle type is an outcome
  – PLAN 721 comes full CIRCLE! WOOHOOO!
Determining Market Share

- **Survey**
  - University of Southern California:
    - Stated Preferences of 700 respondents from Southern California in a mail-back survey completed in 1991
    - Study of South Coast Air Quality Management District (SCAQMD)

- **Factors influencing purchase choice**
  - Price
  - Fuel Cost
  - Range
  - Emissions
  - Horsepower
  - Fuel Availability
Calculation of Market Shares

• The Market Share \( (MS) \) of each vehicle type \( (v) \) is given as:

\[
MS_v = \frac{e^{U_v}}{\sum_{i=1}^{5} e^{U_i}}
\]

• \( U_v \) = Utility of each vehicle type \( v \)
• \( U_v = b1 \times \text{UtilityFactor}1 + b2 \times \text{UtilityFactor}2 \ldots \) etc.
Equation for Purchase Price

\[ \text{purchase\_price}[V] = \text{base\_price}[V] + \text{fee}[V] - \text{rebate}[V] \]

Base Prices are constants

- \( \text{base\_price}[CV] = 15000 \)
- \( \text{base\_price}[EV] = 25000 \)
- \( \text{base\_price}[HEV] = 27000 \)
- \( \text{base\_price}[CNG] = 20000 \)
- \( \text{base\_price}[AL] = 18000 \)
“Utility” from Price, Fuel Cost...

- $U1[M] = \text{coef}_1 \times \text{purchase\_price}[M]/1000$
- $U2[M] = \text{coef}_2 \times \text{fuel\_cost}[M]$
- $U3[M] = \text{coef}_3A \times (\text{range}[M]/100) + \text{coef}_3B \times ((\text{range}[M]/100)^2)$
- $U4[M] = \text{coef}_4A \times \text{emission\_fr}[M] + \text{coef}_4B \times \text{emission\_fr}[M]^2$
- $U5[M] = \text{coef}_5A \times \text{fuel\_availability}[M] + \text{coef}_5B \times \text{fuel\_availability}[M]^2$
- $U6[M] = \text{coef}_6 \times \text{horse\_power}[M]$

Coefficient on Price

- $\text{coef}_1 = -0.143$
Say CV and EV are the only vehicles.

The MLR model would give CV 90% of sales and the EV 10% of sales.
EV Market Share Jumps to 26% if Price Cut from $25K to $17K

<table>
<thead>
<tr>
<th></th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
<th>F</th>
<th>G</th>
<th>H</th>
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<tbody>
<tr>
<td>16</td>
<td>$U (CV) = e^U$</td>
<td></td>
<td></td>
<td></td>
<td>0.86391</td>
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<td>17</td>
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<td>2.372419</td>
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<tr>
<td>19</td>
<td><strong>Vehicle Attributes</strong></td>
<td><strong>same coefficients</strong></td>
<td><strong>EV attributes</strong></td>
<td><strong>EV &quot;Points&quot;</strong></td>
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<td>20</td>
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<td>(see p. 261)</td>
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<td>21</td>
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<tr>
<td>22</td>
<td>price in thousands of $</td>
<td>-0.143</td>
<td>17</td>
<td>U1(EV)=</td>
<td>-2.431</td>
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<tr>
<td>23</td>
<td>fuel cost in cents/mile</td>
<td>-0.175</td>
<td>5.3</td>
<td>U2(EV)=</td>
<td>-0.9275</td>
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<td>24</td>
<td>range in hundreds of miles</td>
<td>2.060</td>
<td>1</td>
<td>U3(EV)=</td>
<td>1.757</td>
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<tr>
<td>25</td>
<td>range squared</td>
<td>-0.303</td>
<td>1</td>
<td>U4(EV)=</td>
<td>0</td>
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<td>26</td>
<td>emissions fraction</td>
<td>-3.080</td>
<td>0</td>
<td>U5(EV)=</td>
<td>0.881</td>
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<tr>
<td>27</td>
<td>emission fraction squared</td>
<td>1.530</td>
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<td>U6(EV)=</td>
<td>0.5174</td>
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<td>28</td>
<td>fuel availability</td>
<td>2.240</td>
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<td>29</td>
<td>fuel availability squared</td>
<td>-0.956</td>
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<td>U5(EV)=</td>
<td>0.881</td>
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<td>30</td>
<td>horsepower</td>
<td>0.00796</td>
<td>65</td>
<td>U6(EV)=</td>
<td>0.5174</td>
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<tr>
<td>31</td>
<td>$U (EV)= e^U$</td>
<td></td>
<td></td>
<td></td>
<td>-0.2031</td>
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<td>0.816197</td>
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<td>33</td>
<td>ignore the other three types of vehicles for this worksheet</td>
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<tr>
<td>34</td>
<td>the denominator in the market share equation is Sum e^U:</td>
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<td></td>
<td>3.188615</td>
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<td>35</td>
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<tr>
<td>36</td>
<td>CV Market Share = 2.372/2.632</td>
<td>74%</td>
<td></td>
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<tr>
<td>37</td>
<td>EV Market Share = .260/2.632</td>
<td>26%</td>
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</table>
Is the Discrete Choice Model Plausible?

• The 90% for CV and 10% for EV is reasonable
• The Model Guarantees that the Sum of Market Shares = 100%
• Equivalency Tests: Cut EV price by $8K to see what we get. Then Increase EV Range by 100 miles to see what we get.
Is An Extra 100 Miles of Range Really Worth an Extra $8,000?

• Yes!
  – Empirical evidence from Stated Preferences of 700 respondents from Southern California in a mail-back survey completed in 1991
What about the Fund? Add Cash Flow

- fees collected
- rebate
- fees collected
- rebate
- sales
- interest earnings
- interest rate
Illustrative Simulations

- **Do Nothing**
  - Get approx. 1.5 million EVs
- **$5K/$5K “Balanced Approach”**
  - Todd gets fired
- **$5K/$5K then Cancel Program:**
  - Todd also gets fired
- **$2K/$8K, Lower the Rebate Over Time:**
  - 2.9 million EVs
Example Conclusions

• Yes, Feebates could be controlled, but the State must:
  – Give me the freedom to change the feebate each year
  – Don’t expect me to hold to $10K
  – Expect major swings in the balance in the fund
Are These Conclusions Reliable?

- The coefficients may not be accurate.
- The coefficients might change.
- The vehicle attributes will surely change.
- The student may have known what to do from lots of practice.
Expanding the Feebate Model

• How could we expand this model?
  – EV Adopters Educate their Friends
    • Word of Mouth Loop
  – Driving Privileges in Santiago, Chile
    • Modify choice based on government driving restrictions
  – Scrappage payments for old cars combined with Feebates for new cars
  – Taxbates