Green Stimulus: A Dynamic Discrete Analysis of Vehicle Scrappage Programs

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1. Motivation and Objectives

Green Stimulus

- Stimulus programs with substantial green components have been adopted in many countries during this economic crisis.

- Green stimulus (Strand and Toman 2010): policies and measures to stimulate short-run economic activity while at the same time preserving, protecting and enhancing environmental and natural resource quality both near-term and longer-term.

- Strand and Toman (2010) identified stimulus packages in major developed (such as U.S., EU, Japan, Canada) and developing countries (such as China and India). Out of US$2.8 trillion, about US$435 billion (about 15 percent) classified as green stimulus.
1. Motivation and Objectives

Cash for Clunkers

- Examples: energy efficiency improvement/retrofit in buildings, renewable energy, battery R&D, Cash for Clunkers


- Similar programs existed in many other countries: Germany, UK, France, Italy, Spain, China.

Environmental benefits are viewed as co-benefits, rather than at the expense of the stimulus objective.

Tinbergen’s rule (1952): the number of policy instruments should be no less than the number of policy goals

How would the pursuit of the environmental goal (positively or negatively or neutrally) impact the stimulus objective?

We develop and estimate a dynamic discrete choice model of vehicle ownership to examine the tension between the two goals in the context of CFC.
1. Motivation and Objectives

Cash for Clunkers

- Total spending: $2.85 billion, 0.68 million eligible transactions
- CFC Eligibility Rules
  1. Trade-in vehicles less than 18 MPG, newer than 25 years, insured, registered to the same owner at least 1 year prior to trade-in;
  2. MPG of new vehicles must be higher than 22, 18, 15 for cars, category 1, and 2 trucks;
  3. Two levels of rebate amount, $3,500 and $4,500 depending on the MPG difference and the types of new vehicles;
1. Motivation and Objectives

Monthly Sales 01/2007-12/2009
1. Motivation and Objectives

Literature on CFC

- Christopher Knittel (2009) back-of-the-envelop analysis of the benefit-cost analysis for the environmental goal ($207-$365 dollars per ton of CO$_2$ reduction)
- Mian and Sufi (2010), Copeland and Kahn (2011) examine the stimulus effect
- Li, Linn and Spiller (2010) look at both stimulus and environmental impacts
- Studies on CFC in other countries: Jimenez, Perdiguero and Garcia (2011), Huse (2011)
- None of the studies examine the interaction/tradeoff between the two goals
2. Model
Dynamic Discrete Choice Model

- Build upon Adda and Cooper (2000): evaluate short-term and long-term effects on sales and government revenue of vehicle scrappage programs in late 90’s in France

- Our assumptions:
  - Vehicle models differ by age, type and fuel efficiency
  - At most one vehicle per household in a given year
  - No second-hand market for vehicles
  - New vehicle purchased out of current income

- Model will be extended.
Household Choices

- Two types of households: owners and non-owners.

- Choices of a vehicle-owner: \( J + 2 \) options at the beginning of each period
  1. Keep the current vehicle
  2. Scrap the current vehicle and purchase a new vehicle \( \Omega_j, j = 1, 2, \ldots J \)
  3. Scrap the current vehicle and not purchase a new vehicle, \( j = 0 \)

- Choice of a non-owner: \( J + 1 \) options
  1. Continue to be a non-owner, \( j = 0 \)
  2. Purchase a new vehicle \( \Omega_j, j = 1, 2, \ldots J \)
State Variables

- **Aggregate state variables** ($S$)
  - Gasoline price ($O$)
  - Aggregate income ($Y$)
  - Average price of new vehicles ($P$)
  - Aggregate taste shock ($\xi$)

- **Household state variables** ($s$)
  - Vehicle attributes: age ($a$), other attributes ($\Omega = \{\text{type}(g), \text{fuel efficiency}(x)\}$)
  - Idiosyncratic income deviation ($y$),
  - Vector of choice-specific idiosyncratic taste shocks ($z$)
2. Model

Single-Period Utility Function

\[
U(a, \Omega_j, c, z_j) = u(a, \Omega_j, c) + z_j
\]

\[
u(a, \Omega_j, c) = \begin{cases} 
\phi_0, & \text{If } j \neq 0 \\
\phi_0 + \phi_1 \log(a + 1) + \phi_2 \log x + \xi \frac{c^{1-\gamma}}{1-\gamma}, & \text{If } j = 0
\end{cases}
\]

- \( c \) is non-vehicle consumption good
- \( \xi \) is i.i.d. common shock affecting intratemporal and intertemporal choice between the flow of the vehicle service and the consumption good
- \( i = 0, 1, \ldots, J \) denotes previous choice, \( j \) denotes current choice

\[
c = \begin{cases} 
\begin{align*}
c^k_i &= Y + y - fc_j \\
c^r_{ij} &= Y + y - p_j - fc_j + \pi_{ij} \\
c^r_{i0} &= Y + y + \pi_i \\
c^n_{00} &= Y + y \\
c^n_{0j} &= Y + y - p_j - fc_j
\end{align*}
\end{cases}
\]

- If keep the vehicle
- If \( i \neq j \) and \( i, j \neq 0 \), replace with new
- If \( i \neq j \) and \( j = 0 \), replace with no
- Non-owner before and now
- Non-owner to owner
Vehicle Owner’s Problem

- A vehicle owner has \( J + 2 \) choices (keep, or replace with \( 0, 1, \ldots, J \))
- \( \alpha_k \) captures utility from keeping the status quo

Value function: \( V(y, a, \Omega_i, z, S) \)

\[
V(y, a, \Omega_i, z, S) = \max \left\{ V^k_i (y, a, \Omega_i, S) + \alpha_k + z_k, \max_{0 \leq j \leq J} \{ V^r_{ij} (y, a, \Omega_i, S) + z_j \} \right\}
\]

Keeping the vehicle: \( V^k_i (y, a, \Omega_i, S) \)

\[
V^k_i (y, a, \Omega_i, S) = u(a, \Omega_i, c^k_i) + \beta E(s', S' | s, S) V(y', a + 1, \Omega_i, z', S')
\]

Replacing the vehicle: \( V^r_{ij} (y, a, \Omega_i, S) \)

\[
V^r_{ij} (y, a, \Omega_i, S) = \begin{cases} 
  u(1, \Omega_j, c^r_{ij}) + \beta E(s', S' | s, S) V(y', 2, \Omega_j, z', S') & j \neq 0 \\
  u(0, \Omega_0, c^r_{i0}) + \beta E'(s', S' | s, S) V^n (y', z', S') & j = 0 
\end{cases}
\]
Non-owner’s Problem

- A non-owner has \( J + 1 \) choices (0, 1, ..., \( J \))
- \( \alpha_n \) captures utility from keeping the status quo (no vehicle)

\[
V^n(y, z, S) = \max_{0 \leq j \leq J} \{ V^n_{0j}(y, S) + \alpha_n \mathbf{1}(j = 0) + z_j \}
\]

\[
V^n_{0j}(y, S) = \begin{cases} 
  u(1, \Omega_j, c^n_{0j}) + \beta E(z', S' | z, S) V(y', 2, \Omega_j, z', S') & j \neq 0 \\
  u^n(c^n_{00}) + \beta E(z', S' | z, S) V^n(y', z', S') & j = 0 
\end{cases}
\]
Choice Probabilities of Owners

Probability of keeping: \(\mu^k_i (y, a, \Omega_i, S)\)

\[
\frac{\exp \left[ V^k_i (y, a, \Omega_i, S) + \alpha_k \right]}{\exp \left[ V^k_i (y, a, \Omega_i, S) + \alpha_k \right] + \sum_{j=0}^{J} \exp \left[ V^r_{ij} (y, a, \Omega_i, S) \right]}
\]

Probability of replacing: \(\mu^r_{ij} (y, a, \Omega_i, S)\)

\[
\frac{\exp \left[ V^r_{ij} (y, a, \Omega_i, S) \right]}{\exp \left[ V^k_{ii} (y, a, \Omega_i, S) + \alpha_k \right] + \sum_{j=0}^{J} \exp \left[ V^r_{ij} (y, a, \Omega_i, S) \right]}
\]
Choice Probabilities of Non-owners

Probability of continuing: \( \mu_{00}^n (y, S) \)

\[
= \frac{\exp \left[ V_{00}^n (y, S) + \alpha_n \right]}{\exp \left[ V_{00}^n (y, S) + \alpha_n \right] + \sum_{j=1}^J \exp \left[ V_{0j}^n (y, S) \right]}
\]

Probability of buying: \( \mu_{0j}^n (y, S) \)

\[
= \frac{\exp \left[ V_{0j}^n (y, S) \right]}{\exp \left[ V_{00}^n (y, S) + \alpha_n \right] + \sum_{j=1}^J \exp \left[ V_{0j}^n (y, S) \right]}
\]
Transition Dynamics of Aggregate State Variables

\[
\begin{bmatrix}
Y_t \\
O_t \\
P_t \\
\xi_t
\end{bmatrix}
= \begin{bmatrix}
\mu_Y \\
\mu_o \\
\mu_p \\
\mu_\xi
\end{bmatrix}
+ \begin{bmatrix}
\rho_{yy} & \rho_{yo} & \rho_{yp} \\
\rho_{oy} & \rho_{oo} & \rho_{op} \\
\rho_{py} & \rho_{po} & \rho_{pp}
\end{bmatrix}
\begin{bmatrix}
Y_{t-1} \\
O_{t-1} \\
P_{t-1}
\end{bmatrix}
+ \begin{bmatrix}
e_Yt \\
e_ot \\
e_pt \\
e_{\xi t}
\end{bmatrix}
\]

- \(Y\): income, \(O\): gas price, \(P\): vehicle price, \(\xi\): aggregate taste shock

\[
\Omega = \begin{bmatrix}
\omega_{yy} & \omega_{yo} & \omega_{yp} & 0 \\
\omega_{oy} & \omega_{oo} & \omega_{op} & 0 \\
\omega_{py} & \omega_{po} & \omega_{pp} & 0 \\
0 & 0 & 0 & \omega_{\xi \xi}
\end{bmatrix}
\]
3. Data
Data

- Aggregate state variables: average household income, vehicle prices, and gasoline prices from 1967-2010
- Vehicle registration data: total number of vehicles by vintage-model in 2000 and 2005
- Sales of new vehicles by model from 2001 to 2005
- Match them with EPA fuel economy database to get vehicle fuel efficiency
Income, Vehicle Price, Gas Price, Sales

- Average Household Income ($10,000)
- Average Vehicle Price ($10,000)
- Gasoline Price ($)
- New vehicle sales (10 mil.)
3. Data

Number of Vehicles by Age

![Graph showing the number of vehicles by age for the years 2000 and 2005. The graph indicates a decrease in the number of vehicles with age, with a sharper decline in the year 2005 compared to 2000.](image-url)
Average MPG by Age

The graph shows the average MPG by vehicle age for two years: 2000 and 2005. The data indicates a significant increase in average MPG over the years, particularly between 2000 and 2005. The graph uses blue and green lines to differentiate between the two years, with blue representing Year 2000 and green representing Year 2005.
Average Scrappage Rate by Type and Age
### Scrappage Rate Regression

<table>
<thead>
<tr>
<th>Dependent var.: log(scrappage rate)</th>
<th>Est.</th>
<th>S.E.</th>
<th>Est.</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>GPM (gallon per mile)</td>
<td>-13.790</td>
<td>0.477</td>
<td>-9.553</td>
<td>0.500</td>
</tr>
<tr>
<td>Age</td>
<td>0.101</td>
<td>0.001</td>
<td>0.101</td>
<td>0.001</td>
</tr>
<tr>
<td>Cars</td>
<td>-2.027</td>
<td>0.027</td>
<td>-2.431</td>
<td>0.056</td>
</tr>
<tr>
<td>Vans</td>
<td>-1.603</td>
<td>0.034</td>
<td>-2.176</td>
<td>0.062</td>
</tr>
<tr>
<td>SUVs</td>
<td>-1.729</td>
<td>0.035</td>
<td>-2.249</td>
<td>0.063</td>
</tr>
<tr>
<td>Pickup trucks</td>
<td>-1.662</td>
<td>0.036</td>
<td>-2.288</td>
<td>0.064</td>
</tr>
</tbody>
</table>

Make fixed effects: No, Yes
4. Estimation
Parameters in VAR(1)

- Estimate VAR parameters for income, gas price, and vehicle price outside of the dynamic model

<table>
<thead>
<tr>
<th></th>
<th></th>
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<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>( \mu_y )</td>
<td>1.674</td>
<td>0.963</td>
<td>( \mu_o )</td>
<td>0.589</td>
<td>1.638</td>
<td>( \mu_p )</td>
<td>1.034</td>
<td>0.458</td>
</tr>
<tr>
<td>( \rho_{yy} )</td>
<td>0.588</td>
<td>0.111</td>
<td>( \rho_{oy} )</td>
<td>0.301</td>
<td>0.188</td>
<td>( \rho_{py} )</td>
<td>-0.138</td>
<td>0.053</td>
</tr>
<tr>
<td>( \rho_{yo} )</td>
<td>-0.098</td>
<td>0.068</td>
<td>( \rho_{oo} )</td>
<td>0.840</td>
<td>0.116</td>
<td>( \rho_{po} )</td>
<td>-0.016</td>
<td>0.032</td>
</tr>
<tr>
<td>( \rho_{yp} )</td>
<td>0.445</td>
<td>0.233</td>
<td>( \rho_{op} )</td>
<td>-0.998</td>
<td>0.396</td>
<td>( \rho_{pp} )</td>
<td>0.858</td>
<td>0.111</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>( \omega )</th>
<th>( Y )</th>
<th>( O )</th>
<th>( P )</th>
</tr>
</thead>
<tbody>
<tr>
<td>( Y )</td>
<td>0.0131</td>
<td></td>
<td></td>
</tr>
<tr>
<td>( O )</td>
<td>-0.0066</td>
<td>0.0378</td>
<td></td>
</tr>
<tr>
<td>( P )</td>
<td>0.0023</td>
<td>-0.0068</td>
<td>0.0030</td>
</tr>
</tbody>
</table>
Estimation: NLS

- Need to recover preference parameters and distribution of $\xi$
- For a given parameter set, the dynamic model can simulate forward the cross-sectional distribution and generate sales of new vehicles.

$$\min_{\theta} J(\theta) = \sum_{i=1}^{l_1} \left\{ q_{i0} \left[ \prod_{t=1}^{5} r_{it} \right] - q_{i5} \right\}^2 + \sum_{i=1}^{l_t} \sum_{t=1}^{5} \left\{ \tilde{q}_{it} - q_{it} \right\}^2$$

- $q_{i0}$: number of vehicles of model $i$ in 2000; $q_{i5}$: for 2005
- $r_{it}$ is the survival rate of vehicle $i$ in year $t$
- $\tilde{q}_{it}$: predicted sales of new model $i$ in year $t$ and $q_{it}$: observed sales of model $i$. 
# Parameter Estimates

<table>
<thead>
<tr>
<th>Variables</th>
<th>Est.</th>
<th>S.E.</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\gamma$ (risk aversion parameter)</td>
<td>3.436</td>
<td>0.703</td>
</tr>
<tr>
<td>$\phi_{0,\text{car}}$ (intercept for cars)</td>
<td>7.671</td>
<td>2.507</td>
</tr>
<tr>
<td>$\phi_{1,\text{car}}$ (log(age) for cars)</td>
<td>-0.068</td>
<td>0.014</td>
</tr>
<tr>
<td>$\phi_{2,\text{car}}$ (log(GPM) for cars)</td>
<td>0.892</td>
<td>0.275</td>
</tr>
<tr>
<td>$\phi_{0,\text{truck}}$ (intercept for trucks)</td>
<td>7.417</td>
<td>2.545</td>
</tr>
<tr>
<td>$\phi_{1,\text{truck}}$ (log(age) for trucks)</td>
<td>-0.085</td>
<td>0.014</td>
</tr>
<tr>
<td>$\phi_{2,\text{truck}}$ (log(GPM) for trucks)</td>
<td>1.037</td>
<td>0.291</td>
</tr>
<tr>
<td>$\alpha_k$ (status quo for owners)</td>
<td>7.520</td>
<td>3.048</td>
</tr>
<tr>
<td>$\alpha_n$ (status quo for non-owners)</td>
<td>7.081</td>
<td>2.490</td>
</tr>
</tbody>
</table>

| Distribution of aggregate taste shock $\xi$ | |
|---------------------------------------------|-------|-------|
| Mean                                       | 253.779 | 37.901 |
| Std. Dev.                                  | 0.590  | 505.745 |
4. Estimation

Model Fit: Survival Rate by Type

- Vehicle age
- Average cumulative survival rate

- Passenger cars
- Light trucks
- Predictions for cars
- Predictions for light trucks

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4. Estimation

Model Predictions: New Vehicle Purchase Probabilities

- **Aggregate Gasoline Price**
  - Low MPG
  - High MPG

- **Aggregate Household Income**
  - Low MPG
  - High MPG

- **Aggregate Vehicle Price**
  - Low MPG
  - High MPG

- **Aggregate Taste Shock**
  - Low MPG
  - High MPG

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Green Stimulus
5. Policy Simulations
5. Policy Simulations

Road Map

- Examine cost-effectiveness of different policy designs by conducting policy simulation in year 2009

- Because of decision horizon is one year, we cannot replicate the true CFC program. Instead examining a one-year program

- Generate cross-sectional distribution in 2008 based on 2005 data and model parameters

  1. Benchmark: CFC for one year in 2009 (same rules as real policy)
  2. Alternative 1: One-tiered subsidy
  3. Alternative 2: Relax new MPG requirement ($\geq$ old MPG)
  4. Alternative 3: No MPG requirement on new
  5. Alternative 4: Relax the requirement on old (increase max MPG to 22 from 18)
5. Policy Simulations

Policy Impacts of the Benchmark CFC Policy

- New vehicle sales and gasoline consumption by year under benchmark CFC policy relative to the no policy scenario

<table>
<thead>
<tr>
<th>Year</th>
<th>New Vehicle Sales in millions</th>
<th>Gas Consumption in mil gallons</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2015</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2020</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2025</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2030</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph showing new vehicle sales and gasoline consumption under benchmark and no policy scenarios](image-url)
Comparison of Alternative Designs

- For alternative policies, adjust the subsidy level to have the same total spending level as the benchmark policy.
- CO\textsubscript{2} reductions aggregated over 2009-2033. Compare $ per increased sale under different alternatives.

<table>
<thead>
<tr>
<th>Policy Scenarios</th>
<th>Spending ($billion)</th>
<th>CO\textsubscript{2} ($billion)</th>
<th>Eligible Sales (mil.)</th>
<th>Increased Sales (mil.)</th>
<th>$ per vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td>Benchmark</td>
<td>9.85</td>
<td>0.47</td>
<td>2.46</td>
<td>1.34</td>
<td>6,979</td>
</tr>
<tr>
<td>One-tiered subsidy</td>
<td>9.85</td>
<td>0.47</td>
<td>2.49</td>
<td>1.36</td>
<td>6,884</td>
</tr>
<tr>
<td>New MPG $\geq$ Old MPG</td>
<td>9.85</td>
<td>0.35</td>
<td>2.90</td>
<td>1.55</td>
<td>6,134</td>
</tr>
<tr>
<td>No restriction on new</td>
<td>9.85</td>
<td>0.33</td>
<td>2.92</td>
<td>1.56</td>
<td>6,099</td>
</tr>
<tr>
<td>Increase old MPG to 22</td>
<td>9.85</td>
<td>0.04</td>
<td>5.44</td>
<td>1.82</td>
<td>5,398</td>
</tr>
</tbody>
</table>
5. Policy Simulations

Mechanism

- Green arrows: benchmark CFC; Red arrows: alternative 3 (no requirement on new MPG)
Conclusions and Extensions

- Many recent policies (green stimulus) aim to stimulate the economy and improve the environment simultaneously. We examine the tradeoff between the two goals in the context of CFC.

- The design elements for the environmental goal significantly limits the effectiveness of the program: for the same amount of spending, the stimulus effect could be 35% stronger; the net cost per unit of increased sale could be 23% lower, after netting out the environmental benefit from the program.

- In designing stimulus policies, one should bear in mind the principle of efficient economic policy design: Tinbergen’s rule.

- Will extend the baseline model to account for credit constraint and more consumer heterogeneity.