Estimation of Discrete Choice Models with Aggregate Data: An Application to the Adoption of Conservation Tillage

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Outline

• Introduction
• Economic model
• Econometric model
• Application to 2002 and 2004 Iowa data
• Conclusions
Conservation tillage

- Conservation tillage (CT) is any tillage system that leaves at least 30% of crop residue on the soil surface at the time of planting.

- Umbrella term used for:
  - Mulch till (disturbs the entire soil surface)
  - No-till (disturbs only the minimal amount of soil)
    - Strip-till
    - Vertical tillage
    - Fluffing harrows

- CT is known to reduce soil erosion, reduce nutrient runoff, increase soil carbon sequestration, and improve overall soil health.

Conservation tillage adoption costs, Wade et al., trwade@ncat.edu
Costs of the adoption of conservation tillage (CT)

- Farmers adopt CT if
  - Profits from CT exceed those from conventional till plus a premium due to uncertainty (risk aversion, option value or incentive to learn more)
  \[ \pi_{CT} \geq \pi_0 + P \]

- Opportunity cost of adopting CT (subsidy) is the minimum compensation that is needed to entice a farmer to use CT instead of the conventional one
  - The cost is zero for those already using CT
  \[ S = \max \left\{ \pi_0 - \pi_{CT} + P, \ 0 \right\} \]
Econometrics: binary choice model

\[ Y = \begin{cases} 1, & \text{if CT is adopted} \\ 0, & \text{otherwise} \end{cases} \]

\[ \Pr(Y = 1) = \Pr(\pi_{CT} - \pi_0 - P \geq \sigma_\eta \eta) \]

\[ = \Pr(\alpha'w - \pi_0 - \gamma'z \geq \sigma_\eta \eta) = \Pr(\beta'x \geq \eta) \]

Here

\[ \beta' = \begin{pmatrix} \frac{1}{\sigma_\eta} \alpha', & -\frac{1}{\sigma_\eta} \gamma', & -\frac{1}{\sigma_\eta} \end{pmatrix}, \quad x = \begin{pmatrix} w \\ z \\ \pi_0 \end{pmatrix}. \]
Standard Logit model

\[ Y_i = \begin{cases} 
1, & \text{if CT is adopted} \\
0, & \text{otherwise} 
\end{cases} \quad , \ i = 1, \ldots, N. \]

\[ \Pr(Y_i = 1) = \frac{\exp(\beta'x_i)}{1 + \exp(\beta'x_i)} \]

\[ E[Y_i] = \frac{\exp(\beta'x_i)}{1 + \exp(\beta'x_i)} \]

Likelihood of observing tillage choice \( y_i \) (1 or 0) by the \( i^{th} \) farmer:

\[ L \left( \beta \left| y_i, x_i \right. \right) = \left( \frac{\exp(\beta'x_i)}{1 + \exp(\beta'x_i)} \right)^{y_i} \left( \frac{1}{1 + \exp(\beta'x_i)} \right)^{1-y_i} \]
Data on CT use

- “Old” NRCS-NRI – up to year 1992
- NRI-CEAP – very limited data
- USDA-NASS ARMS – limited access, relatively small sample size
- CTIC (Purdue University) – county-average CT use rates, by crop, 1989-2004
Grouped dependent variable logistic model (GDVLM)

- $N$ farmers, each farming $a_i$ acres, are divided into groups $G_j, \ j = 1, \ldots, J$
- The observed group-average proportion of CT adoption represents an expert opinion which is thought to be the expected value of the group-average of the binary outcome variable, subject to a random noise

$$p_j = \frac{1}{\sum_{i \in G_j} a_i} \sum_{i \in G_j} \frac{a_i \exp(\beta'x_i)}{1 + \exp(\beta'x_i)} + \epsilon_j, \ \epsilon_j \sim N(0, \sigma_\epsilon)$$

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Estimating GDVLM

- Likelihood for the j-th group of observations

\[
L(\beta, \sigma_\varepsilon \mid p_j, x_i (i \in G_j)) = -\frac{1}{2} \ln(2\pi \sigma_\varepsilon^2) \]

\[
- \frac{1}{2\sigma_\varepsilon^2} \left\{ p_j - \frac{1}{\sum_{i \in G_j} a_i} \sum_{i \in G_j} \frac{a_i \exp(\beta'x_i)}{1 + \exp(\beta'x_i)} \right\}^2
\]
Application to Iowa: CT use data

- Collected by CTIC
- County-average proportion of CT use in 2002 and 2004
- Corn and soybeans
- $J = 396$
Explanatory variables: crop and previous crop

- USDA/NASS, GIS-based, CCM
- Overlaid with digital soils maps
- \( N = 123,157 \) fields
  - 15% in CC
  - 39% in CS
  - 46% in SC
- Median group size: 333 fields
- Average field size \((a_j)\): 303 ac

Map source: Secchi et al., 2009
Estimation of the GDVLM on Iowa data

- **Dependent variable:** county-average proportion of CT use in 2002 and 2004, corn and soybeans
- **Explanatory variables:**
  - Crop and previous crop grown
  - Field and soil properties
    - Slope, permeability, flood frequency
  - $\pi_0$ varying with soil quality
  - Climatic factors
    - Average temperature, precipitation amount and variability
  - Farmer and farm characteristics from Census of Ag.
    - Experience, gender, farm ownership
Model estimated

\[ \beta'x = \beta_1 \cdot I_S + \beta_2 \cdot I_{CS} + \beta_3 \cdot SLOPE + \beta_4 \cdot PERM + \beta_5 \cdot FLOOD \\
+ \beta_6 \cdot PRCP + \beta_7 \cdot TMAX \\
+ \left\{(\beta_8 \cdot I_C + \beta_9 \cdot I_S) \cdot \pi_0 + (\beta_{10} \cdot I_C + \beta_{11} \cdot I_S) \cdot EXP \right\} \\
+ (\beta_{12} \cdot I_C + \beta_{13} \cdot I_S) \cdot MALE + (\beta_{14} \cdot I_C + \beta_{15} \cdot I_S) \cdot CORP \right\} \cdot \sigma^2_{prcp} \\
+ \beta_{16} \cdot \pi_0 \]

- Relative error of the estimated proportion of acres in CT ranges from 2% (NW) to 10% (Central)
- Counterpart of $R^2 = 0.433$
Estimated costs of CT adoption

\[ S = \max \left\{ \left( \pi_0 - \pi_{CT} \right) + \hat{P}, \ 0 \right\} \]

<table>
<thead>
<tr>
<th>Cropping sequence</th>
<th>Acres, %, observed</th>
<th>CT Acres, %, estimated</th>
<th>Cost, per acre (s.d.), estimated</th>
</tr>
</thead>
<tbody>
<tr>
<td>CC</td>
<td>15</td>
<td>23</td>
<td>$43 ($31)</td>
</tr>
<tr>
<td>CS</td>
<td>39</td>
<td>49</td>
<td>$14 ($19)</td>
</tr>
<tr>
<td>SC</td>
<td>46</td>
<td>76</td>
<td>$2.6 ($9.5)</td>
</tr>
</tbody>
</table>
Willingness to adopt CT within the given subsidy ranges

<table>
<thead>
<tr>
<th>Subsidy, $/ac</th>
<th>All</th>
<th>Corn</th>
<th>Soybeans</th>
</tr>
</thead>
<tbody>
<tr>
<td>S &lt; 10</td>
<td>67%</td>
<td>47%</td>
<td>92%</td>
</tr>
<tr>
<td>10 ≤ S &lt; 20</td>
<td>9%</td>
<td>13%</td>
<td>3%</td>
</tr>
<tr>
<td>20 ≤ S &lt; 30</td>
<td>6%</td>
<td>10%</td>
<td>2%</td>
</tr>
<tr>
<td>30 ≤ S &lt; 40</td>
<td>5%</td>
<td>8%</td>
<td>1%</td>
</tr>
<tr>
<td>40 ≤ S &lt; 50</td>
<td>4%</td>
<td>6%</td>
<td>1%</td>
</tr>
<tr>
<td>50 ≤ S</td>
<td>10%</td>
<td>16%</td>
<td>1%</td>
</tr>
</tbody>
</table>
Subsidies grouped by flood frequency

- Estimating individual probabilities allows flexibility in policy analysis
- Permits the consideration of other groupings
  - Watersheds

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Conclusions

• Estimating individual probabilities expands the scope of the type of analysis that may be done with the aggregated choice data

• Average 2002, 2004 costs of CT adoption estimated at $13/acre

• The methodology of combining the grouped and individual- or field-level data could be applied to other BMPs
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