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

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

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

$$\begin{aligned} \Pr(Y=1) &= \Pr\left(\pi_{CT} - \pi_0 - P \geq \sigma_\eta \eta\right) \\ &= \Pr\left(\boldsymbol{\alpha}'\mathbf{w} - \pi_0 - \boldsymbol{\gamma}'\mathbf{z} \geq \sigma_\eta \eta\right) = \Pr\left(\boldsymbol{\beta}'\mathbf{x} \geq \eta\right) \end{aligned}$$

Here

$$\boldsymbol{\beta}' = \left(\frac{1}{\sigma_\eta}\boldsymbol{\alpha}', \; -\frac{1}{\sigma_\eta}\boldsymbol{\gamma}', -\frac{1}{\sigma_\eta} \right), \quad \mathbf{x} = \begin{pmatrix} \mathbf{w} \\ \mathbf{z} \\ \pi_0 \end{pmatrix}.$$

Standard Logit model

N farmers

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

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

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

$$L\Bigg(\underbrace{\beta}_{parameters} \Bigg| \underbrace{y_i, x_i}_{data}\Bigg) = \left(\frac{\exp(\beta' x_i)}{1 + \exp(\beta' x_i)}\right)^{y_i} \left(\frac{1}{1 + \exp(\beta' x_i)}\right)^{1 - y_i}$$

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

$$p_j = \frac{1}{\sum_{i \in G_j} a_i} \sum_{i \in G_j} \frac{a_i \exp\left(\boldsymbol{\beta}'\mathbf{x}_i\right)}{1+\exp\left(\boldsymbol{\beta}'\mathbf{x}_i\right)} + \varepsilon_j \ , \varepsilon_j \sim N\left(0, \sigma_\varepsilon\right)$$

Estimating GDVLM

- Likelihood for the j-th group of observations

$$L(\boldsymbol{\beta}, \sigma_\varepsilon \,|\, p_j, \mathbf{x}_i (i \in G_j)) = -\frac{1}{2}\ln(2\pi\sigma_\varepsilon^2)$$

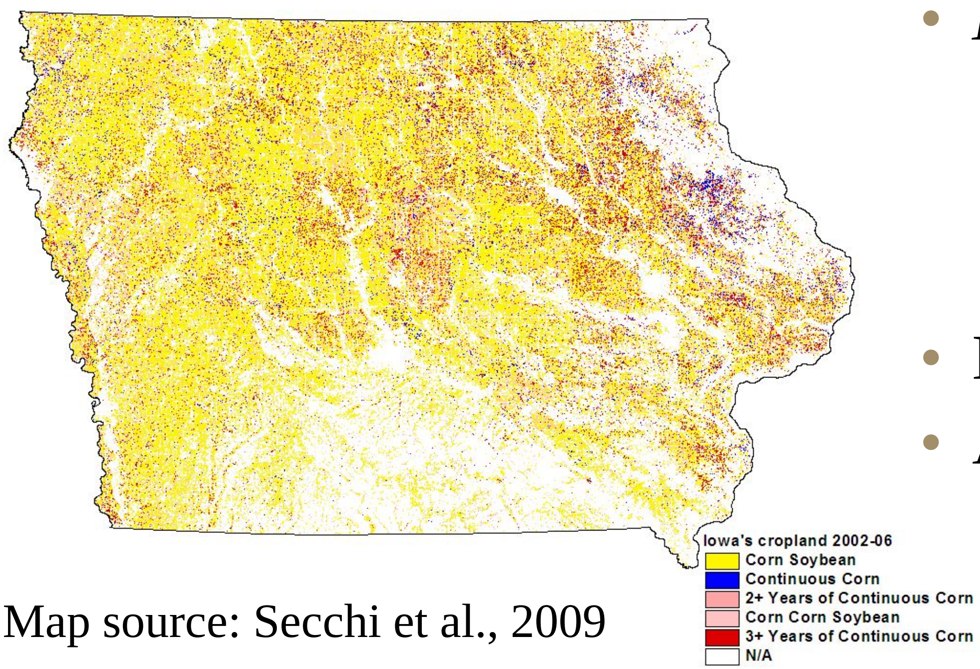
$$-\frac{1}{2\sigma_\varepsilon^2}\left\{ p_j - \frac{1}{\sum_{i \in G_j} a_i} \sum_{i \in G_j} \frac{a_i \exp\left(\boldsymbol{\beta}'\mathbf{x}_i\right)}{1+\exp\left(\boldsymbol{\beta}'\mathbf{x}_i\right)} \right\}^2$$

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
- 2002 (2001) and 2004 (2003) crop and previous year crop data
- 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
  - π_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

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

- 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

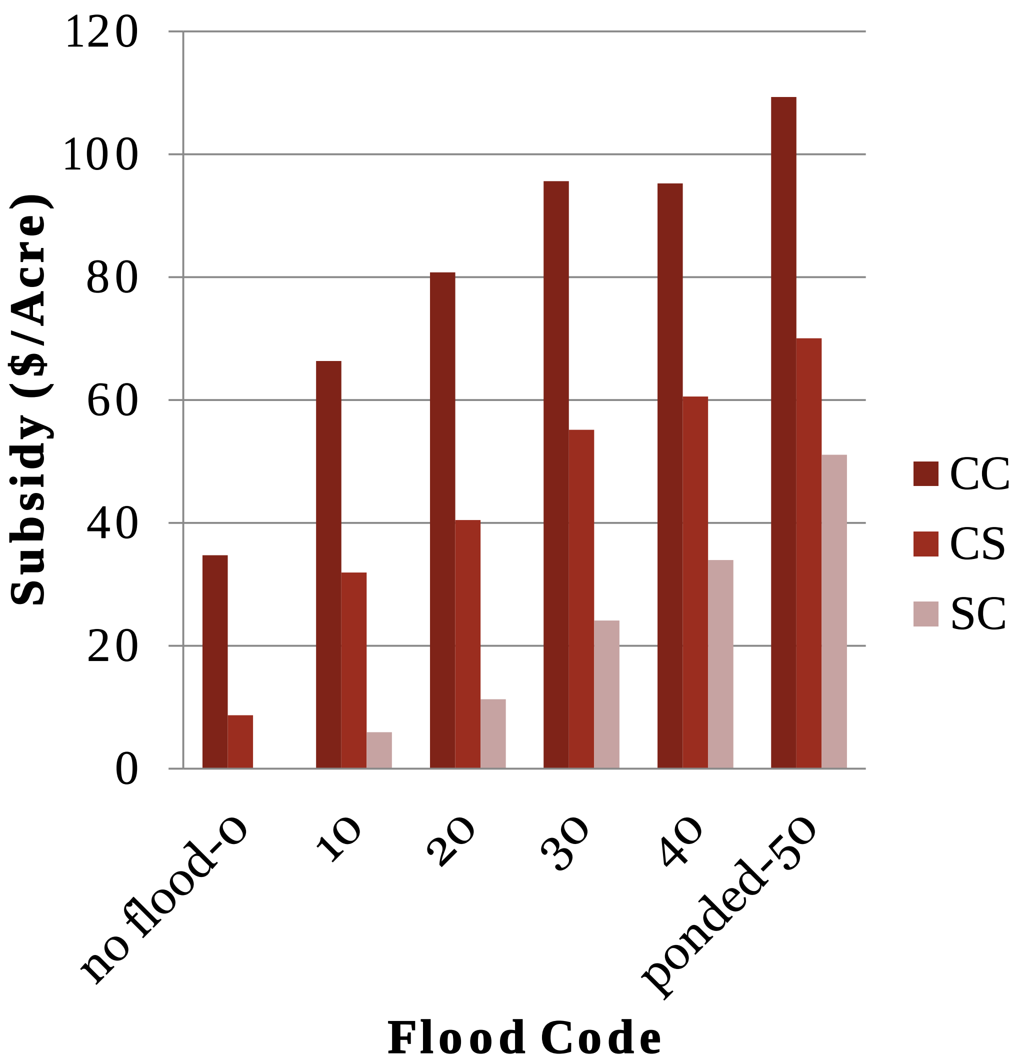
$$S = \max\left\{\left(\pi_0 - \widehat{\pi_{CT}}\right) + \hat{P},\ 0\right\}$$

Cropping sequence	Acres, %, observed	CT Acres, %, estimated	Cost, per acre (s.d.), estimated
CC	15	23	$43 ($31)
CS	39	49	$14 ($19)
SC	46	76	$2.6 ($9.5)

Willingness to adopt CT within the given subsidy ranges

Subsidy, $/ac	All	Corn	Soybeans
S < 10	67%	47%	92%
10 ≤ S < 20	9%	13%	3%
20 ≤ S < 30	6%	10%	2%
30 ≤ S < 40	5%	8%	1%
40 ≤ S < 50	4%	6%	1%
50 ≤ S	10%	16%	1%

Subsidies grouped by flood frequency



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

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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