Incorporating Misclassification into Capture-Recapture Methodology in the 2012 Census of Agriculture

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Census of Agriculture: history

- Conducted in years ending in 2 and 7.
- Before 1997: U.S. Census Bureau
- 1997-present: USDA/NASS
Census of Agriculture: purpose

- Quantity of interest: number of farms
  - State
  - Farm type
  - Race
  - Gender

- Factor in allocation of funds for Federal agriculture programs
  - e.g. land grant universities
Farm definition

- Target population: operations that meet USDA farm definition.
- An agricultural operation that either
  - Produces at least $1,000 of sales in a year,
  - Normally produced $1,000 in sales,
  - OR 1,000 points of agricultural items
Examples of Point Farms

- 5 horses
- 1 acre of Christmas trees
- 100 acres of pasture land
- $1,000 in government payments
Documented farm misclassification

- **Farm Numbers Research Project (2009):** tracts in June Area Survey (JAS) were incorrectly identified as non-agricultural when agriculture was present.

- **Classification Error Survey following 2007 Census:** classification errors made during both Census and JAS.

- **June Area Survey (JAS):** used as supplemental survey to Census for farm number estimation.
Purpose of talk

- Accounting for farm misclassification in 2012 Census of Agriculture
- Adjusts traditional methodology
  - Dual System Estimation (DSE)
  - Capture-recapture
Dual system estimation or capture-recapture methodology

- Similar methodologies in different contexts (in this presentation, used interchangeably)
- DSE
  - U.S. Census of Population
  - UK Census Coverage Assessment
- Capture-recapture
  - fish and wildlife populations
Main ideas of DSE and capture-recapture

- **DSE**
  - supplementary (independent) survey to quantify Census undercount
  - i.e. What proportion of units from the supp. survey are counted by the Census?
- **Capture-recapture**
  - Capture, tag, and return
  - Recapture
  - What proportion of animals captured in second catch are tagged from first catch?
Example: catching trout (taken from UK Census documentation)

- Day One: catch 100 trout. Tag each and release
- Day Two: catch 50 trout. 25 have tags.
- Estimate of total

\[ \hat{N} = 100 \left( \frac{25}{50} \right)^{-1} = 200 \]
## Analogy between DSE and capture-recapture

<table>
<thead>
<tr>
<th>Capture-recapture</th>
<th>DSE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Day one catch</td>
<td>Records counted by the Census</td>
</tr>
<tr>
<td>Day two catch</td>
<td>Records counted by supp. survey</td>
</tr>
<tr>
<td>Tagging process</td>
<td>Matching of Census and survey records</td>
</tr>
</tbody>
</table>

\[
\hat{N} = N_{Census} \left( \frac{N_{Census \& Supp.S}}{N_{Supp.S}} \right)^{-1}
\]
Supp. Survey: June Area Survey
DSE for Census of Agriculture

- Challenge: traditional DSE does not deal with misclassification errors
- Census of Agriculture has 4 types of enumeration errors, including
  - under-coverage
  - non-response
  - 2 types of misclassification.
Errors in Enumeration Process

- **List under-coverage**: the omission of farms from the Census Mailing List (CML)
- **Non-response**: The failure of farm operators to return a completed Census questionnaire.
- Both conditioned on farms
Errors in Enumeration Process II

- **Misclassification**: Errors in Census reporting cause two types of misclassification errors:
  - Farms are classified as non-farms
  - Non-farms are classified as farms
Summary of Enumeration Errors

1. CML under-coverage of farms
2. Farm non-response
3. Farms are misclassified as Census non-farms
4. Non-farms are misclassified as Census farms

1-3: undercount, 4: overcount
Venn Diagram

- Operations on CML
- U.S. Farms
- Census Farms
- Census Respondents
- U.S. Agricultural Operations
Adjustments to traditional DSE

- Probability of farm imputed for unresolved records: where Census and JAS disagree on farm status
- Three undercount errors are combined into “capture”
- Account for “differential catchability”
- Correct for misclassification overcount
Definition of Capture

- An operation is “captured” by the Census if it is
  - on CML | Farm
  - Responds | CML, Farm
  - Classified as Census Farm | CML, Responds, Farm
Product of probabilities

\[ P(\text{capture}) = P(\text{on CML} \mid \text{Farm}) \times P(\text{Responds} \mid \text{CML, Farm}) \times P(\text{Classified as Census Farm} \mid \text{CML, Responds, Farm}) \]

Or

\[ p_{\text{Cap}} = p_{\text{Cov}} p_{\text{Resp}} p_{\text{CCF}} \]
Dual System Estimation

- Dual System Estimator using capture:

\[ \hat{N} = \left( \frac{F_{JC}}{F_J} \right)^{-1} F_C \]

- \( F_{JC} \): number of farms captured by JAS and Census
- \( F_J \): number of farms captured by JAS
- \( F_C \): number of farms captured by Census
Two problems with first-adapted DSE

- Doesn’t account for heterogeneity in capture probabilities
- Doesn’t account for misclassification of non-farms as Census farms (overcount)
Example: Heterogeneity in capture probabilities

- Catching trout, roach, and catfish.

<table>
<thead>
<tr>
<th></th>
<th>First day catch, #Tagged</th>
<th>Second day catch, Fraction tagged</th>
<th>Estimate of Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trout</td>
<td>100</td>
<td>25/50</td>
<td>200</td>
</tr>
<tr>
<td>Roach</td>
<td>50</td>
<td>5/20</td>
<td>200</td>
</tr>
<tr>
<td>Catfish</td>
<td>10</td>
<td>1/10</td>
<td>100</td>
</tr>
<tr>
<td>All fish</td>
<td>160</td>
<td>31/80</td>
<td>413</td>
</tr>
</tbody>
</table>

- Account for differential capture rates = 500
- Don’t account = 413
Heterogeneity in capture probabilities: estimator

- Partition farms into groups so that the probability of capture is about the same within each group.
- Example: by state, farm sales, farm type, race, gender
- Sum DSE’s for each group

\[ \hat{N} = \sum_{i=1}^{n_{\text{groups}}} \left( \frac{F_{JC,i}}{F_{J,i}} \right)^{-1} F_{C,i} \]
Logistic regression

- Logistic regression extends this approach: allows
  - continuous variables
  - more complex models.
- Each Census record has its own capture probability.

\[
\hat{N} = \sum_{j=1}^{n_{\text{records}}} p_{Cap,j}^{-1}
\]
Logistic regression

- The 0/1 capture indicators $Y_i$ follow a Bernoulli($\pi_{Ci}$) distribution, where

$$\pi_{Ci} = \logit^{-1}(x_{Ci}' \beta_C)$$

- $\beta_C$ is estimated using the matched dataset (of JAS and Census)
- Then Census record probabilities of capture are

$$p_{Cj} = \logit^{-1}(x_{Cj}' \hat{\beta}_C)$$
Two problems with traditional DSE

- Doesn’t account for heterogeneity in capture probabilities
- Doesn’t account for misclassification of non-farms as Census farms (overcount)
Adjustment for Misclassification

- The probability of correct Census farm classification is
  \[ p_{CCFC} = P(\text{Farm} | \text{Census Farm}) \]
- Multiplied by capture weights to correct for overcount.

\[
\hat{N} = \sum_{j=1}^{n_{\text{records}}} \frac{p_{CCFC,j}}{p_{Cap,j}}
\]
Final estimator

- The final estimator is obtained after expanding the capture probability into its components.

\[ \hat{N} = \sum_{j=1}^{n_{\text{records}}} \frac{p_{\text{CCFC},j}}{p_{\text{Cov},j} p_{\text{Resp},j} p_{\text{CCF},j}} \]
Computing probabilities

- The 4 probabilities
  - $p_{\text{Cov}} = P(\text{on CML} \mid \text{Farm})$
  - $p_{\text{Resp}} = P(\text{Responds} \mid \text{CML, Farm})$
  - $p_{\text{CCF}} = P(\text{Classified as Census farm} \mid \text{CML, Responds, Farm})$
  - $p_{\text{CCFC}} = P(\text{Farm} \mid \text{Census farm})$

- Use different subsets of the matched dataset depending on the conditions.
Wrap-up

- Census of Agriculture
- Adjusts traditional DSE/capture-recapture methods for misclassification.