The Chitwan ABM

Alex Zvoleff\(^1\), Li An\(^*\)

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*San Diego State University; San Diego, USA

\(^1\)azvoleff@mail.sdsu.edu
• Land-use and land-cover and human-decision making are intimately linked

• Micro-level decision-making can lead to broader scale ("emergent") patterns on the landscape
Introduction

- How does micro-level demographic decision making impact macro-level resource consumption and land use and land cover (LULC)?

- What role do feedbacks play in this relationship?
Introduction

INTRODUCTION

Submodels
Results
Verification
Discussion
Conclusion
Chitwan Valley Family Study

• Longitudinal survey – began in 1996

• Focuses on social context and family formation

• Human survey data
  – Household registry (monthly since Feb. 1997)

• Environmental data
Methods

• Agent-based models (ABM) represent individual “agents” and model their interactions

• ABM allows:
  – Representation of human-decision making
  – Consideration of feedbacks
  – Examination of system dynamics
  – Testing of alternative hypotheses
Submodels
• First births after marriage are modeled separately from other births

• In each month following marriage, calculate probability of a live birth in that month based on regression results (based on Ghimire and Hoelter 2007 and Axinn and Ghimire 2010)

• Only live births are modeled
First-born Timing Model (based on Ghimire and Axinn, 2010)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Percent land area under agriculture</td>
<td>1.002</td>
<td>0.458</td>
</tr>
<tr>
<td><strong>Community characteristics</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood area</td>
<td>0.420</td>
<td>0.428</td>
</tr>
<tr>
<td>Distance to urban center</td>
<td>1.007</td>
<td>0.548</td>
</tr>
<tr>
<td>Electricity in 1996</td>
<td>1.298</td>
<td>0.105</td>
</tr>
<tr>
<td>Non-family services within a 15-min walk</td>
<td>0.996</td>
<td>0.619</td>
</tr>
<tr>
<td><strong>Controls</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Respondent’s parents’ characteristics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mother’s number of children</td>
<td>0.977</td>
<td>0.504</td>
</tr>
<tr>
<td>Mother’s education</td>
<td>0.922</td>
<td>0.678</td>
</tr>
<tr>
<td>Mother’s work</td>
<td>0.930</td>
<td>0.686</td>
</tr>
<tr>
<td>Father’s education</td>
<td>0.874</td>
<td>0.324</td>
</tr>
<tr>
<td>Father’s work</td>
<td>0.721</td>
<td>0.021*</td>
</tr>
<tr>
<td>Parents’ contraceptive use</td>
<td>0.968</td>
<td>0.824</td>
</tr>
<tr>
<td><strong>Respondent’s ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low Caste Hindu</td>
<td>1.026</td>
<td>0.922</td>
</tr>
<tr>
<td>Hill Tibeto-burmese</td>
<td>0.539</td>
<td>0.003**</td>
</tr>
<tr>
<td>Newar</td>
<td>0.619</td>
<td>0.210</td>
</tr>
<tr>
<td>Terai Tibeto-burmese</td>
<td>0.958</td>
<td>0.816</td>
</tr>
</tbody>
</table>

Continued on next slide.
### First-birth Timing Model (based on Ghimire and Axinn, 2010)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Respondent’s marital experiences</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age at first marriage</td>
<td>0.968</td>
<td>0.201</td>
</tr>
<tr>
<td><strong>Marriage duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Marriage duration before 1997</td>
<td>0.994</td>
<td>0.452</td>
</tr>
<tr>
<td><strong>Marriage duration during obs. period</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Married for 1–6 months</td>
<td>11.300</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Married for 7–12 months</td>
<td>7.118</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Married for 13–18 months</td>
<td>5.386</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Married for 19–24 months</td>
<td>3.156</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Married for 25–30 months</td>
<td>1.523</td>
<td>0.236</td>
</tr>
<tr>
<td>Married for 31–36 months</td>
<td>2.278</td>
<td>0.010*</td>
</tr>
<tr>
<td>Married for 37–42 months</td>
<td>1.300</td>
<td>0.476</td>
</tr>
<tr>
<td><strong>Schooling</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4–7 years of schooling</td>
<td>1.621</td>
<td>0.043*</td>
</tr>
<tr>
<td>8–11 years of schooling</td>
<td>2.345</td>
<td>0.063.</td>
</tr>
<tr>
<td>12 or more years of schooling</td>
<td>3.688</td>
<td>0.019*</td>
</tr>
<tr>
<td><strong>Intercept</strong></td>
<td>0.028</td>
<td>&lt;.001***</td>
</tr>
</tbody>
</table>

Model continued from previous slide.
Second and subsequent births

• For all other births, choose the interval until the next child from empirical probability distribution

• Births can occur until:
  – The desired number of children is reached
  – (or) woman reaches maximum birth age (45)
  – (or) woman dies/out-migrates
Birth Interval

![Bar chart showing birth interval probabilities](chart.png)
Desired Number of Children

![Histogram of Desired Number of Children](image)

- Male
- Female

**FERTILITY**
- Mortality
- Marriage
- Divorce
- Migration
- Education
- Fuelwood

**SUBMODELS**

<table>
<thead>
<tr>
<th>Introduction</th>
<th>Results</th>
<th>Verification</th>
<th>Discussion</th>
<th>Conclusion</th>
</tr>
</thead>
</table>

August 6, 2012

2012 NSF PIRE Project Meeting
Mortality

![Graph showing annual probability of dying by age and gender.]

- **Introduction**
- **SUBMODELS**
- **Results**
- **Verification**
- **Discussion**
- **Conclusion**
Marriage Timing

1. Minimum marriage age is 15
2. Beginning at minimum marriage age, calculate a probability ($p$) of marriage for each agent for that month
3. Draw a random number – if the random number is less than the probability $p$, add person to ‘to be married’ list

Note: Marriage timing regression model is based on Yabiku (2006a, 2006b)
## Marriage Timing Model (based on Yabiku, 2006)

### Variable | Odds Ratio | 2-sided p-value
--- | --- | ---
Log(Percent Agricultural Land (interpolated)) | 1.138 | 0.064.
**Nonfamily organizations (minutes by foot)**
School | 1.012 | 0.138
Health post | 0.999 | 0.711
Bus stop | 1.005 | 0.282
Market | 0.999 | 0.842
Employer | 1.003 | 0.305
**Schooling**
Years schooling completed | 0.997 | 0.893
Enrolled in school | 0.669 | <.001***
**Female** | 2.245 | <.001***
**Ethnicity**
Lower Caste Hindu | 1.014 | 0.942
Newar | 0.786 | 0.229
Hill Tibetoburmese | 1.187 | 0.256
Terai Tibetoburmese | 0.906 | 0.508
**Age**
Age | 2.107 | 0.004**
Age-squared | 0.986 | 0.018*
**Intercept** | 0.000 | <.001***

*Table showing odds ratios and p-values for various variables in the marriage timing model.*
Spouse choice

1. Once ‘to be married’ list is constructed, loop over list in random order
2. Each time through list, choose a person (psn1)
3. Calculate probability that psn1 would marry each other person in the list
   – Assign zero probability to anyone from a different ethnic group or from the same sex
   – Calculate probability for all others based on age difference between spouses (using empirical data)
4. Choose a spouse (psn2) by sampling from the potential spouses with each potential spouse weighted by their calculated probability of marriage to psn1
5. Unpaired spouses marry in-migrants – with spouse age chosen using spouse age model
New household establishment (part 1)

1. Once a couple is formed, decide if couple will form a new household, by drawing a random number and comparing to the *household fission rate*

   - If a new household is **not** formed, move the new couple into the husband’s household

   - If a new household is **is** formed, draw the size (area in sq. m) of the household plot from empirical probability distribution
New Household Establishment (part 1)
New household establishment (part 2)

2. Find a neighborhood with sufficient free land (agricultural or non-agricultural vegetation, in that order) to build new household
   
   — First try husband’s parent’s neighborhood
   
   — Move outwards by distance from parent’s neighborhood until first neighborhood with free land is found

3. Assign new household to chosen neighborhood
Divorce

• If a random number is less than the calculated divorce probability for a person, that person will divorce their spouse

• The woman will either:
  – Return to her parent’s household
  – (or) If her parent’s household no longer exists, she will establish a new household in a randomly selected neighborhood following the household establishment submodel

• The man will remain in the original household, together with any child agents

Note: this model is under development – suggestions appreciated. Currently the divorce probability is set to a constant.
Individual out-migration: Prob. of out-migration

- For each individual older than the *minimum out-migration age*, a probability of migration is calculated for each timestep (following Massey et al. 2010)
- If a random number is less than the calculated migration probability for a person, that person will out-migrate
- For each migrating person:
  - Length of migration is drawn from empirically observed distribution
  - A portion of the migrants (determined by ‘*permanent out migration probability*’) do not return
- After the duration of each person’s migration is complete, they return to their household
## Migration Model (based on Massey et al. 2010)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Enrolled in school</td>
<td>0.820</td>
<td>0.062</td>
</tr>
<tr>
<td>Years of schooling</td>
<td>1.075</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Female</td>
<td>0.624</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td><strong>Physical capital</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Market access</td>
<td>1.026</td>
<td>0.516</td>
</tr>
<tr>
<td>Farmland</td>
<td>0.930</td>
<td>0.528</td>
</tr>
<tr>
<td><strong>Age</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>15-25</td>
<td>2.797</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>25-35</td>
<td>1.544</td>
<td>0.021*</td>
</tr>
<tr>
<td>35-45</td>
<td>0.940</td>
<td>0.751</td>
</tr>
<tr>
<td>45-55</td>
<td>1.050</td>
<td>0.807</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-Caste Hindu</td>
<td>1.109</td>
<td>0.477</td>
</tr>
<tr>
<td>Hill Tibeto-Burmese</td>
<td>1.222</td>
<td>0.083</td>
</tr>
<tr>
<td>Newar</td>
<td>0.854</td>
<td>0.339</td>
</tr>
<tr>
<td>Terai Tibeto-Burmese</td>
<td>0.617</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td><strong>Duration</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Month</td>
<td>0.568</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Month squared</td>
<td>1.123</td>
<td>0.050</td>
</tr>
<tr>
<td><strong>Intercept</strong></td>
<td>0.007</td>
<td>&lt;.001***</td>
</tr>
</tbody>
</table>
Individual out-migration: Out-migration length

![Histogram of Out-migration Length](image)
Household-level In/Out migration

- Household-level in and out-migration can be allowed by specifying a *probability of household out-migration* and/or a *probability of household in-migration*

- Households that out-migrate leave the model permanently, and their land is returned to agriculture

- Households that in-migrate randomly locate in a neighborhood with available land, following the household establishment model
1. At age 6, calculate child’s final schooling level

2. Increment education level each timestep until:
   - Person dies or outmigrates
   - (or) Final schooling level is reached
## Education Model (ordinal logistic regression)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neighborhood Level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Avg. years non-family services (15 min. ft.)</td>
<td>1.050</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td><strong>Individual Level</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Female</td>
<td>0.124</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-Caste Hindu</td>
<td>0.133</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td>Hill Tibeto-Burmese</td>
<td>0.227</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td>Newar</td>
<td>0.983</td>
<td>0.954</td>
</tr>
<tr>
<td>Terai Tibeto-Burmese</td>
<td>0.083</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td><strong>Intercepts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Years schooling greater than 0, less than 4</td>
<td>7.991</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td>Years schooling greater than 4, less than 8</td>
<td>3.890</td>
<td>&lt; 0.001***</td>
</tr>
<tr>
<td>Years schooling greater than 8, less than 11</td>
<td>0.987</td>
<td>0.944</td>
</tr>
<tr>
<td>Years schooling greater than 11</td>
<td>0.186</td>
<td>&lt; 0.001***</td>
</tr>
</tbody>
</table>

n = 715, pseudo $R^2 = .435$
Household-level fuelwood usage is modeled in two parts:
1. Probability of fuelwood usage
2. Quantity of fuelwood usage

The predicted quantity of fuelwood usage is scaled by the probability of fuelwood usage.

This is consistent with Wolong ABM, and the fact that not all households use fuelwood (though most do)
# Probability of Fuelwood Usage

<table>
<thead>
<tr>
<th>Variable</th>
<th>Odds Ratio</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Neighborhood Level Covariates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electricity Available</td>
<td>0.272</td>
<td>0.102</td>
</tr>
<tr>
<td>Distance to Narayanghat</td>
<td>1.100</td>
<td>0.005**</td>
</tr>
<tr>
<td>Closest forest is CNP</td>
<td>0.621</td>
<td>0.274</td>
</tr>
<tr>
<td><strong>Household Level Covariates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Household size</td>
<td>1.394</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Mean gender (1 = female)</td>
<td>2.683</td>
<td>0.029*</td>
</tr>
<tr>
<td><strong>Ethnicity</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-Caste Hindu</td>
<td>2.994</td>
<td>0.015*</td>
</tr>
<tr>
<td>Hill Tibeto-Burmese</td>
<td>0.996</td>
<td>0.989</td>
</tr>
<tr>
<td>Newar</td>
<td>0.476</td>
<td>0.012*</td>
</tr>
<tr>
<td>Terai Tibeto-Burmese</td>
<td>2.712</td>
<td>0.002**</td>
</tr>
<tr>
<td><strong>Intercept</strong></td>
<td>2.814</td>
<td>0.240</td>
</tr>
</tbody>
</table>

n = 2125, Log likelihood = -464.3, Deviance = 928.6
## Fuelwood Usage Quantity

**Dependent variable:** dry kg firewood / (person * day)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Regression Coefficient</th>
<th>2-sided p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intercept</td>
<td>1.816</td>
<td>&lt;.001***</td>
</tr>
<tr>
<td>Mean household size</td>
<td>-0.408</td>
<td>.087</td>
</tr>
<tr>
<td>Mean household size (squared)</td>
<td>0.034</td>
<td>.191</td>
</tr>
<tr>
<td>Upper Caste Hindu</td>
<td>-0.051</td>
<td>.655</td>
</tr>
<tr>
<td>Own any non-wood stove</td>
<td>-0.255</td>
<td>.044 *</td>
</tr>
</tbody>
</table>

Adjusted $R^2$: .22, n=37
Fuelwood Usage Quantity

Adjusted $r^2 = .22$
Results
Scenarios

• We will explore several sets of scenarios exploring the impact of varying key variables on population, fuelwood consumption, and LULC
  – Household fission rate
  – Out migration rate
  – Desired number of children
Results – Household Fission Scenario

![Graph showing the number of households over time for different fission rates.](chart)

**Scenario**
- .150 HH Fission Rate
- .300 HH Fission Rate
- .600 HH Fission Rate

**Time**
- 2000
- 2005
- 2010
- 2015
- 2020

**Number of Households**
- 1500
- 2000
- 2500
- 3000
- 3500
Results – Household Fission Scenario

![Graph showing metric tons of fuelwood per month over time with different fission rates.

- 0.150 HH Fission Rate
- 0.300 HH Fission Rate
- 0.600 HH Fission Rate

Chart indicates increasing metric tons of fuelwood from 2000 to 2020.]
Results – Household Fission Scenario

↑ household fission rate →
Little change in population size
↑ Number of households
↓ Household size
↑ Fuelwood usage
↑ Rate of land conversion from agriculture
Results – Varying Permanent Out-migration
Results – Varying Permanent Out-migration
Results – Varying Permanent Out-migration

↑ permanent individual out-migration →

↓ In population size
Little change in number of households
↓ Household size
Little change in fuelwood usage
Little change in rate of land conversion from agr.
Results – Varying Desired Family Size

![Graph showing total population over time for different scenarios: Fewer Children, Baseline, More Children.](image-url)
Results – Varying Desired Family Size

![Graph showing varying family size over time](image)

**Scenario**
- Fewer Children
- Baseline
- More Children

**Axes**
- Metric Tons of Fuelwood / Month
- Time (2000 to 2020)
Results – Varying Desired Family Size

↑ desired family size →

↑ in population size
Little change in number of households
↑ Household size
↑ (small) in fuelwood usage
Little change in rate of land conversion from ag.
Where is LULC occurring?

Initial (1996 observed)  
Final (simulated 2020)

(.150 household fission rate)
Where is LULC occurring?

0% - 25% Agricultural Land in Neighborhood

25% - 50% Agricultural Land in Neighborhood

50% - 75% Agricultural Land in Neighborhood

75% - 100% Agricultural Land in Neighborhood

(.150 household fission rate)
Where is LULC occurring?

(.150 household fission rate)
Where is LULC occurring?

(.150 household fission rate)
Where is LULC occurring?

(.600 household fission rate)
Verification and Validation
Verification and Validation

1. Progress model building and debugging
2. Uncertainty testing (extreme test, and extreme combination test)
3. Empirical validation—comparing model output data to empirical data
4. Sensitivity analysis—examining how model outcomes vary with a small change in key parameters, and
5. Experience or expert opinion

(from An et al. 2005)
Simplified First Birth Model (for verification)

![Bar chart showing probability of time to first birth (in months) ranging from 0 to 30. Peaks are observed at intervals (9,12], (12,17], and (17,22].]
Sensitivity Analysis – Example Household Fission Rate

Total population does not vary significantly. (as expected)
Number of households varies only slightly. (as expected)
Fuelwood demand varies only slightly. (as expected)
Land use varies only slightly between the three scenarios.

Model is not overly sensitive to small changes in fission rate.
Parameterization Dataset

![Graph showing parameterization dataset and testing dataset with data points for births, deaths, and marriages over years from 1998 to 2008.]

Legend:
- Births
- Deaths
- Marriages
Simulated vs. Observed – Deaths

![Graph showing simulated vs. observed deaths]

**Data Source**
- ABM
- Observed
Simulated vs. Observed – Births
Simulated vs. Observed – Marriages

Data Source
- ABM
- Observed
Simulated vs. Observed – Number of Households
Discussion
The Chitwan ABM tends towards a higher degree of demographic detail than other comparable ABMs

- This enables controlling for many covariates, and can ‘drop-in’ existing regression models
- But: can complicate interpretation of results

Step-by-step approach can untangle complicated reciprocal relationships
Discussion – Key Findings

• As in Wolong, household size is key to resource consumption
  – But: smaller households in Chitwan are also more likely to transition away from fuelwood
  – Out-migration may be as important as fission rate

• Though household size is main driver of consumption in Chitwan, consumption of downed wood is difficult to tie directly to CNP habitat

• Though areas bordering the CNP are currently primarily agricultural, they will soon be more densely populated
Conclusions

• Out-migration and household size are key determinants of consumption patterns and LULC change

• Areas bordering the national park are likely to transition away from dense agriculture in near future

• Future areas of work:
  – Directly explore and model human-wildlife interactions along park perimeter, taking into account spatial patterns of growth
  – Model spatial impact of feedbacks between LULC and demography (scheduled for submission in the fall)
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• Binoj Shrestha
• Krishna Shrestha
• ISER-Nepal
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Built with:

Python
R

San Diego State University
GEOGRAPHY

Introduction Submodels Results Verification Discussion CONCLUSION
Chitwan Valley Family study (CVFS):

ABM:

First birth timing:

Marriage timing:

Migration:

Fuelwood usage:
• 2009 and 2011 field surveys (Zvoleff).
ChitwanABM is free and open-source:
http://rohan.sdsu.edu/~zvoleff/ChitwanABM.php

PyABM is an free and open-source ABM toolkit for Python:
http://rohan.sdsu.edu/~zvoleff/PyABM.php

Thank you. Questions?

azvoleff@mail.sdsu.edu
http://rohan.sdsu.edu/~zvoleff/
End of show.
Results – Varying Desired Family Size

![Graph showing the number of households over time with different scenarios.]

- **Scenario**
  - Fewer Children
  - Baseline
  - More Children

- **Axes**
  - **Y-axis**: Number of Households (1500–3000)
  - **X-axis**: Time (2000–2020)
## Land-use and land-cover change: 1996-2006

<table>
<thead>
<tr>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>Agricultural Vegetation</strong></td>
<td>879.9 (80.0%)</td>
<td>875.6 (79.4%)</td>
<td>854.2 (77.6%)</td>
<td>-25.7 (-2.4%)</td>
</tr>
<tr>
<td><strong>Non-agricultural Vegetation</strong></td>
<td>50.2 (4.6%)</td>
<td>35.3 (3.2%)</td>
<td>54.4 (4.9%)</td>
<td>+3.2 (+.03%)</td>
</tr>
<tr>
<td><strong>Private Buildings</strong></td>
<td>82.3 (7.5%)</td>
<td>88.4 (8.0%)</td>
<td>94.4 (8.6%)</td>
<td>+12.1 (+1.1%)</td>
</tr>
<tr>
<td><strong>Public Buildings</strong></td>
<td>59.2 (5.4%)</td>
<td>64.3 (5.8%)</td>
<td>66.9 (6.1%)</td>
<td>+7.7 (+.07%)</td>
</tr>
<tr>
<td><strong>Other</strong></td>
<td>28.4 (2.6%)</td>
<td>39.5 (3.6%)</td>
<td>31.2 (2.8%)</td>
<td>+2.8 (+.02%)</td>
</tr>
<tr>
<td><strong>Total:</strong></td>
<td>1100.1 (100%)</td>
<td>1103.1 (100%)</td>
<td>1101 (100%)</td>
<td></td>
</tr>
</tbody>
</table>
Why do you cook with firewood?

- Startup Costs: 30
- Cheap to Use: 27
- Prefer: 9
- No Alternatives: 2
Why do you cook with ....?
What portion of the firewood you collect is live?

- None: 30
- < Half: 6
- Half: 4
- > Half: 2
- NA: 41
Simplified Marriage Timing Model (for verification)
Ordinal logistic model, for a response variable equal to 0, 1, 2, ..., k, is:

\[
\Pr[Y \geq j | X] = \frac{1}{1 + e^{-(\alpha_j + X\beta)}}
\]

where \( j = 1, 2, ..., k \). (Harell, 2001)

For example, in our case, for education:

\[
\Pr[Y = 1 | X] = 1 - \Pr[Y \geq 2 | X]
\]

\[
\Pr[Y = 2 | X] = 1 - \Pr[Y = 1 | X] - \Pr[Y \geq 3 | X]
\]

\[
\Pr[Y = 3 | X] = 1 - \Pr[Y = 1 | X] - \Pr[Y = 2 | X] - \Pr[Y \geq 4 | X]
\]

\[
\Pr[Y = 4 | X] = 1 - \Pr[Y = 1 | X] - \Pr[Y = 2 | X] - \Pr[Y = 3 | X]
\]