Location, Social Norms and Recycling

Fedor Iskhakov[1], Efthymia Kyriakopoulou[2], Philip Ushchev[3], Yves Zenou[4]

[1]Australian National University
[2]Athens Uni of Economics and Business & Swedish Uni of Agricultural Sciences
[3]ECARES, Université Libre de Bruxelles
[4]Monash University

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Overall plan

- What are the best ways to encourage recycling of household waste?
- Recycling behavior depends on how *other households* recycle and how *social norms* form in this environment
- We develop a two-stage equilibrium model where households
  1. choose their social reference group (residence community)
  2. decide how much effort to spend towards recycling
- Structurally estimate the model using Swedish survey and aggregate data on recycling behavior
- Use counterfactual experiments to investigate the relative efficiency of recycling policies

(work in progress)

Waste polution and recycling targets

- Waste pollution is a major environmental problem
  - Landfill and incineration are the most common waste management methods
  - Recycling and reuse is the most environmentally friendly option, widely supported in the EU, US and other countries
- In the US 41 out of the 50 states already in 1993 had laws that require certain percentage of wastes to be recycled
  - These laws have been effectively implemented and about 34% of municipal solid waste (MSW) was recycled in 2010
- UK government set a goal to recycle 30% of its MSW in 2004
- in EU 65% of MSW target is set by the European Commission in the *Circular Economy Action Plan*

Grogan (1993), U.S. Environmental Protection Agency (2011), Tonglet et al. (2004)

What drives recycling behavior?

- Recycling is voluntary contributions to a public good
  - costly to the individual (time and inconvenience)
  - environmental benefits are non-rival, non-excludable
- Economic incentives: cost of recycling, taxes, monetary
- Intrincic motivation: altruism, morally motivated behavior
- Social pressure: peer effects, regulation effects, social norms
  - consistently found in the literature including experimental

Kirakozian (2016) Bruvoll and Nyborg (2004), Brekke, Kverndokk and Nyborg (2006), Abbott (2013), Guerin et al. (2001), Hage et al. (2009), Brekke et al. (2010), Halvorsen (2008), Tankard and Paluck (2016), Nyborg et al. (2016), Fishbacher et al. (2001), Croson et al.(2005), Krupka and Weber (2013)

Social norms as equilibrium outcome

- We can not simply relate observed behavior to the observed average behavior (social norm) in an econometric model
- Network links have been formed potentially in part due to the studied effect $\rightarrow$ potential endogeneity bias.
- Network structure is the outcome of social interaction, interaction between individuals.
- Endogenous network formation!
- Structural equilibrium model stated in terms of individual preferences with equilibrium behavior emerging as part of the solution.

Our contribution: two stage model

- First stage: households *choose* their social environment by selecting into residential communities
- Social network is based on the residence locations $\rightarrow$ *endogenous formation of social norms*
- Social norm $\equiv$ average effort exerted by all residents
- Locations also *differ* in recycling facilities and other amenities to reflect the *cost of effort*
- Second stage: households decide how much effort to exert in recycling $\rightarrow$ aggregate behavior emerges

- Empirical application: recycling behavior in Sweden

Related Literature on Social Networks

1. Models with exogenous (fixed) networks
    - Relatively simple to use in empirical analysis
    - Suffer from endogeneity of the network structure

    1.1 Local aggregate models
    The effect of the peers in the network is cumulative, i.e. the sum of the actions of the peers matters

    - Ballester et al. (2010) on criminal network; Helsley and Zenou (2014) on interaction in cities

    1.2 Local average models $\ni$*this paper*
    The effect of the peers is averaged out, i.e. the average of the actions of the peers matters

    - Ushchev and Zenou (2018) on tech adoption; Boucher et al. (2024) on peer effects

2. Models with endogenous networks $\ni$*this paper*
    - Solid, but harder to implement and analyze

    - Kinateder and Merlino (2017); de Paula (2020) survey

The Model

Locations

- $i \in \{1, ..., n\}$ index of the locations, n locations in total
- r_i marginal recycling cost at location i
  (proxied by distance to recycling station)
- a_i net utility of living at location i
  (amenities, other than recycling-related)

Individuals

- $s \in [s_{min}, s_{max}]$ individual intrinsic propensity to recycle, absolutely continuously distributed over $[s_{min}, s_{max}]$
- $p(s)$ pdf of s, continuously differentiable on (s_{min}, s_{max})

Optimal recycling behavior results in

- $y_i(s)$ s-individuals' *equilibrium* recycling effort at location i

Preferences

$$U_i(s,\epsilon_i) = \underbrace{a_i}_{\text{amenity}} \underbrace{-\frac{1}{2}\left[y_i(s) - \widehat{y}(s,r_i)\right]^2}_{\text{identity effect}} \underbrace{-\frac{\phi}{2}\left(y_i(s) - \overline{y}_i\right)^2}_{\text{conformity effect}}$$

$$\underbrace{+\,\theta y_i(s)\overline{y}_i}_{\text{spillover effect}} \underbrace{-\,\alpha\Psi\left(\mathcal{M}_i\right)}_{\text{congestion effect}} + \gamma\epsilon_i$$

- $U_i(s)$ direct utility level at location i dependent on equilibrium spatial distribution $(\mathcal{M}_1, \ldots, \mathcal{M}_n)$ and $(\bar{y}_1, \ldots, \bar{y}_n)$
- $\hat{y}(s, r_i) = s - r_i$ intrinsic motivation recycle for location i
- $\bar{y}_i$ social norm, average recycling effort at i
- $\phi \geq 0$ taste for conformity, $\theta < 1$ spillover coefficient.

Preferences

$$U_i(s,\epsilon_i) = \underbrace{a_i}_{\text{amenity}} \underbrace{-\frac{1}{2}\left[y_i(s) - \widehat{y}(s,r_i)\right]^2}_{\text{identity effect}} \underbrace{-\frac{\phi}{2}\left(y_i(s) - \overline{y}_i\right)^2}_{\text{conformity effect}}$$

$$\underbrace{+\,\theta y_i(s)\overline{y}_i}_{\text{spillover effect}} \underbrace{-\,\alpha\Psi\left(\mathcal{M}_i\right)}_{\text{congestion effect}} +\gamma\epsilon_i$$

- $\epsilon = (\epsilon_1, \ldots, \epsilon_n)$ idiosyncratic preference for living at location i, EV1, i.i.d. across individuals and locations, independent of s
- γ is scale parameter
- $\alpha > 0$ marginal disutility of agglomeration
- $\Psi\left(\mathcal{M}_i\right)$ local externalities, for example, pollution, congestion, crime, etc. Assume $\Psi_i'(\cdot) > 0$ and $\Psi_i(0) = 0$, i.e. $\Psi_i(\mathcal{M}) = (\mathcal{M})^{\psi_i}$

Spatial distribution

- $\mu(i|s)$ probability for individual s to reside in location $i = 1, ..., n$

$$\sum_{i=1}^{n} \mu(i|s) = 1 \text{ for all } s$$

- $\mathcal{M}_i$ unconditional share of individuals at location $i = 1, ..., n$

$$\mathcal{M}_i = \int_{s_{min}}^{s_{max}} \mu(i|s) p(s) ds$$

Aggregate behbavior and type

- $\bar{y}_i$ social norm of recycling in location i

$$\bar{y}_i = \frac{1}{\mathcal{M}_i} \int_{s_{min}}^{s_{max}} y_i(s)\mu(i|s)p(s)ds$$

- $\bar{s}_i$ average propensity to recycle at location i

$$\bar{s}_i = \frac{1}{\mathcal{M}_i} \int_{s_{min}}^{s_{max}} s\mu(i|s)p(s)ds$$

Optimal recycling effort (second stage)

- A1: Assume $s_{min} > \max_i\{r_i\}$ to ensure interior solution
- FOC for $U_i(s)$ maximization with respect to $y_i(s)$ leads to *linear-in-means* form

$$y_i(s) = \tfrac{1}{1+\phi}(s - r_i) + \tfrac{\phi+\theta}{1+\phi}\bar{y}_i,$$

- plugging this into the definition of $\bar{y}_i$ gives

$$\bar{y}_i = \tfrac{1}{1-\theta}\big(\bar{s}_i - r_i\big),$$

- and thus we obtain the expression for the equilibrium level of recycling

$$y_i^\star(s) = \tfrac{1}{1+\phi}(s - \bar{s}_i) + \tfrac{1}{1-\theta}(\bar{s}_i - r_i),$$

Indirect utility function

- With equilibrium level of effort $y_i^\star(s)$ at hand, the *indirect utility* at location i for individual s is given by

$$U_i^\star\left(s, \mathcal{M}_i, \overline{s}_i, \varepsilon_i\right) = u_i^\star\left(s, \mathcal{M}_i, \overline{s}_i\right) + \gamma\varepsilon_i,$$

$$\begin{aligned} u_i^\star\left(s, \mathcal{M}_i, \overline{s}_i\right) &= a_i + \frac{\theta}{2(1-\theta)}(s-r_i)^2 + \frac{\theta}{2(1-\theta)^2}\left(\overline{s}_i - r_i\right)^2 \\ &\quad -\frac{1}{2}\frac{\theta+\phi}{(1-\theta)(1+\phi)}\left(s-\overline{s}_i\right)^2 - \alpha\Psi\left(\mathcal{M}_i\right) \end{aligned}$$

- Random utility structure where $u_i^\star\left(s, \mathcal{M}_i, \overline{s}_i\right)$ measures the utility of alternative i for individual s taking as given the aggregate objects $\left(\mathcal{M}_i, \overline{s}_i\right)$

Spatial equilibrium (first stage)

Assuming that ϵ has EV(1) distribution, the choice probability for location i is given by

$$\mu(i|s) = \frac{\exp\left(u_i^\star(s)/\gamma\right)}{\sum_j \exp\left(u_j^\star(s)/\gamma\right)}$$

By definition, a spatial equilibrium is given by a vector

$$\boldsymbol{\mu}^\star(s) \equiv (\mu^\star(1 \mid s), \mu^\star(2 \mid s), \ldots, \mu^\star(n \mid s))$$

such that each agent makes utility-maximizing choices of residential location and recycling effort, taking the actions of the others as given.

How to compute equilibria?

For each s consider the following composite mapping

$$\begin{pmatrix} \mathcal{M}_1 \\ \mathcal{M}_2 \\ \vdots \\ \mathcal{M}_n \\ \bar{s}_1 \\ \bar{s}_2 \\ \vdots \\ \bar{s}_n \end{pmatrix} \xrightarrow{f_s} \begin{pmatrix} u_1^\star(s) \\ u_2^\star(s) \\ \vdots \\ u_n^\star(s) \end{pmatrix} \xrightarrow{g_\gamma} \begin{pmatrix} \mu(1|s) \\ \mu(2|s) \\ \vdots \\ \mu(n|s) \end{pmatrix} \xrightarrow{h_s} \begin{pmatrix} \mu(1|s) \\ \mu(2|s) \\ \vdots \\ \mu(n|s) \\ \mu(1|s)s \\ \mu(2|s)s \\ \vdots \\ \mu(n|s)s \end{pmatrix}$$

Equilibrium mapping

Integrating the collection of such maps over s we have a new map

$$I(\mathcal{M}, \bar{s}) = \int_{s_{min}}^{s_{max}} (f_s \circ g_\gamma \circ h_s)(\mathcal{M}, \bar{s}) p(s) ds$$

With the help of one more mapping

$$\begin{pmatrix} x_1 \\ \vdots \\ x_n \\ y_1 \\ \vdots \\ y_n \end{pmatrix} \xrightarrow{K} \begin{pmatrix} x_1 \\ \vdots \\ x_n \\ y_1/x_1 \\ \vdots \\ y_n/x_n \end{pmatrix}$$

Spatial equilibrium is then given by the fixed point of the equilibirum mapping

$$\varphi = K \circ I$$

Existence and uniqueness

Theorem

1. *Spatial equilibrium as defined above exists*
2. *There exists a threshold* $\overline{\gamma} > 0$ *such that the spatial equilibrium is unique if* $\gamma > \overline{\gamma}$.

Sketch of the proof.

(a) Conditions of Brower's fixed point theorem apply

(b) We show that the Lipschitz constant $L_{\boldsymbol{\varphi}}(\gamma)$ of $\boldsymbol{\varphi}$ satisfies $\lim_{\gamma\to\infty} L_{\boldsymbol{\varphi}}(\gamma) = 0$, hence the set $\{\gamma \in \mathbb{R}_+ : L_{\boldsymbol{\varphi}}(\gamma) < 1\}$ is non-empty.

(c) Hence, $\overline{\gamma} := \inf\{\gamma \in \mathbb{R}_+ : L_{\boldsymbol{\varphi}}(\gamma) < 1\} < \infty$ and $\boldsymbol{\varphi}$ is a contraction mapping for all $\gamma > \overline{\gamma}$

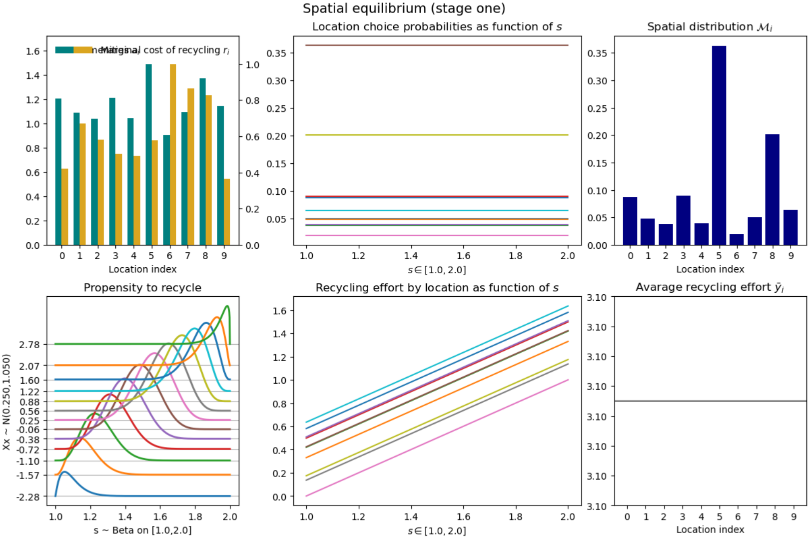
(d) By Banach's contraction mapping principle, $(\boldsymbol{\mathcal{M}}^*, \overline{\boldsymbol{s}}^*)$ is unique, and therefore $(f_s \circ g_\gamma)(\boldsymbol{\mathcal{M}}^*, \overline{\boldsymbol{s}}^*) = \boldsymbol{\mu}^*(s)$ is too

□

Numerical implementation

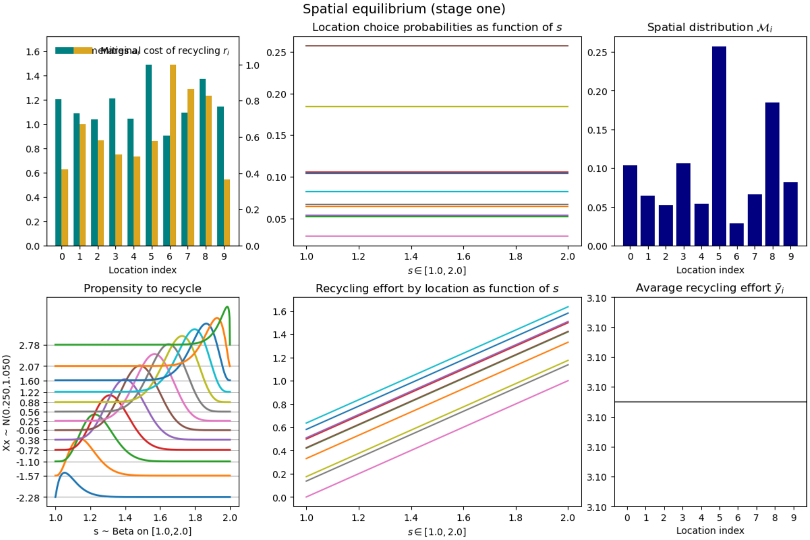
- Computation of a fixed point of a contraction mapping
  1. Successive approximations
  2. Newton-Kantorovich iterations
- Lipschitz constant depends on the parameters
  - In practice around $0.4 - 0.6$ leading to quick convergence
  - $\theta < 1$ is crucial
  - Monitor the value of spectral norm of the Jacobian of the mapping during estimation
- Automatic differentiation with Python JAX

Case 0: Multinomial logit with no social effects



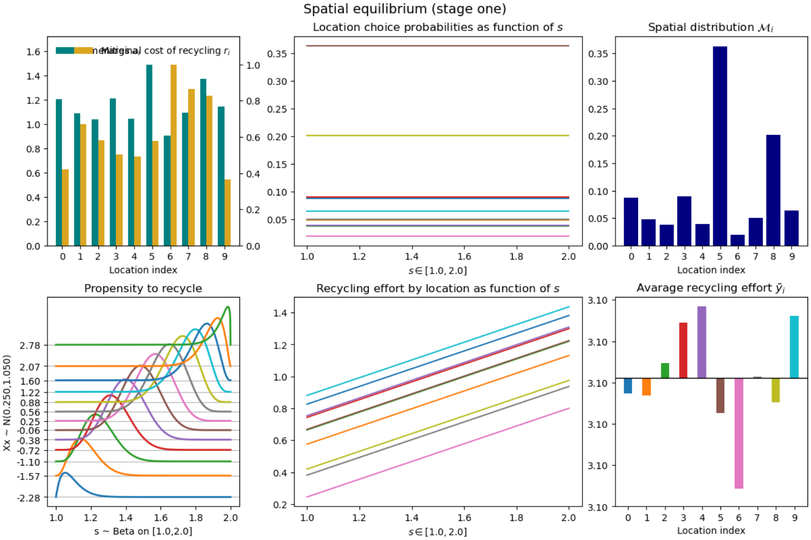
$\phi = \theta = \alpha = 0$: no confirmity, no spillover, no congestion effects

Case 1: adding congestion



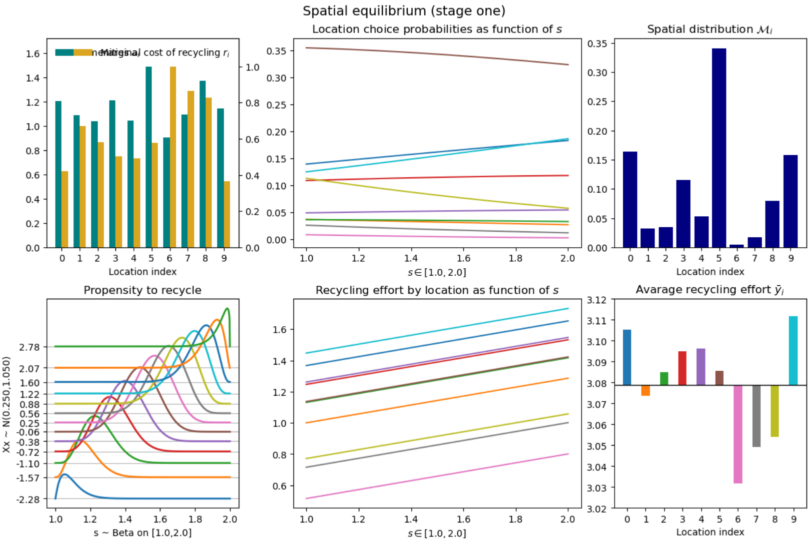
$\theta = \phi = 0$: no spillover, no conformity, but $\alpha > 0$ to add congestion effect

Case 2: adding confirmity



$\theta = \alpha = 0$: no spillover, no congestion, but $\phi > 0$ to add conformity effect

Case 3: adding spillover



$\theta > 0, \phi > 0$: spillover to add conformity effect

Data

1. Individual data
   - Household survey data (collected for OECD, 2011). Info about residential location, recycling rates by material, recycling facilities, and individual data including age, education, income, family size and other environmental preferences.
2. Municipal-level data
   - Average recycling data by municipality (Swedish Waste Management Association)
   - Location data for all the recycling stations in Sweden (Förpacknings och Tidningsinsamlingen company),
   - Statistics Sweden data on other location characteristics. Municipal level variables, such as recycling rates, amenities, population densitiy, average income/age/education level etc.

Location: amenities, cost of recycling, aggregate recycling rates
Individual: location choice, recycling effort, personal characteristics

Does recycling matter for location choice?

Conditional logit estimates of location choice

	(1)	(2)	(3)	(4)
GRDP per employed, 1000SEK	-7.889^{***}	-8.853^{***}	-1.600^{***}	
	(2.028)	(2.214)	(0.310)	
Population density per square km in 2011	0.648^{***}	0.572^{**}	-0.595^{***}	-0.611^{***}
	(0.225)	(0.239)	(0.076)	(0.075)
GRDP per employed $\times$ Years of schooling	0.126	0.147		-0.116^{**}
	(0.126)	(0.137)		(0.050)
GRDP per employed $\times$ Age	0.064^{***}	0.073^{***}		0.008
	(0.021)	(0.023)		(0.015)
GRDP per employed $\times$ Employed	1.474^{**}	1.704^{***}		
	(0.600)	(0.649)		
Population density $\times$ Years of schooling	0.022	0.022		
	(0.014)	(0.014)		
Population density $\times$ Age	-0.004^{*}	-0.005^{*}		
	(0.002)	(0.002)		
Population density $\times$ Employed	-0.070	-0.085		
	(0.067)	(0.071)		
Distance to nearest recycling station (km)		-0.305^{***}	-0.233^{***}	-0.242^{***}
		(0.038)	(0.040)	(0.036)
Population in 2011			0.000^{***}	0.000^{***}
			(0.000)	(0.000)
Land area square km in 2011			-0.000	
			(0.000)	
Observations	289,578	289,578	289,578	289,578

Note: Standard errors in parentheses. ${}^{*}p < 0.1$, ${}^{**}p < 0.05$, ${}^{***}p < 0.01$

Empirical specification

Location:

- amenities $Y \rightarrow a_i = Y\xi_a$
- cost of recycling $\rightarrow r_i$
  (measured as distance to the nearest recycling station)
- aggregate recycling rates $\rightarrow \bar{y}_i$
  (measured as percentage of household waste recycled, scaled)

Individual:

- location choice $\rightarrow$ observed location indicator $l_i^\star \in \{0, 1\}$
- recycling effort $\rightarrow y_i(s)$
- personal characteristics $X \rightarrow X\xi_s$ informs s

Preliminary data analysis to find suitable variables to include into X and Y

Distributional assumptions

- Intrinsic propensity to recycle $s \sim B(a, b)$
  Beta distribution rescaled to $[s_{min}, s_{max}]$
- Parameters a and b are assumed to depend on individual characteristics X

$$a = \frac{\phi_s \exp(X\xi)}{1 + \exp(X\xi)}, \quad b = \frac{\phi_s}{1 + \exp(X\xi)}$$

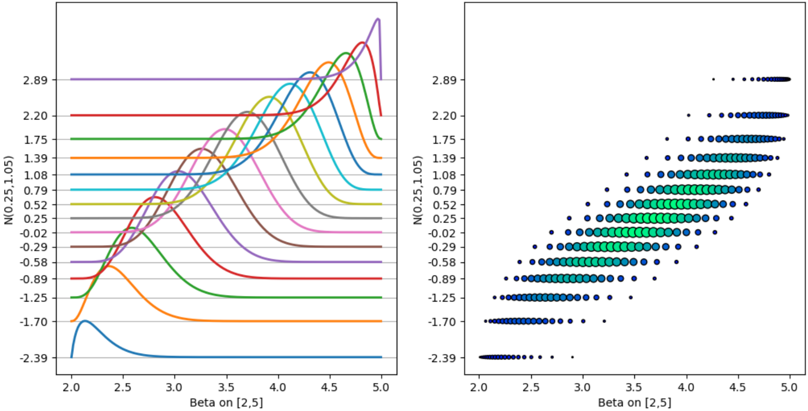
- $\phi_s = a + b$ and ξ are to be estimated
- The moments of the propensity distribution are given by

$$E(s|X) = \frac{a}{a+b} = \frac{\exp(X\xi)}{1 + \exp(X\xi)}$$

$$\text{Var}(s|X) = \frac{ab}{(a+b)^2(a+b+1)} = \frac{1}{\phi_s + 1} \cdot \frac{\exp(X\xi)}{(1 + \exp(X\xi))^2}$$

- ξ control the conditional mean while scale parameter ϕ_s controls only the conditional variance

Conditional quadrature scheme



- Unconditional expectations over $p(s)$ are computed using all quadrature points
- Individual specific expectations conditional on $X\xi_s$ are computed using only the "rows" of quadrature points

Structure of the estimator

- Nested fixed point MLE estimator (NFXP)
  - Inner loop: equilibrium calculation for given values of parameters
  - Outer loop: maximization of the likelihood over parameters
- Mixed data types: likelihood combines contributions from both individual and aggregate data

  Grieco, Murry, Pinkse, Sagl (2022) on demand estimation using both micro and market level data

- Measurement error approach for effort variables
  - Assuming Gaussian errors

Likelihood function

- The location choice probability of a particular household j with characteristics X_j is given by integral over conditional Beta distribution $f_B(s|X_j\xi)$

$$\pi_i(X_j\xi) = \int_{s_{min}}^{s_{max}} \mu(i|s) f_B(s|X_j\xi) ds$$

- Let $d_j \in \{0, 1\}$ denote the binary indicator of whether the household j has been surveyed or not
- Location choice likelihood is given by

$$logL(\theta) = \sum_i \sum_j l^\star_{ij} \big(d_j \log \pi_i(X_j, \theta) + (1 - d_j) \log \mathcal{M}_i(\theta) \big)$$

- We can use the aggregate "unconditional" shares $\mathcal{M}_i(\theta)$ in place of choice probabilities for unsurveyed individuals
- Of course, location choice $l^\star_{ij}$ is not observed when $d_j = 0$...

Likelihood function

- Add and subtract the term $\sum_i \sum_j l^\star_{ij} d_j \log \mathcal{M}_i(\theta)$ to $logL(\theta)$ to get rid of d_j in the aggregate term

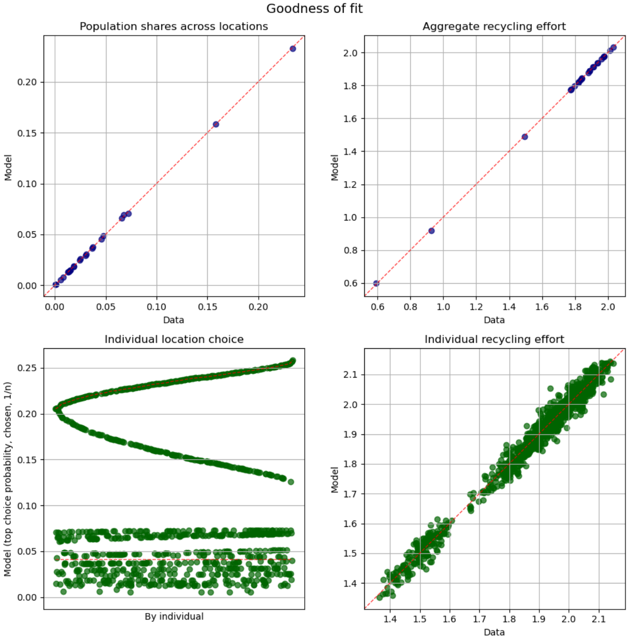
$$\sum_i \sum_j \left(l^\star_{ij} d_j \log \pi_i(X_j, \theta) + l^\star_{ij} \log \mathcal{M}_i(\theta) - l^\star_{ij} d_j \log \mathcal{M}_i(\theta) \right)$$

- Denote the observed population in location i as $m_i = \sum l^\star_{ij}$
- The final form of the likelihood is

$$logL(\theta) = \sum_i \sum_j l^\star_{ij} d_j \log \frac{\pi_i(X_j, \theta)}{\mathcal{M}_i(\theta)} + \sum_i m_i \log \mathcal{M}_i(\theta).$$

- The third and fourth terms are added to include the measurement error contribution of the observed individual and aggregate recycling efforts

Preview of fit dashboard



Policy Implications

We will consider a social planner who seeks to spend a lump-sum amount on environmental issues. What are the better policies to increase recycling?

- Reducing recycling costs uniformly across
  - Transport policy to facilitate commuting
  - Mobile recycling stations
- Reducing recycling costs at particular locations
  - Creating more recycling stations
- Information campaigns
  - Increase conformity effect
  - Increase spillover effect
- Policies aimed changing spatial distribution
  - Housing policy that to reduce the cost of living in some areas

Contribution

Theoretical part

- Novel two stage model with endogenous formation of social networks (norms)
- Equilibrium existence and uniqueness results

Empirical part (in progress)

- Estimation using both individual and aggregate data
- Counterfactual simulations to explore policy space
- Policy comparisons to inform policymakers