Estimation of an equilibrium model with externalities: Post-disaster neighborhood rebuilding
Fu, C. and Gregory, J., 2019

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Environmental Reading Group

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Motivation

- Individuals' decisions are often interrelated. One's choice is affected by the choices of others.
- Examples:
  - New technology adoption.
  - Investment in financial markets.
- **Key question**: How to measure this **spillover effects (externality)**?
- **Why important?** The prediction of policy outcome can be biased if spillover effects are not correctly captured.

This Paper

- The Louisiana Road Home program (RH) that provided financial assistance to homeowners affected by Hurricane Katrina.
- Regression Discontinuity Design (RDD) to identify the spillover effects of the RH program.
- Build a dynamic equilibrium model to capture this spillover effect, and run counterfactual analysis.
  - Partial equilibrium: no spillover
  - General equilibrium: with spillover

Data

- Assessor's property data: time of home repairs & sales; transaction prices. 2004-2010
- Road Home program data: application dates, grant amounts, grant type, cost appraisal, and private insurance payments paid to households.
- FEMA data: damage assessments (depth of flooding).
- 2000 Census data: demographic characteristics of the neighborhood.
- DNORS, ACS: salary and employment data.
- Federal Reserve Bank of New York Consumer Credit Panel/Equifax: neighborhood-level credit scores.

Data are merged by street address: 60175 households living in 4795 blocks.

Summary Statistics (Table 1)

TABLE I

DESCRIPTIVE STATISTICS, HOUSEHOLDS[a]

Variable	All HHs	HHs With Initially Damaged Homes
Demographic composition:		
Percent black (Census block)	57	65
Percent college educated (Census tract)	51	49
Pre-Katrina block flood exposure:		
<2 feet	46	23
2–3 feet	12	16
3–4 feet	11	16
4–5 feet	10	15
5–6 feet	6	9
>6 feet	15	21
Equifax risk score (spatial moving average):		
<600	20	21
600–625	17	18
625–650	17	18
650–675	14	14
675–700	12	9
700–725	10	10
>725	11	9
Home damage and insurance:		
Damage fraction (repair cost ÷ replacement cost)	0.39 (sd = 0.32)	0.58 (sd = 0.21)
Insurance fraction (insurance ÷ replacement cost)	0.23 (sd = 0.21)	0.30 (sd = 0.22)
Importance of Road Home grant formula discontinuity:		
Damage fraction within 2 pct. pts. of RD threshold	4.4	6.6
Road Home participation:		
Nonparticipant	49	36
Rebuilding grant (option 1)	44	55
Relocation grant (option 2 or 3)	6	9
Home repaired by the pre-Katrina owner by year:		
Immediately after Katrina	33	0
1 year after Katrina	42	13
2 years after Katrina	47	21
3 years after Katrina	52	29
4 years after Katrina	65	47
5 years after Katrina	70	54

Two Facts of the Program

(1) There are two types of grant packages:

1. Rebuilding: up to $150,000
2. Relocation: up to $150,000 conditional on turning over the property to the state.

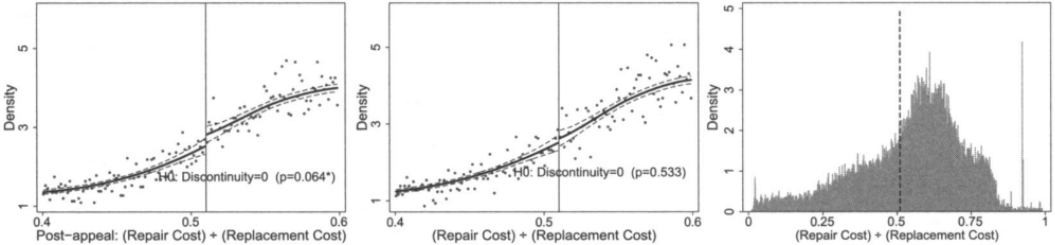
(2) There is a threshold of 51% damage to determine the RH grant.

$$\text{RH Grant} = \begin{cases} \min\left([\textit{RepairCost}] - [\text{Insurance Payout}]; \$150\text{k}\right) \\ \quad \text{if } \dfrac{[\textit{RepairCost}]}{[\text{Replacement Cost}]} < 51\%, \\ \min\left([\text{Replacement Cost}] - [\text{Insurance Payout}]; \$150\text{k}\right) \\ \quad \text{if } \underbrace{\dfrac{[\textit{RepairCost}]}{[\text{Replacement Cost}]}}_{\text{Damage Fraction}} \geq 51\%. \end{cases}$$

A **financial incentive shock** for households just above 51% damage.

Regression Discontinuity Design I

- Validity assumptions: Households cannot perfectly control damage fractions.
- Sample balance: Table 2
- Continuity at 51% in damage appraisal



(a) (b) (c)

Regression Discontinuity Design II

Empirical challenge: identify two effects with one policy shock

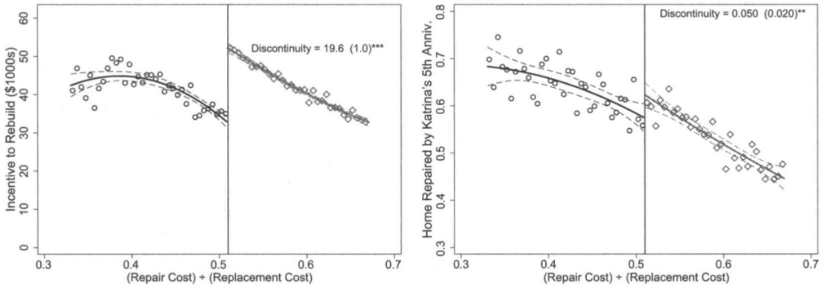
- **Direct effect**: the effect of the RH grant on the household's decision to rebuild.
- **Spillover effect**: the effect of the the rebuilding decisions of neighbors on the households.

Estimation Strategy:

- Group A: households with damage just above 51%
- Group B: households with damage just below 51%
- Group C: neighbors of group A.
- Group D: neighbors of group B.

- direct effect: A-B
- spillover effect: C-D

Regression Discontinuity Design III



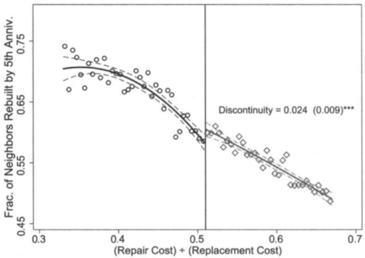
(a) (b)

Direct financial effect:

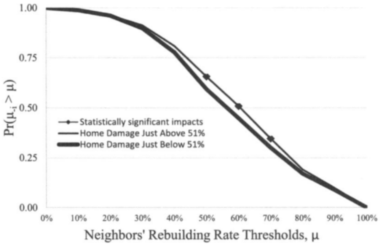
- Figure (a): opportunity cost of relocating increased by $19.6k at the 51% threshold.
- Figure (b): the probability of rebuilding increases by 5% at the threshold.

Regression Discontinuity Design IV

- Spillover effect = 2.7%
- Spillover effect operates primarily for the blocks that have experienced rebuilding rates of 50%-70%.



(a) Neighbors' Rebuilding Rate by Home Damage Fraction



(b) Neighbors' Rebuilding Rate CDF Above/Below Grant Threshold

Model Framework I

- blocks: j, household: i.
- **Dynamic model**: hurricane occurs at year $t = 0$. Households decide to rebuild, relocate, or neither from $t = 1$ to $t = 5$.
- households' per-period utility

$$v_{it}(\mu_{j(i),t}; d_{it}) = \begin{cases} \ln(c_{it}) & \text{if } d_{it} < 1, \\ \ln(c_{it}) + a_{j(i)} + g(\mu_{j(i),t}) + \eta_i & \text{if } d_{it} = 1, \end{cases}$$

  - c_{it}: consumption.
  - $a_j(i) + g(\mu_{i(i),t})$: neighborhood amenities:
    - $a_j(i)$: exogenous constant. $\mu_{i(i),t}$: the fraction of neighbors who have rebuilt.
    - **contribution**: $g(\mu) = \mathbf{S} \times \Lambda(\mu; \lambda)$
  - $d_{it} = 1$: rebuilding. $d_{it} = -1$: relocating. $d_{it} = 0$: neither.

Model Framework II

- Monetary incentives: Mortgage balance, cost/values of houses, cost of repairing/restoring houses, RH grants, insurance payments, wages.
- intertemporal budget constraint:

$$
\begin{aligned}
c_{it} = {} & 1(d_{it}=1)\times w_i^1 + 1(d_{it}<1)\times w_i^0 && \}\ \text{labor earnings} \\
& - 1(d_{it}<1)\times \text{rent}_i - 1(d_{it}>-1)\times \textit{mortgage}_{it} && \}\ \text{flow housing costs} \\
& \left.\begin{aligned} & - 1(d_{it}>d_{i,t-1})\times k_i \\ & + 1(d_{i3}=1 \text{ and } t=3)\times G_{1i} \\ & + 1(d_{it}>d_{it-1} \text{ and } t>3)\times G_{1i} \end{aligned}\right\} && \text{repair costs/reimbursements} \\
& + 1(d_{it}<d_{it-1})\times \max(G_{2i}, p_i) && \}\ \text{home sale proceeds} \\
& + A_{it} - A_{it+1}/R_t && \}\ \text{change in asset holding.}
\end{aligned}
$$

Household Problem: dynamic choice

- V^0: waiting, V^1: rebuilding, V^{-1}: relocating.
- $\mathcal{T}$: endogenous law of motion of rebuilding rate.

At $t \in \{1, 2, \ldots, T\}$, households that have not rebuilt or sold their houses choose to rebuild, sell, or wait, such that

$$V_{it}^{0}(\mu_{j(i),t-1}) = \max \left\{ \begin{matrix} v_{it}(\mu_{j(i),t}; 0) + \beta V_{it+1}^{0}(\mu_{j(i),t}), \\ V_{it}^{-1}(\mu_{j(i),t-1}), \\ V_{it}^{1}(\mu_{j(i),t-1}) \end{matrix} \right\} \tag{10}$$

$$\text{s.t.} \quad \mu_t = \Gamma_{jt}(\mu_{t-1}).$$

Beyond T, rebuilding is not an option, so that $\Gamma_{jt}(\mu_T) = \mu_T$ for all $t > T$ and

$$V_{i,T+1}^{0}(\mu_{j(i),T}) = \max\left\{ V_{it}^{-1}(\mu_{j(i),T}), \sum_{t' \geq T} \beta^{t'-T} v_{it'}(\mu_{j(i),T}; 0) \right\}.$$

Equilibrium

DEFINITION 1: Given $\mu_{j,0}$ and $\mu_t = \mu_T$ for all $t > T$, an equilibrium in community j consists of (i) a set of optimal household decision rules $\{\{d^*_{it}(\cdot)\}_{t=1}^T\}_{i \in I_j}$, (ii) a sequence of period-specific rebuilding rates $\{\mu_{j,t}\}_{t=1}^T$, and (iii) laws of motion $\{\Gamma_{jt}(\cdot)\}_{t=1}^T$ such that:

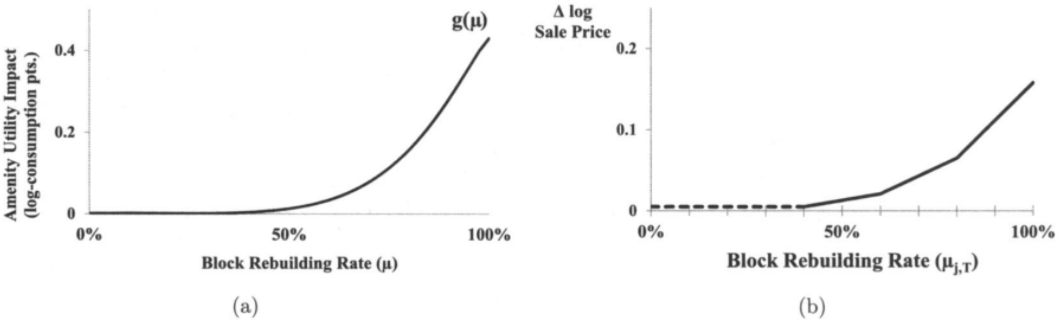
(a) Given $\{\mu_{j,t}\}_{t=1}^T$, $\{\{d^*_{it}(\cdot)\}_{t=1}^T\}_{i \in I_j}$ comprise optimal decisions.

(b) The laws of motion $\{\Gamma_{jt}(\cdot)\}_{t=1}^T$ are consistent with individual choices such that

$$\mu_{j,t} = \Gamma_{jt}(\mu_{jt-1}) = \mu_{jt-1} + \frac{\sum_{i \in I_j} I\left(d^*_{i,t} > d^*_{i,t-1}\right)}{I} \quad \text{for } 1 \leq t \leq T.$$

Results

Full results (Table 3)



- Full rebuilding increases utility by an amount equivalent to a 53% increase in consumption.
- Full rebuilding increases the house sale price by 20%.

Decoposition of the grant effects

TABLE IV

RH'S PARTIAL-EQUILIBRIUM AND EQUILIBRIUM EFFECTS ON REBUILDING[a]

	(1)	(2)	(3)	(4)
		Rebuilding Rate Impacts		
Subgroup	No Grants Rebuilding Rate	Partial Equilibrium Road Home	Equilibrium Road Home	Spillover Multiplier
All	61.7	+6.3	+8.0	1.27
Flood depth:				
<2 feet	76.2	+4.0	+4.5	1.13
2–3 feet	59.7	+10.5	+14.1	1.34
3–4 feet	59.5	+7.9	+11.2	1.42
4–5 feet	46.2	+9.4	+12.6	1.34
5–6 feet	35.6	+7.6	+9.3	1.22
>6 feet	42.4	+6.3	+8.0	1.27
Rebuilding Rate w/o RH:				
90–100%	99.3	+0.1	+0.2	2.00
80–90%	85.1	+3.5	+5.3	1.51
70–80%	75.6	+5.5	+8.8	1.60
60–70%	66.0	+7.4	+11.0	1.49
50–60%	55.1	+8.0	+11.2	1.40
40–50%	45.4	+9.0	+11.8	1.31
30–40%	36.7	+9.7	+11.7	1.21
20–30%	26.2	+10.3	+11.9	1.16
10–20%	16.6	+13.4	+14.7	1.10
0–10%	4.7	+14.7	+14.9	1.01

RH vs. Unconditional Grants

- Rebuilding grant > relocation grant: households' choices are biased, **welfare loss**.
- more rebuilding increases block amenity: **welfare gain**.
- welfare change: $dW_i^{RH} = EV_i^{RH} - (\text{Grant}_i^{RH} - \text{Grant}_i^{Uncon})$

TABLE VI

DECOMPOSING THE WELFARE EFFECTS OF RH'S REBUILDING STIPULATIONS[a]

Group	Marginal (%)	Inframarginal Households ($)	Marginal Households ($)	Total ($)
All	9.1	4950	−24,360	**2177**
<2 feet	4.8	1954	−35,050	**140**
2–3 feet	15.7	12,890	−19,170	**7726**
3–4 feet	13.4	10,010	−18,350	**6133**
4–5 feet	14.8	7384	−21,300	**2988**
5–6 feet	11.0	2894	−26,570	**−475**
>6 feet	9.7	4453	−23,240	**1656**

- No spillover: RH < Unconditional grants.
- With spillover: RH > Unconditional grants.

Optimal Policy

relocation grant = $(1-\rho)*$ rebuilding grant. Given optimal fraction ρ^*,

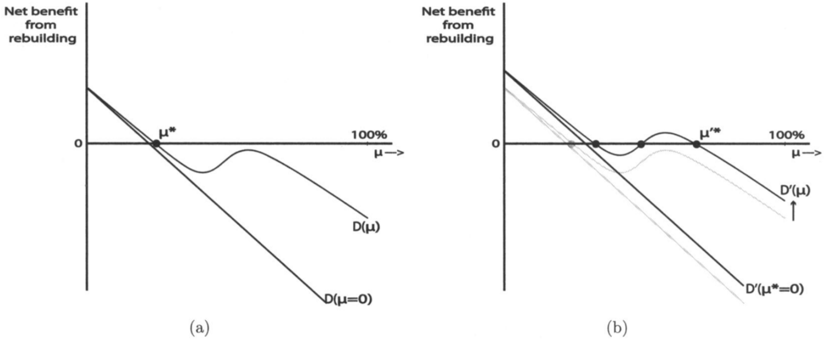
TABLE VII

THE WELFARE CONSEQUENCES OF ALTERNATIVE POLICIES[a]

	(1)	(2) Per Capita	(3)	(4) Aggregate
Policy	Govt. Savings	Δ HH Welfare	Δ Tot. Welfare	Δ Tot. Welfare
Unconditional grants **[reference policy]**	\$0	\$0	\$0	\$0
Category-specific welfare-maximizing ρ^*:				
City is one category (uniform policy)	\$9593	−\$6945	\$2648	+\$159M
Categories based on block demographics	\$9555	−\$6618	\$2936	+\$177M
Categories based on $t=0$ damage-%	\$9111	−\$6022	\$3090	+\$186M
Categories based on flood depth	\$8342	−\$4731	\$3611	+\$217M
Categories based on $t=0$ damage-%, and flood depth interactions	\$7047	−\$2980	\$4066	+\$244M
Perfect block-level targeting	\$3951	\$2048	\$6000	+\$361M

Tipping I

Multiple equilibria could exist, and policy can intervene to restrict the choice set.



Tipping II

TABLE V

NEIGHBORHOOD TRAITS, REBUILDING RATE IMPACTS, AND WELFARE IMPACTS BY NUMBER OF EQUILIBRIA

	Group 1: Unique	Group 2: Multiple
A. Neighborhood Characteristics		
Pre-Katrina block flood exposure:		
<2 feet	51	16
2–3 feet	10	24
3–4 feet	9	23
4–5 feet	9	14
5–6 feet	7	3
>6 feet	14	19
Demographic composition:		
Percent black (Census block)	55	67
Percent college educated (Census tract)	52	47
Equifax risk score (spatial moving average):		
<600	18	22
600–625	16	21
625–650	17	17
650–675	14	15
675–700	13	6
700–725	10	8
>725	12	10
Percent of replicated blocks	84.0	16.0
B. RH Rebuilding Impacts		
No grants Rebuilding Rate	62.1	58.0
Partial Eqm. RH Impact	+5.9	+8.7
Equilibrium RH Impact	+6.3	+16.6
Multiplier	1.07	1.92
C. RH Welfare Impacts		
Equilibrium RH Impact (per capita)	$627	$8602

Take aways

- This paper proposes a dynamic equilibrium model to capture the spillover effects.
- Including spillover effects will result in different policy predictions.