Optimal Subsidies in an Equilibrium Model with Externalities*

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Abstract

We study the problem of optimally targeting subsidies when the decisions of individual recipients impose externalities on others. In particular, we develop a structural equilibrium model of post-disaster rebuilding when neighborhoods’ amenity values are directly affected by the rate of rebuilding. We estimate and identify the structural parameters of the model via indirect inference, exploiting a discontinuity in the formula for determining the size of grants for rebuilding in New Orleans after Hurricane Katrina, which helps isolate the causal effect of additional nearby rebuilding on households’ rebuilding choices. We find that one household choosing to rebuild significantly increased the probability of nearby neighbors rebuilding. Counterfactual policy experiments find that total-welfare-maximizing subsidy policies bias grant offers against relocation, but the optimal degree of bias decreases with the severity of damages from the disaster.

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1 Introduction

Individuals’ choices are sometimes inevitably and endogenously inter-related due to spillover effects from one individual’s choices on to others’ choice-specific payoffs. Amenity spillovers in urban settings, where one household’s effort to maintain its property can affect the attractiveness of a neighborhood, are one typical example of this phenomenon. Understanding the nature of spillovers is key to the optimal design of many policies.\(^1\) As one example, government disaster relief packages in the U.S. regularly include grants to individual property owners, the amount of which is often substantially higher if one rebuilds in one’s pre-disaster location than if one does not. Since individuals often do not internalize the spillover effects of their own decisions, equilibrium rebuilding rates may be inefficiently low without these location constraints. However, the precise extent to which grants should be tilted toward rebuilding requires depends on the value of any amenity improvements from increased rebuilding relative to the excess burden associated with distorting privately optimal resettlement choices.

Essential as they can be for well-informed policy designs, the nature of the spillover effects is often hard to identify.\(^2\) Furthermore, identification of social interactions alone is often not sufficient for policy analysis. Predicting the impacts of alternative counterfactual policies on equilibrium outcomes requires a unified framework for understanding both the factors that shape private choices and the way private choices spillover onto others’ choices in equilibrium.\(^3\) In this paper, we develop such a unified framework.

We develop an equilibrium model of neighbors’ post-disaster rebuilding and location choices that embeds amenity spillovers. Households have private preferences for consumption and for residing in their home and derive utility from a neighborhood amenity that depends on the fraction of neighbors who rebuild. In each period, households who have not yet rebuilt decide whether or not to do so. Households’ rebuilding decisions are inter-related because of amenity spillovers, the shape and scale of which is embedded in the structure of the model. An equilibrium requires that such decisions are best responses to each other.

We apply our model to the rebuilding and relocation decisions made by households affected by Hurricane Katrina. We estimate our model using administrative microdata from

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\(^{1}\) For instance, negative spillovers from home foreclosures are a commonly cited motivation for subsidized mortgage modifications (Cambell, Giglio, Pathak, 2010). And arguments against rent controls often cite the possibility that undermaintained properties reduce the value of nearby non-controlled properties (Autor, Palmer, and Pathak, 2012).

\(^{2}\) Manski (1993) raises the so-called reflection problem. Brock and Durlauf (2007) show that point identification of social interactions can fail even when there is no reflection problem in settings where important group-level variables are not observed by the researcher.

\(^{3}\) In an ideal world, carefully designed random experiments can help conquer these obstacles, although with substantial cost.
the Louisiana Road Home program (RH), which offered rebuilding grants and less generous net relocation grant packages to all Katrina-affected homeowners in the state with uninsured losses. The RH grant formula yielded significantly larger grant offers when an index measuring the extent of home damages fell above a particular threshold. As a result, otherwise similar households with index values just above/below this threshold faced greatly different financial incentives to rebuild. We exploit this program artifact as a source of identification of our structural equilibrium model.

Our estimates suggest that RH’s full equilibrium impact, including “feedback” effects from positive amenity spillovers, are XXX times as large as the impact generated by the program’s financial incentives alone (holding amenities fixed). The spillover effects are not sufficient to justify the particular conditional grant policies used by RH, which offered less generous grant packages to households who did not rebuild. In counterfactual simulations, we find that average household welfare among homeowners city-wide would have been $3,147 higher had RH offered the same rebuilding grant to households who chose to rebuild and households who chose to relocate.

Given that non-trivial externalities from rebuilding exist, alternative conditional grant policies may still be welfare-improving relative to an unconditional grant policy. We examine this possibility by exploring a particular group of conditional grant policies, which offer a fraction \((1 - \rho)\) of the RH rebuilding grant to households if they choose to relocate without requiring them to turn over their properties. We search for the optimal \(\rho\)’s given different constraints. We find that, compared to the case under the unconditional grant policy, average household welfare would improve by $169 if \(\rho\)’s are restricted to be the same for all households, by $184 if \(\rho\)’s can differ based on flooding severity and by $475 if \(\rho\)’s are allowed to be household-specific. Given that a household receives a lower grant if it relocates than if it rebuilds, compared to the unconditional grant policy, these conditional grant policies not only improve household welfare but also involve lower government spending.

While the broader literature on social interactions and “neighborhood effects” has established results for the identification of social interactions in many frameworks and with many combinations of identifying assumptions, confounding factors such as endogenous selection into neighborhoods and unobserved neighborhood level covariates often present practical obstacles to the point identification of causal spillover effects with purely observational data (e.g., Brock and Durlauf 2007). Brock and Durlauf (2003) and Brock and Durlauf (2007) provide methods for identification of social interactions in discrete choice models with endogenous group formation that involve modeling the process of selection into groups to generate selection corrections, and Brock and Durlauf (2007) demonstrate partial identification of social interactions from observational data in discrete choice models with unobserved
neighborhood-level covariates. Bayer and Timmins (2007) propose an instrument for peers’ behavior based on exogenous location characteristics and the structure of a formal location choice demand model as the basis of an IV approach to identifying spillovers in the presence of unobserved location traits.

Our work relates directly to a growing literature that identifies neighborhood spillover effects by exploiting natural experiments and actual experiments that generate exogenous variation in neighborhood characteristics. Our estimates are consistent with evidence from the reduced-form literature that policies stimulating investment in housing, such as the removal of rent controls (Autor, Palmer, and Pathak 2012) or the introduction of revitalization subsidies (Rossi-Hansberg, Sarte, and Owens 2010), boost the value of nearby homes not directly affected by the policies, presumably because of housing investment externalities. Similarly, studies of the contagion effects of “forced” home sales and foreclosures find modest negative spillover effects that are larger for more proximate homes (Campbell, Giglio, and Pathak 2011; Harding, Rosenblatt, and Yao 2009). Galiani, Murphy, and Pantano (2012) use the experimentally randomized variation in neighborhood-specific financial incentives from the Moving to Opportunity (MTO) demonstration to identify the structural parameters of an individual neighborhood choice model (without social interactions).

Also closely related to our paper are studies on social interactions in a structural model framework. For example, de Paula (2009) studies inference in a continuous time model where an agent’s payoff to quit an activity depends on the participation of other players. We study neighbors’ inter-related choices of the timing of rebuilding, which resembles a discrete time analog of the model in de Paula (2009). Our paper combines the strength of the literature on quasi-experiments and that on structural social-interaction models. It embeds the quasi-experimental variation in our structural model to estimate the shape and strength of social spillovers.

This paper is also related to the narrower literature studying the post-Hurricane Katrina locations, labor market outcomes, and wellbeing of displaced New Orleans residents (Groen and Polivka, 2010; Zissimopolous and Karoly, 2010; Vigdor, 2007 and 2008; Paxson and Rouse, 2008; and Elliott and Pais, 2006). The present paper relates most closely to Gregory (2014), which estimates a structural individual decision model of New Orleans homeowners’ resettlement choices. Gregory (2014) uses the estimated model to study the optimal overall

\textsuperscript{4}See Blume, Brock, Durlauf, and Ioannides (2010) for a comprehensive review of the literature on the identification of social interaction effects.

\textsuperscript{5}Recent work by Anenberg and Kung (forthcoming) finds evidence that the negative effect of foreclosures on nearby home transaction prices is attributable more to supply-side competition (more homes on the market) than to a direct disamenity effect.

\textsuperscript{6}Kling, Liebman, and Katz (2007) provide experimental estimates from the MTO demonstration of neighborhood effects on a host of child and adult outcomes.
generosity of post-disaster bailouts for balancing their short run insurance benefits against
the long run efficiency losses caused by expected future bailouts distorting households’ loca-
tion choices (moral hazard). The individual level model is well suited for quantifying that
trade-off, which depends mainly on households’ ability to smooth consumption in the ab-
sence of bailouts and on the elasticity of location choices with respect to private financial
incentives. This paper asks a different question: Conditional on offering post-disaster grants,
should they be targeted to encourage rebuilding in the pre-disaster location? The answer to
this question depends critically on the nature of spillover effects from individual households’
rebuilding choices and households’ interactions in equilibrium.

The rest of the paper is organized as follows: Section 2 provides additional policy back-
ground. Section 3 describes the structural equilibrium model. Section 4 describes estimation.
Section 5 describes our dataset. Section 6 describes our reduced reduced form estimates and
estimates of the model’s structural parameters. Section 7 describes the results of counter-
factual experiments, and section 8 concludes.

2 Additional Background Information

Hurricane Katrina struck the U.S. Gulf Coast on August 29, 2005. In the days following
the storm’s initial impact, the levees that protect New Orleans gave way in several places,
allowing flood waters to cover roughly 80% of the city (McCarthy et al., 2006). The storm
and subsequent flooding left two thirds of the city’s housing stock uninhabitable without
extensive repairs, the costs of which significantly exceeded insurance payouts for most pre-
Katrina homeowners in New Orleans. Among the nearly 460,000 displaced residents, many
spent a considerable amount of time away from the city or never returned.

In the months following Hurricane Katrina, Congress approved supplemental relief block
grants to the Katrina-affected states.7 Possible uses of these grants were hotly debated,
with proposals ranging from mandated buyouts that would have effectively closed some
neighborhoods to universally subsidized reconstruction. The state of the Louisiana chose
to use its federal allocation to create the Louisiana Road Home program, which provided
cash grants for rebuilding or relocating to pre-Katrina Louisiana homeowners with uninsured
damages.

A participating household could accept its RH grant as a rebuilding grant or as a reloca-
tion grant. Both grant types provided compensation equal to the “value of home damages”

7Congress has regularly provided large Community Development Block Grants to local and state govern-
ments to assist with disaster recovery. Localities typically have considerable discretion over the use of these
grants.
minus the value of any insurance payouts already received. Grants were capped at a maximum of $150,000. RH applied a discontinuous rule for deciding which of two methods to use for “valuing” damages in households’ grant calculations. Our identification strategy relies on this program artifact, which we embed directly in the structure of our equilibrium model.

There were several important differences between rebuilding and relocation grants. While both provided the same cash payout, relocation grant recipients were required to turn their properties over to a state land trust. For households with partial home damages, this stipulation introduced a sizable opportunity cost to relocating. Rebuilding grant recipients signed covenant agreements to use their grants for rebuilding and to not sell their homes for at least three years. We provide additional details below on the incentive effects of these program rules and differences in these incentives on either side of the grant formula discontinuity.

Grant recipients often experienced lengthy delays between initiating their grant applications and receiving a grant. RH was announced in February, 2006, but the median grant payment date occurred after Katrina’s second anniversary in 2007. Our equilibrium model captures the timing of the program’s rollout. Despite the program’s slow rollout, RH had disbursed nearly ten billion dollars to Louisiana homeowners by Katrina’s fifth anniversary.

3 Model

We consider a model in which displaced households (homeowners) make dynamic decisions about moving back to (and rebuilding) their pre-Katrina home. In every period, a household that has not moved back or sold its property can choose to move back and rebuild, or to sell the property, or to wait until the next period. Each household’s decision potentially influences the block’s attractiveness, a spillover effect that is not internalized by individual households. The model incorporates the following factors that influence a household’s net payoff to rebuilding: (i) the cost of home repairs relative to other non-repair options, (ii) household’s labor market opportunities in and out of New Orleans, (iii) the strength of the household’s idiosyncratic attachment to the neighborhood, (iv) the exogenous state of the neighborhood (the extent of flood damages, infrastructure repairs, etc.), and (v) the influence of neighbors’ rebuilding choices on the attractiveness of the neighborhood.

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8Moving back and rebuilding are defined as one indivisible action.
3.1 Primitives

There are $J$ communities/blocks, each of which is a closed economy. There are $I$ households living in different communities. Let $j(i)$ be the block household $i$ belongs to, and $I_j$ be the set of households living in $j$. Time $t$ starts from $t = 0$ when Hurricane Katrina occurs. Each household lives forever but has the option to rebuild each period only from 1 to $T$, where each period is one year. Households differ in their housing-related costs, labor market opportunities, levels of attachment to their community and accesses to credit. All information is public among neighbors.

3.1.1 Monetary Incentives

Housing-Related Costs Several housing-related costs and prices influence the financial consequences of each of the three options (rebuilding, staying away and selling); 1) $i$’s remaining mortgage balance when Katrina occurred ($M_i \geq 0$); 2) the cost/value of the pre-Katrina physical structure of $i$’s house ($p^s_i$) (superscript $s$ for structure); 3) the cost of repairing/restoring the house from it’s damaged state ($k_i \leq p^s_i$); 4) the market value of the property (the damaged house and the land) if sold privately $p_i$, 5) the value of insurance payments received ($\text{ins}_i \leq k_i$); and 6) the additional incentives created by RH.

If household $i$ has yet to rebuild entering period $t$, the household may return and reside on the block in period $t$ by paying a one time repair cost $k_i$ at the beginning of period $t$. Households who rebuild are reimbursed for uninsured damages by a RH (option 1) grant $G_{1i} = \min(150,000, k_i - \text{ins}_i)$. Reflecting RH’s slow rollout, grants are dispersed at $t = 2$ if repairs occurred earlier and are dispersed at the time repairs occur otherwise.

For each period that it resides away from its pre-Katrina block, a household rents accommodation comparable to its pre-Katrina home at a cost of $\text{rent}_i = \delta \times p^s_i$, where $\delta$ is the user cost of housing. The household can sell its property either through RH (option 2) for a price $G_{2i}$ or privately for a price $p_i$. The private sales price, as we specify later, depends on the replacement cost of the structure ($p^s_i$), its damage ($k_i$), neighborhood characteristics, and, as in for example Bayer and Timmins (2005), the neighborhood’s rebuilding rate $\mu_j$.\footnote{Bayer and Timmins (2005) study a model of spillovers in which the fraction of neighbors taking the relevant action enters individuals utility linearly, a linear-in-means assumption. We follow Bayer and Timmins (2005) by assuming that spillovers depend on the fraction of neighbors who rebuild, but we allow individual utility to be an arbitrary continuous function of the rebuilding rate, a weaker nonlinear-in-means assumption.}

Labor Market Opportunities Households differ in their human capital levels ($h_i$). Let $r^1$ and $r^0$ represent rental rates of human capital in and out of New Orleans. A household

\footnote{It will be interesting to embed our model into a general equilibrium framework that treats the whole region as one economy. We leave this extension for future work.}
with human capital levels \( h_i \) faces the following wages,

\[
u_i^l = r^l h_i, \text{ for } l = 0, 1.
\]

### 3.1.2 Household Preferences

A household derives utility from consumption \((c)\), neighborhood amenities, and an idiosyncratic taste for a place. The values of the last two components are normalized to zero for the outside option. The (relative) value of amenities in community \( j \) consists of an exogenous part \( a_j \) and an endogenous part that depends on the fraction \((\mu_j)\) of neighbors who rebuild. Households differ in their attachment to their community \((\eta_i)\), which stands for their private non-pecuniary incentives to return home.

Household \( i \)'s per-period utility payoffs are characterized by,

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

where \( d_{it} = 1 \) if household \( i \) has chosen to rebuild by period \( t \), \( d_{it} = -1 \) if \( i \) has sold its house by time \( t \), and \( d_{it} = 0 \) if neither is true. \( \mu_j(i,t) \in [0, 1] \) is the fraction of neighbors who have rebuilt by time \( t \), and \( g(\mu) \) is a non-decreasing function governing the amenity spillovers.\(^{11}\)

**Remark 1** Notice that \( d_{it} \) represents one’s status at time \( t \); one’s action at time \( t \) is reflected by a change in \( d_{it} \) relative to \( d_{it-1} \). Moreover, since the only feasible changes in \( d_{it} \) over time are \( 0 \to 1 \) or \( 0 \to -1 \), \( d_{it} > d_{it-1} \) is equivalent to rebuilding in period \( t \); and \( d_{it} < d_{it-1} \) is equivalent to selling in period \( t \).

### 3.1.3 Intertemporal Budget Constraint/Financing Constraints

The household intertemporal budget constraint is given by

\(^{11}\)A non-decreasing spillover function rules out crowding effect, which is reasonable in our framework as the number of residents will not exceed the pre-disaster equilibrium level.
\[ c_{it} = \begin{cases} 1(d_{it}=1) \times w_i^1 + 1(d_{it}<1) \times w_i^0 \quad & \{ \text{labour earnings} \\ - 1(d_{it}<1) \times \text{rent}_i - 1(t \leq T \text{ or } d_{it}=1) \times \text{mortgage}_{it} \quad & \{ \text{flow housing costs} \\ - 1(d_{it}>d_{it-1}) \times k_i \\ + 1(d_{i3}=1 \text{ and } t=3) \times G_{1i} \\ + 1(d_{it}>d_{it-1} \text{ and } t>3) \times G_{1i} \\ + 1(d_{it}<d_{it-1}) \times \max(G_{2i}, p_i) \\ + A_t - A_{t+1}/R_t \quad & \{ \text{change in asset holding} \end{cases} \]

The first line gives one’s labor income, depending on whether one lives in or out of New Orleans, where \( 1(\cdot) \) is the indicator function. The second line is the flow housing cost, which equals the rent cost if one lives outside of the city and the mortgage payment if one has moved back. The next line is the one-time repair cost one incurs if one rebuilds in this period \((d_{it} > d_{it-1})\). The next two lines summarize the grant one gets for rebuilding. If one rebuilds at year \( t \leq 3 \), i.e., one has rebuilt by time \( t = 3 \) \((d_{i3} = 1)\), one can only obtain the grant at time \( t = 3 \) due to the delay in grant payment. If one rebuilds \((d_{it} > d_{it-1})\) at time \( t > 3 \), one obtains the grant at \( t \). The second last line represents the event of one selling his property \((d_{it} < d_{it-1})\). It is trivial that one will choose the better option between selling to RH and selling privately, hence obtaining \( \max \{G_{2i}, p_i\} \). Finally, one can also change his asset holding at interest rate \( R_t \), with the restriction that

\[
A_t \geq \begin{cases} 0 & \text{if } \text{risk}_i < \rho^* \\ -\infty & \text{if } \text{risk}_i \geq \rho^* \end{cases},
\]

where \( \text{risk}_i \) is household \( i \)'s Equifax credit risk score \( \text{risk}_i \), which affects its access to credit. Households with risk scores above a threshold \( \rho^* \) may borrow to finance home repairs, and households with risk scores below \( \rho^* \) are ineligible for loans.

**Property Sales Price** Private sales price \( p_i \) is endogenous and affected by the equilibrium neighborhood rebuilding status, such that

\[
\ln(p_i) = P(p_i^e, k_i, z_{j(i)}, \mu_{j(i),T}) + e_i.
\]
The sales prices contain three parts. The first part is the physical value, which depends on the house’s pre-Katrina physical structure cost \( p^s_i \) and its damage status captured by \( k_i \), the cost of the repairs needed to fully restore the structure. The second part is the amenity value, which depends both on exogenous observable block characteristics captured by the vector \( z_j(i) \), and on the endogenous block rebuilding rate \( (\mu_j(i), T) \). The final part is a random error term \( e_i \). We use the final rebuilding rate \( \mu_j(i), T \) as a determinant of the price to capture the idea that house buyers are forward looking and care about the future amenity in the neighborhood.\(^\text{12}\)

### 3.2 Household Problem

We model both rebuilding and selling one’s property as absorbing states. In every period, a household that has done neither \( (d_{it-1} = 0) \) can choose to move back and rebuild so that \( \{d_{it'}\}_{t' > t} = 1 \), or to sell the property so that \( \{d_{it'}\}_{t' > t} = -1 \), or to wait until the next period so that \( d_{it} = 0 \).

Given the fraction of households who have rebuilt by the end of last period \( (\mu_j(i), t-1) \), the value of discounted (at rate \( \beta \)) remaining lifetime utility for households who have already rebuilt at the beginning of period \( t \) is,

\[
V_{it}^1 (\mu_j(i), t-1) = \sum_{t' \geq t} \beta^{t'-t} \ v_{it'} (\mu_j(i), t'; 1),
\]

\[\text{s.t. } \mu_{t'} = \Gamma_{jt'}(\mu_{t'-1}) \text{ for all } t' \geq t.\]  

where \( \Gamma_{jt}(\mu) \) is the endogenous law of motion for \( \mu \).

The value of discounted remaining lifetime utility for households who have sold their houses by the beginning of period \( t \) is,

\[
V_{it}^{-1} (\mu_j(i), t-1) = \sum_{t' \geq t} \beta^{t'-t} \ v_{it'} (\mu_j(i), t'; -1).\]  

At each period \( t \in \{1, 2, .., T\} \), households that have not rebuilt or sold their houses make their decisions after observing the fraction \( \mu_j(i), t-1 \) of neighbors who had already moved back back\(^\text{12}\)A more flexible specification will allow the price to be period-specific and to depend on all future rebuilding rates (e.g., price at time \( t \) depends on \( \{\mu_j(i), t'_{t'=t}\}^T \)). However, this may make the incentive to move back non-monotone over time, leading to great complications in solving the model. Given that our focus is not on the housing market, we leave this flexible specification for future work.
by period $t - 1$. The value function for such a household is

$$
V_0^0 (\mu_{j(i), t-1}) = \max \left\{ \begin{array}{c}
v_{it} (\mu_{j(i), t}; 0) + \beta V_0^0 (\mu_{j(i), t}) , \\
V_{i-1}^1 (\mu_{j(i), t-1}) , \\
V_{i-1}^1 (\mu_{j(i), t-1}) \end{array} \right\}
$$

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

Households who have not rebuilt by time $T$ are assumed to derive the outside-option utility from then on, so $\Gamma_{jt} (\mu_T) = \mu_T$ for all $t > T$, and

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

**Remark 2** Notice that the fraction of neighbors who rebuild $\mu_j$ affects both the utility associated with rebuilding and the price at which a home can be sold privately. As such, depending on the relative magnitudes of the two effects and on their interactions with household private incentives, it is possible that an increase in $\mu_j$ could increase the incentive to rebuild for some households and reduce that incentive for others.

### 3.3 Equilibrium

**Definition 1** Given the terminal value functions $\{V_{i,T+1} (\cdot)\}_{i \in I_j}$, an equilibrium in community $j$ consists of (i) a set of optimal household decision rules $\{d^*_it(\cdot)\}_{t=1}^T$ for all $i \in I_j$, (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 $\{\mu_{j,t}\}_{t=1}^T$ and $\{\Gamma_{jt}(\cdot)\}_{t=1}^T$, $\{d^*_it(\cdot)\}_{t=1}^T$ comprise optimal decisions.

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

$$
\Gamma_{jt} (\mu_{t-1}) = \mu_{t-1} + \frac{\sum_{i \in I_j} I(d_{it}^* > d_{i,t-1}^*)}{I} \text{ for } t \leq T,
$$

(c) Equilibrium rebuilding rates $\{\mu_{t}\}_{t=1}^T$ follow that law of motion, such that,

$$
\mu_{j,t} = \Gamma_{jt} (\mu_{j,t-1}) \text{ for all } t.
$$

With social spillover effects, multiple equilibria may exist (from the researcher’s point of view) on any given block. One commonly assumed equilibrium selection rule for empirical applications of equilibrium models is that agents agree on the equilibrium that maximizes
their joint welfare.\textsuperscript{13} We deem this equilibrium selection rule to be a reasonable one in the context of a game among neighbors, and apply this selection rule in our empirical analyses. A necessary step before selecting the equilibrium of interest is to compute all possible equilibria, which is feasible given the structure of our model.

### 3.3.1 Discussion

Even though agents agree on the equilibrium that maximizes their joint welfare given the set of possible equilibria, there can still be room for intervention because the set of equilibria to choose from can be affected by policy changes. For example, a policy change can introduce a new equilibrium with a higher rebuilding rate that would not have been self-consistent otherwise, i.e., a “tipping” phenomenon. As an illustration, the top panel of Figure (1) plots a hypothetical private demand schedule for rebuilding evaluated at the amenity level associated with a 0\% rebuilding rate and the actual marginal benefit curve.\textsuperscript{14} Self-consistent rebuilding rates are the zeros of the latter curve. Tipping is shown in the bottom panel, where a subsidy causes additional higher rebuilding rates to become self-consistent.

In many cases, it is both convenient and perhaps reasonable for researchers to approximate and predict the outcome variable as a smooth function of explanatory variables. With “tipping” being a potential event, such an approach becomes particularly questionable: when “tipping” happens, there will necessarily be a “jump” in the equilibrium outcomes. Modifying the smooth approximation by adding certain discontinuity points may help if one knows the locations (e.g., combinations of community characteristics and policies) and the nature of these jumps, which is unfortunately often infeasible for the purpose of ex ante policy evaluations. Our framework lends itself toward obtaining such knowledge by explicitly modeling and solving for the equilibrium.

### 3.4 Empirical Specification

In the following, we introduce further specifications of the model used in our empirical analysis.

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\textsuperscript{13}For example, Jia (2008) assumes that the data is generated from an extremal equilibrium, one that is most profitable for one player.

\textsuperscript{14}The private demand curve is downward sloping by definition as it is simply a highest-to-lowest ordering of individual households’ net benefits to rebuilding. The actual marginal benefit curve incorporates each additional household’s positive contribution to block amenities and can thus be downward or upward sloping.
3.4.1 Unobservable Components

All information is public in the model, but not all model components are observable to the researcher. At the household level, a household’s occupation \( (o_i) \), human capital \( (h_i) \) and level of attachment to the community \( (\eta_i) \) are unobservable to the researcher. We model the distribution of \( (o_i, h_i) \) as being correlated with observable household characteristics \( x_i \), and distributed as \( H (o_i, h_i | x_i) \). Idiosyncratic home attachment \( \eta_i \) is assumed to be drawn from i.i.d. \( N (0, \sigma^2_\eta) \). Denote the block-specific distribution of household observable characteristics with \( Q_j (x) \).\(^{15}\)

Amenity values are not directly observable to the researcher, and are modeled as

\[
a_{j(i)} = z'_{j(i),t} \gamma + b_j(i),
\]

where \( z'_{j(i),t} \gamma \) captures heterogeneity in amenity values across blocks based on pre-determined block characteristics \( (z) \) that are observable to the researcher, including flood exposure, pre-Katrina demographic composition, and a linear time trend to capture city-wide improvements in infrastructure. \( b_j \sim N (0, \sigma^2_b) \) is a random effect that captures heterogeneity in block amenity values that are not observable to the researcher.

3.4.2 Amenity Spillovers

The amenity spillover function is given by

\[
g(\mu) = S \times \Lambda (\mu; \lambda),
\]

where \( S \) measures the total change in amenity utility associated with a block transitioning from a 0% rebuilding rate to a 100% rebuilding rate. \( \Lambda : [0, 1] \rightarrow [0, 1] \) is the Beta cumulative distribution function, with parameters \( \lambda = [\lambda_1, \lambda_2]' \). \( \lambda_1 \) measures the location of a steeper spillover “threshold” region, and \( \lambda_2 \) measures the steepness of that threshold.\(^{16}\)

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\(^{15}\)For estimation, we stochastically impute a set of exogenous variables to each household using a procedure that exploits the much more detailed information available to us for the approximately 1% of households who completed Displaced New Orleans Residents Survey interviews. Details are in the appendix.

\(^{16}\)The Beta CDF is a convenient choice, because it has support over the unit interval and nests many shapes. For instance \( [\lambda_1, \lambda_2] = [1, 2] \) leads to a spillover function \( g(\mu) = S \times \mu \). By setting \( \lambda_2 \) sufficiently high, this parameterization can generate a spillover function that is arbitrarily close to 0 for \( \mu < \lambda_1 \) and arbitrarily close to \( S \) for \( \mu > \lambda_1 \). Less extreme non-linear functions occur at intermediate values of \( S \).
3.4.3 Rebuilding Load Credit Risk Score Threshold

Our data from Equifax contain spatial moving averages of credit risk scores within 1/4-mile radius buffers, but do not contain individual level risk scores. The within-buffer standard deviation of risk scores is 85, so we model individual risk scores as draws from

\[ risk_i \sim N(\overline{risk}_{buf(i)}, 85) \]

where \( \overline{risk}_{buf(i)} \) is the average risk-score within the 1/4-mile buffer centered around household \( i \)'s block centroid.

4 Data, Policy Details, and Descriptive Analysis

A. Data

The main data for our analysis are the administrative property records of the Orleans Parish Assessor’s Office (Assessor’s property data) and the administrative program records of the Louisiana Road Home grant program (Road Home data). The Assessor’s property data provide information on the timing of home repairs and home sales for the full universe of New Orleans properties. For each property, the data provide annual appraised land and structure values for 2004-2010 (one year before Katrina to five years after Katrina), which we use to infer the timing of home repairs, and the date and transaction price of all post-Katrina home sales.

The administrative program records from the Louisiana Road Home program provide detailed information on the grant amount offered to each program applicant and a record of whether each applicant household chose a rebuilding grant (which required the household to rebuild its home and then not sell for at least three years), a relocation grant (which stipulated that the household to turn its property over to a state land trust with no additional compensation for any as-is value of the property), or chose not to participate. Most important for our regression discontinuity analysis, the data also include all of the inputs to the RH grant offer formula; including a repair cost appraisal for each home, a replacement cost appraisal for each home, and the total value of private insurance payments paid to each household.

We merge the RH data to the Assessor’s property data at the property level by street address. We also obtain measures of the depth of flooding on each Census block from a FEMA-provided data set created from satellite images, and we obtain measure of the demographic composition of each Census block from the 2000 decennial Census. Because our
focus is on spillover effects from homeowners’ rebuilding choices, we exclude homes that were renter-occupied when Katrina occurred and we exclude Census blocks that contained fewer than five owner occupied homes. The resulting dataset contains 60,175 homes/households.

Table 1 presents descriptive statistics for our sample of homeowning households. Less than one third of the sample is from an area that received no flooding, and nearly one third is from areas that received more than four feet of flooding. Private insurance payouts averaged about half of the cost of needed home repairs. More than half of households with damaged homes accepted a RH rebuilding grant, and a similar fraction had completed repairs by Katrina’s fifth anniversary. More than half of the sample is from majority black Census blocks.

B. The RH Grant Discontinuity and Post-Katrina Rebuilding

RH provided grant compensation to households equal to the “value of their home damages” minus the value of any insurance payouts already received.\textsuperscript{17} Our identification strategy exploits the fact that RH applied a discontinuous rule for deciding which of two methods to use for “valuing” damages in households’ grant calculations. Home damages were valued at the cost of component-by-component repairs in cases where the estimated repair cost was 51\% or less of the home’s estimated full replacement cost. Home damages were valued at the full replacement cost in cases where the repair cost was more than 51\% of replacement cost. All grants were capped at $150,000, yielding the grant offer formula,

\[
\text{RH Grant} = \begin{cases} 
\min \left( \frac{\text{RepairCost}}{\text{Replacement Cost}} - \text{Insurance Payout} ; \: \$150k \right) & \text{if } \frac{\text{RepairCost}}{\text{Replacement Cost}} < 51\% \\
\min \left( \text{Replacement Cost} - \text{Insurance Payout} ; \: \$150k \right) & \text{if } \frac{\text{RepairCost}}{\text{Replacement Cost}} \geq 51\% 
\end{cases}
\]

Our analysis exploits the fact that the size of grant offers increased discontinuously at the 51\% home damage fraction (repair cost \div replacement cost) threshold. Assuming households could not perfectly control their appraised damage fractions, variation in the grant offers very close to the 51\% damage threshold can be thought of as approximately random and thus orthogonal to the sorts of unmeasured neighborhood-level variables that generally

\textsuperscript{17}Grants were capped at a maximum of $150,000.
confound the identification of social spillovers in purely observational settings.\textsuperscript{18} This policy cutoff approximates an experiment in which the private incentives of some households were experimentally manipulated without directly changing the incentives of those households’ neighbors. Assuming households responded to private incentives, spillover effects are identified by differences between the rebuilding patterns of neighbors of households with just above versus just below 51% damage.

Figure 2 shows that the policy discontinuity did in fact discontinuously affect households’ private incentives to rebuild and in turn their private rebuilding choices. The left panel of Figure 2 plots the average opportunity cost of declining a RH rebuilding grant, as a fraction of households’ home replacement values, within damage-fraction bins.\textsuperscript{19} The right panel of Figure 2 plots the rebuilding rate as of Katrina’s fifth anniversary within damage-fraction bins. Overlaying the scatter plots are predicted values from the regressions,

\[
Cost_i = \frac{\text{cost}}{\text{cost}} + \Delta^{(\text{cost})} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + e_i \tag{5}
\]

\[
Y_i = \frac{\text{Repair Dummy}}{y} + \Delta^{(y)} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + e_i \tag{6}
\]

where \(i\) indexes households, \(R_i\) is \(i\)’s damage fraction minus .51. The average opportunity cost of relocating increased by 20% of households’ home replacement cost at the 51% damage threshold, and the probability of rebuilding increases by 5.0 percentage points.

This quasi-experiment is only credible for studying spillover effects if households were unable to perfectly control the the value of their “damage fraction” running variable relative to the 51% damage threshold. Panels (a) and (b) of Figure 3 compute McCrary tests for continuity in the density of damage fractions at 51% based on two different definitions of the damage fraction variable. The damage fraction variable summarized in panel (a) is based on households’ final damage appraisals, incorporating the adjudicated decisions on all household appeals of initial damage appraisals, and unsurprisingly exhibit a somewhat larger density just above 51% than just below 51% (\(p=.064\)). The damage fraction variable summarized in panel (b) is based on households’ initial damage appraisals. A McCrary test applied to these “first-appraisal” damage fractions fails to reject continuity at the 51% threshold (\(p=0.533\)). These patterns lead us to treat the first-appraisal damage fraction as the running variable in all of the paper’s substantive analyses. Panel (c) confirms that a non-trivial portion of the overall damage-fraction distribution falls near the 51% threshold.

\textsuperscript{18}See Brock and Durlauf (2007) for a discussion of the non-identification of binary choice models with social interactions in observational settings when there are group-level unobservables, and possible approaches to partial identification in those cases.

\textsuperscript{19}For each household, the opportunity cost measure is defined as the smaller of the as-is value of the household’s damaged property (the opportunity cost of choosing a Road Home relocation grant instead of a rebuilding grant) and the size of the household’s Road Home grant offer (the opportunity cost of selling privately).
Table (2) assesses the balance of pre-determined covariates above and below the 51%-damage grant threshold. Columns (1) and (2) report each variable’s mean among households with just below 51% damage and just above 51% damage, and column (3) reports the p-value of the null that the two are equal. These tests fail to reject the null of balance for any covariates; including the fraction of same-block neighbors with undamaged homes, the fraction of block neighbors who are black, the fraction of block group neighbors with a college degree, the tract poverty rate, the nearby average Equifax credit score, and the depth of flooding. The table also assesses the balance of these covariates’ higher moments by comparing the probability of each covariate exceeding its unconditional 10th, 25th, 50th, 75th, and 90th percentiles above/below the 51% damage threshold, and again fails to reject balance in each case.

Having failed to reject the validity of the grant formula RDD, we exploit the quasi-experiment to examine spillover effects from rebuilding. We first measure the spatial scope of spillovers by estimating regressions of the form

$$\mu_i^{(d)} = \mu + \Delta^{(d)} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + e_i$$

(7)

where $\mu_i^{(d)}$ is the repair rate of homes located between $d$ and $d+.01$ miles from $i$, and $\Delta^{(d)}$ captures the difference between the rebuilding rate $d$ miles from households with just above 51% damage and just below 51% damage. Figure (4) plots the estimated values of $\Delta^{(d)}$ for $d = 0$ to 1 miles. While the rebuilding rate of the directly subsidized households increased by 5.0 percentage points at the 51% damage threshold, the rebuilding rate of immediate neighbors’ increased by about 2.5 percentage points. That spillover effect was roughly constant with distance up to $1/3$ of a mile from directly subsidized households before decaying to zero beyond that.

In the context of our equilibrium model, the impact of private rebuilding choices on equilibrium rebuilding rates can depend critically on nonlinearities in the spillover function $g(\mu)$. To examine such nonlinearities, we next estimate spillover effects across the distribution of nearby rebuilding rates. For this analysis, we define “nearby” neighbors as those in the same Census block, the standard Census geographic unit that best corresponds to the spatial

20Specifically, we restrict the sample to households with a damage fraction between 0.33 and 0.67, and for each variable $Z_i$ we estimate a flexible regression of the form,

$$Z_i = \tau + \Delta^{(z)} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + e_i$$

Columns (1) and (2) of Table (2) report the left limit ($\tau$) and right limit ($\tau + \Delta^{(z)}$) of each variable’s conditional expectation as the damage fraction goes to .51. Column (3) reports the p-value associated with null that $\Delta^{(z)} = 0$. 

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extent of spillovers estimated above. Specifically, we estimate the regressions,

\[
\mu_{j(i),-i} = \overline{\mu} + \Delta \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + \epsilon_i
\]  

\[
1(\mu_{j(i),-i} < .1) = F^{(10)} + \Delta^{(10)} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + \epsilon_i
\]

\[
1(\mu_{j(i),-i} < .2) = F^{(20)} + \Delta^{(20)} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + \epsilon_i
\]

\[
\vdots
\]

\[
1(\mu_{j(i),-i} < .9) = F^{(90)} + \Delta^{(90)} \times 1_{R_i > 0} + a_1 R_i + a_2 R_i^2 + a_3 R_i \times 1_{R_i > 0} + a_4 R_i^2 \times 1_{R_i > 0} + \epsilon_i
\]

where \( j(i) \) denotes household \( i \)’s census block, and \( \mu_{j(i),-i} \) denotes the rebuilding block of \( i \)’s same block neighbors (excluding \( i \)). Because the running variable \( R_i \) is normalized to be zero at a damage fraction of 51%, the parameter \( \overline{\mu} \) recovers the rebuilding rate of the neighbors of those with just below 51% damage, and \( F^{(10)}, F^{(20)}, \ldots, F^{(90)} \) recover the probability that the neighbors of those with damage just below 51% rebuild below rate of 10%, 20%, ..., 90%. Similarly, the parameter \( \Delta \) recovers the difference above versus below 51% damage in neighbors’ rebuilding rate, and \( \Delta^{(10)}, \Delta^{(20)}, \ldots, \Delta^{(90)} \) recover differences above versus below 51% damage in the probability that the neighbors rebuild at rates below 10%, 20%, ..., 90%.

Figure (5) summarizes these results. The top panel of Figure (5) plots the rebuilding rate of households’ same-block neighbors within narrow damage fraction bins, and finds that the rebuilding rate of same block neighbors jumps by 2.4 percentage at the 51% damage grant threshold, the point at which a household’s own probability of rebuilding increases by 5.0 percentage points. The bottom panel of Figure (5) plot CDFs of neighbors’ rebuilding rates for households with just below 51% damage (constructed from the estimated values of \( F^{(10)}, F^{(20)}, \ldots, F^{(90)} \)) and just above 51% (constructed from the estimated values of \( F^{(10)} + \Delta^{(10)}, F^{(20)} + \Delta^{(20)}, \ldots, F^{(90)} + \Delta^{(90)} \)). The relatively steep slope of the neighbors’ rebuilding rate CDF for below-51% damage households over a wide range of rebuilding rates implies that the grant discontinuity quasi-experiment occurred on blocks with a wide range of “baseline” rebuilding rates, and the neighbors’ rebuilding rate CDF for above-51% damage households, by comparison, shows that rebuilding spillover effects operated primarily by pushing some blocks above the repair rate thresholds of 50%, 60%, and 70%. This patterns suggest that an exogenous shock to rebuilding has a large effect on amenity values in areas with baseline rebuilding rates in this range and a relatively small effect on amenity values in areas with very low and very high baseline rebuilding rates.

\[^{21}\text{In New Orleans, 98\% of Census blocks are less the 1/3 of a mile wide, the distance over which spillover effects appear to be roughly constant. On the other hand, more than half of Census block groups, the next largest geographic unit, are over 1/3 of a mile wide.}\]
5 Estimation

We next turn to estimation of the equilibrium model’s structural parameters. The vector of structural parameters ($\theta$) to be estimated consists of the dispersion of household attachment ($\sigma_\eta$), the parameters governing exogenous block-specific amenity values ($\gamma, \sigma_b$), the parameters governing the nature of amenity spillovers ($S, \lambda$), and the parameters governing the borrowing interest rate function ($\rho$).

The estimation is via indirect inference. The approach involves two stages. The first step is to compute from the data a set of “auxiliary models” that summarize the patterns in the data to be targeted for the structural estimation and to estimate a reduced form housing offer price “policy” function. The second step involves repeatedly simulating data with the structural model, computing corresponding auxiliary models using the simulated data, and searching for the model parameters that cause the auxiliary model estimates computed from the simulated data and from the true data to match as closely as possible. Indirect inference is well-suited for estimating models like ours that are straightforward to simulate (under any particular parameterization) but for which it is difficult to evaluate a likelihood function or a set of model-implied moments directly.

5.1 Stage One: Auxiliary Models and Home Offer Policy Function

The auxiliary models the we target include:

1. RDD estimates of the private rebuilding elasticity: specifically the parameters $\bar{y}$ and $\Delta^{(y)}$ from equation (6) characterizing the left and right limits of the private rebuilding rate at the 51% damage fraction grant threshold.

2. RDD estimates of spillovers from private rebuilding choices onto neighbors’ rebuilding choices: specifically the parameters $\bar{\mu}$ and $\bar{\Delta}$ from Equation (8) characterizing the left and right limits of a household’s neighbors’ rebuilding rate at the 51% damage fraction grant threshold, and the parameters $\mu^{(p)}$ and $\Delta^{(p)}$ from equations (9) for $p = 10, 20, ..., 90$ characterizing the left and right limits of the likelihood that a household’s neighbors’ rebuilding rate exceeds each threshold at the 51% damage fraction grant threshold.

3. Descriptive regressions of year $t$ private rebuilding indicators on block flood exposure and average block credit scores for $t=1,...,5$. 

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Our estimating equation to obtain a home price offer policy function takes the form.

\[ \ln(p_i) = P(p^*_i, k_i, z_{j(i)}; a_0) + h(\mu_{-i,j(i),T}; a_1) + \epsilon_i \]  

(10)

where \( P() \) is a flexible function specified using polynomials and interactions, and \( h() \) is a linear spline in the rebuilding rate of same-block neighbors. OLS estimates of this equation are likely to be biased for several reasons. First, \( \mu_{-i,j(i),T} \) is likely to be correlated with the residual \( \epsilon_i \), because unobserved block amenities \( b_{j(i)} \) that directly affect offered home prices should also affect neighbors’ rebuilding choices. Second, offered prices are only observed for households who choose to sell, which will cause selection bias if idiosyncratic household attachment \( \eta_i \) is correlated with unobserved house traits \( \epsilon_i \).

We use fixed effects \( \theta_{\tau(i)} \) for Census tracts, a larger unit of geography nesting Census blocks, to control for unobserved block amenities. We account for selection using the Heckman two-step procedure. We treat the Road Home grant formula discontinuity as the excluded instrument in a first stage probit predicting the probability of a home sale, and include the associated inverse Mills ratio as a regressor in the second stage estimating equation,

\[ \ln(p_i) = P(p^*_i, k_i, z_{j(i)}; a_0) + h(\mu_{j(i),T}; a_1) + \rho \lambda(\Phi^{-1}(\widehat{sale}_i)) + \theta_{\tau(i)} + \epsilon_i \]  

(11)

5.2 Stage Two: Estimation Algorithm

Our estimation algorithm involves an outer loop searching over the space of structural parameters, and an inner loop that computes auxiliary models using simulated data from the structural model.

The Inner Loop  With simulated data, computing auxiliary models is straightforward and follows the same procedure as described in Stage One. We focus on describing the solution to the model, given a set of parameter values \( \Theta \).

Given \( \Theta \), for each community \( j \) observed in the data, simulate \( N \) copies of communities \( j_n \) that share the same observable characteristics but differ in unobservables, at both the individual and the community level. The unobservables are drawn from the distributions governed by \( (\sigma_\eta, \gamma, \sigma_b) \). For each simulated community, solve for the equilibrium as follows, where we suppressing the block subscript \( j \).

1. For each block, locate all possible “self-consistent” period \( T \) block rebuilding rates by repeatedly (for each \( n_T = 1, ..., I \)), guessing that \( n_T/I \) is the rebuilding rate, computing the implied offered price for each household \( p_i = P(p^*_i, k_i, z_{j(i)}, \mu_{j,T} = n_T/I) \), counting
the number of simulated block households \( n^*_T(n_T; \Theta) \) who prefer to rebuild when \( \mu^*_{j,T} = n_T/I \), and deeming \( \mu^*_{j,T} = n_T/I \) self consistent if \( n^*_T(n_T; \Theta) = n_T \).

2. Select the self-consistent \( \mu_{j,T} \) that maximizes total block welfare \( W_{T-1} = \sum_i V_{i,T-1} \). Store the associated offered price for each household.

3. Taking equilibrium home prices as given, locate all possible “self-consistent” period \( T-1 \) block rebuilding rates by repeatedly (for each \( n_{T-1} = 1, ..., I \)), guessing that \( n_{T-1}/I \) is the rebuilding rate, counting the number of simulated block households \( n^*_{T-1}(n_T; \Theta) \) who prefer to rebuild when \( \mu^*_{j,T-1} = n_T/I \), and deeming \( \mu^*_{j,T-1} = n_T/I \) self consistent if \( n^*_{T-1}(n_{T-1}; \Theta) = n_{T-1} \).

4. Select the self-consistent \( \mu_{j,T-1} \) that maximizes total block welfare \( W_{T-1} = \sum_i V_{i,T-1} \).

5. Repeat steps 3 and 4 for \( t = T-2, T-3, ..., 1 \).

The Outer Loop  Let \( \beta \) denote our chosen set of auxiliary model parameters computed from data. Let \( \hat{\beta}(\Theta) \) denote the corresponding auxiliary model parameters obtained from simulating \( S \) datasets from the model (parameterized by a particular vector \( \theta \)) and computing the same estimators. The structural parameter estimator is then the solution

\[
\hat{\theta} = \arg\min_\theta [\hat{\beta}(\theta) - \beta]'W[\hat{\beta}(\theta) - \beta],
\]

where \( W \) is a weighting matrix. Standard errors may be obtained by numerically computing \( \partial\hat{\theta}/\partial\beta \) and applying the delta method to VCE(\( \beta \)).

We augment the indirect inference strategy with an importance sampling technique suggested by Sauer and Taber (2012) that ensures a smooth objective function even though the procedure is simulation-based and the model outcomes are discrete.

6 Parameter Estimates and Model Fit

Table 3 presents estimates of the model’s structural parameters. The estimated amenity spillover function, illustrated graphically in the top panel of Figure (6), finds that additional rebuilding contributes most strongly to a block’s amenity value on blocks with rebuilding rates between 40% and 70%. A block’s flow amenity value increases by the equivalent of 11% of non-housing consumption if the block’s rebuilding rate changes from 40% to 70%. The estimated impact of block rebuilding on house price offers is illustrated in the bottom
panel of Figure (6).\textsuperscript{22} The total change to offered prices when a block’s rebuilding rate increases from no rebuilding to complete rebuilding is about 20%. These spillovers onto house prices are most pronounced for rebuilding rates above 80%. The relatively shallow slope of this home price offer function over the range of rebuilding rates where spillovers onto the amenity utility of prior block residents are steepest (40% to 70%) suggests that potential in-migrants begin to perceive a neighborhood as attractive at a significantly higher rebuilding rate threshold than prior residents.

Amenity utility increases monotonically with time, presumably reflecting city-wide infrastructure repairs, and decreases with block flood exposure above two feet. The negative coefficient on the “less than 2 feet” flood category (relative to the “2-3 feet” reference category) is somewhat puzzling. We suspect that this coefficient is partly picking up the influence of unmodeled characteristics that are unique to the relatively small fraction of households whose homes suffered severe damage from relatively minor flooding. The estimated minimum Equifax credit score needed to secure a rebuilding loan is 592 points. Because federally subsidized loans for rebuilding are made available after all disasters in the U.S., it is not surprising that this threshold is slightly below the commonly-cited 620 “rule of thumb” cutoff for securing a standard mortgage (Keys, Mukherjee, Seru, and Vig 2008).

Figures (7) and (8) illustrate the model’s fit to rebuilding trends and to the distribution of block rebuilding rates five years after Katrina. Both figures show results for the full sample and within smaller categories defined by block flood exposure and average neighborhood Equifax credit scores. The model successfully replicates the city’s aggregate rebuilding trend and the unconditional distribution of block rebuilding rates. The model also successfully captures many of the major differences in rebuilding trends and in block rebuilding rate distributions across flood categories and across credit-score categories, moments which are not directly targeted during estimation.

7 Counterfactual Policy Simulations

We use our structural model to first measure the importance of the “feedback” effects from positive amenity spillovers by comparing the full equilibrium impact of RH with the impact generated by the program’s financial incentives alone (holding amenities fixed). Then, we measure the effect of RH’s stipulation that relocation grant recipients turn their properties over to a state land trust, by comparing the baseline with a case without such a requirement. Finally, we study the extent to which subsidies should be biased toward rebuilding and against relocation.

\textsuperscript{22}Specifically, the figure plots the estimated spline from equation (11).
7.1 A. The Importance of the Feedback Effect

To BE REDONE.

B. RH versus Unconditional Grants

RH required that recipients of relocation grants turn their properties over to a state land trust, which supposedly would discourage relocation relative to rebuilding. To measure this discouraging effect, we compare the baseline with a new equilibrium under unconditional grants, i.e., applying the RH grant formula used for rebuilders to all households unconditional on their choices. Table (4) summarizes rebuilding rates by Katrina’s 5th anniversary under both policies. RH’s effective penalty for relocating increased the equilibrium rebuilding rate by 7.9 percentage points (from a base of 56.9%). The impact varies across flood categories, being the smallest for areas with the least severe (less than 2 feet) flooding and largest in areas with 4-5 feet of flooding.

Column 2 of Table (5) shows the fraction of marginal households, who rebuilt under RH but would not have if rebuilding grants were provided unconditionally (i.e. without requiring relocating households to turn their properties over to the state). Overall, 8% households were marginal; and this fraction was smaller in the least and the most flooded areas. The next three columns show the changes in average household welfare, measured in dollar equivalence, under RH relative to the case of unconditional grants. For an average inframarginal households, welfare improved by $1,995 as the result of positive spillovers from the rebuilding of marginal households. This difference is larger for an average households living in areas with medium levels of flooding. An average marginal households, however, was worse off by the equivalent of $63,092. The welfare loss was particularly large ($92,758) for marginal households living in heavily-flooded areas. The last column shows that, overall, RH decreases average household welfare by $3,147, relative to the unconditional grant policy. The loss increases monotonically with the severity of flooding.

\[ \text{23 Note that this equilibrium impact estimate is larger than the partial equilibrium program impact computed by Gregory (2014) holding amenity values constant across policy regimes. The larger equilibrium impact is consistent with this paper’s reduced form evidence that private rebuilding choices generate substantial behavioral spillover effects.} \]

\[ \text{24 Compared to an unconditional grant policy, a policy that offers smaller grants to households who do not rebuild can affect a household’s welfare (measured in dollars) in three ways: (1) change the household’s equilibrium property value, (2) change the non-pecuniary utility the household derives from it’s equilibrium location choices (measured as an equivalent variation), and (3) reduce the size of a household’s grant payment (for inframarginal non-rebuilding households). Because item (3) is an equal-sized benefit to the government, the total change to social welfare is the sum of (1) and (2).} \]
C. The Optimal Generosity of Relocation Grants

We have shown that RH, which is a particular conditional subsidy policy, caused over $3,100 loss in average household welfare relative to an unconditional grant policy. Given that rebuilding is found to be capable of generating significant positive amenity spillovers, conditional subsidies of some other forms presumably would still be welfare-improving relative to the unconditional grant policy. We examine this possibility by exploring a particular form of conditional subsidy policy: we take as given the RH rebuilding grant formula and make the relocation grant a fraction \((1 - \rho)\) of that of the rebuilding grant, but without the requirement that relocating households turn their property over to a state land trust, where the penalty fraction \(\rho \in [0, 1]\) can vary across households.\(^{25}\) We consider different constraints on how variable \(\rho\) can be; and for a given constraint, we search for the vectors of \(\rho\)'s that maximizes the equilibrium total household welfare. The three different constraints we consider require that a uniform \(\rho\) be applied to 1) all households, 2) all households within the same flood exposure category, 3) all households living in blocks where the rebuilding rate under the unconditional grant policy falls into the same range, e.g., 40% to 45%.

Subfigures (9.a), (9.b) and (9.c), respectively, trace out the net welfare gain in the three constrained cases, relative to the unconditional grant policy. In the most restrictive case (9.a), the optimal policy involves a substantial penalty of 21% to the grants of households who choose not to rebuild. When the policy can discriminate across flood exposure categories, the optimal penalty decreases monotonically with the severity of flooding. Consistently, (9.c) shows that penalties should be larger in areas with higher rebuilding rates under the unconditional grant policy. That is, the extent to which subsidies should be biased against relocation and toward rebuilding depends largely on how attractive the areas already are absence of the additional manipulative nature of the policy.

Table (10) summarizes the welfare consequences of the different subsidy policies. Relative to the welfare level occuring under the unconditional grant policy, each of the three constrained-optimal conditional subsidies that bias grant offers against relocation increases average household welfare, with a gain ranging from $169 to $209 per household. Although it would be hard implement, we also consider a fully optimal conditional subsidy that allows \(\rho\) to be household-specific. In this case, welfare improves by $475 per household relative to the unconditional grant case. Notice that these welfare gains are achieved at lower government costs.\(^{26}\) XXX: add the government cost comparison.

\(^{25}\)We only consider a particular subset of conditional subsidy policies to illustrate the main idea. Larger welfare gains can be expected if a broader policy space is explored.

\(^{26}\)Recall that the relocation grant, being a fraction of the rebuilding grant, is no higher than the rebuilding grant and that the unconditional grant policy subsidizes all households using the rebuilding grant formula.
It is worth noting that in the absence of externalities an action-specific biased subsidy policy could not improve household welfare relative to an unconditional subsidy policy. In the presence of externalities, not only can carefully-designed action-specific subsidies improve household welfare, but also at lower government costs, creating possible “win-win” scenarios.

8 Conclusion [To UPDATE]

Many housing policies are predicated on the idea that housing investments can generate positive externalities. This paper studies amenity spillovers from an extreme type of housing investment, residential reconstruction in New Orleans after Hurricane Katrina. We develop an equilibrium model of households’ rebuilding decisions, allowing for the possibility that rebuilding choices cause amenity spillovers and, hence, are inter-related. We have estimated the structural model via indirect inference.

We find that rebuilding caused economically important amenity spillovers: the Louisiana Road Home rebuilding grant program’s full equilibrium impact – including “feedback” effects from positive amenity spillovers – was almost twice the impact generated by the program’s financial incentives alone (holding amenities fixed). We have shown that although the particular form of conditional subsidies used in RH decreases household welfare compared to an unconditional subsidy policy, carefully-designed conditional subsidies can be welfare-improving and at lower government costs. Such a “win-win” situation would be an implausible prediction if researchers were to treat household decisions in isolation.....

To be done.....

References


Appendix I. Data Imputations

Our data include individual-level demographic and labor market data only for the roughly 1% of New Orleans homeowners sampled by the Displaced New Orleans Residents Survey (DNORS). For use in model simulations, we impute these variables for non-DNORS respondents using a matching-based imputation procedure that treats the subpopulation covered by DNORS as the pool of “donor” records. Using nearest Mahalanobis distance matching on the set of variables that are present for all of the records in our dataset (appraised pre-Katrina home values, pre-Katrina neighborhood demographics information, block-level flood exposure, Katrina-related home damages, and the timing of post-Katrina home repairs and sales), we match a donor record to each “target” record requiring imputation. We then assign the donor record’s values to any missing variables on each target record.

We then impute post-Katrina New Orleans wage offers and post-Katrina “outside option” wage offers to each worker using a regression of workers’ pre-Katrina annual earnings on a set of human capital variables, the contemporaneous composition-adjusted local wage in the worker’s occupation (measured in the American Community Survey), and a worker fixed effect. We impute post-Katrina wage offers by evaluating the estimated regression equation with period-specific and market-specific composition-adjusted occupation wages. When generating these predictions, we define the “outside option” to be the set of other Southern metropolitan areas.

Finally we impute home replacement cost and home repair cost estimates for households who did not apply to RH (and thus did not undergo RH damage appraisals). We first impute estimated replacement costs using the predicted values from a regression estimated among RH applicants of the log RH replacement cost estimate on log pre-Katrina appraised home value, pre-Katrina neighborhood demographic traits, and flood exposure. We then impute a damage fraction using the predicted estimate from nonlinear least squares estimates ($r^2 \approx .9$) of the statistical model:

$$\text{DamageFraction}_i = \frac{\tilde{X}_i a}{1 + \exp(\tilde{X}_i a)}$$

where $\tilde{X}_i$ includes a polynomial in flood exposure, a polynomial in the percentage drop in the OPAO appraised value, and interactions of the two. Note that this imputation model is a smooth function of continuously distributed exogenous variables, and thus imputed records for nonapplicants do not contribute to any observed “jumps” in outcomes at the 51% grant formula threshold in expectation.
Table 1: Descriptive Statistics

<table>
<thead>
<tr>
<th>Variable</th>
<th>Mean</th>
<th>S.D.</th>
<th>N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>All households:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Neighborhood demographics:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Percent black (Census block)</td>
<td>57</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>Percent college educated (Census tract)</td>
<td>51</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>Pre-Katrina block flood exposure:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 feet</td>
<td>46</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>2 - 3 feet</td>
<td>12</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>3 - 4 feet</td>
<td>11</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>4 - 5 feet</td>
<td>10</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>5 - 6 feet</td>
<td>6</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>&gt; 6 feet</td>
<td>15</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>Percent with severely damaged homes</td>
<td>67</td>
<td>60,175</td>
<td></td>
</tr>
<tr>
<td>Households with severely damaged homes:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Damages and available resources:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Repair cost (as percentage of home's replacement cost)</td>
<td>58</td>
<td>21</td>
<td>40,291</td>
</tr>
<tr>
<td>Private insurance (as percentage of home's replacement cost)</td>
<td>30</td>
<td>22</td>
<td>40,291</td>
</tr>
<tr>
<td>Equifax risk score (spatial moving average):</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt;600</td>
<td>21</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>600-625</td>
<td>18</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>625-650</td>
<td>18</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>650-675</td>
<td>14</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>675-700</td>
<td>9</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>700-725</td>
<td>10</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>&gt;725</td>
<td>9</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>Road Home participation:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Nonparticipant</td>
<td>36</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>Rebuilding grant (option 1)</td>
<td>55</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>Relocation grant (option 2 or 3)</td>
<td>9</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>Home repaired by the pre-Katrina owner by year:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1 year after Katrina</td>
<td>13</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>2 years after Katrina</td>
<td>21</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>3 years after Katrina</td>
<td>29</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>4 years after Katrina</td>
<td>47</td>
<td>40,291</td>
<td></td>
</tr>
<tr>
<td>5 years after Katrina</td>
<td>54</td>
<td>40,291</td>
<td></td>
</tr>
</tbody>
</table>

Note: This table reports summary statistics for the dataset analyzed in this paper. The sample includes all homes that were owner occupied in 2005, and located in Census blocks that contained at least five owner occupied homes in 2005. Source: Merged Orleans Parish Assessors Office property records and Lousiana Road Home administrative program microdata linked to block/tract/neighborhood background data from FEMA, and the 2000 Decennial Census.
Table 2: Balance of Predetermined Covariates Above and Below the 51% Home Damage

<table>
<thead>
<tr>
<th>Fraction of homes undamaged (Census block):</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \geq 51% ) (1)</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \leq 51% ) (2)</th>
<th>p-value of difference between (1) and (2) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.048 (0.004)</td>
<td>0.046 (0.004)</td>
<td>0.698</td>
<td></td>
</tr>
</tbody>
</table>

| Fraction black (Census block):        | 0.713 (0.011)                   | 0.717 (0.01)                    | 0.768                           |

<table>
<thead>
<tr>
<th>Fraction college (Census block group):</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \geq 51% ) (1)</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \leq 51% ) (2)</th>
<th>p-value of difference between (1) and (2) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fraction college</td>
<td>0.474 (0.005)</td>
<td>0.480 (0.005)</td>
<td>0.342</td>
</tr>
<tr>
<td>Fraction college &lt; 10th city-wide pctile</td>
<td>0.088 (0.009)</td>
<td>0.098 (0.008)</td>
<td>0.373</td>
</tr>
<tr>
<td>Fraction college &lt; 25th city-wide pctile</td>
<td>0.215 (0.012)</td>
<td>0.213 (0.011)</td>
<td>0.910</td>
</tr>
<tr>
<td>Fraction college &lt; 50th city-wide pctile</td>
<td>0.491 (0.015)</td>
<td>0.484 (0.013)</td>
<td>0.729</td>
</tr>
<tr>
<td>Fraction college &lt; 75th city-wide pctile</td>
<td>0.845 (0.013)</td>
<td>0.816 (0.012)</td>
<td>0.094</td>
</tr>
<tr>
<td>Fraction college &lt; 90th city-wide pctile</td>
<td>0.943 (0.009)</td>
<td>0.946 (0.008)</td>
<td>0.778</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Poverty rate (Census tract):</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \geq 51% ) (1)</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \leq 51% ) (2)</th>
<th>p-value of difference between (1) and (2) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Poverty rate</td>
<td>0.198 (0.003)</td>
<td>0.200 (0.003)</td>
<td>0.774</td>
</tr>
<tr>
<td>Poverty &lt; 10th city-wide pctile</td>
<td>0.052 (0.009)</td>
<td>0.054 (0.008)</td>
<td>0.875</td>
</tr>
<tr>
<td>Poverty &lt; 25th city-wide pctile</td>
<td>0.194 (0.013)</td>
<td>0.194 (0.011)</td>
<td>0.979</td>
</tr>
<tr>
<td>Poverty &lt; 50th city-wide pctile</td>
<td>0.522 (0.015)</td>
<td>0.523 (0.014)</td>
<td>0.974</td>
</tr>
<tr>
<td>Poverty &lt; 75th city-wide pctile</td>
<td>0.788 (0.012)</td>
<td>0.790 (0.011)</td>
<td>0.916</td>
</tr>
<tr>
<td>Poverty &lt; 90th city-wide pctile</td>
<td>0.924 (0.009)</td>
<td>0.909 (0.008)</td>
<td>0.192</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Equifax risk score (neighborhood s.m.a.):</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \geq 51% ) (1)</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \leq 51% ) (2)</th>
<th>p-value of difference between (1) and (2) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average risk score</td>
<td>636.7 (1.4)</td>
<td>638.4 (1.4)</td>
<td>0.425</td>
</tr>
<tr>
<td>Average risk score &lt; 10th city-wide pctile</td>
<td>0.103 (0.009)</td>
<td>0.119 (0.008)</td>
<td>0.177</td>
</tr>
<tr>
<td>Average risk score &lt; 25th city-wide pctile</td>
<td>0.260 (0.013)</td>
<td>0.260 (0.012)</td>
<td>0.992</td>
</tr>
<tr>
<td>Average risk score &lt; 50th city-wide pctile</td>
<td>0.567 (0.015)</td>
<td>0.535 (0.013)</td>
<td>0.116</td>
</tr>
<tr>
<td>Average risk score &lt; 75th city-wide pctile</td>
<td>0.830 (0.013)</td>
<td>0.831 (0.011)</td>
<td>0.929</td>
</tr>
<tr>
<td>Average risk score &lt; 90th city-wide pctile</td>
<td>0.958 (0.009)</td>
<td>0.949 (0.008)</td>
<td>0.462</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flooding (Census tract):</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \geq 51% ) (1)</th>
<th>( \frac{\text{repair cost}}{\text{replacement cost}} ) ( \leq 51% ) (2)</th>
<th>p-value of difference between (1) and (2) (3)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flood depth</td>
<td>3.14 (0.06)</td>
<td>3.17 (0.05)</td>
<td>0.753</td>
</tr>
<tr>
<td>Flooding &lt; 2 feet</td>
<td>0.293 (0.012)</td>
<td>0.288 (0.011)</td>
<td>0.772</td>
</tr>
<tr>
<td>Flooding 2-4 feet</td>
<td>0.409 (0.014)</td>
<td>0.411 (0.013)</td>
<td>0.910</td>
</tr>
<tr>
<td>Flooding 4-6 feet</td>
<td>0.222 (0.012)</td>
<td>0.229 (0.011)</td>
<td>0.676</td>
</tr>
<tr>
<td>Flooding &gt; 6 feet</td>
<td>0.077 (0.010)</td>
<td>0.072 (0.009)</td>
<td>0.729</td>
</tr>
</tbody>
</table>

Note: Columns (1) and (2) report the average values of background variables among households with appraised home damage fractions \( \frac{\text{repair cost}}{\text{replacement cost}} \) just above 51% versus just below 51%, the threshold at which RH grant offers increased discontinuously. Column (3) reports the p-value associated with the null that the two are equal. Source: Merged Orleans Parish Assessors Office property records and Louisiana Road Home administrative program microdata linked to block/tract/neighorhood background data from FEMA, and the 2000 Decennial Census.
Table 3: Structural Parameter Estimates

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Estimate</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Year-specific intercepts</strong></td>
<td></td>
</tr>
<tr>
<td>Year 1</td>
<td>-0.49</td>
</tr>
<tr>
<td>Year 2</td>
<td>-0.27</td>
</tr>
<tr>
<td>Year 3</td>
<td>-0.10</td>
</tr>
<tr>
<td>Year 4</td>
<td>0.43</td>
</tr>
<tr>
<td>Year 5+</td>
<td>0.73</td>
</tr>
<tr>
<td><strong>Observable heterogeneity in flow location payoffs:</strong></td>
<td>Zγ</td>
</tr>
<tr>
<td>Flood exposure:</td>
<td></td>
</tr>
<tr>
<td>&lt; 2 feet</td>
<td>-0.46</td>
</tr>
<tr>
<td>2-3 feet (reference)</td>
<td>---</td>
</tr>
<tr>
<td>3-4 feet</td>
<td>-0.01</td>
</tr>
<tr>
<td>4-5 feet</td>
<td>-0.13</td>
</tr>
<tr>
<td>5-6 feet</td>
<td>-0.53</td>
</tr>
<tr>
<td>&gt; 6 feet</td>
<td>-0.67</td>
</tr>
<tr>
<td><strong>Unobserved heterogeneity in flow location payoffs:</strong></td>
<td></td>
</tr>
<tr>
<td>σ_η: Variance of idiosyncratic attachment to pre-Katrina block</td>
<td>0.46</td>
</tr>
<tr>
<td>σ_β: Variance of unobserved block effect</td>
<td>0.11</td>
</tr>
<tr>
<td><strong>Spillover function</strong>: S x BetaCDF(μ; λ_1, λ_2)</td>
<td></td>
</tr>
<tr>
<td>S: Spillover magnitude (flow payoff diff. b/w a 0% and 100% rebuilt block)</td>
<td>0.11</td>
</tr>
<tr>
<td>λ_1: Location of spillover threshold</td>
<td>0.53</td>
</tr>
<tr>
<td>λ_2: Steepness of spillover threshold</td>
<td>19.09</td>
</tr>
<tr>
<td><strong>Credit Access:</strong></td>
<td></td>
</tr>
<tr>
<td>Cutoff Credit Score for Rebuilding Loans (ρ*)</td>
<td>592.2</td>
</tr>
<tr>
<td><strong>Observations</strong></td>
<td></td>
</tr>
<tr>
<td>household-periods</td>
<td>300,875</td>
</tr>
<tr>
<td>households</td>
<td>60,175</td>
</tr>
</tbody>
</table>

Note: This table reports indirect inference estimates of the equilibrium rebuilding model’s structural parameters. Source: Authors’ calculations using Orleans Parish Assessor’s Office administrative property data linked with administrative application/participation data from the Louisiana Road Home program.
Table 4: The Road Home Program’s Impact on the Home Rebuilding Rate Relative to an Unconditional Grant Policy

<table>
<thead>
<tr>
<th>Subgroup</th>
<th>Unconditional Grants</th>
<th>Road Home Grants</th>
<th>Impact</th>
</tr>
</thead>
<tbody>
<tr>
<td>All</td>
<td>56.9</td>
<td>64.8</td>
<td>7.9</td>
</tr>
<tr>
<td>Flood depth:</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 feet (46% of pop.)</td>
<td>74.8</td>
<td>79.4</td>
<td>4.6</td>
</tr>
<tr>
<td>2-3 feet (12% of pop.)</td>
<td>60.2</td>
<td>72.3</td>
<td>12.1</td>
</tr>
<tr>
<td>3-4 feet (11% of pop.)</td>
<td>59.8</td>
<td>70.9</td>
<td>11.1</td>
</tr>
<tr>
<td>4-5 feet (10% of pop.)</td>
<td>49.2</td>
<td>62.2</td>
<td>13.0</td>
</tr>
<tr>
<td>5-6 feet (6% of pop.)</td>
<td>21.7</td>
<td>31.8</td>
<td>10.1</td>
</tr>
<tr>
<td>&gt; 6 feet (15% of pop.)</td>
<td>17.9</td>
<td>25.8</td>
<td>7.9</td>
</tr>
</tbody>
</table>

Note: This table reports the results of simulation experiments comparing rebuilding rates 5 years after Katrina under the Louisiana Road Home program, which required households who accepted “relocation” grants to turn their properties over to a state land trust, to rebuilding rates under an unconditional grant policy, paying RH “rebuilding” grants to all households regardless of their rebuilding choices. Source: Authors’ calculations using the estimated equilibrium model.

Table 5: Decomposing the Welfare Effects of the Road Home Program’s Rebuilding Stipulations

<table>
<thead>
<tr>
<th>Group</th>
<th>Marginal</th>
<th>Change to Welfare Per Household: RH vs. Unconditional Grants</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Inframarginal Households ($)</td>
</tr>
<tr>
<td>All</td>
<td>7.9</td>
<td>1,995</td>
</tr>
<tr>
<td>Flood depth:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>&lt; 2 feet</td>
<td>4.6</td>
<td>1,146</td>
</tr>
<tr>
<td>2-3 feet</td>
<td>12.1</td>
<td>4,118</td>
</tr>
<tr>
<td>3-4 feet</td>
<td>11.1</td>
<td>3,502</td>
</tr>
<tr>
<td>4-5 feet</td>
<td>13.0</td>
<td>3,639</td>
</tr>
<tr>
<td>5-6 feet</td>
<td>10.1</td>
<td>1,312</td>
</tr>
<tr>
<td>&gt; 6 feet</td>
<td>7.9</td>
<td>1,209</td>
</tr>
</tbody>
</table>

Note: This table reports the impact of the Louisiana Road Home program on average household welfare relative to an unconditional grant policy. RH required households who accepted “relocation” grants to turn their properties over to a state land trust, while the unconditional grant policy pays RH “rebuilding” grants to all households regardless of their rebuilding choices. RH offering smaller net grant packages to households who do not rebuild affects welfare through three channels: (1) changes to equilibrium property values, (2) changes to the non-pecuniary utility households derive from their equilibrium location choices (measured as equivalent variations), and (3) reductions to the size of net grant packages (for inframarginal non-rebuilding households). Because item (3) is an equal-sized benefit to the government, the total change to social welfare is the sum of (1) and (2). Source: Authors’ calculations using the estimated equilibrium model.
Table 6: The Welfare Consequences of Alternative Policies

<table>
<thead>
<tr>
<th>Policy</th>
<th>Δ Welfare Per HH</th>
<th>Δ Welfare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unconditional grants</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Welfare improvements relative to &quot;unconditional grants&quot;:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road Home program</td>
<td>-$3147</td>
<td>-$189.4M</td>
</tr>
<tr>
<td>Optimal uniform reduction to grants for non-rebuilders</td>
<td>+$169</td>
<td>+$10.2M</td>
</tr>
<tr>
<td>Optimal targeting by flood exposure</td>
<td>+$184</td>
<td>+$11.0M</td>
</tr>
<tr>
<td>Optimal targeting by baseline block rebuilding rate</td>
<td>+$209</td>
<td>+$12.6M</td>
</tr>
<tr>
<td>Optimal full-information household-level targeting</td>
<td>+$475</td>
<td>+$28.6M</td>
</tr>
</tbody>
</table>

Note: This table summarizes the results of counterfactual experiments comparing average household welfare under policies that offer smaller grants to households who do not rebuild to average welfare under a policy that pays RH rebuilding grants unconditionally. Specifically, we consider policies that offer a fraction $(1 - \rho)$ of the RH rebuilding grant to households if they choose to relocate, where $\rho$ is chosen optimally subject to various constraints. The constraints we consider include: (1) that $\rho$ be uniform city-wide, (2) that $\rho$ be uniform within flood depth categories, (3) that $\rho$ be uniform within baseline-block-rebuilding-rate categories, and (4) that $\rho$ may be household-specific. Source: Authors’ calculations using the estimated equilibrium model.
Note: This figure provides a stylized illustration of equilibria in our equilibrium model. Both panels plot hypothetical private demand schedules for rebuilding evaluated at the amenity level associated with a 0% rebuilding rate as well as actual marginal benefit curves. The private demand curve is downward sloping by definition as it is simply a highest-to-lowest ordering of individual households’ net benefits to rebuilding. The actual marginal benefit curve incorporates each additional household’s positive contribution to block amenities and can thus be downward or upward sloping. Self-consistent rebuilding rates are the zeros of the latter curve. The bottom panel illustrates how “tipping” can occur if a subsidy causes additional higher rebuilding rates to become self-consistent.
Figure 2: Households’ Financial Incentives and Rebuilding Choices by Appraised Home Damage Fraction

Discontinuity = 0.201  (0.010)***

(a)

Discontinuity = 0.050  (0.020)**

(b)

Note: The left panel of this figure shows the average opportunity cost of relocating instead of rebuilding within narrow home-damage-fraction bins. The opportunity cost of relocating instead of rebuilding was the smaller of a household’s RH rebuilding grant offer (which the household passed up if it sold its home privately) and its home’s as-is value (which the household had to turn over to the state if it accepted a RH relocation grant). The opportunity cost is reported as a fraction of each home’s replacement cost. The right panel shows the average rebuilding rate 5 years after Katrina within narrow home-damage-fraction bins. Source: Authors’ calculations using Orleans Parish Assessor’s Office administrative property data linked with administrative application/participation data from the Louisiana Road Home program.
Figure 3: Distribution of Appraised Home Damage Fractions

Note: Panel (a) of this figure plots the density of RH-appraised home damage fractions (repair cost ÷ replacement cost) close to the 51% RH grant threshold once all appeals of initial appraisals had been adjudicated. Panel (b) plots the density of initial RH-appraised home damage fractions close to the 51% grant-offer threshold. Panel (c) shows the full distribution of RH-appraised damage fractions. Source: Administrative application/participation data from the Louisiana Road Home program.
Figure 4: Difference Above vs. Below 51% Home Damage in the Rebuilding Rate of Close-by Neighbors

Note: This figure shows the difference between the rebuilding rates of neighbors households with just above versus just below 51% home damage (repair cost ÷ replacement cost) by distance from the home. Specifically the figure plots the estimated values of $\Delta^{(d)}$ from Equation (7) for $d = 0, ..., 1$. Source: Authors' calculations using Orleans Parish Assessor’s Office administrative property data linked with administrative application/participation data from the Louisiana Road Home program.
Figure 5: Difference Above vs. Below 51% Home Damage in the Distribution of Same-Block Neighbor Rebuilding Rates

Note: The top panel of this figure plots the average rebuilding rate of households’ same-Census-block neighbors within narrow home-damage-fraction (repair cost ÷ replacement cost) bins. The bottom panel shows the CDF of same-block-neighbor rebuilding rates for households with just above and just below 51% home damage. See the discussion of Equation (9) in the text for details about the estimation procedure. Source: Authors’ calculations using Orleans Parish Assessor’s Office administrative property data linked with administrative application/participation data from the Louisiana Road Home program.
Figure 6: Spillover Effects of Rebuilding on Flow Amenity Utility and Offered Home Prices

Note: The top panel of this figure plots the estimated shape of the equilibrium model’s amenity spillover function $g(\mu)$ . The bottom panel plots the estimated impact of same-block neighbors’ rebuilding on home price offers (specifically, the neighbors’ rebuilding rate spline from Equation (11)). Source: Authors’ calculations using Orleans Parish Assessor’s Office administrative property data linked with administrative application/participation data from the Louisiana Road Home program.
Figure 7: Goodness of Fit: Trends in Fraction of Homes Livable by Neighborhood Characteristics

(a) All Blocks

(b) < 2 feet of flooding

(c) 2-3 feet of flooding

(d) 3-4 feet of flooding

(e) 4-5 feet of flooding

(f) 5-6 feet of flooding

(g) 6+ feet of flooding

(h) Avg. Score < 600

(i) Avg. Score 600-625

(j) Avg. Score 625-650

(k) Avg. Score 650-675

(l) Avg. Score 675-700

(m) Avg. Score 700-725

(n) Avg. Score > 725
Figure 8: Goodness of Fit: Histogram of 5th-Anniv. Block Repair Rates by Neighborhood Characteristics

(a) All Blocks

(b) < 2 feet of flooding
(c) 2-3 feet of flooding
(d) 3-4 feet of flooding

(e) 4-5 feet of flooding
(f) 5-6 feet of flooding
(g) 6+ feet of flooding

(h) Avg. Score <600
(i) Avg. Score 600-625
(j) Avg. Score 625-650
(k) Avg. Score 650-675

(l) Avg. Score 675-700
(m) Avg. Score 700-725
(n) Avg. Score >725
Figure 9: Net Welfare Consequences of Reducing the Value of Relocation Grants

Note: This figure shows the welfare consequences of reducing the size of relocation grants relative to rebuilding grants. Specifically, we consider policies that offer a fraction \((1 - \rho)\) of the RH rebuilding grant to households if they choose to relocate. Panel (a) plots the net welfare gain by \(\rho\) when \(\rho\) is constrained to be uniform city-wide. Panel (b) plots net welfare gains by \(\rho\) separately within flood-depth categories. Panel (c) plots net welfare gains by \(\rho\) separately by block rebuilding rates under unconditional grants. Source: Authors’ calculations using the estimated equilibrium model.

Figure 10: Optimal Reductions to the Value of Relocation Grants

Note: This figure shows the total-welfare-maximizing reductions to the size of relocation grants relative to rebuilding grants. Specifically, we consider policies that offer a fraction \((1 - \rho)\) of the RH rebuilding grant to households if they choose to relocate, where \(\rho\) is chosen optimally subject to various constraints. The left panel shows the optimal values of \(\rho\) when \(\rho\) must be uniform within flood depth categories. The left panel shows the optimal values of \(\rho\) when \(\rho\) must be uniform within baseline-block-rebuilding-rate categories. Source: Authors’ calculations using the estimated equilibrium model.
A. Appendix: Tables and Figures

Table A.1: The Impact of Financial Incentives on Rebuilding Choices

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<td>[Reduced Form]</td>
<td>[2sls]</td>
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Notes: This table reports estimates of the effects of financial incentives to rebuild on the probability of rebuilding. The sample includes households who were not fully insured and with a running variable (the Road Home repair cost estimate divided by the Road Home replacement cost estimate) between .33 and .67. The opportunity cost of not rebuilding is the smaller of the home’s as-is value (foregone by households who accept a Road Home grant) and the cost of needed repairs not covered by insurance payments (foregone by households who sell privately). Source: Authors’ calculations using Orleans Parish Assessor’s Office administrative property data linked with administrative application/participation data from the Louisiana Road Home program.