Rebuild or Relocate?

Recovery after Natural Disasters

Shifrah Aron-Dine *

Stanford University

October 29, 2024

[link to latest version]

Abstract

This paper studies the distributional effects of natural disasters and the impact of post-disaster policies. Using flight data and original survey evidence from Puerto Rico after Hurricane Maria, I document that 7% of the population migrated to the mainland U.S. in the immediate aftermath, but that even temporary migration was prohibitively expensive for most households. Those who stayed faced widespread damages to housing, infrastructure, and the local economy. I find that age, wealth, and housing tenure shaped post-disaster choices: many homeowners with severe property damage defaulted on their mortgages, wealthier homeowners rebuilt with government assistance, and younger renters were most likely to leave the island permanently. These empirical findings inform a dynamic equilibrium model of migration, housing, and infrastructure with heterogeneous households. Homeowners with property damage experience significant welfare losses from direct reductions in home equity and housing consumption, while renters and undamaged homeowners also face welfare declines from infrastructure destruction and through general equilibrium price movements. Local infrastructure investment is a cost-effective policy, due to complementarities with both housing consumption and production. In contrast, rebuilding subsidies for homeowners, though effective in preventing mortgage defaults and mitigating housing shortages, are not cost-effective. Homeowners with property damage value these subsidies below cost because they are not guaranteed and do not provide any payout if the home is foreclosed on or sold. More flexible policy schemes could yield large welfare improvements for similar cost.

*Email: arondine@stanford.edu.

I am especially grateful to my advisers Melanie Morten, Monika Piazzesi, Martin Schneider, and Chris Tonetti for all of their guidance and support. I would also like to thank Ran Abramitzky, Adrien Auclert, Adrien Bilal, Luigi Bocola, Rebecca Diamond, Wendy Dunn, Liran Einav, Larry Goulder, Brian Higgins, Caroline Hoxby, Joanne Hsu, Chad Jones, Benny Kleinman, Pete Klenow, Emmanuella Kyei Manu, Alessandra Peter, Isaac Sorkin, Brigitte Roth Tran, and participants in the Stanford Macro Lunch and Macro-Finance Reading Group for helpful feedback and suggestions. This research was supported by the Leonard W. Ely and Shirly R. Ely Graduate Student Fellowship through a grant to the Stanford Institute for Economic Policy Research.

1. Introduction

Recent natural disasters such as Hurricanes Beryl, Helene, and Milton have renewed debate about the effectiveness of the US post-disaster policy.[1] Current policy focuses on the "restoration of a community's physical structures to pre-disaster conditions (FEMA, 2016)." The federal government pursues this goal in two ways: rebuilding subsidies to help homeowners make repairs and avoid forced sales or foreclosures, and funding for restoring infrastructure to support the local economic recovery, indirectly benefiting all households. However, strict screening processes often lead to denied or delayed payments for homeowners, and renters and those without property damage receive little direct assistance. These policies also distort post-disaster migration decisions, anchoring households in the affected region in the immediate aftermath of a disaster. Evaluating these programs is challenging, as it requires detailed measurement of the many ways households cope with disasters and a model that can account for complex interactions between counterfactual policies, household behavior, and housing markets.

In this paper, I study the distributional effects of natural disasters and evaluate the impacts of post-disaster policies. I focus on the setting of Puerto Rico after Hurricane Maria in 2017 and use high-frequency flight data and an original survey of affected households to understand how post-disaster choices, such as migration, mortgage default, and rebuilding, depend on property damage, demographic characteristics, and asset positions. To translate these empirical findings into welfare effects and to understand how policies affect household decisions, housing markets, and the broader local economy, I develop a heterogeneous agent general equilibrium model. The detailed flight and survey data discipline key model parameters. Finally, I use the model to show that households value current policy below its budget cost, but that alternative policy schemes could deliver greater welfare improvements at a similar cost.

Migration, both temporary and permanent, serves as a crucial but costly coping mechanism after a disaster. Measuring household migration patterns immediately after a disaster is challenging, because most migration data is low-frequency and cannot capture short-term displacements. Puerto Rico, a Caribbean island and US territory, offers a unique setting for estimating high-frequency migration patterns. Puerto Ricans are US citizens with the right to live and work anywhere in the US. Since the island is located 1,000 miles from the mainland US, all travel between the two occurs via commercial flights.[2] Therefore, I use high-frequency airline passenger traffic data to directly measure that 7% of the island's population migrated to the mainland US in the first three months after Hurricane Maria. Of these migrants, approximately 43% returned to Puerto Rico within a year, while 57% remained in the mainland US permanently.

Although the flight data reveal significant disaster-induced migration, the migration estimates also highlight that most Puerto Ricans remained in storm-ravaged Puerto Rico. Because no existing dataset captures both housing damage and post-disaster decisions such as migration and mortgage

[1] The Washington Post (2024); The New York Times (2024).

[2] All travel between Puerto Rico and the mainland US occurs via commercial air travel. Although there are many passenger cruises that stop in Puerto Rico, boats are not a practical option for the over 1,000-mile journey.

default, I designed and conducted an original survey of individuals affected by the hurricane. The survey shows that high migration costs and financial constraints prevented many households from relocating. Temporary migration was most common among homeowners with significant property damage, while I infer from Census data that most permanent migrants were young renters. Among homeowners who did not permanently relocate to the mainland US, default rates increased in the years following Hurricane Maria; 5% of those with a mortgage defaulted, with rates rising to 20% among those with the most severe damage. Most homeowners who did not default eventually repaired their homes, funded largely through federal assistance and personal savings, while all households, including renters, faced months without reliable electricity due to widespread infrastructure damage.

Motivated by this empirical evidence and to better understand the economic effects of natural disasters, I develop a model with realistic features of households' post-disaster decisions that incorporates housing, migration, and public infrastructure. At its core, the model features overlapping generations of households who face idiosyncratic income risk and make a range of choices: whether to rent or own; if they own, to default on their mortgage, sell, repair damage, or apply for government assistance after a natural disaster. Households can also choose to migrate, temporarily or permanently, to the mainland US. Such migration is costly, must be financed upfront, and is subject to borrowing constraints. Non-pecuniary costs, such as preferences for living near other Puerto Ricans, also influence migration decisions. On the supply side, a local government uses tax revenue to fund infrastructure, which is an input into firm production and households' housing services. New capital, including housing, takes time to build, and congestion in the construction sector can lead to federal rebuilding transfers that crowd out private rebuilding efforts. The richness of the model allows me to translate the empirical findings on post-disaster household behavior into welfare effects and to understand the distributional effects of disasters and policies.

The model's ability to match observed behavior both before and after Hurricane Maria makes it a useful tool for studying the effects of natural disasters and post-disaster policies. Using Census data, I parameterize the model's steady state before the hurricane to match the observed distribution of homeownership, house values, and home equity positions in Puerto Rico. Matching the initial distribution is important for accurately capturing the direct effects of the natural disaster, which causes heterogeneous damages to owner-occupied housing, and in turn, to household wealth and home equity. I map the survey responses directly to key parameters of the model, including migration costs, returns to migration, and preferences for living near other Puerto Ricans. After the hurricane, the model is able to match the temporary and permanent migration response observed in flight data, as well as the cross-section of mortgage defaults captured in the survey data.

With the fully quantified model, I study the distributional impacts of Hurricane Maria. I find that welfare losses are largest for homeowners with property damage, though renters and owners of undamaged homes are also negatively affected. For homeowners with property damage, the disaster is not only a shock to housing consumption but also a wealth shock and for those with a mortgage, a home equity shock that may lead to default. All households experienced lower wages due to the destruction of firms' capital, reductions in the utility from housing due to the destruction of critical infrastructure, and disaster-induced price movements in the housing market. House prices and rents rise immediately after the hurricane due to damage to the housing stock, inelastic short-run supply, and the fact that migration is expensive which makes housing demand relatively inelastic.

In the immediate aftermath of the disaster, households differ not only in whether they own or rent and the extent of damage to their property, but also in their asset positions, which shape their response. Even among households with property damage, the welfare effect of the shock depends on both their house size and home equity position. The size of the house matters, because natural disasters cause fractional damage to houses. For example, a hurricane may tear the roof off both a small and large house, causing similar proportional damage but resulting in much higher dollar losses for the larger house. Mortgage default mitigates some of the losses for households with low home equity, shifting the financial burden onto lenders. Wealthier households who have more equity in their home, must absorb the entire loss. In contrast to a model without household leverage, the option to default generates low correlation between the wealth and welfare losses from a disaster.

On average, all households benefit from the current federal policy of infrastructure investment and rebuilding subsidies for homeowners. These policies reduce average welfare losses by 33%, with the largest gains accruing to homeowners with property damage. Wealthier households benefit the most because they would otherwise bear the full loss from any property damage. They are also better positioned to hold onto their home until their application for rebuilding assistance is approved. Rebuilding subsidies, which function as a form of 'in-kind' transfers for lost home equity, reduce the aggregate mortgage default rate from 16% to 7% and help alleviate the housing shortage in the immediate aftermath of the hurricane. Infrastructure investment speeds up the economic recovery, improving the value of living in Puerto Rico for all households and thereby reducing permanent migration.

To evaluate the effectiveness of current programs, I compare federal expenditures on these policies to the value households assign them. I determine the value of a policy to a household by calculating the size of the cash transfer that makes the household indifferent between experiencing the aftermath of Hurricane Maria with and without the policy in place. I find that infrastructure investment is highly effective; households value this component of current policy above its budget cost. This multiplier effect reflects the fact that faster rebuilding of local infrastructure boosts wages and housing consumption, due to infrustructure's complementarity with private firms and housing services production. In contrast, households value rebuilding subsidies at only a fraction of their budget cost. Even homeowners with property damage, the direct beneficiaries, value these subsidies at just \$0.70 for every \$1 received. However, rebuilding subsidies play a critical role in reducing mortgage defaults, benefiting lenders who would face significantly larger losses without these transfers to households.

Households undervalue rebuilding subsidies because these transfers are, in effect, a risky and non-transferable asset. The payouts are not guaranteed, which introduces uninsurable policy risk. Additionally, even households that are approved for the subsidy may not receive the funds until several years after the disaster. Homeowners must therefore hold onto their damaged property in order to qualify, as payouts are conditional on rebuilding. This non-transferable aspect means that homeowners who sell or default without rebuilding receive nothing. These features make rebuilding subsidies poor insurance as they provide no payout in a bad state of the world where the household needs to sell or default.

The model provides a framework to evaluate the effects and effectiveness of alternative post-disaster policies. I first explore how changes to the implementation of current policies could improve post-disaster outcomes. I consider two improvements to the screening process: one guaranteeing rebuilding subsidies after five years, and another offering immediate approval, though still requiring a year-long repair period. Both changes increase the policy's value to households, but they also raise the budget cost, as more households qualify, and the marginal recipient has both more property damage and a large house. Even when subsidies are guaranteed immediately, households still value them below budget cost both due to their non-transferability and the general equilibrium effects of widespread simultaneous rebuilding.

I next evaluate a recent change in US policy, which provides a \$750 cash transfer to all households in regions hit by major natural disasters, in addition to existing aid programs. This policy would have had a limited effect on aggregate behavior if implemented after Hurricane Maria, since the transfer is small compared to the magnitude of property damages. However, households value the immediate liquidity. On average, households value this cash transfer at \$1.18 for every \$1 received. This multiplier effect is because the cash transfer relaxes borrowing constraints for some households.

Post-disaster migration has both positive and negative externalities. If more households leave, even temporarily, it both eases housing market pressure in the immediate aftermath when supply is inelastic and also raises the marginal product of workers who remain in Puerto Rico. However, it may have negative effects since households value their local community. As an alternative to a \$750 cash transfer, I consider a \$750 migration subsidy, which would roughly cover the cost of two round trip plane tickets between Puerto Rico and the mainland US. This policy proves to be very cost effective. Although only a small number of households "take-up" the subsidy, migration rates increase from 7.5% to 8.2%, it effectively changes the slope of the housing demand curve. The budget cost is just \$60 per household but the general equilibrium effects on wages and rents generate \$1,000 of value to households on average.

Finally, I consider a major policy change: reallocating current spending from in-kind transfers to uniform lump sum cash payments. Under this approach, each household would receive \$35,600. This policy results in roughly the same level of mortgage defaults as seen without any post-disaster policy, but households are generally better off. Renters and homeowners without any property damage benefit the most, since they are receiving a much larger transfer relative to the indirect benefits from infrastructure investment and rebuilding subsidies. Homeowners with property damage are slightly worse off than under current policies, as they are receiving much smaller transfers. However, even these homeowners would prefer to receive smaller, more flexible cash transfers over the larger, but restrictive rebuilding subsidies.

Related Literature. This paper connects to several strands of related literature. The model I develop This paper connects to several strands of related literature. The model I develop builds on and extends heterogeneous agent models that study household portfolio choice with housing (Campbell and Cocco, 2015; Piazzesi and Schneider, 2016; Favilukis et al., 2017; Berger et al., 2017; Kaplan et al., 2020; Guren et al., 2021; Greenwald and Guren, 2021).[3] These models were originally developed to study changes in credit conditions, house price movements, and mortgage defaults during the Great Recession. Their structure makes them a useful tool for understanding the effects of natural disasters, which directly destroy housing wealth and mortgage collateral. I extend these models to incorporate migration and study the dynamic effects of natural disasters, especially the interaction between migration and housing markets. The response of house prices and rents to a shock depends crucially on the cost of migration. If migration is expensive, few households can migrate and local housing demand is therefore relatively inelastic.

I also contribute to a large literature studying the effects of shocks on the spatial distribution of economic activity.[4] My model captures a "location-as-an-asset" effect (Bilal and Rossi-Hansberg, 2021), where all households face a shock to the stream of payoffs from living in Puerto Rico after Hurricane Maria in the form of lower wages, higher rents, and less infrastructure. In addition, I introduce an "asset-in-a-location" effect, where households who hold wealth in housing face direct losses from physical damage to their assets. The fact that their wealth is anchored to a physical location discourages households from relocating in the aftermath of the disaster. Current policies exacerbate this issue by discouraging households from abandoning or selling their damaged asset because doing so would forfeit their claim to the rebuilding subsidy.[5]

Prior research on disaster policies in the US has primarily focused on the effects of rebuilding subsidies. Gregory (2017) studies how these policies influence the individual rebuilding decisions of homeowners with property damage after Hurricane Katrina, while Fu and Gregory (2019) highlight the positive externalities these subsidies generate by encouraging entire neighborhoods to rebuild. I focus instead on the general equilibrium effects of a natural disaster and subsequent policy interventions, both rebuilding subsidies and infrastructure investment, across the entire population distribution, including homeowners without property damage and renters. Fried (2021)

[3] I find direct evidence of strategic default, with default rates ten times higher for households experiencing severe property damage (Bhutta et al., 2017; Ganong and Noel, 2023).

[4] See Redding and Rossi-Hansberg (2017) for a review of this literature and more recent examples focusing on the dynamics of shocks such as Caliendo et al. (2019); Desmet et al. (2021); Bilal and Rossi-Hansberg (2023); Kleinman et al. (2023); Cruz and Rossi-Hansberg (2023) In addition, new work such as Greaney (2023) and Greaney et al. (2023) combine key features of quantitative spatial models with macro-housing models. My focus is on the richness of households' choices (including not only rent/own and migration, but also default and rebuilding) rather than locations.

[5] Rebuilding subsidies generate a form of location 'lock-in' (Quigley, 1987; Ferreira et al., 2010; Bernstein and Struyven, 2022; Fonseca and Liu, 2023)

shows how both rebuilding and adaptation subsidies affect the exposure of regions to natural disasters in steady-state. I focus instead on the dynamic equilibrium interaction between migration, mortgage defaults, and housing markets, underscoring the importance of capturing these forces when evaluating post-disaster policies.

This paper also relates to a growing literature on migration as an adaptation strategy to climate change (Desmet and Rossi-Hansberg, 2015; Desmet et al., 2021; Cruz and Rossi-Hansberg, 2023). Prior work has studied the response of agents to slow-moving anticipated changes, whereas I focus on the response to sudden unanticipated large natural disasters. Bilal and Rossi-Hansberg (2023) develop a model with heterogeneously exposed locations, immobile capitalists, mobile hand-to-mouth workers and natural disasters which destroy local capital stocks. They use the model to study how the spatial distribution of economic activity in the US changes in anticipation of future shocks. Future research could study how anticipation of post-disaster interventions affects migration in a model with both renter- and owner-occupied housing as well as the potential for these policies to introduce moral hazard.[6]

This paper also adds to a literature measuring how disasters affect migration and related outcomes. Prior studies of disaster-induced migration have used annual or decennial census data (Vigdor, 2008; Hornbeck, 2012; Hornbeck and Naidu, 2014; Sastry and Gregory, 2014; Boustan et al., 2020; Sheldon and Zhan, 2022; Leduc and Wilson, 2023; Roth Tran and Wilson, 2023) or tax records (Deryugina et al., 2018; Nakamura et al., 2022) to show that post-disaster migration can affect a variety of outcomes ranging from income to health.[7] Leveraging the unique setting of Hurricane Maria in Puerto Rico, I add to this literature by using higher-frequency flight data to reveal that temporary migration is an important coping strategy. Other papers in this literature have also studied the effects of disaster related property damage on household finances. These papers generally link damage from disasters to household outcomes at an aggregate level, such as by county or census tract (Gallagher and Hartley, 2017; Farrell and Greig, 2018; Groen et al., 2020; Gallagher et al., 2023). By surveying impacted households, I can jointly measure individual damage levels, household financial positions at the time of the shock, and their subsequent decisions.

My findings on how households value government rebuilding subsidies offer valuable insights into the puzzlingly low uptake of disaster insurance in exposed housing markets (Gallagher, 2014; Kousky et al., 2018; Wagner, 2022; Mulder, 2024; Ostriker and Russo, 2024). In my model, I abstract from natural disaster insurance since very few households in Puerto Rico were insured before Hurricane Maria (Kousky and Lingle, 2018). However, the structure of insurance payouts after a natural disaster closely mirrors that of government rebuilding subsidies. Both require verification of individual damages, a time-consuming process that frequently results in denied claims. Additionally, many homeowners face strict requirements to provide proof that insurance

[6] Hsiao (2023) quantifies the magnitude of the moral hazard effects of government policy in a model with renters and property developers

[7] The Census Current Population Survey added a new question on displacement after Hurricane Katrina, but given its sampling frame was largely limited to individuals who were staying with family or friends (Groen and Polivka, 2008, 2010).

payouts are used specifically for repairs, reducing flexibility for homeowners who might otherwise consider selling their property in the aftermath of a disaster. This relates to a broader literature on insurance non-payment risk and low take-up (Luttmer and Samwick (2018), Briggs et al. (2024)).

The remainder of the paper is organized as follows. Section 2 provide institutional background. Section 3 describes the flight and survey data, and documents household rebuilding and relocation behavior after Hurricane Maria. Section 4 develops a model of natural disasters with housing, migration, and infrastructure. Section 5 discusses the quantification of the model. Section 6 studies the distributional effects of natural disasters and the role of current policy in mitigating these impacts. Section 7 studies the effects of alternative post-disaster policies. Section 8 concludes.

2. Setting

2.1 Puerto Rico and Hurricane Maria

Puerto Rico, in the aftermath of Hurricane Maria, is a compelling context to study households' post-disaster decisions for two reasons. First, in this setting observed migration reflects individuals' preferences and pecuniary and non-pecuniary migration costs, rather than legal barriers to migration. As US citizens, Puerto Ricans face no restrictions on migration to or employment within the mainland US. The US acquired the Caribbean island in 1898 at the end of the Spanish-American War and while part of the US, Puerto Rican is considered"foreign in a domestic sense" (1901 Downes v. Bidwell) and classified as unincorporated territory. This status has continuing implications for taxation, federal transfer programs, and electoral representation. Since the mid-20th century, economic opportunities have driven many Puerto Ricans to move to the mainland US, leading to a Puerto Rican diaspora community that today comprises a significant share of all Puerto Ricans (Meléndez-Badillo, 2024). In the aftermath of Hurricane Maria, the mainland US was therefore the primary destination for displaced Puerto Ricans.

The second feature that makes Puerto Rico a compelling setting for studying households' post-disaster choices is its island geography, which allows for precise measurement of migration. Since Puerto Rico is located over 1,000 miles from the coast of Florida, air travel is the only method of transit between the island and the mainland U.S., with no regular passenger boats other than cruise ships. Hurricane Maria made landfall on September 22, 2017, as a Category 4 hurricane, causing catastrophic damage: 90% of homes were damaged, 80% of utility poles were knocked down, and roads were left impassable. The disruptions from the hurricane were long-lasting; even five months after the storm made landfall, a quarter of the population remained in the dark without any electricity. Given Puerto Rico's distance from the mainland US, households seeking to escape the widespread devastation after Hurricane Maria had to rely on air travel.

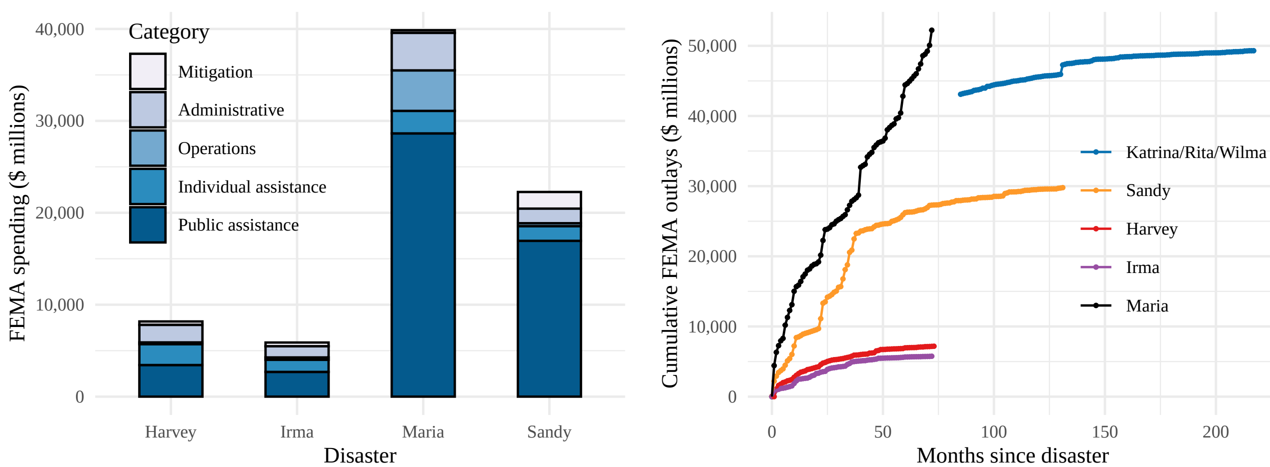
2.2 Post-Disaster Policy in US

Over the past decade large natural disasters in the US such as hurricanes, floods, and wildfires have caused over $1 trillion in damages to housing, utilities, roads, and other infrastructure (NOAA). In response to these events, the federal government has provided over $200 billion to subsidize rebuilding affected communities. These funds have been dispersed through an array of federal agencies and programs: the Federal Emergency Management Agency (FEMA), Department of Housing and Urban Development (HUD), Small Business Administration (SBA), Department of Transportation, Army Corps of Engineers, and others. Figure 1a shows the breakdown of FEMA post-disaster spending for four of the largest and costliest natural disasters since 2010: Hurricanes Sandy, Harvey, Irma, and Maria while Figure 1b plots the timing of the disbursement of this assistance after the disaster. Although these figures only show numbers for FEMA, the patterns are representative across other agencies.

Figure 1: FEMA Post-Disaster Spending

(a) Composition of FEMA Post-Disaster Spending

(b) Timing of FEMA Post-Disaster Spending



Notes: Outlays data from FEMA Disaster Relief Fund monthly reports. The left panel shows the composition of FEMA post-disaster spending for Hurricanes Sandy (October 2012), Harvey (August 2017), Irma (September 2017), and Maria (September 2017). The right panel plots nominal cumulative FEMA outlays after a natural disaster. Data from FEMA Disaster Relief Fund Monthly Reports.

After Hurricane Maria, financial assistance for homeowners with uninsured or under-insured property damage was distributed through FEMA's Individual Assistance Program ($1.5 billion) and HUD's Community Development Block Grant Disaster Recovery Program ($20 billion), following a structure similar to that used after major hurricanes like Sandy and Katrina.[8] Applicants for these programs were required to submit official identification, proof of ownership, income verification, primary residence proof, and additional documentation to determine eligibility. Many households in Puerto Rico were initially denied due to non-standard property deeds. Upon submitting the

[8]SBA loans were a very small share of total funding for rebuilding Puerto Rico totaling roughly $300 million (SBA OIG). National flood insurance payouts totaled less than $5 million (FEMA).

correct documentation, applicants underwent a property assessment, with a damage assessor, environmental inspector, and appraiser jointly evaluating the property to determine eligibility and award amounts. Approved funds were earmarked for repairs and, in many cases, transferred directly from HUD to contractors responsible for the work Department of Housing (2024).

After Hurricane Maria, the majority of federal disaster aid was allocated to rebuilding Puerto Rico's public infrastructure, with large grants directed to the Puerto Rico Electric Power Authority ($9.4 billion), Puerto Rico Aqueduct and Sewer Authority ($3.6 billion), and Puerto Rico Department of Education ($2 billion). The structure of post-disaster assistance encourages disaster-affected areas to restore infrastructure largely as it existed before the disaster, often with only minor improvements. FEMA's public assistance funding is designed to reimburse local governments and nonprofits for rebuilding costs, covering at least 75% of eligible expenses. For example, the Puerto Rico Department of Education contracted local firms to repair structural damage to public schools after Maria, directly paying the contractors and later submitting the costs to FEMA for reimbursement. While FEMA typically reimburses 75% of eligible costs, Congress often increases this share to nearly 100% for specific disasters, as it did following Hurricane Maria.

3. Post-Disaster Relocation and Rebuilding Choices

3.1 Data

Bureau of Transportation Statistics. To understand aggregate migration behavior after Hurricane Maria, I use data on passenger flows and airline tickets from the Bureau of Transportation Statistics (BTS). These data are particularly useful in the setting of migration between Puerto Rico and the mainland US. I use two BTS data sets: the T-100 Airline Passenger Traffic dataset, which contains the universe of airline passenger flows at a monthly frequency, and the DB1B dataset, a 10% random sample of all itineraries sold by commercial airlines. By aggregating passenger flows or one-way tickets between Puerto Rican and mainland US airports, I can compute net population flows between Puerto Rico and the mainland US. To validate that net airline passengers are a reliable measure of net migration, I compare population estimates for Puerto Rico derived from these data with official census data. The two estimates are nearly identical at an annual frequency, but using airline passenger flow data enables me to estimate migration at a monthly or quarterly frequency. Additional methodological details can be found in Appendix B.

Survey of Puerto Rican Households. To better understand how Puerto Rican households responded to the aftermath of Hurricane Maria, I designed and conducted a new survey of adults residing in Puerto Rico. The sampling frame is restricted to households that either did not migrate after the hurricane or migrated to the mainland US only temporarily. The survey was conducted online in two waves by TGM Research, a market research firm. The first wave as conducted in June 2023 with a second wave following in May 2024.[9] Each wave had approximately 500 respondents, broadly representative of the current population of Puerto Rico along dimensions such as English fluency, birthplace, income, and homeownership. As is typical of online surveys, the sample population is relatively younger and more educated than the Puerto Rican population overall. To address this, all results are weighted to better reflect the true population's income and age distribution. Appendix C provides additional details on the representativeness of the survey sample and response quality.

The primary focus of the survey was on a household's experiences following Hurricane Maria, with questions designed to shed light on household decision making in response to the disaster. The survey included questions on housing tenure at the time of the hurricane, the extent of property damage, and timing and financing of repairs.[10] I also included questions on post-disaster migration both within Puerto Rico and to the mainland US. I asked not only, where households evacuated to and for how long, but also where they stayed, such as in shelters, hotels, or with friends or family. Among households who did not evacuate, I asked whether they hosted friends or family after the hurricane and for how long. Additionally, I asked whether respondents were forced to default on their mortgage or sell their home due to the effects of the hurricane, and whether they received government support for rebuilding or other forms of assistance, such as unemployment insurance.

Beyond these disaster-related questions, I collected detailed demographic data as well as information on current income and wealth. I also asked respondents about their expectations of future hurricanes and whether the household has changed any behaviors after Hurricane Maria in expectation of future storms. To better understand how Puerto Rican households evaluate the costs and benefits of migration, I asked respondents to estimate how costly it would be to migrate with their household to the mainland US, either temporarily or permanently. I also asked about their expected earnings and housing costs if they were to move to the mainland US. Finally, I used preference elicitation techniques to benchmark how much households value living near other Puerto Ricans versus how much households value living in Puerto Rico. Many results from the survey will be presented below; others are discussed in Section 5, where I quantify the model.

Census. I use the American Community Survey (ACS) and Puerto Rican Community Survey (PRCS), the Puerto Rican counterpart to the ACS, to learn about the population of Puerto Ricans living in Puerto Rico and the mainland US before Hurricane Maria. I also infer the composition of permanent migrants from changes in population distribution in the PRCS.

[9] TGM Research directly recruits individuals to take the online survey. Respondents are recruited though emails, push notifications, or in-app pop-ups. There is little overlap of respondents between the two survey waves.

[10] To increase salience, the definitions of property damage given to survey participants match those used by FEMA. Households would have used the FEMA definitions to fill out any aid applications. Destroyed: Complete failure of two or more major structural components (e.g. collapse of walls, foundation, or roof). Severe Damage: Failure or partial failure of at least one structural element (e.g. walls, foundation, or roof). Moderate Damage: Damage to roof or walls. Damage to mechanical components (furnace, boiler, water heater, HVAC). Minor Damage: No essential living space or mechanical components were damaged or submerged. Cosmetic damage such as paint discoloration. Missing shingles or siding. Damage to property such as gutters, screens, or downed trees that did not affect access to the residence.

3.2 Household Behavior after a Natural Disaster

Fact 1. ***Many households migrate after a large natural disaster***

To measure the aggregate migration response to Hurricane Maria, I estimate the following regression, following local projection methods developed in Jordà (2005) :

$$y_t = \sum_{i=-3}^{12} \beta_i H_{t-i} + \mu_{m(t)} + \tau t + \epsilon_t \quad (1)$$

where y_t is net out-migration measured using net passenger outflows from Puerto Rico to the mainland US in period t. The effects of Hurricane Maria on migration are captured by the coefficients β_i on the indicator variable H_{t-i}, which is equal to one if the hurricane occurred i months ago and zero otherwise. The model controls for monthly seasonal variations, and a linear time trend in migration. Figure 2a below plots these point estimates as well as the cumulative estimates for net out-migration.[11] The data show significant population outflows in the first three months after the hurricane followed by inflows in subsequent months. These estimates indicate that, in the short-run, nearly 250,000 people or 7% of the pre-Hurricane Maria population of Puerto Rico migrated to the mainland US, while in the long run, 4% of the pre-Maria population migrated permanently to the mainland US. [12]

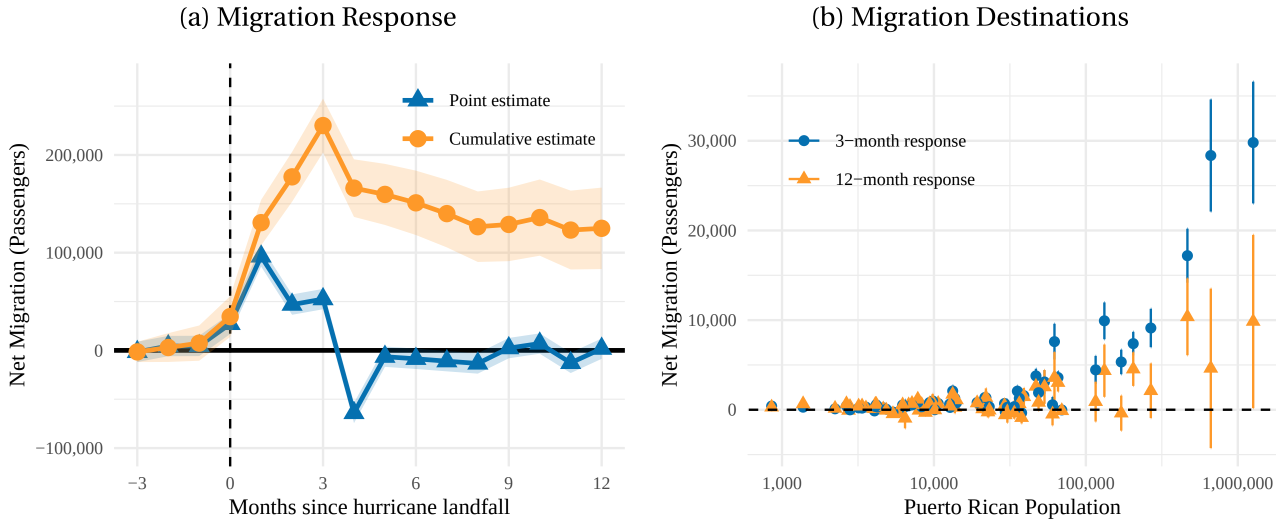
Individuals who migrated after Hurricane Maria primarily relocated to mainland US cities with significant pre-existing Puerto Rican communities. Using the BTS ticket data, which tracks passengers to their final destination, I use the same specification to estimate the migration response for individual Metropolitan Statistical Areas (MSAs) at a quarterly frequency. The dependent variable in this case is net one-way tickets between all Puerto Rican airports and all airports associated with an MSA. Figure 2b, plots the cumulative 3-month and 12-month migration response as measured by net one-way tickets. The top destinations of both temporary and permanent migrants were cities with the largest pre-hurricane Puerto Rican populations: New York, NY, Orlando, FL, and Miami, FL.[13] This positive elasticity of migration flows with respect to stocks is suggestive evidence that Puerto Ricans value living near other Puerto Ricans, something that I will quantify more formally in Section 5.

[11] Figure A1 plots the residual passengers flows that drive the estimate of the migration response. The migration resposne is robust to including additional leads and lags (Figure A2) and to using one-way tickets instead of flows (Figure A3).

[12] Prior work estimating the migration response to Hurricane Maria such as Alexander et al. (2019) and Acosta et al. (2020) find similar timing patterns but estimate much larger out-migration rates. This is likely due the fact that the authors use social network and cell phone tracking data sets which likely have a different age composition that the overall population.

[13] This positive migration elasticity with respect to the pre-shock Puerto Rican population is robust to controlling for distance, average airfare, average income and rents of Puerto Ricans living in the destination, the size of non-Puerto Rican Spanish speaking population, and weather. The pattern is also robust to dropping the top 3 destination. See Appendix Table A1 for more details. Many studies have documented the positive effect of immigrant enclaves on economic outcomes such as wages (Edin et al. (2003)) and ethnic enclaves are common instruments to estimate the effects of migration on incumbent populations (see Morales (2018) and Altındağ et al. (2020) for recent examples).

Figure 2: Migration after Hurricane Maria



Notes: The left panel plots the estimated migration response to Hurricane Maria. The blue triangles show point estimates for the out-migration response in a specific month after Hurricane Maria. The orange circles show the cumulative out-migration response. The shaded areas correspond to the 90% confidence interval. These estimates are based on monthly data on passenger flows. The right panel plots the estimated 3-month and 12-month cumulative out-migration response from Hurricane Maria to MSAs in the mainland US by the MSA's pre-hurricane Puerto Rican population. These estimates are based on a 10% random sample of all itineraries sold, which track passengers to their final destinations.

While the flight data is very useful for measuring aggregate migration, it contains no information about the identity of these post-Maria migrants. To learn more about the composition of temporary migrants, I turn to my survey of Puerto Rican households currently in Puerto Rico. Table 1 columns (1)-(2) report the coefficients of a linear probability model, where the dependent variable is whether respondents migrated to the mainland US temporarily due to Hurricane Maria. I find that temporary migrants were primarily those whose homes sustained severe structural damage and those who are *currently* wealthier. Overall, only 3% of survey respondents report that they migrated temporarily, in line with the flight data estimates. The regression results show that households with significant damage were 8 percentage points more likely to migrate, while a household with $20,000 in wealth holdings at the time of the survey was 5 percentage points more likely to have migrated after Hurricane Maria. Finally, I find no significant relationship between lower expected migration costs and the decision to migrate.

The characteristics of temporary and permanent migrants differ. Although permanent migrants are not within the sampling frame of my survey, it is possible to infer the composition of permanent migrants from changes in the Census distribution of households in Puerto Rico. I compute changes in the population share by age and housing tenure bins between 2016—the year before Hurricane Maria—and 2019, when most migration induced by the hurricane had concluded. Table 1 column (3) reports the coefficients of a regression, where I regress the change in population share on bin characteristics. The regression reveals that there were fewer young individuals in Puerto Rico after Hurricane Maria. This is suggestive evidence that young individuals, who were primarily renters

Table 1: Demographic Characteristics of Migrants

	Dependent variable:		
	Temporary Migrant		Permanent Migrant
	(1)	(2)	(3)
Severe Damage	0.081^{***}	0.082^{***}	
	(0.018)	(0.018)	
Moderate Damage	0.022	0.022	
	(0.014)	(0.014)	
Homeowner	-0.008	-0.008	0.013
	(0.016)	(0.016)	(0.004)
Age	0.004^{*}	0.004^{*}	-0.012^{***}
	(0.002)	(0.002)	(0.0002)
Age^2	-0.0001^{*}	-0.00005^{*}	0.0002^{***}
	(0.00003)	(0.00003)	(0.00000)
Family/close friends in US	0.037^{*}	0.036	
	(0.022)	(0.022)	
Income($10,000)	-0.003	-0.003	
	(0.009)	(0.009)	
Income^2	0.001	0.001	
	(0.001)	(0.001)	
Wealth ($10,000)	0.028^{***}	0.028^{***}	
	(0.009)	(0.009)	
Wealth^2	-0.003^{***}	-0.003^{***}	
	(0.001)	(0.001)	
Temorary Migration Cost		0.001	
		(0.002)	
Observations	672	672	24
R^2	0.059	0.059	0.399

Notes: Columns (1)-(2) report the coefficients of a linear probability model, where the dependent variable is whether respondents migrated to the mainland US temporarily due to Hurricane Maria. Column (3) reports the coefficients of a regression, where the dependent variable is the change in population share between the 2016 and 2019 PRCS for an age/homeownership bin.

*p<0.1; **p<0.05; ***p<0.01

before the Hurricane were likely to have migrated permanently to the mainland US.

Fact 2. ***Puerto Rican households believe that migrating to the mainland US is costly***

The true cost of migration between Puerto Rico and the mainland US encompasses more than just the cost of a plane ticket; it also includes the costs associated with temporary housing, moving personal belongings, etc. I elicit households' expectations about the full pecuniary costs of temporary migration to the mainland US:

> Imagine that you decided to move to the mainland US permanently. How much do you think it would cost for you and your household to move? *Think about the total cost of plane tickets and other moving expenses such as the cost of moving furniture and other household items.*

as well as permanent migration:

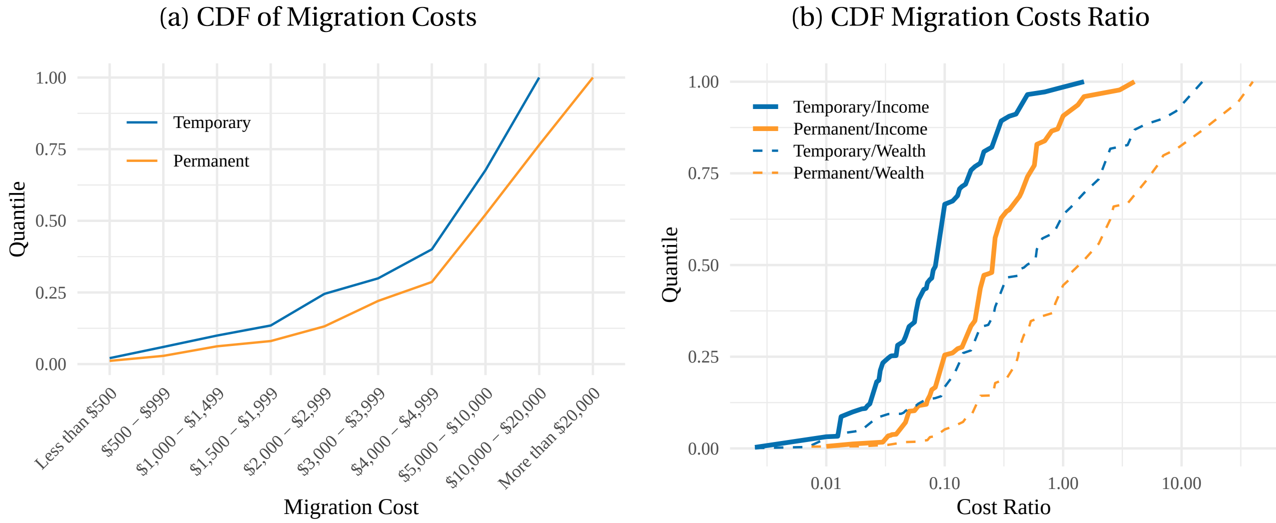
> Imagine that you decided to move to the mainland US for a few months. How much do you think it would cost for you and your household to move? *Think about the total cost of plane tickets to travel to the mainland US and return to Puerto Rico, where you would stay, and other expenses.*

I find that household's expected migration costs are large, especially when compared to household income and non-housing wealth. Figure 3a presents the cumulative distribution function (CDF) of expected temporary and permanent migration costs, while Figure 3b plots the CDF of these costs as a fraction of income and wealth. The mean expected cost of temporary migration is approximately $4,500 representing 15% of a household's reported income and 230% of its non-housing wealth. The mean expected cost of permanent migration is more than twice as large, at approximately $11,000, representing 50% of a household's reported income and nearly 700% of its non-housing wealth. Given that household's expected costs of migration are so large relative to non-housing wealth, migration may be out of reach for many households as a way to escape the local effects of a natural disaster. To understand the extent to which financial constraints prevented migration following Hurricane Maria I asked respondents directly if they were financially constrained to remain in Puerto Rico after Hurricane Maria.[14] More than half of respondents who remained in Puerto Rico after Hurricane Maria responded that they wanted to migrate but were unable to afford the cost.

This is a setting where households have accurate information about migration costs. In the survey I ask whether respondents have family or close friends living in the mainland US, and whether they have ever lived in the mainland U.S. for at least one month. Nearly all respondents (90%) report having family or close friends who live in the mainland US, and nearly half report having spent at least one month in the mainland US. If Puerto Ricans lack accurate information about migration costs, we would expect to observe differences in the perceived costs between those who have connections in the mainland US as well as between individuals with prior migration

[14]The full question text reads: *If you had been able to afford the costs of air travel and temporary housing, would you have gone to the mainland US at least temporarily after Hurricane Maria?*

Figure 3: Pecuniary Migration Cost Distributions



Notes: The left panel plots the cdf of household reported temporary and permanent migration costs. The right panel plots the CDF of the ratio of temporary and permanent migration to respondent reported household income and non-housing wealth. This figure excludes respondents who report no income or wealth.

experience and those without. However, I find no statistically significant difference in expected migration costs when conditioning on whether respondents have family or close friends living in the mainland US, or on their past migration experiences.[15]

Fact 3. ***Most homeowners did not migrate and coped with the disaster impacts of in other ways***

While a significant portion of the population migrated after Hurricane Maria, the majority of households remained in Puerto Rico, adopting various strategies to cope with the aftermath of the disaster. Since over 80% of households at the time of the hurricane were homeowners, I focus on how homeowners dealt with the impacts of the hurricane. Table 2 provides a comprehensive overview of the different choices homeowners made after the hurricane as a function of the severity of their property damage. Nearly all homeowners (85%) reported some degree of property damage from Hurricane Maria. The severity of damage varied substantially: 41% of households experienced minor damage, such as missing shingles or paint discoloration, while 28% reported moderate damage, including significant damage to roof or walls, and 16% faced severe structural damage, such as collapsed roofs or walls.

Among those who did leave, most migrated within Puerto Rico (88%), while only 10% relocated to the mainland U.S. The length of displacement varied substantially by the severity of damage. Households with severe damage spent an average of 174 days away from their homes, compared to

[15]Additionally, none of the respondents, who were living in Puerto Rico at the time of the survey, believed that the present value of higher real wages in the mainland U.S. outweighs the costs of migration. In Section 5 I discuss how households perceive the benefits of moving to the mainland US in more detail. In general though, very few households perceive *real* wage gains from moving to the mainland US. The median expected increase in income is $7,500 but the expected increase in housing cost is more than $1,000 per month

much shorter displacement periods for those with minor (29 days) or moderate (27 days) damage. Nearly half of the displaced households went to stay with family or friends, while others found refuge in rental housing, hotels, or public shelters.

Table 2: Post-Disaster Decisions of Homeowners by Damage

	Owner	Minor Damage	Moderate Damage	Severe Damage
Fraction of Population	0.80	0.41	0.28	0.16
Migration				
Temporarily left home	0.18	0.07	0.16	0.65
went elsewhere in PR	0.88	0.85	0.81	0.90
went to mainland US	0.12	0.15	0.19	0.10
stayed with famiy/friends	0.42	0.56	0.28	0.44
Average duration (days)	111	29	27	174
Repair Duration				
Completed Repairs	0.88	0.87	0.88	0.89
Within a few weeks	0.24	0.37	0.14	0.06
Within a year	0.55	0.61	0.56	0.29
Repair Financing				
Government assistance	0.43	0.26	0.58	0.62
Personal savings	0.56	0.64	0.56	0.38
Home Sale and Mortgage Default				
Mortgage at time of Hurricane	0.46	0.54	0.34	0.33
Defaulted due to Hurricane	0.05	0.02	0.07	0.20
Sold due to Hurricane	0.07	0.04	0.14	0.08

Notes: This table reports summary statistics at the household level

Nearly all homeowners with property damage who were still living in Puerto Rico managed to repair their homes by the time the survey waves were conducted, six and seven years after the hurricane. Homeowners with minor or moderate damage generally rebuilt faster, with over half completing repairs within a year (61% for minor damage and 56% for moderate damage). In contrast, only 29% of households with severe structural damage managed to complete repairs within the same time frame. Many homeowners continued to live in their damaged properties while repairs were underway, particularly those with minor or moderate damage, while others sought temporary refuge with friends or relatives within Puerto Rico.

Households report that repairs were financed through a mix of government assistance and personal savings. Households with severe damage were more likely to rely on government support, with 62% receiving assistance, compared to 26% of those with minor damage and 58% of those with moderate damage. On the other hand, personal savings played a larger role for households with minor damage, with 64% using savings to finance repairs, compared to only 38% of those with severe damage. Notably, very few households received insurance payouts, with only 11% of homeowners reporting some insurance payment. These insurance payouts were concentrated among wealthy and highly educated households with a mortgage at the time of Hurricane Maria.

Despite the availability of government rebuilding subsidies, a significant number of homeowners with a mortgage experienced financial distress following Hurricane Maria. Among homeowners with a mortgage, 5% reported that they defaulted on their mortgage as a direct result of Hurricane Maria. Default rates were much higher among those with severe structural damage, with 20% of these households reporting a default, compared to only 2% of those with minor damage and 7% of those with moderate damage. This pattern suggests that some households may have "strategically" defaulted, choosing to stop mortgage payments because the value of their outstanding debt exceeded the value of the house, even though they may have been able to continue making payments. While it is possible that income shocks caused by Hurricane Maria were correlated with property damage, it is unlikely that such correlation could fully explain the higher rates of default among those with larger home equity losses.

The impacts of Hurricane Maria extended beyond damage to owner-occupied housing. Many respondents, including those with undamaged properties, or who rented at the time of the hurricane, experienced prolonged disruptions in electricity and water supply. The median survey respondent reported being without reliable electricity for several months following the hurricane. Hurricane Maria also had significant effects on the local economy beyond housing and infrastructure. In the three months following Hurricane Maria, there was a 300% increase in initial unemployment claims as in the same period in the prior year. Other social safety net programs expanded as well. Nearly 40% of survey respondents report receiving a new government benefit after the hurricane, the most common being supplemental nutritional assistance (SNAP) and Medicaid.

4. Model of Natural Disasters, Housing, Migration, and Infrastructure

In this section, I develop a model of housing, migration, and infrastructure that is designed to be able to match the rich heterogeneity in household's post-disaster behavior described in the prior section. I model Puerto Rico as a small open economy. Puerto Rican households rent from landlords or own housing with a potentially defaultable mortgage. They face idiosyncratic productivity shocks and can save in a liquid asset at an exogenous world interest rate. Each period, they can migrate temporarily or permanently to the mainland US. I assume that the outside option of moving permanently to the mainland US depends on the household's age, idiosyncratic productivity, and asset holdings. Puerto Rican firms produce a tradable good using their private capital stock, government provided infrastructure and by hiring local labor. I model a natural disaster as a capital destruction shock that destroys local production capital, infrastructure, rental housing and causes heterogenous damages to owner-occupied housing. Housing both owner-occupied and rental is traded locally and so house prices and rents are affected by natural disaster shocks.

4.1 Households

Demographics. Time is discrete and a period corresponds to one year. There is a unit mass of Puerto Rican households of different ages j. Households work from age 20 to $j^{ret} - 1$ and are retired from age j^{ret} until age J. Households have conditional survival probability from age $j-1$ to j of ϕ_j and die with certainty after age J.

Locations. Puerto Rican households live either in Puerto Rico or in the Mainland US. The total Puerto Rican population in Puerto Rico at time t is $N_{pr,t}$. The total Puerto Rican population in the Mainland US is $N_{us,t} = 1 - N_{pr,t}$.

Preferences. During their lifetime, households derive utility from numeraire consumption c_t, owning or renting housing services s_t, and living near other Puerto Ricans, $N_{\ell,t}$. Households also have a warm glow bequest motive. Households maximize expected lifetime utility and discount the future with parameter β:

$$\mathbb{E}\left[\sum_{j=1}^{J-1} \phi_j \beta^j u_j(c_t, s_t, N_{\ell,t}) + \phi_J \beta^J v(a_J)\right], \tag{2}$$

where $u_j(c_t, s_t, N_{\ell,t})$ is the flow utility for the household during their life and $v(a_J)$ is the utility from bequests, as in De Nardi (2004). The flow utility of a household of age j living in Puerto Rico takes the form:

$$u_j(c_t, s_t, N_t) = \frac{1}{1-\gamma}\left(\frac{s_t^{\eta} c_t^{1-\eta}}{e_j}\right)^{1-\gamma} + \theta_0 N_t^{\theta_1}, \tag{3}$$

where utility from consumption and utility from living near other Puerto Ricans is assumed to be additively separable[16]. Households have power utility over a Cobb-Douglas aggregator of numeraire consumption, c_t, and housing services, s_t. Changes in the household size and composition over the life-cycle are captured by the equivalence scale, e_j. The household's relative taste for housing services is governed by the parameter η while γ is both the household's intertemporal elasticity of substitution and their risk aversion. Finally, the parameter θ_0 governs the scale of preferences for living near other Puerto Ricans while θ_1 governs the returns to scale.

Income. Working-age households supply their labor inelastically and receive idiosyncratic labor income $y_{j,t}$ given by

$$y_{t,j} = w_t \chi_j z_t, \tag{4}$$

where w_t is the wage per effective labor unit. Individual labor productivity has two components: a deterministic age profile χ_j that is common to all households and a persistent idiosyncratic component z_t. I assume that while the household is employed, z_t follows an AR(1) process in logs. Retired households receive a pension proportional to their idiosyncratic productivity at retirement.

Liquid Savings. Households in all locations can save in a one-period risk-free asset with an exogenous interest rate r. Unsecured borrowing is not allowed.

[16]The assumption that there is no complementary between consumption and living near other Puerto Ricans implies that the number of other Puerto Ricans in a location does not effect a household's consumption, saving, or housing decisions but does play a role in migration decisions.

Housing. Households must either rent or own a house. Houses are characterized by their size h, which takes on a finite set of of values. The size of available rental units is described by the set $H^{\mathcal{R}}$ and the size of available owner-occupied units is described by the set $H^{\mathcal{O}}$. The flow of housing services generated from a household occupying a house of size h_t for one period is given by:

$$s_t = h_t(1 + \mathbb{1}_{\text{own}}\omega)(1 - d_t)f(g_t), \tag{5}$$

where $\omega \geq 0$ captures additional utility benefits of homeownership, d_t is any potential property damage, and $f(g_t)$ reflect potential complementarity between housing consumption and per-capita government infrastructure, g_t. [17]

In addition to making any potential mortgage payments, homeowners must pay property taxes on the market value of their home, $\tau_h p_t^h h_t(1 - d_t)$, where τ_h is the tax rate, and p_t^h is the house price. Maintenance costs are $\delta_h p_t^c h_t(1 - d_t)$ where δ_h is the depreciation rate of housing, and p_t^c is the current construction cost. Households can also undertake repairs of their house with an upfront cost of $d_t h_t p_t^c$. The repair will be completed the following period. When buying or selling their home, households pay a transaction cost κ. Households have i.i.d preference shocks for owning or renting which are drawn from an extreme value distribution with scale parameter σ_h.

Mortgages. Households can finance the purchase of housing with a mortgage. All mortgages are long-term, subject to constraints at origination, amortized over the remaining life of the buyer at the interest rate r_m equal to the risk free rate r times an intermediation wedge, and defaultable. A household who takes out a new mortgage receives the principle balance b_t in units of the numeraire good in the period that the mortgage is originated. The initial mortgage balance b_t must be less than a fraction, ψ^{ltv}, of the collateral value of the house being purchased. If a household chooses to default, they walk away from their house and any outstanding mortgage debt. Households are not subject to recourse and retain any non-housing assets but do incur a utility penalty $\bar{u}_d$ and cannot buy a house for one period following evidence from Diamond et al. (2020).[18]

Migration. Each period, households can migrate to the mainland US either temporarily or permanently by paying a pecuniary cost. In the period of migration, the household earns no income and receives utility $\bar{u}_m$. A household that migrates temporarily, pays an idiosyncratic migration cost m_T and returns to their starting location at the end of the period. A household that migrates permanently, pays an additional idiosyncratic migration cost m_P and begins the next period as a renter in the mainland US. The indirect utility the household receives in the mainland US is a function of their individual state(age, idiosyncratic productivity, and savings) as well as the prices(wage, rent, house price), and Puerto Rican population in the mainland US. The migration

[17] My survey of Puerto Rican households after Hurricane Maria shows that those whose electricity was restored earlier also rebuilt their homes faster. In a large natural experiment in urban Mexico, McIntosh et al. (2018) also find that increased government infrastructure investment increases housing investment by homeowners.

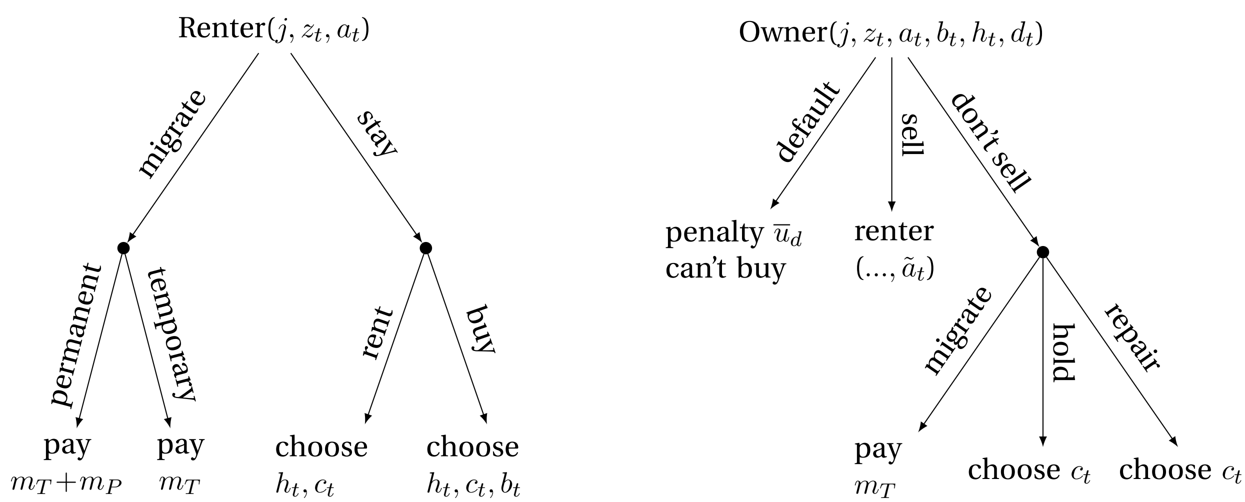
[18] In the model I abstract from Home Equity Lines of Credit (HELOC) since very few households report using bank lending to finance repairs following Hurricane Maria.

costs are iid, symmetric, denoted in terms of numeraire, and must be financed out of start of period liquid savings. The cost of migrating permanently is weakly larger than the cost of migrating temporarily ($m_T + m_P \geq m_T$).

4.2 Household Problem

Households begin each period as either an owner or a non-owner (renter). Here, I describe the set of decisions households face, as illustrated in Figure 4. Appendix D.1 contains the detailed Bellman equations.

Figure 4: Household Decisions



Renters. At the start of each period, renters decide whether migrate temporarily or permanently to the mainland US or to stay in Puerto Rico. The individual state of a renter is described by their age, j, idiosyncratic productivity, z_t, and liquid assets, a_t. In order to migrate, households must pay their idiosyncratic migration cost m_T out of their start of period liquid assets a_t. At the end of the period, the household must decide whether to return to Puerto Rico(temporary migration) or to pay an additional idiosyncratic cost m_P and remain in the mainland US (permanent migration).

If the household decides to stay, they must choose between renting and buying a house. Those who decide to rent choose the size of their rental unit, how much to consume, and how much to save. Those who choose to become homeowners choose the size of house to buy, together with their initial mortgage balance subject to a loan-to-value constraint. They make a down payment, choose the quantity of nondurable goods to consume, and how much to save.

Owners. At the start of each period, owners must choose whether to default on their mortgage, to sell their house in its current condition, or to keep their house and continue making mortgage payments. If the household chooses to keep their house, they can either migrate temporarily, repair any damage, or live in their house in its current condition. The individual state of an owner is described by their age, j, idiosyncratic productivity, z_t, liquid assets, a_t, remaining mortgage balance b_t, house size h_t, and any potential fractional house damage d_t.

If the household chooses to default, they face a utility penalty are excluded from buying a house again for one period. If the household decides to sell their house, they immediately become a renter with any potential proceeds from the sale of their house. This timing assumption implies that a household can sell their house and buy again in the same period as well as sell their house or default on their mortgage and migrate permanently in the same period. A household cannot migrate permanently and retain ownership of their house.

Households who choose not to default or sell must continue to make mortgage payments and pay property taxes and maintenance costs for their house. They can decide not to live in their house this period by paying their idiosyncratic migration cost, m_T, out of their start of period non-housing assets a_t and going to the mainland US temporarily. A household with property damage can choose to repair their house with or without government assistance. The cost of the repair must be paid upfront but the repair is not completed until the following period. While repairs are in progress, the household receives a diminished flow of housing services. Finally the household can choose to live in the house in its current condition.

4.3 Financial Sector

Mortgages and liquid assets are issued by risk-neutral foreign agents with deep pockets. Mortgages are offered at an exogenous spread over the risk free rate. If a household defaults, the lender absorbs the loss, calculated as $p_t^h h_t(1-d_t) - b_t$.

4.4 Rental Sector

A competitive rental sector in Puerto Rico owns and rents out houses. Rental companies can frictionlessly buy and sell existing houses. They must pay the construction firm for the construction of new houses and any repairs and maintenance to existing units at the price per unit of new construction, p_t^c . They are subject to the same depreciation cost δ_h and property tax τ_h as homeowners. Rental companies are subject to an additional per-period operating cost, ψ^r per rental unit. The rental company must be indifferent between selling a unit of housing in the current period versus collecting rent, paying the operating cost and property taxes and selling their unit of housing in the next period:

$$p_t^h = p_t^r - \psi^r - \tau_h - \delta_h p_t^c + \frac{p_{t+1}^h}{1+\bar{r}} \tag{6}$$

They are also indifferent between constructing a new unit to be delivered next period or buying an existing unit next period:

$$p_t^c = \frac{p_{t+1}^h}{1+r}. \tag{7}$$

The full problem of the landlord can be found in Appendix D.3.

4.5 Production

There is one homogeneous tradable non-durable consumption good whose price is normalized to one. Competitive firms in Puerto Rico operate a constant returns to scale technology:

$$Y_t = A(K_t)^{\alpha_K}(L_t)^{\alpha_L}(G_t)^{\alpha_G} \tag{8}$$

where K_t is the firm's private capital stock, L_t is the total quantity of inelastically supplied local labor units, G_t is the government infrastructure, and A is total factor productivity. Firms face decreasing returns to private inputs, capital, and labor, while infrastructure as a public good is subject to congestion externalities. Firm profits equal revenue minus the wage bill, $w_t L_t$, taxes, $\tau_G Y_t$, and investment expenditure I_t^K. Firms maximize dividends and purchase new capital from the construction firm at price p_t^c. Appendix D.4 contains details on the firm's optimization problem.

4.6 Construction Sector

The competitive construction sector produces new capital: I_t^H (housing units and maintenance and repairs of existing units), I_t^K (production capital) and I_t^G(government infrastructure). The cost to produce X_t units of new capital given that the sector produced X_{t-1} units in the last period in units of numeraire is given by:

$$c(X_t, X_{t-1}) = \psi_0 X_t + (X_t - X_{t-1})^{\psi_1}. \tag{9}$$

This cost function captures the fact that when facing higher levels of demand the construction firm will need to pay higher costs to bring in a locally limited factor such as construction workers and specialized equipment. The firms contracts for investment in the current period t, but does not deliver until the start of period $t+1$.

4.7 Local Government

The local government in Puerto Rico collects revenue from an output tax and immediately uses the revenues to construct government infrastructure. Infrastructure depreciates at rate δ_G. The law of motion for G is

$$G_{t+1} = (1-\delta_G)G_t + I_t^G \tag{10}$$

where the quantity of government infrastructure investment depends on aggregate output, the output tax, and the construction price: $I_t^G = \tau_G Y_t / p_t^c$.

4.8 Federal Post Disaster Assistance

The federal government provides two types of transfers to Puerto Rico following a natural disaster: infrastructure aid and homeowner rebuilding subsidies. Infrastructure aid is delivered as deterministic transfers to the local government for infrastructure rebuilding. These transfers are spread evenly over several years after the disaster and cover a fraction of the destroyed infrastructure's value. The actual investment by the local government depends on construction costs. Rebuilding subsidies are a risky transfer from the perspective of the household. Homeowners with property damage can apply for these subsidies each period. The approval probability, $\pi_t^{approve}$, varies exogenously over time, reflecting capacity constraints such as the limited availability of home inspectors and the extensive documentation required. Many reports after Hurricane Maria highlight the challenges households faced in accessing these programs, especially in the first few years. If approved, the homeowner must undertake repairs that period, with the subsidy covering the cost up to a cap. If denied, the household remains in their damaged home for the period but can reapply the following period.

4.9 Equilibrium, Steady State, and Natural Disaster Shocks

Given initial conditions for capital stocks and an initial distribution of household states, a competitive equilibrium is defined as a sequence of wages, rents, house prices, construction costs, and distribution of household states such that households, landlords, and firms optimize, and housing, labor, and construction markets in Puerto Rico clear. Appendix D.5 provides a detailed description of the equilibrium conditions.

A steady state is an equilibrium where prices and the distribution of household states remain constant. Due to constant returns to scale in production and construction, per-capital capital and infrastructure are independent of the population level. As a result, steady-state wages, rents, and house prices also do not depend on Puerto Rico's population level. As long as the outside option of living in the mainland US is not too attractive, and migration costs are sufficiently large, any distribution of the Puerto Rican population between the mainland US and Puerto Rico is a steady state (see Appendix D.6 for details). This model therefore exhibits path dependency, natural disaster shocks and the subsequent federal policy response have lasting implications for the population of Puerto Rico and the size of the Puerto Rican economy.

A natural disaster is a one-time unanticipated shock which destroys a fraction of aggregate private capital K_t, government infrastructure G_t, rental housing stock $\tilde{H}_t$, and owner occupied housing H_t. Damages to owner-occupied housing, d_t, are heterogeneous but sum to the total shock size. There is no policy uncertainty – households the set of transfers the federal government will make immediately after the disaster and therefore have full information and rational expectations about the recovery path.

4.10 Discussion: The Effects of a Natural Disaster and Post-Disaster Policy

Immediately on impact, a natural disaster destroys capital and infrastructure. Unless there is massive out-migration, this results in lower wages at least in the period of the shock. In the housing market, short-run supply is inelastic due to the one-period time-to-build, though some conversion between owner and rental units is possible. Housing demand responds on two margins. The extensive margin depends on migration costs and the wealth distribution at the time of the shock. If migration is relatively cheap and many households can afford to leave, demand will be relatively elastic, limiting rent and house price increases. Conversely, if migration is expensive and unaffordable for most, housing demand will be relatively inelastic, leading to larger rent and house price increases. On the intensive margin, households will reduce their housing demand due to lower wages and diminished utility from housing, due to the complementarity between housing services and infrastructure. In later periods, housing supply is more elastic, but congestion in the construction sector will drive up construction costs which in turn increases house price and rents unless rebuilding occurs incrementally over a long time horizon.

Some households will become "underwater," where the value of their home $(1 - d_t)p_t^h h_t$ falls below their outstanding mortgage balance b_t. This can lead to default, particularly if repair costs, exacerbated by congestion in the construction sector, exceed the recouped home equity. Since there are utility costs of default, both due to the explicit default penalty but also due to being excluded from buying a house for one period, underwater households do not immediately default but may default if their home-equity and liquid asset holdings fall below a certain threshold. Rebuilding subsidies may induce some of these households at risk of default to hold onto their home. Inducing potential defaulters to remain in their damaged home may also affect post-disaster house prices and rents, depending on whether these households would increase their housing consumption if they defaulted and transitioned to renting.

Post-disaster migration dynamics are most shaped by push factors, while pull factors of the mainland US remain constant. In Puerto Rico, after Hurricane Maria, renters face lower wages, higher rents, and reduced housing services due to infrastructure damage. The difference in indirect utility between the mainland US and Puerto Rico is now larger so renters are more likely to migrate both temporarily and permanently if they can afford the costs. Homeowners face additional frictions to migrate permanently, such as the need to sell or repair damaged homes before moving, but are similarly more likely to migrate temporarily. All else equal, federal transfers to rapidly rebuild infrastructure will increase the indirect utility of living in Puerto Rico by increasing wages and housing services and thereby decrees migration.

5. Model Quantification

I quantify the model in two steps. First, I estimate the parameters that govern the model's steady state to match the equilibrium that existed in Puerto Rico before Hurricane Maria.Given the significant role of property damage and mortgage default risk observed in the survey data, I try to accurately capture the distribution of homeownership, home equity positions, and house values that existed prior to Hurricane Maria. In the second step, I estimate the remaining parameters that can only be identified from the model's transition dynamics under the current post-disaster policy regime. These parameters that govern household decisions on migration, rebuilding, and mortgage default. In each step, some parameters are directly estimated using empirical evidence or drawn from the literature, while others are calibrated by minimizing the distance between model-generated equilibrium moments and their data counterparts. More details can be found in Appendix E.

5.1 Initial Steady State

I parameterize the initial steady state of the model to be consistent with key cross-sectional features of the 2011-2016 waves of the PRCS. Unlike U.S. states, Puerto Rico is not included in the sampling frame of the Federal Reserve's Survey of Consumer Finances (SCF), which means there is limited detailed household wealth data. The PRCS provides information on household income, homeownership rates, a course measure of home equity(whether a household has a mortgage or not), households self-reported property values, rents, and owner costs. Table 3 summarizes the jointly estimated steady state parameters and corresponding data moments. Parameters are listed with the data targets they affect most quantitatively.

In the initial steady state, I assume that there is no migration and no mortgage default. I defer discussion of the parameters governing this behavior until section 5.3.

Demographics. A period in the model is one year. Households enter the model at age 20, retire at age 65, and die at age 80. I take age-dependent survival probabilities from the U.S. Social Security Administration actuarial life tables. The initial age distribution of households is set to match the age distribution observed in the year preceding Hurricane Maria (2016).

Preferences. I set the parameter γ which governs both the household's risk aversion and intertemporal elasticity of substitution to 1.5 as in Gourinchas and Parker (2002). The household consumption equivalence scales, e_j, are based on OECD standards and are calculated to reflect the average household composition by age, using data from the 2011-2016 (PRCS).

The discount factor, $\beta = 0.977$, is estimated to match the fraction of households over age 75 who own their home "free and clear." Since mortgages in the model are amortized over the agent's remaining lifespan, I define the model counterpart to the "free and clear" status observed in the data as households with more than 95% equity in their home. The bequest motive, $\nu = 20$, governs household saving behavior in retirement. I estimate a relatively strong bequest since such a large share of older households own their house with little mortgage debt. The weight on housing services, $\eta = 0.4$, is identified from the average rent burden (rent as a share of household income). This estimate is somewhat higher than estimates for cities in the mainland US (see Davis and Ortalo-Magné (2011)), but is driven by the fact that the average ratio of rent to household income in Puerto Rico (0.38) is higher than in the mainland US (0.3).

The parameter ω governs the additional utility from owning versus renting an equivalent unit of housing. I calibrate the utility benefit of ownership $\omega = 1.09$ to match the aggregate homeownership rate in Puerto Rico. The shape of the taste shock distribution, σ_h, governs the income composition of renters. If taste shocks are small and economic considerations dominate household decision making, then there will be very few wealthy renters. If idiosyncratic taste plays a significant role in decision making then there will be more wealthy renters. Given that there are few high income renters, I estimate $\sigma_h = 0.001$.

Finally I parameterize the role of per-capita government infrastructure in housing services production such that in steady state $f(g_t) = g_t/g_{ss}$ where g_t is the per-capita level of government infrastructure in Puerto Rico and g_{ss} is the steady state level.

Income. I estimate the deterministic age profile of the income process using household income from the 2011-2016 PRCS. Due to the lack of panel data on Puerto Rican household incomes, I assume an annual income persistence of 0.97, consistent with estimates for U.S. households from panel data studies (Heathcote et al., 2010; Krueger et al., 2016). The standard deviation of income shocks (0.6) and pension replacement rate (85%) are calibrated to match the observed income distribution in Puerto Rico before Hurricane Maria. Additional details on the estimation of the income process are in Appendix E.1.

Financial Assets. I set the risk-free rate r equal to 3.5% and the wedge between the risk-free rate and the mortgage interest rate $\iota = 1.33$ following Kaplan et al. (2020). Together, these imply a mortgage rate of $r_m = 4.66\%$ consistent with financial conditions in Puerto Rico pre-hurricane. In line with Greenwald (2018), the maximum loan to value allowed at origination is $\psi = 0.85$.

Housing. I set the depreciation rate of housing, $\delta_h = 0.02$, based on estimates from the Bureau of Economic Analysis (BEA), and the property tax rate, $\tau_h = 0.01$, reflecting the average rate in Puerto Rico. The transaction cost for buying and selling properties in the model is $\kappa = 0.05$. In the steady state, the price-to-rent ratio is determined by the landlord's per-unit rental operating cost, ψ^r, and the construction firm's marginal cost, ψ_0. This price-to-rent ratio influences the relative cost of buying versus renting, which is a critical factor for young households deciding between the two options. Steady-state rents are normalized to 1.

I allow for 4 different house sizes in the set of houses available to own and rent. I set the minimum rental size such that it rents for \$100/month and the spacing of the rental grid is calibrated to match the average rent in the top quartile of the income distribution.The smallest size available for ownership is set based on the average house value in the bottom quartile of the income distribution, while the spacing of the owner-occupied grid is determined by house values in the top quartile. In addition to the relative price of owning versus renting, the minimum house size, and degree of segmentation between the owner-occupied and rental market also plays a role in the relative attractiveness of owning versus renting. All these moments are estimated jointly.

Production. I set the infrastructure factors share, α_G , and local government tax rate, τ_G, equal to the ratio of state and local government tax revenue to GDP (0.015). I set the capital factor share to $\alpha_K = 0.325$ and the labor factor share to $\alpha_L = 0.66$. I choose the level of total factor productivity A

such that the wage per efficiency unit in steady state is equal to one. I set the depreciation rate for private and government capital (structures) as $\delta_K = \delta_G = 0.02$.

Table 3: Internally Estimated Steady State Parameters

Parameter	Value	Target Moment	Data	Model
Preferences				
Housing services weight η	0.4	Average rent burden	0.38	0.38
Utility from owning ω	1.09	Homeownership rate	0.82	0.80
Bequest motive ν	20	Homeownership rate >75	0.92	0.84
Homeownership taste shocks σ_h	0.001	Homeownership rate top income quartile	0.89	0.95
Discount rate β	0.977	Fraction owners w/o mortgage >75	0.82	0.70
Housing				
Price to rent ratio p^r/p^h	13.5	Homeownership rate <25	0.22	0.23
Minimum owner size	$93,150	Average value bottom income quartile	$120,000	$100,000
Owner size spacing	$72,900	Average value top income quartile	$230,000	$240,000
Renter-occupied size spacing	$300	Average rent top income quartile	$1,000	$1,000

Notes: Data moments are derived from the 2011-2016 PRCS.

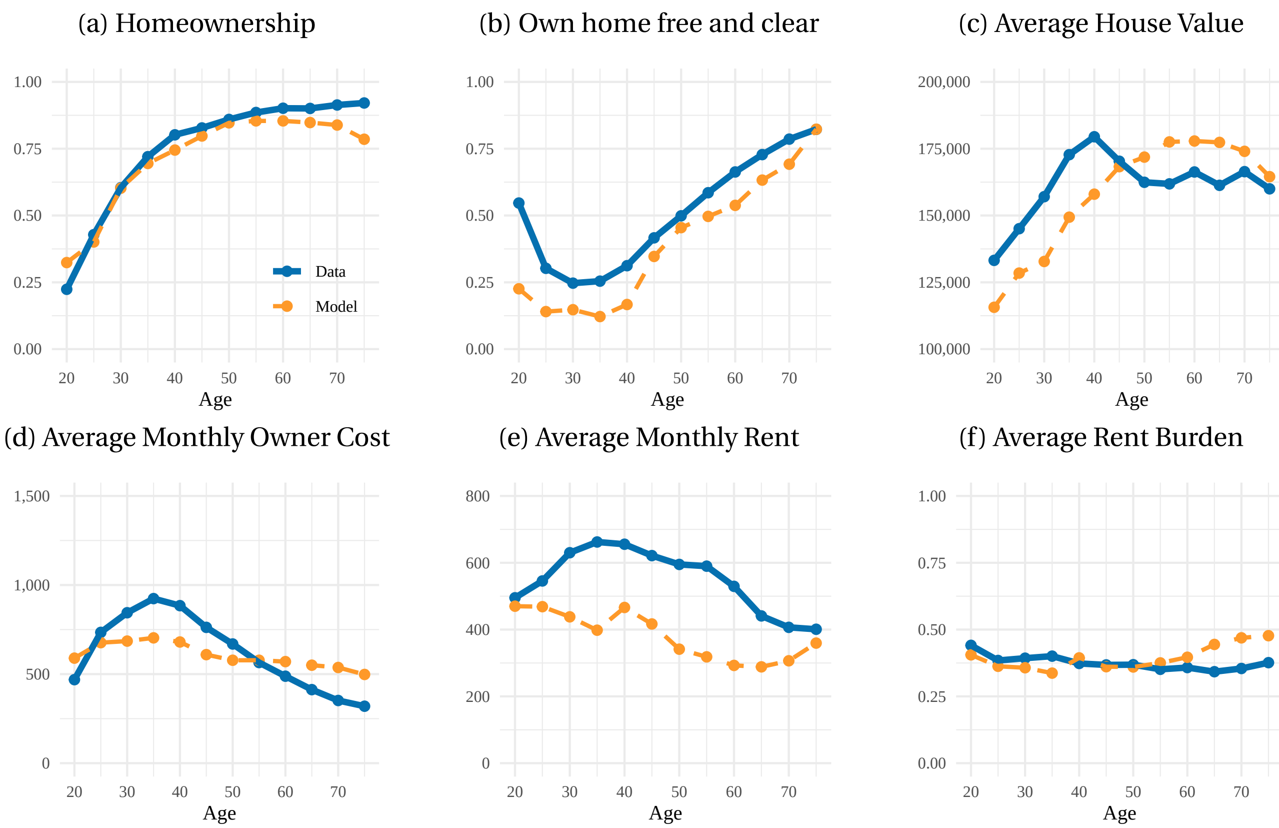
5.2 Steady State Model Fit

As a test of the model's quantification, I evaluate its ability to fit a range of non-targeted data moments that are crucial for determining a household's exposure to a natural disaster shock. Figure 5 model-generated age profiles with observed data for homeownership rates, the share of households that own their homes without a mortgage, average house values, average monthly owner costs, average monthly rent, and average rent burden. While some of these moments are explicit calibration targets, most are untargeted.

Although homeownership rates for both the youngest and oldest households are explicit calibration targets, the model is reasonably successful in matching the entire lifecycle profile. It accurately captures the four-fold increase in homeownership between ages 20 and 40. The model struggles to match the fact that in the data there is no decline in homeownership after retirement. Similarly, while I explicitly target the share of households over age 75 who own their homes free and clear, the model also captures key lifecycle features of households' home equity positions. The share of households who own their home without a mortgage starts relatively high among younger households, declines in middle age, and then rises again as households approach retirement. The model also accurately reflects that younger households tend to own less valuable, smaller homes, and that the value of owner-occupied housing generally increases over the lifecycle.

In addition to these age-related patterns, the model is able to reasonably match the same key moments across the income distribution as well as when broken out by age and by above and below the median income. (see Figures E4 and E5). The model struggles to match the fraction of households who own their home without a mortgage across the income distribution. The model also struggles to match the rent burden among low income households.

Figure 5: Steady State Model and Data Age Profiles



Notes: The figures compare steady state model age profiles for homeownership, the fraction of homeowners who own their home without a mortgage ("free and clear"), average house value, average monthly owner costs (mortgage + maintenance + taxes), average monthly gross rent, and average rent burden with data profiles computed using the 2011-2016 PRCS. The targeted moments plotted here are the fraction of homeowners less than age 25 and over age 75, and the fraction of homeowners above age 75 who own their home free and clear. Since mortgages are amortized over the lifecycle, I define "free and clear" in the model to be greater than 95% home-equity.

5.3 Post-Shock Equilibrium

The remaining parameters governing the post shock equilibrium are: current post disaster policy, returns to migration, pecuniary and non-pecuniary migration costs, the utility cost of default, and the construction sector adjustment cost. Table 4 summarizes the jointly estimated post-shock parameters and corresponding data moments. Parameters are listed with the data targets they affect most quantitatively.

Current Post Disaster Policy Regime. The first component of the current post-disaster policy is transfers to the local government, which are allocated directly to rebuilding local infrastructure. I model these transfers as equal installments disbursed over a six-year period, matching the estimated value of damaged government infrastructure at the time of the shock.

The second component of the current post-disaster policy consists of rebuilding subsidies for homeowners with property damage. I model these subsidies as non-transferable claims, available only to households that owned their homes and experienced damage at the time of the hurricane. Each period, eligible homeowners who do not default or sell their properties can apply for rebuilding assistance. I base the approval probabilities, π_t, on actual program approval rates. In the immediate aftermath of Hurricane Maria, funding was provided primarily through the Federal Emergency Management Agency's (FEMA) Individual Assistance Program, where approximately 60% of applicants were denied. Accordingly, I set the approval probability during the first year after Hurricane Maria at 40%. Subsequent funding for homeowner rebuilding was administered through Department of Housing and Urban Development (HUD) block grants, which offered more flexible terms and had higher approval rates (HUD OIG). For the remaining periods, I set the approval rate at 75%. Finally, I assume that these subsidies are available only for the first six years following the shock.

Returns to Migration. Post-disaster migration decisions are shaped not only by the costs of migrating and local conditions in Puerto Rico but also by the potential longer term benefits that households anticipate from relocating. To quantify the value of the outside option of permanently relocating from Puerto Rico to the mainland U.S., it is essential to understand households' perceptions of relative wages and rents. I use both direct survey questions and Census data for this purpose. In the survey I ask households about their expected change in wages from moving to the mainland US:

> Imagine that you decided to move to the mainland US permanently. How much do you think you would earn at a job in the mainland US relative to what you earn now?

As well as their expected change in housing costs:

Imagine that you decided to move to the mainland US permanently. How much do you think your rent or mortgage in the mainland US would cost relative to what you pay now?

The responses to these two questions indicate that while relative wages in the mainland U.S. are significantly higher than in Puerto Rico, housing costs are also much larger. On average, respondents expect to earn 36% more if they move to the mainland, aligning roughly with post-tax income data from the American Community Survey (ACS) and Puerto Rico Community Survey (PRCS). The ratio of earnings is higher using post-tax household income data from the Census. This is likely due to both composition and selection effects, but also because survey respondents are unlikely accounting for differences in taxation across the two locations. Households in Puerto Rico are typically exempt from federal income tax but are also ineligible to receive social benefits distributed through the tax code such as the Earned Income Tax Credit.

On average, survey respondents expect to pay more than $1,000 more per month in housing costs. Using Census data, I can control for other factors such as quality differences in housing between the two locations. I find that housing costs in the mainland U.S. are twice that in Puerto Rico. This ratio is robust to controlling for all housing characteristics observable in Census data such as house size, age of the structure, and location-specific cost adjustments, including high-cost areas like New York City. The real wage gains of moving to the mainland U.S. are therefore much lower than the nominal gains.

Pecuniary Migration Costs. I use the survey responses to the questions on pecuniary temporary and permanent migrations costs to discipline the distribution of migration costs in the model. For temporary migration costs, I directly discretize the survey responses into five values and use the corresponding empirical probabilities. In the model, the cost of permanent migration is an additional cost that the household incurs on top of the temporary migration cost. Since the survey question explicitly included costs such as plane tickets that are common to both temporary and permanent migration, I define the permanent migration cost as the difference between the costs of permanent and temporary migration. Many households report the same expected cost for temporary and permanent migration costs, therefore in the model I explicitly allow for this cost to be 0 for a fraction of households. The correlation in survey responses between temporary migration costs and this definition of permanent migration costs is low (0.1).

Non-pecuniary Migration Costs. I designed a sequence of survey questions to estimate household preferences for living near other Puerto Ricans. Each question had two parts: first, respondents were asked to choose between two mainland U.S. cities that were identical except for the size of the Puerto Rican population. In a follow-up question, they were then asked how much compensation would be required for them to choose the other option. A sample question text is below:

Suppose City A has **1,000** Puerto Ricans living there and City B has **10,000** Puerto Ricans living there. Assume cities A and B are otherwise identical, that is they are of similar size, total population, and economic opportunities. They also have similar weather and other amenities such as restaurants and public transportation.

If you are someone who would prefer living in a city with more Puerto Ricans, you would choose city B. If you are someone who would prefer living in a city with fewer Puerto Ricans, you would choose city A.

1. Which city would you choose?
2. Hoe much would you have to be paid to choose the other city?

I use respondents' answers to estimate household preferences for living near other Puerto Ricans within the framework of my model. I replicate the survey population in the model by creating agents with the same age, income, and wealth characteristics as the respondents. These agents are then posed with the same questions, using values for the parameters θ_0 and θ_1, which govern the scale and return to scale of household preferences for living near other Puerto Ricans. I then estimate the parameter values by minimizing the distance between the survey responses and the answers provided by the simulated agents in the model's steady state. The estimated parameter values are $\theta_0 = 0.0069$ and $\theta_1 = 0.18$. The magnitude of the estimates suggests that if we shift from the current equilibrium, where Puerto Ricans are dispersed across multiple locations, to a scenario where all Puerto Ricans are concentrated in a single location (holding all else constant), the average household would experience a welfare gain of $2,000 per year. The only remaining free parameter governing household migration behavior is the utility households receive during the period of migration. I estimate this parameter by minimizing the difference between the total migration responses in the model in the period of the hurricane and that observed in the flight data. The value implies that in the period of migration it is as if the household is living in the smallest rental unit and consuming $1,000 units of the numeraire.

Construction sector congestion. The strength of the congestion force in the construction sector, ψ^1, is estimated to match the observed movement in house prices in the period of the shock. A higher congestion force leads to increased house prices, as determined by the first-order condition of the landlord, which links these variables. I estimate ψ^1= 1.05.

Cost of default. I estimate the disutility from mortgage default by targeting an aggregate foreclosure rate of 5%. To ensure consistency between data and model moments, I use the same sampling frame as my survey when calculating this moment, restricting the model sample to households still residing in Puerto Rico five years after Hurricane Maria. The calibrated value implies an average consumption-equivalent loss of approximately 6% in the period of default from this additional utility penalty.

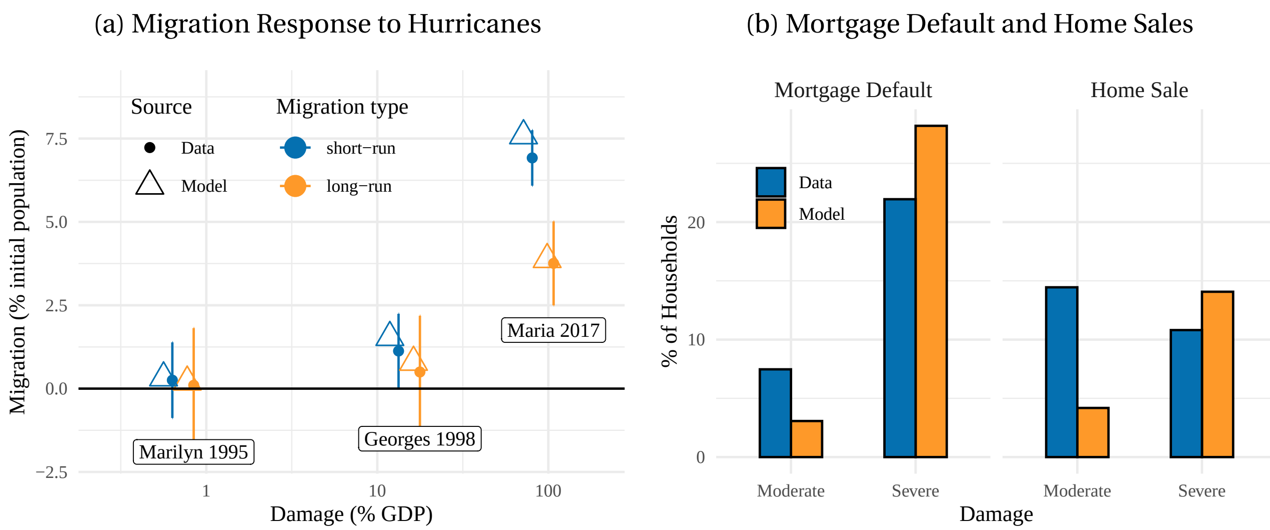
Table 4: Internally Estimated Post Shock Parameters

Parameter	Target Moment	Model	Data	Source
Utility cost of default u_d	Aggregate default rate	7.2	5.0	Household Survey
Utility in period of migration u_m	Short-run migration rate	7.5	6.9	Flight Data
Construction adjustment cost ψ_1	Date 0 House Price Growth	6.8	7.5	FHFA

5.4 Post Hurricane Model Fit

Temporary and permanent migration. The model is able to not only successfully match the short- and long-run migration responses to Hurricane Maria but to several past hurricanes as well. Figure 6(a) plots the short-run (temporary and permanent) and long-run (permanent) migration responses to hurricanes expressed as a fraction of the pre-shock population of Puerto Rico as a function of the estimated physical damages of the hurricane as a fraction of Puerto Rican GDP in the preceding year (NOAA). The only targeted moment in figure is the short-run migration response to Hurricane Maria. The plot also shows both data and model moments for two major hurricanes that previously impacted Puerto Rico: Hurricane Georges in 1998 and Hurricane Marilyn in 1995. I use the same estimation procedure described in Section 3.2 to estimate the aggregate migration response to these past events from flight data. To compute the corresponding model moments, I introduce smaller capital destruction shocks to the same initial steady state

Figure 6: Migration, Mortgage Default, and Home Sales



Notes: The left figure shows the short and long run migration response to Hurricane Maria (2017), Hurricane Georges (1998), and Hurricane Marilyn (1995) estimated from both the flight data and the model as a function of estimated physical damages as a fraction of pre-shock Puerto Rican GDP. The right figure shows mortgage default rates by damage severity from both the household survey and the model. The denominator here is the fraction of all homeowners who have a positive mortgage balance at the time of the shock. It also shows home sale rates by damage severity from both the household survey and the model. The denominator here is the fraction of all homeowners who have that level of damage.

Mortgage default. In addition to matching the aggregate default rate, the model matches survey data on the default rate by damage level reasonably well. Figure 6(b) shows the data and model implied default rates by damage level. Slightly too many households with severe property default in the model and slightly too few households with moderate damage default. The model is able to match the rate the households sell their homes reasonably well.

The magnitude of the home equity shock of Hurricane Maria is similar to shocks in the most impacted regions during the Great Recession. Compared with the generosity of post-disaster rebuilding assistance, policies were much more limited for homeowners who experienced home equity shocks due to house price movements during the Great Recession. For example, peak to trough in Miami, FL, house prices fell by 50%, between the home equity shock for "Minor" and "Severe" damage in the model, and foreclosure rates in the Miami CBSA, peaked at 20% in the year prices bottomed out.[19] The foreclosure rates in the model are not annual but rather that fraction of households who initially had mortgage debt at the time of the hurricane and *ever* defaulted.

Construction costs, house prices, and rents. The model is reasonably successful in matching movements in the Federal Housing Finance Agency experimental house price index for Puerto Rico. I do not explicitly target changes in the rental rate in Puerto Rico. Recent work using proprietary rental data for Puerto Rico estimates a cross-section elasticity of rents with respect to the fraction of the local housing stock that was destroyed by Hurricane Maria of 1.27(se =0.5) (Santiago-Bartolomei et al., 2022). The model predicts that rents rise 25.8%. The number is within the 95% confidence interval of this micro estimate, given the shock size of Hurricane Maria that I feed into the model (25%).

6. Current Post-Disaster Policy

In this section, with the fully quantified model, I first study the distributional impacts of a natural disaster in the absence of any post-disaster transfers. Then, I study the effects of current policy and decompose the role of transfers for rebuilding infrastructure and rebuilding subsidies for homeowners with property damage.

6.1 The Effects of Natural Disasters Absent Policy

In the absence of any policy intervention, the model predicts that Hurricane Maria would have led to widespread mortgage default, significant out-migration, and substantial welfare losses. Table 5 summarizes the outcomes for mortgage default, owner repair, migration and consumption equivalent welfare losses across four different post-disaster policy scenarios: column (1) reports results under current post-disaster policy, column (2) reports results absent any federal post-disaster policy response, column (3) reports results when only infrastructure rebuilding in effect, and column (4) reports results when only rebuilding subsidies in effect. I report average

[19] Sources: S&P CoreLogic Case-Shiller FL-Miami Home Price Index, CoreLogic (2017)

consumption equivalent welfare losses relative to steady state for homeowners with property damage, homeowners without any property damage, homeowners with and without a mortgage and renters.

Table 5: Current Policy

	Baseline	No Policy	Infrastructure Investment	Rebuilding Subsidies
Mortgage Default				
Aggregate	7.2	15.9	15.1	7.4
Moderate damage(31%)	3.0	10.1	8.8	3.0
Severe damage(18%)	27.6	50.2	48.1	28.2
Repair				
Moderate damage(31%)	89.8	57	61.6	89.5
Severe damage(18%)	73.6	8.6	8.7	72.8
Migration				
Total	7.5	12.9	10	8.9
Permanent	3.7	7.1	5.1	5.0
Renters	80	59	65	74
Owners sell/default leave	20	41	35	26
Temporary	3.8	5.7	5.0	4.0
Renters	64	59	63	61
Owners	36	41	37	39
Consumption Equivalent Welfare				
Average	-10.5	-15.9	-14.5	-12.4
Owner (80%)	-11.7	-18.2	-16.7	-13.9
Owner with Damage (48%)	-14.6	-26.1	-24.9	-16.8
Undamaged Owner (52%)	-8.93	-10.4	-8.59	-10.9
Owner with Mortgage (72%)	-10.5	-16.9	-15.4	-12.7
Owner w/o Mortgage (28%)	-14.9	-21.7	-20.1	-16.9
Renter (20%)	-4.66	-6.16	-5.15	-5.68

Notes: Column 1 reports results for the baseline when the infrastructure rebuilding and rebuilding subsidy are in effect. Column 2 reports results for when no post-disaster policy is in effect. Columns 3 and 4 report results for when only the infrastructure rebuilding policy or rebuilding subsidy are in effect respectively. Rows 1-3 report mortgage default rates as defined as the fraction of households who ever default out of the initial stock of households who had any mortgage debt at the time of the shock. Rows 4-5 report repair rates are defined as the fraction of households who ever repair their home out of the initial stock of households who have a damage. Rows 6-9 report numbers related to migration in the period of the shock. Owner temporary is defined as the fraction of households who were initially owners who choose to migrate while still retaining ownership of their home. Rows 10-15 report consumption equivalent (CE) welfare losses on average and broken out by homeownership, damage, and mortgage status.

In the absence of policy, default and migration increase substantially, and far fewer households repair their homes. The aggregate mortgage default rate rises to 16%, compared to only 7.2% under the current-policy. Among households with an outstanding mortgage balance at the time of the shock, half of those with severe damage default, roughly double the rate under current policy. The increase in default is particularly pronounced among households with only moderate damage, which rises more than three fold from 3% to 10%. Absent government intervention, the permanent out-migration rate nearly doubles from 3.7% to 7.1% and temporary migration also increases, from 3.8% to 5.7%. Without a rebuilding subsidy, the composition of permanent and temporary migrants shifts to include more homeowners. Many households with moderate damage repair their homes even absent intervention (57%), repair rates among households with severe damage drop sharply from 74% to 9%.

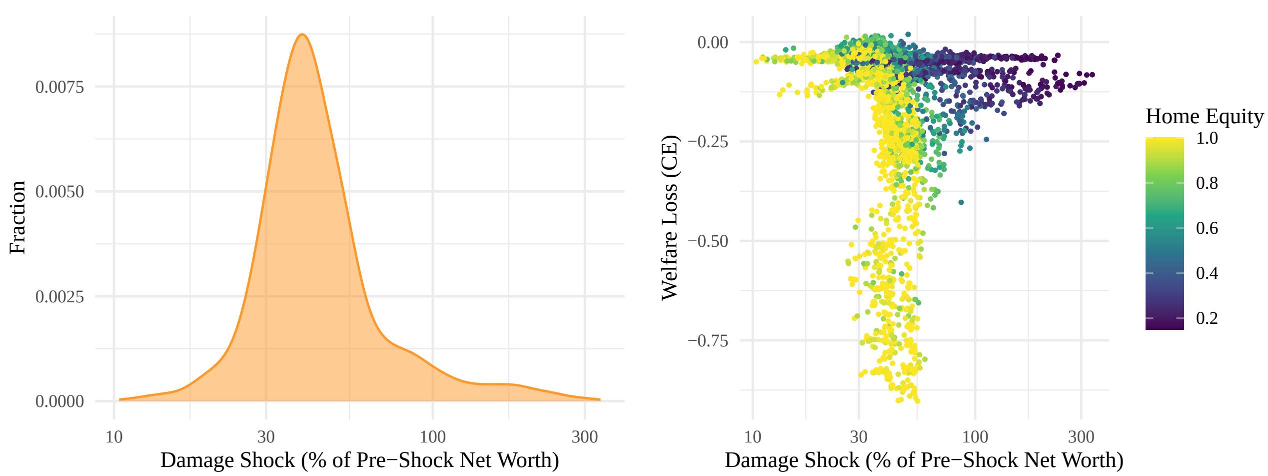
The overall consumption equivalent welfare loss without any policy intervention is substantial, with households experiencing an average reduction of 10.5%.[20] The losses are particularly severe for homeowners with damage averaging 26%. For these households, the hurricane is a shock to their housing consumption, their wealth, and if they have a mortgage, their home equity. Even among homeowners with property damage, there is substantial heterogeneity in the effects of a natural disaster. I model natural disaster damage shocks as proportion to house size meaning that both large and small houses hit by the hurricane may both have their roofs torn off, but in dollar terms, the loss is larger for households with larger homes.

Figure 7a shows the distribution of wealth shocks as a fraction of pre-shock net worth by idiosyncratic damage. On average, homeowners with moderate damage face a wealth shock of 25%, while those with severe damage experience a wealth shock of 75%. However, these averages mask the heterogeneity in how the same damage shock to a house translates into dramatically different effects on household wealth depending on the composition of a household's portfolio and in particular their home equity position. Figure 7b shows how the wealth shock maps into welfare. Those in the right tail of this distribution tend to be less wealthy, with little home equity, where the shock exceeds their total net worth, while those in the left tail are the very wealthy.

Figure 7: Wealth and Welfare Shocks

(a) Wealth Shock

(b) Welfare Shock



Notes: The left panel shows the distribution of wealth shocks as a function of pre-maria net worth (house value - mortgage balance + non-housing asset). The right panel shows the relationship between the wealth and welfare shock suffered by households. Color shows households pre-shock home equity position.

The mapping between the magnitude of the wealth shock and the magnitude of the welfare shock depends both on the households net-worth before the shock and on their home equity

[20]The magnitude of the consumption equivalent welfare loss from Hurricane Maris is the same order of magnitude as estimates of welfare losses of Axis powers during WWII using country level consumption data(Auray et al. (2014)).

position. Figure 8 plots the welfare effects of the shock across the pre-shock net worth distribution, the dashed orange line shows the effects for homeowners with damage. The welfare losses for lower net-worth homeowners are smaller than those for higher net-worth homeowners. This is because low net-worth homeowners typically had little equity in their homes before the shock and could therefore default and partially offload the loss to the mortgage lender. Although default is costly, households lose any opportunity to recover wealth, are barred from buying a home for one period, and incur a utility cost, for these households, the costs of retaining their underwater property exceeds the costs of default. In contrast, high net-worth homeowners, who often own their homes outright without a mortgage, must absorb the full loss of property value.

All households are affected by the hurricane's destruction of the firm's private capital, local infrastructure, and the housing stock. Wages fall by 8% in the immediate aftermath of the shock, as the hurricane damages both private capital and infrastructure, which are inputs into the firm's production. Due to crowding out in the construction sector by households trying to rebuild, the private firm does not immediately invest in replacing its capital stock and so wages recover only gradually. In addition, damage to infrastructure not only affects households indirectly through wages but also directly through housing services. The same unit of housing in the immediate aftermath of the disaster only delivers 78% as much utility due to complementarities with infrastructure.[21] Finally the acute housing shortage in the immediate aftermath of the disaster causes rents to rise 30% relative to steady state levels, and house prices to rise 8%. Despite not suffering direct impacts of the storm, these general equilibrium effects translate into sizable welfare losses for renters (-4.7%) and homeowners without property damage (-8.9%).

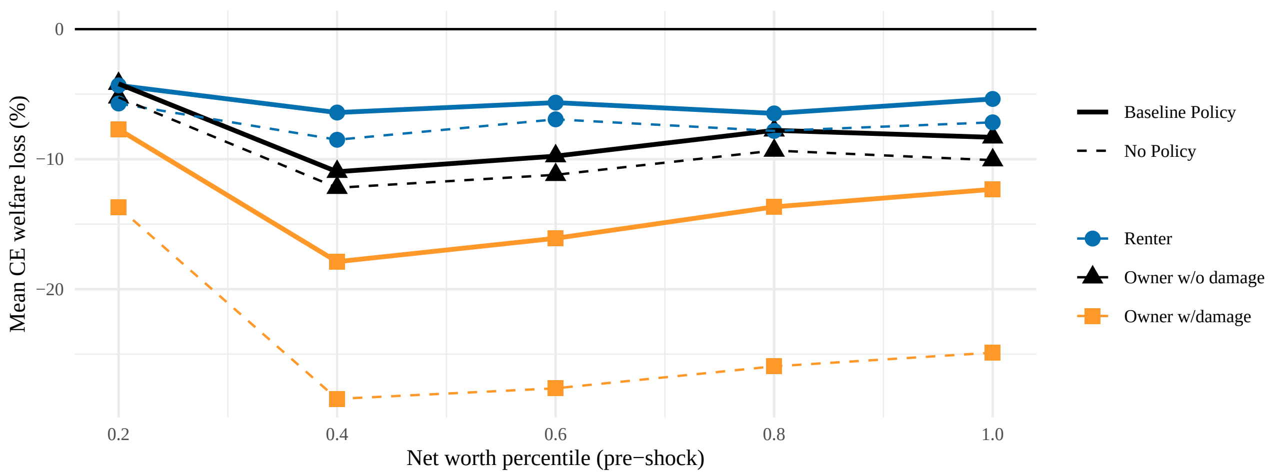
6.2 The Effects of Current Post-Disaster Policy

Current policy reduces the average welfare loss from the hurricane by 26%. Homeowners with property damage experience the largest average gains, but renters and homeowners without damage also benefit on average. Figure 8 plots average welfare losses under no policy, and current policy across deciles of pre-hurricane wealth distribution broken out by renters, homeowners without property damage, and homeowners with property damage.

Given that a significant portion of the aid is directed specifically to homeowners with property damage, it is unsurprising that they are the largest beneficiaries of the policy. However, within this group, the gains from the policy are unevenly distributed. Since low net worth households are much more likely to default in the absence of policy, their losses without intervention are smaller, and thus their gains from the policy are also more limited. Higher net worth households, who are less likely to default, benefit much more from this policy for two reasons. First, they tend to own larger homes,

[21] I perform sensitivity analysis to better understand the role of infrastructure in driving the results. Table 7 column (5) reports results shutting down the role of infrastructure in both production and housing services. Column (6) reports results only shutting down the complementarity between infrastructure and housing services. Infrastructure complementarity with housing services accounts for 2.3 percentage points of the average welfare effects. Amplification of the shock to wages through the additional shock to infrastructure accounts for an additional 0.9 percentage points of the average welfare effects.

Figure 8: Average CE Welfare Effects Across the Pre-Shock Wealth Distribution



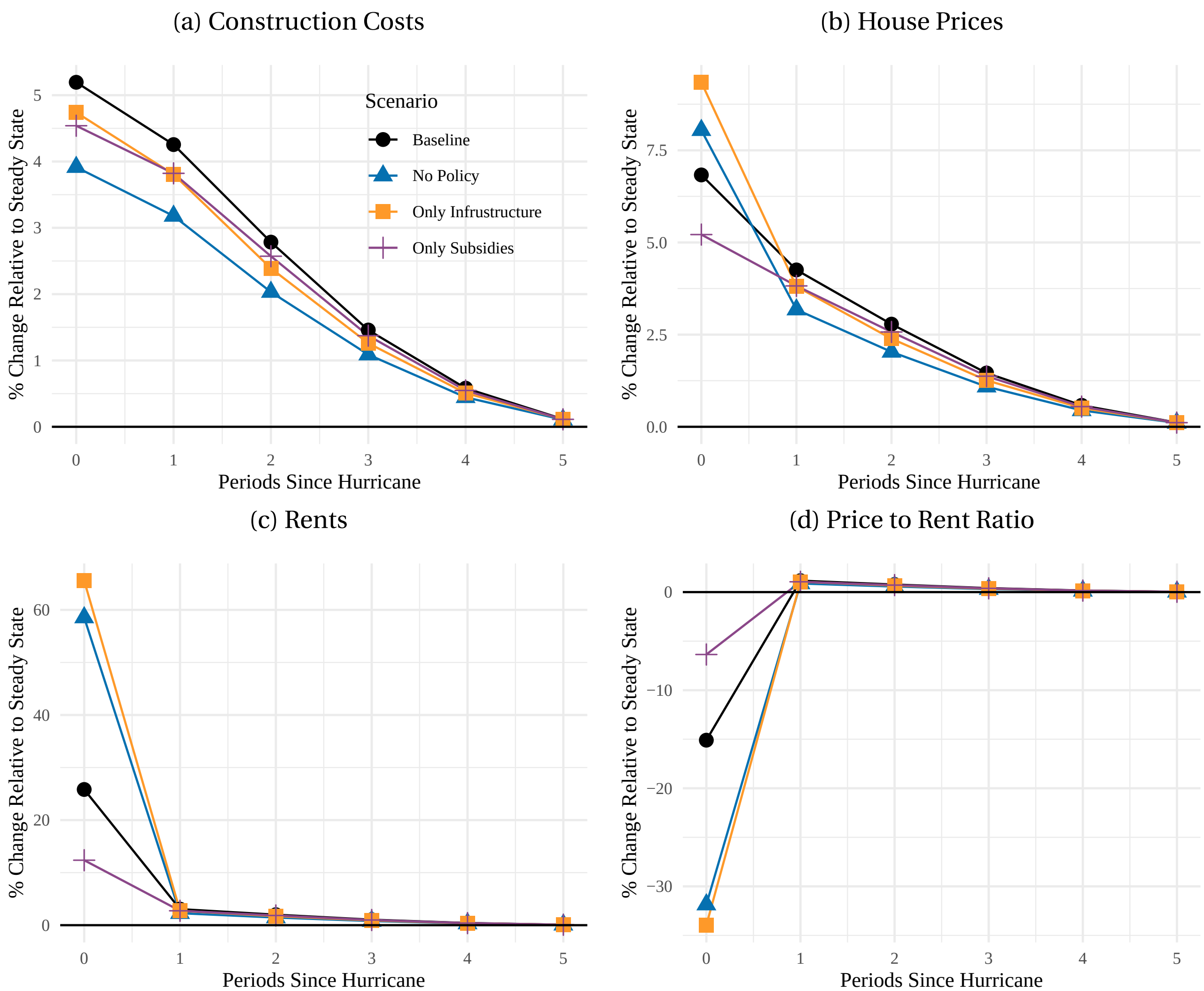
Notes: The figure shows the consumption equivalent welfare effects of Hurricane Maria across the pre-shock wealth distribution broken out by renters (blue circles), homeowners without damage (black triangles), and homeowners with property damage (orange squares) without policy (dashed lines) and with current post-disaster policy in effect (solid lines).

which results in larger damages in dollar terms and therefore mechanically larger transfers. Second, they have sufficient liquidity to wait through the application process without needing to sell their homes in the interim.

The baseline policy, in addition to being highly effective at preventing mortgage defaults and encouraging households to repair their homes, also helps alleviate the housing shortage in the immediate aftermath of the disaster. Figure 9 shows that, in the absence of any policy, rents would have risen by 57% relative to pre-hurricane levels in the period of the shock compared to the more modest 20% increase observed under current policy. But how does providing transfers for rebuilding lead to lower rents? Since the rebuilding subsidy is non-transferable, homeowners are required to retain their properties in order to receive the transfer, which in turn reduces default and therefore the number of households entering the rental market. These households who remain in their home in order to apply for the transfer are in fact under-consuming housing and if they were to default or sell would increase their housing consumption. This effect offsets the fact that fewer households migrate under current policy and there are therefore more households in Puerto Rico demanding housing.

Transfers to the local government to rebuild infrastructure facilitates a quicker economic recovery, benefiting all households. With higher levels of infrastructure per-capita, housing is nicer to live in, and wages recover to pre-shock levels faster. Table 5 column (3) reports results from a counterfactual scenario where only infrastructure rebuilding is in effect after Hurricane Maria and Figure 9 shows counterfactual price paths. Rebuilding infrastructure faster affects prices in the housing market through congestion in the construction sector.

Figure 9: Prices after Hurricane Maria



Notes: The figure shows housing market price movements after Hurricane Maria under various post-disaster policy scenarios: current policy baseline(black circles), no post-disaster policy(blue triangles), only infrastructure investment(orange squares), and only rebuilding subsidies(purple plus sign).

However these movements in house price, relative to no policy, are not large enough to offset the equity loss for households with damage and so the default rate is very similar to the scenario with no policy in effect. Despite the fact that house prices appreciate, owners without property damage do not gain disproportionately from this policy. This is because they cannot fully realize the capital gains from rising house prices. If they sell, they must either purchase a new home at higher prices or rent at significantly increased rates, and wait to buy in later periods when house prices are lower.

6.3 The Effectiveness of Current Post-Disaster Policy

To evaluate the effectiveness of current policy, I calculate the transfer necessary to make each household indifferent between living in a world with a specific post-disaster policy in effect and a world with no post-disaster policy. Table6 reports the dollar value that households assign to current policy, as well as the components of current policy implemented in isolation. The table also reports the cost of the policy to the federal government per household living in Puerto Rico at the time of the shock, broken down by spending on infrastructure versus spending on rebuilding subsidies.[22]

Table 6: Household Valuation of Current Policy

	Baseline	Infrastructure Investment	Rebuilding Subsidies
Money Metric Welfare Gain Relative to No Policy			
Average	\$30,500	\$8,430	\$18,600
Owner (80%)	\$37,600	\$10,100	\$23,200
Owner with damage (48%)	\$65,500	\$8,080	\$50,100
Undamaged owner (52%)	\$10,000	\$12,000	-\$3,450
Renter (20%)	\$3,100	\$2,160	\$774
Policy Costs			
Total (per household)	\$41,100	\$ 6,100	\$34,000
Infrastructure transfers (per household)	\$ 6,100	\$ 6,100	\$ 0
Rebuilding subsidy (per household)	\$29,500	\$ \$0	\$ 29,100
Rebuilding subsidy (per recipient)	\$73,800	\$ 0	\$72,700

Notes: This table reports the money metric households assign to a policy relative to no post-disaster policy. Column 1 reports results for the baseline when the infrastructure rebuilding and rebuilding subsidy are in effect. Column 2 and 3 reports results for when only the infrastructure rebuilding policy or rebuilding subsidy are in effect respectively. Rows 1-5 report average values for different groups of households. Rows 6-9 report the budget cost of different components of the policy in effect.

Households value the current combined policy of transfers to rebuild infrastructure and rebuilding subsidies for homeowners with property damage below its cost. On average, households assign a value of \$0.74 to each dollar spent by the federal government.[23] Homeowners with property damage, unsurprisingly, value these policies, which are directly targeted at them, higher than the

[22] The cost of the policy to the federal government is computed within the model. But it is possible to compare this number with the actual per-person costs. Total expenditures by FEMA and HUD as of November 2021 totaled over \$75 billion and there were roughly 1.2 million households living in Puerto Rico according to the 2016 PRCS. This results in a realized cost of \$63,000 per household, similar to the model implied cost.

[23] If the marginal cost of raising a dollar of public funds through distortionary taxation is larger than one dollar, this effect would only strengthen the argument that the cost of these policies exceed their value to affected households.

average household, but on average still below the value of the rebuilding subsidy they receive. This low valuation is driven by three key features of the policy: the lack of guaranteed approval, long delays in receiving the funds, and the non-transferable nature of the benefits. I discuss in more detail how these features of the policy reduce a household's valuation of the policy in Section 7.

Unlike rebuilding subsidies, there is a multiplier effect of federal spending to rebuild infrastructure. Households on average value the infrastructure rebuilding component of policy alone at $1.4 per dollar spend. Households value having infrastructure rebuilt faster because of its complementarity with both firm production and housing services. Under current policy, lenders lose -$0.034 per dollar of outstanding mortgage debt at the time of hurricane. Absent policy, lenders would lose -$0.079 per dollar of mortgage debt. These losses can also be expressed as a loss per household living in Puerto Rico of -$2,198 without any post-disaster policy and -$900 under current policy.

6.4 Robustness and Generalizability

There are several features that make Puerto Rico a unique setting. Relative to other nearby Caribbean islands that are struck by hurricanes, such as the Dominican Republic, all households in Puerto Rico have the option to migrate somewhere in the mainland US that is unaffected by a disaster. Table 7 column (2), shows results from a counterfactual where migration is not allowed after Hurricane Maria but post-disaster policy is still in place.[24] In this counterfactual, since housing demand is even less elastic than in the baseline, rents rise dramatically (108%). Without migration, the marginal product of labor is also lower and wages fall *more* after the hurricane relative to a world with costly migration. The rise in house prices (15%) that results, offsets some of the home equity losses and therefore mortgage default rates are slightly lower. All of these general equilibrium effects translate into larger welfare losses, particularly for renters.

Even though migration is possible after Hurricane Maria, plane tickets are expensive. Migrating away from the aftermath of a natural disaster is likely more expensive in this setting as compared to recent hurricanes in the southeast mainland US where people could just put all of their stuff in their cars and drive away. Table 7 column (3), shows results from a counterfactual where migration is 25% cheaper after Hurricane Maria but other post-disaster policies are still in place. Many more households migrate both permanently (5.4%) and temporarily (14.9%) in this scenario. In fact there is so much migration in this scenario that rents *fall* after Hurricane Maria. House prices only go up 2% but there is in fact less mortgage default because homeowners with significant damage can wait in the mainland US until the probability that they will receive the rebuilding subsidy is higher. Welfare losses are significantly smaller for all households (-7.4%).

There are also large income differences between Puerto Rico and the mainland US that make the "outside option" after Hurricane Maria relatively more attractive than in other settings such as Hurricane Sandy in New York/New Jersey. Table 7 column (7), reports results from a counterfactual

[24] For a country like the Dominican Republic international assistance plays a similar role to US federal rebuilding policies.

Table 7: Robustness and Generalizability

	Baseline	No Migration	Lower Cost	No Difference	No Infrastructure	No Complementary	Elastic Supply
Initial Price Changes							
Construction Cost	5.2	5.9	3.4	5.6	6.5	5.5	0
Rent	25.8	103	-10.4	49.1	23.9	15.7	46.9
House Price	6.8	13.2	2.4	8.9	7.9	6.3	3.5
Wages	-7.9	-9.4	-3.5	-8.8	-4.1	-8.7	-8.3
Mortgage Default							
Aggregate	7.2	6.8	7	6.9	7.2	7.3	9.3
Moderate damage(31%)	3	2.4	3	2.7	3.2	3.1	3.6
Severe damage(18%)	27.6	27.2	26.7	28.4	26.7	27.6	30.5
Repair							
Moderate damage(31%)	89.8	91	80.7	88	90.6	90.6	90.8
Severe damage(18%)	73.6	73.8	69	72.1	75.1	74.6	76.2
Migration							
Total	7.5	0	20.3	6.3	3.4	4.3	6.6
Permanent	3.7	0	5.4	1.7	1.2	1.9	2.7
Renters	80	0	68	14	62	76	76
Owners sell/default leave	20	0	32	86	38	24	24
Temporary	3.8	0	14.9	4.6	2.2	2.5	3.9
Renters	64	0	36	61	59	63	66
Owners	36	0	64	39	41	37	34
Consumption Equivalent Welfare							
Average	-10.5	-13.1	-7.4	-15	-7.3	-8.2	-9.7
Owner (80%)	-11.7	-13.9	-9.4	-16.3	-8.6	-9.4	-11
Owner with Damage (48%)	-14.6	-16.9	-12.1	-19.4	-11.2	-12	-13.7
Undamaged Owner (52%)	-8.9	-10.9	-6.8	-13.4	-6	-6.9	-8.2
Owner with Mortgage (72%)	-10.5	-12.6	-8.3	-15.4	-7.4	-8.3	-9.7
Owner w/o Mortgage (28%)	-14.9	-17.2	-12.3	-18.9	-11.7	-12.4	-14.3
Renter (20%)	-4.7	-9.2	1.2	-9.3	-1.6	-2.7	-3.7

Notes: This table reports results for various changes in model parameters: no migration (infinite migration cost), lower cost (migration costs 75% of baseline), no difference (no steady state difference between Puerto Rico and the outside option), no infrastructure (no infrastructure in firm production or housing services), no complementarity (no infrastructure in housing services), elastic supply (no investment adjustment cost). Rows 1-4 report date 0 prices changes. Rows 5-7 report mortgage default rates as defined as the fraction of households who ever default out of the initial stock of households who had any mortgage debt at the time of the shock. Rows 8-9 report repair rates are defined as the fraction of households who ever repair their home out of the initial stock of households who have a damage. Rows 10-16 report the number of temporary and permanent migrants as a fraction of the initial population. For each type of migration, it also reports the composition broken out between households who were initially renters or owners. Rows 17-23 report consumption equivalent (CE) welfare losses on average and broken out by homeownership, damage, and mortgage status.

where there are no steady state differences between Puerto Rico and the mainland US (wage, rents, PR population). In this scenario there is *more* temporary migration (4.6%) and less permanent migration (1.7%). Lower migration means that rents are higher (50%) and wages are slightly lower. Welfare losses are much larger on average in this case (-15%).

The damage Hurricane Maria caused to the Puerto Rican power grid was uniquely bad. The rebuilding process was also mired in political controversy and repair took many months to begin in earnest. It is possible that in other settings damage to infrastructure is repaired much more quickly and so plays little role. Table 7 column (4) and (5) report results from a counterfactual without any infrastructure and without any complementarity between infrastructure and housing consumption respectively. This means that the shock affects wages only through destruction of firm private capital without an additional multiplier for infrastructure destruction. Wages naturally fall less in a version without infrastructure. The situation in Puerto Rico is also less dire because housing services have not been reduced to quite the same extent. So migration in both scenarios is lower. Welfare losses are also smaller on average but the ratio of losses across different types of households is quite similar to the baseline model.

Finally, just like migration from Puerto Rico to the mainland US is more costly than migration between most destinations within the mainland US, it may also be more costly to import the factors needed to increase construction from the mainland US (i.e. construction workers, machines, raw materials etc). Table 7 column (6) reports results from a counterfactual with elastic supply of new investments (though there is still one-period time to build). In this case house prices rise much less which results in a higher aggregate default rate (-9.3%). This in turn means that rents are higher in the initial period (47%)

7. Alternative Post-Disaster Policies

In this section, I first study the effects of potential improvements to the implementation of current policy, specifically reducing the risk of non-payment for homeowners with property damage and reducing the delay in receiving the subsidy. Next, I study the effects of an immediate $750 transfer post-disaster transfer to all affected households recently implemented by FEMA. I also study the effects of an immediate $750 migration subsidy. Finally, I examine what would happen if instead of providing in-kind transfers to households, the federal government provided lump sum payments.

Table 8 reports a wide range of counterfactual outcomes of each of these alternative policies. Table 9 reports how households value these alternatives and provides a breakdown of the total costs of the policy.

7.1 Improvements to Current Policy Implementation

I first consider potential improvements to existing policies focusing on two changes to the structure of rebuilding subsidies for homeowners with property damage: eliminating the risk of denial for eligible households, and immediate disbursement of funds. Denials and delays in the disbursement

Table 8: Alternative Policies

	Baseline	No Policy Risk	Immediate Subsidies	Additional $750 Cash	Additional $750 Subsidy	Uniform $35,600
Initial Price Changes						
Construction Cost	5.2	5.2	8.0	5.2	5.1	4.4
Rent	25.8	25.5	12.2	26.8	22.3	86.7
House Price	6.8	6.8	8.5	6.9	6.5	10.6
Wages	-8.0	-8.0	-8.1	-7.9	-7.7	-6.3
Mortgage Default						
Aggregate	7.3	5.9	0	7.3	7.3	14.3
Moderate damage(31%)	3.0	2.6	0	3.0	2.9	8.3
Severe damage(18%)	27.6	25.9	0	27.2	27.6	48.3
Repair						
Moderate damage(31%)	89.8	89.9	99	90.4	89.6	73.6
Severe damage(18%)	73.6	75.8	98.2	73.4	73	19.4
Migration						
Total	7.5	7.5	6.6	7.7	8.2	14.1
Permanent	3.7	3.7	3.5	3.8	3.8	7.7
Renters	80	80	79	81	81	70
Owners sell/default leave	20	20	21	19	19	30
Temporary	3.8	3.8	3.1	3.9	4.5	6.5
Renters	64	64	72	64	63	61
Owners	36	36	28	36	37	39
Consumption Equivalent Welfare						
Average	-10.5	-10.5	-7.9	-10.4	-10.3	-4.3
Owner (80%)	-11.7	-11.7	-8.5	-11.7	-11.6	-9.4
Owner with Damage (48%)	-14.6	-14.6	-8.0	-14.5	-14.5	-17.1
Undamaged Owner (52%)	-8.9	-8.93	-8.9	-8.9	-8.8	-1.8
Owner with Mortgage (72%)	-10.5	-10.5	-7.7	-10.5	-10.4	-8.5
Owner w/o Mortgage (28%)	-14.9	-14.9	-10.5	-14.8	-14.8	-11.8
Renter (20%)	-4.7	-4.7	-4.5	-4.6	-4.0	16.5

Notes: This table reports results for policy counterfactuals: no risk (homeowners guaranteed to get rebuilding subsidy after 5 years), no delay (homeowners guaranteed to get rebuilding subsidy immediately), immediate additional $750 cash transfers, migration subsidy up to $750, uniform cash transfer of $35,600. Rows 1-4 report date 0 prices changes. Rows 5-7 report mortgage default rates as defined as the fraction of households who ever default out of the initial stock of households who had any mortgage debt at the time of the shock. Rows 8-9 report repair rates are defined as the fraction of households who ever repair their home out of the initial stock of households who have a damage. Rows 10-16 report the number of temporary and permanent migrants as a fraction of the initial population. For each type of migration, it also reports the composition broken out between households who were initially renters or owners. Rows 17-23 report consumption equivalent (CE) welfare losses on average and broken out by homeownership, damage, and mortgage status.

Table 9: Households' Valuation of Alternative Policies

	Baseline	No Policy Risk	Immediate Subsidies	Additional $750 Cash	Additional $750 Subsidy	Uniform $35,600
Money Metric Welfare Gain Relative to No Policy						
Average	$30,500	$30,500	$41,700	$31,500	$31,200	$35,500
Owner (80%)	$37,600	$37,600	$51,600	$38,700	$38,200	$35,700
Owner with damage (48%)	$65,500	$65,600	$94,000	$66,700	$66,200	$35,300
Undamaged owner (52%)	$10,000	$10,000	$9,790	$11,000	$10,600	$36,200
Renter	$3,100	$3,100	$3,320	$3,790	$3,870	$34,600
Policy Costs						
Total (per household)	$ 35,600	$36,300	$65,700	$36,450	$35,700	$35,600
Cash transfers (per household)	$ 0	$ 0	$ 0	$ 750	$ 0	$35,600
Migration subsidy (per household)	$ 0	$ 0	$ 0	$ 0	$57	$ 0
Infrastructure (per household)	$ 6,100	$ 6,100	$ 6,100	$ 6,100	$ 6,100	$ 0
Rebuilding Subsidy (per household)	$ 29,500	$ 30,200	$ 59,600	$ 29,600	$ 29,400	$ 0
Rebuilding Subsidy (per recipient)	$ 73,800	$ 75,400	$148,900	$ 74,000	$ 73,600	$ 0

Notes: This table reports the budget costs and household's money metric benefits from various alternative post-disaster policies. Column (1) reports values under the baseline policy of rebuilding subsidies and transfers to rebuild infrastructure. Columns (2) and (3) report values of modifying current rebuilding subsidies to eliminate risk or delay respectively. Column (4) reports values for an additional $750 immediate cash transfer to all households. Column (5) reports values for an additional $750 migration subsidy. Column (6) reports values for a uniform unconditional cash transfer equal to the per-household cost of the baseline policy.

of aid to eligible households are key concerns frequently raised by policymakers in proposals to reform disaster aid in the US.[25] Currently, subsidies for homeowner rebuilding require verifying household eligibility across programs managed by various government agencies, such as the Department of Homeland Security(FEMA), Department of Housing and Urban Development, and the Small Business Administration. I study the counterfactual effects that streamlining these procedures would have had in the aftermath of Hurricane Maria.

I first consider the counterfactual scenario where, following Hurricane Maria, households with property damage were guaranteed to receive a rebuilding subsidy within five years of the disaster. In this scenario, I hold fixed at their baseline levels the probabilities of receiving aid during the initial periods after the disaster but households are now guaranteed to receive aid if they apply in the final period. Under baseline policy there was a less than 1% chance that a household who applied each period would not receive assistance. Table 8 column (2) reports what would have happened if this policy change had been implemented. Guaranteeing these subsidies reduced aggregate mortgage default by 20% and would lead to a slight increase in the fraction of households who repair their homes, particularly among households with severe damage. However, making these subsidies guaranteed after 5 years, has little effect on prices, migration, or welfare relative to baseline policy.

Table 9 column (2) reports the cost of making the rebuilding subsidies guaranteed and reports

[25] For example Representatives Frank Pallone, Jr. (D-New Jersey), Jenniffer González-Colón (R-Puerto Rico), and Troy Carter (D-Louisiana) recently pushed for FEMA to apply new rules that made accessing assistance easier for affected individuals to apply retroactively to past natural disasters. "The rule also eliminates outdated eligibility requirements, such as removing the mandate that the Small Business Administration reject a survivor's loan application before they could receive FEMA aid, reduced documentation requirements, and a simplified appeals process."

the value households assign to this policy change. Making these subsidies guaranteed raises the cost of the policy by $700 per household. It also shifts the composition of those who are receiving the rebuilding subsidy towards larger and more damaged homes. The costs per recipient therefore goes up by $1,600. Since defaults are slightly lower in this scenario, lender losses are $160 lower per household. On average, households do not value this policy any more than the baseline policy. Even owners with property damage only value this policy $100 more than baseline. Part of this low valuation is driven by the functional form of household preferences and low risk-aversion/intertemporal elasticity of substitution parameter, the other part is that even though the policy is now guaranteed, households still have to hold onto their damaged homes for a long time in order to receive the payout.

The second more drastic policy improvement I consider is the counterfactual scenario where screening occurs accurately and immediately after a natural disaster. For example, FEMA could invest in linking satellite data of destruction to deeds and property tax records allowing them to rapidly identify homeowners, assess the extent of damage, and disburse aid. In this counterfactual scenario, households are guaranteed to get the rebuilding subsidy in the period of the disaster if they apply (and all subsequent periods), though repairs still take one year to complete. Table 8 column (3) reports what would have happened after Hurricane Maria if this had been government policy at the time.

Strikingly in this counterfactual scenario where disbursement is immediate, there would be no mortgage default. In the model, default decisions are largely driven by negative home equity, not income effects. Households with a bad income shock with positive home equity might be forced to sell their home but would not choose to default. In this counterfactual scenario nearly all households choose to repair their house. The fact that there is much more rebuilding after the hurricane causes a large increase in the cost of construction. Since no households default on their mortgage and transition to renting, this policy also relieves pressure in the rental market. Counterfactual rents are 50% lower than under current policy. The rise in construction prices overshadows the fall in rents and drives up house prices. The policy also leads to a small reduction in both temporary and permanent migration which leads to small decline in wages.

This improvement in the efficiency of current policy leads to large welfare improvements relative to baseline. Average welfare losses are 25% smaller and are less than half of current losses for homeowners with property damage. Renters and homeowners also gain somewhat from this policy due to the general equilibrium effects that lead to lower rents and higher house values. Table 9 column (3) reports the cost of making the rebuilding subsidies both guaranteed and immediate and reports the value households assign to this policy change. Households value this streamlined approval process an additional $11,200 on average and homeowners with property damage value it an additional $28,500. However, the cost per household increases by $30,100 and per recipient by $75,100. This is a much higher valuation, but still below cost, as households must hold onto their damaged homes in order to receive the funds.

7.2 Additional $750 Cash Payment

I next consider a counterfactual scenario where, following Hurricane Maria, households received an immediate $750 cash transfer. On January 19th, 2024, FEMA announced the implementation of a new $750 cash payment called "Serious Needs Assistance," intended to help cover immediate expenses related to shelter, evacuation, and basic household needs for those affected by a natural disaster. In this counterfactual, I study the effects of an immediate *additional* $750 cash payment keeping all other policies, such as infrastructure rebuilding and rebuilding subsidies, the same as in the baseline scenario. Table 8 column (4) reports what would have happened after Hurricane Maria if this policy had already been in effect.

Under this policy, there would have been a very small increase in rents and house prices due to the income effects of this transfer on housing consumption. Since these transfers are very small compared to the wealth losses of homeowners with property damage, there is a negligible decline in default. There is a small increase in the repair rate for households with moderate damage who find it now slightly easier to self-finance repairs. There is also a small increase in migration both temporary and permanent though little change in composition of migrants. This migration leads to a slight increase in wages and partially offsets some of the effects on the housing market.

Table 9 column (4) reports the dollar value households assign to this $750 as well as the cost. Households value the immediate transfer above cost, even though it has minimal effect on consumption equivalent welfare relative to steady state. The $750 additional transfer is valued at $1,000 on average to households. The cash transfer also has some interactions on the margin with the rebuilding subsidy. The average cost per household of the rebuilding subsidy increases by $100 and the cost per recipient increases by $200.

7.3 Migration Subsidy

I next consider a counterfactual scenario where, following Hurricane Maria, the federal government provided a $750 migration subsidy. The $750 value of the subsidy would cover roughly two round trip plane tickets from Puerto Rico to the mainland US. This policy would be relatively straightforward to administer, as FEMA could coordinate directly with a few airlines to subsidize particular routes and would not have to process applications individually from households. There are many externalities associated with migration, even temporarily. If a household migrates, they increase the marginal product of remaining labor, and also reduce demand for housing. In the setting of Puerto Rico where pecuniary migration costs are particularly high relative to household income and liquid wealth, relaxing this constraint could be especially valuable.

Table 8 column (5) reports what would have happened after Hurricane Maria if this migration subsidy had been in effect. Subsidies migration lead to more migration. In particular there is much more temporary migration by both renters and homeowners. Since fewer people are living in Puerto Rico in the immediate aftermath of the hurricane, this relieves pressure in the rental market and leads to lower rents. It also increases the marginal product of remaining workers leading to slightly higher wages. There is a small decline in house prices due to less local demand for housing in general. This policy has negligible effect on mortgage defaults and home repair rates.

The policy leads to small aggregate welfare gains concentrated among renters, even those who do not migrate benefit from the general equilibrium effects of migration. Table 9 column (5) reports the dollar value households assign to this $750 migration subsidy as well as the realized cost. The average cost is $57 since relatively few households "take-up" this policy. The average value to households of $1,000 greatly exceeds the cost of the policy. This multiplier effect is due to the general equilibrium effects of migration on rents and wage

7.4 Unconditional Cash Transfers

The amount that the federal government currently spends per household in a disaster-affected region is substantial. Instead of providing "in-kind" rebuilding subsidies, in this counterfactual exercise I explore what would happen if the federal government gave each household in the affected region a cash transfer instead. The total cost of the policy remains the same as the baseline policy, and households receive a uniform, lump sum payment immediately after the hurricane. While the amount of these cash transfers would dwarf the size of any prior direct transfers by the US government, stimulus payments during prior recessions and the Covid-19 pandemic set a precedent.

Table 8 column (6) reports the results of this policy counterfactual. Mortgage default rates are much higher with cash transfer relative to baseline "in-kind" subsidies. Though the aggregate default rate is slightly lower than under the scenario with no post-disaster policy (14.3% versus 15.9%). Mortgage lenders lose an additional $0.033 per dollar of outstanding mortgage debt amounting to an additional $870 loss per household. The large cash transfer generates substantial increase in rents and house prices relative to baseline policy, due to the income effects on housing consumption.[26] However, construction costs are lower, as there is no infrastructure rebuilding and fewer households repair their properties. Repair rates remain relatively high among those with moderate damage (74%) but drop substantially from 74% to 19% among those with severe damage. The cash transfer also leads to nearly double the amount of migration, both temporary and permanent. This migration both partially offsets the income effects on the rental market, easing some of the upward pressure on rents and leads to higher wages for those who stay.

Unconditional cash transfers drastically reduce the average welfare loss from Hurricane Maria. The average consumption equivalent welfare losses from Hurricane Maira falls to 4.3% versus 10.5% under current policy. Renters are better off since these cash transfers are a large positive wealth shock. Homeowners without property damage are also better off, though Hurricane Maria plus the cash transfer is still a net welfare loss. Owners with property damage experience larger welfare losses under this policy than under the current policy (-17.1% versus -14.6%). Table 9 column (6) reports

[26]Consider the case of Cobb-Douglas utility ($h^\eta c^{1-\eta}$), N hand-to-mouth households who earn a wage w and pay rent p^r. With a fixed stock of housing H, each household consumes $\eta w/p^r$ units of housing and so the market clearing price is $p^r = N\eta w/H$. If wages double, rents must double and real housing consumption is unchanged.

the dollar value households assign to this large cash transfer. On average households value the cash transfer slightly below cost. Owners without property damage value the cash slightly above cost due to the fact that it raises the value of their house and wages. Renters value it slightly below cost because some of the transfer goes to pay the large increase in rents. Homeowners with property damage value the transfer slightly below cost because many of them default and face higher rents.

8. Conclusion

This paper presents new evidence on how households cope with natural disasters using high-frequency flight data and an original survey of affected households. After Hurricane Maria struck Puerto Rico in 2017, many households migrated both temporarily and permanently to the mainland U.S. However, even temporary migration proved costly, and financial constraints limited many households' post-disaster location choices. Most households remained in Puerto Rico, coping not only with the direct effects of the storm on their homes but also with widespread disruptions to electricity, transportation, education, and the local economy.

To translate these empirical findings into welfare effects and evaluate counterfactual post-disaster policies, I develop a structural model of natural disasters that incorporates housing, migration, and infrastructure. The model captures a rich set of post-disaster household decisions and accounts for how natural disasters and policy interventions affect rents, house prices, construction costs, and wages. Quantified using Census, flight, and survey data, the model matches key patterns of migration, mortgage defaults, and housing market dynamics observed after Hurricane Maria.

I use the model to analyze counterfactual policies currently under debate. improvements to existing screening processes increase program costs, they offer limited additional value to households. In contrast, modest cash transfers or migration subsidies are highly cost-effective. Uniform cash transfers result in substantial improvements in average welfare for the same budget cost. The general equilibrium interactions of these policies with housing markets are crucial to understanding their overall effects. The framework developed in this paper provides a foundation for evaluating a broad range of post-disaster policy interventions across different settings.

References

Abowd, John and David Card, "On the Covariance Structure of Earnings and Hours Changes," *Econometrica*, 1989, *57* (2), 411–45.

Acosta, Rolando J., Nishant Kishore, Rafael A. Irizarry, and Caroline O. Buckee, "Quantifying the dynamics of migration after Hurricane Maria in Puerto Rico," *Proceedings of the National Academy of Sciences*, December 2020, *117* (51), 32772–32778.

Alexander, Monica, Kivan Polimis, and Emilio Zagheni, "The Impact of Hurricane Maria on Out-migration from Puerto Rico: Evidence from Facebook Data," *Population and Development Review*, 2019, *45* (3), 617–630. Publisher: [Population Council, Wiley].

Altındağ, Onur, Ozan Bakış, and Sandra V. Rozo, "Blessing or burden? Impacts of refugees on businesses and the informal economy," *Journal of Development Economics*, 2020, *146*, 102490.

Auray, Stéphane, Aurélien Eyquem, and Frédéric Jouneau-Sion, "Wars and capital destruction," *Journal of Economic Dynamics and Control*, 2014, *41*, 224–240.

Berger, David, Veronica Guerrieri, Guido Lorenzoni, and Joseph Vavra, "House Prices and Consumer Spending," *The Review of Economic Studies*, 10 2017, *85* (3), 1502–1542.

Bernstein, Asaf and Daan Struyven, "Housing Lock: Dutch Evidence on the Impact of Negative Home Equity on Household Mobility," *American Economic Journal: Economic Policy*, August 2022, *14* (3), 1–32.

Bhutta, Neil, Jane Dokko, and Hui Shan, "Consumer Ruthlessness and Mortgage Default during the 2007 to 2009 Housing Bust," *The Journal of Finance*, 2017, *72* (6), 2433–2466.

Bilal, Adrien and Esteban Rossi-Hansberg, "Location as an Asset," *Econometrica*, 2021, *89* (5), 2459–2495.

_ and _ , "Anticipating Climate Change Across the United States," Working Paper 31323, National Bureau of Economic Research June 2023.

Boustan, Leah Platt, Matthew E. Kahn, Paul W. Rhode, and Maria Lucia Yanguas, "The effect of natural disasters on economic activity in US counties: A century of data," *Journal of Urban Economics*, 2020, *118*, 103257.

Briggs, Joseph, Ciaran Rogers, and Christopher Tonetti, "Risky Insurance: Life-cycle Insurance Portfolio Choice with Incomplete Markets," Working Paper 2024.

Bureau, US Census, "Methodology for the United States Population Estimates: Vintage 2021," *United States Census Bureau*, 2021. Technical Report.

Caliendo, Lorenzo, Maximiliano Dvorkin, and Fernando Parro, "Trade and Labor Market Dynamics: General Equilibrium Analysis of the China Trade Shock," *Econometrica*, 2019, *87* (3), 741–835.

Campbell, John Y. and Joao F. Cocco, "A Model of Mortgage Default," *The Journal of Finance*, 2015, *70* (4), 1495–1554.

CoreLogic, "United States Residential Foreclosure Crisis: Ten Years Later," Technical Report 2017.

Cruz, José-Luis and Esteban Rossi-Hansberg, "The Economic Geography of Global Warming," *The Review of Economic Studies*, 04 2023, *91* (2), 899–939.

Davis, Morris A. and François Ortalo-Magné, "Household expenditures, wages, rents," *Review of Economic Dynamics*, 2011, *14* (2), 248–261.

Deryugina, Tatyana, Laura Kawano, and Steven Levitt, "The Economic Impact of Hurricane Katrina on Its Victims: Evidence from Individual Tax Returns," *American Economic Journal: Applied Economics*, April 2018, *10* (2), 202–33.

Desmet, Klaus and Esteban Rossi-Hansberg, "On the spatial economic impact of global warming," *Journal of Urban Economics*, 2015, *88*, 16–37.

_ , Robert E. Kopp, Scott A. Kulp, Dávid Krisztián Nagy, Michael Oppenheimer, Esteban Rossi-Hansberg, and Benjamin H. Strauss, "Evaluating the Economic Cost of Coastal Flooding," *American Economic Journal: Macroeconomics*, April 2021, *13* (2), 444–486.

Diamond, Rebecca, Adam Guren, and Rose Tan, "The Effect of Foreclosures on Homeowners, Tenants, and Landlords," Working Paper 27358, National Bureau of Economic Research June 2020.

Edin, Per-Anders, Peter Fredriksson, and Olof Åslund, "Ethnic Enclaves and the Economic Success of Immigrants—Evidence from a Natural Experiment*," *The Quarterly Journal of Economics*, 02 2003, *118* (1), 329–357.

Farrell, Diana and Fiona Greig, "Weathering the Storm: The Financial Impacts of Hurricanes Harvey and Irma on One Million Households," Technical Report, JP Morgan Chase Institute 2018.

Favilukis, Jack, Sydney C. Ludvigson, and Stijn Van Nieuwerburgh, "The Macroeconomic Effects of Housing Wealth, Housing Finance, and Limited Risk Sharing in General Equilibrium," *Journal of Political Economy*, 2017, *125* (1), 140–223.

Feenberg, Daniel and Elisabeth Coutts, "An introduction to the TAXSIM model," *Journal of Policy Analysis and Management*, 1993, *12* (1), 189–194.

FEMA, "National Disaster Recovery Framework," Technical Report, US Department of Homeland Security 2016.

Ferreira, Fernando, Joseph Gyourko, and Joseph Tracy, “Housing busts and household mobility,” *Journal of Urban Economics*, 2010, *68* (1), 34–45.

Fonseca, Julia and Lu Liu, “Mortgage Lock-In, Mobility, and Labor Reallocation,” Working Paper, Jacobs Levy Equity Management Center for Quantitative Financial Research Paper June 2023.

Fried, Stephie, “Seawalls and Stilts: A Quantitative Macro Study of Climate Adaptation,” *The Review of Economic Studies*, 12 2021, *89* (6), 3303–3344.

Fu, Chao and Jesse Gregory, “Estimation of an Equilibrium Model With Externalities: Post-Disaster Neighborhood Rebuilding,” *Econometrica*, 2019, *87* (2), 387–421.

Gallagher, Justin, “Learning about an Infrequent Event: Evidence from Flood Insurance Take-Up in the United States,” *American Economic Journal: Applied Economics*, July 2014, *6* (3), 206–33.

_ and Daniel Hartley, “Household Finance after a Natural Disaster: The Case of Hurricane Katrina,” *American Economic Journal: Economic Policy*, 2017, *9* (3), 199–228.

_ , _ , and Shawn Rohlin, “Weathering an Unexpected Financial Shock: The Role of Federal Disaster Assistance on Household Finance and Business Survival,” *Journal of the Association of Environmental and Resource Economists*, 2023, *10* (2), 525–567.

Ganong, Peter and Pascal Noel, “Why do Borrowers Default on Mortgages?,” *The Quarterly Journal of Economics*, 2023, *138* (2), 1001–1065.

Gourinchas, Pierre-Olivier and Jonathan A. Parker, “Consumption Over the Life Cycle,” *Econometrica*, 2002, *70* (1), 47–89.

Greaney, Brian, “Homeownership and the Distributional Effects of Uneven Regional Growth,” Working Paper 2023.

_ , Andrii Parkhomenko, and Stijn Van Nieuwerburgh, “Hynamic Urban Economics,” Working Paper 2023.

Greenwald, Dan, “The Mortgage Credit Channel of Macroeconomic Transmission,” Working Paper 2018.

Greenwald, Daniel L and Adam Guren, “Do Credit Conditions Move House Prices?,” Working Paper 29391, National Bureau of Economic Research October 2021.

Gregory, Jesse, “The Impact of Post-Katrina Rebuilding Grants on the Resettlement Choices of New Orleans Homeowners,” Working Paper 2017.

Groen, Jeffrey A. and Anne E. Polivka, “The Effect of Hurricane Katrina on the Labor Market Outcomes of Evacuees,” *AEA Papers and Proceedings*, 2008, *98* (2), 43–48.

— and — , “Going home after Hurricane Katrina: Determinants of return migration and changes in affected areas,” *Demography*, November 2010, *47* (4), 821–844.

— , Mark Kutzbach, and Anne E. Polivka, “Storms and Jobs: The Effect of Hurricanes on Individuals’ Employment and Earnings over the Long Term,” *Journal of Labor Economics*, 2020, *38* (3), 653 – 685.

Guren, Adam, Arvind Krishnamurthy, and Timothy McQuade, “Mortgage Design in an Equilibrium Model of the Housing Market,” *The Journal of Finance*, 2021, *76* (1), 113–168.

Guvenen, Fatih, “Learning Your Earning: Are Labor Income Shocks Really Very Persistent?,” *American Economic Review*, June 2007, *97* (3), 687–712.

Heathcote, Jonathan, Kjetil Storesletten, and Giovanni L. Violante, “The Macroeconomic Implications of Rising Wage Inequality in the United States,” *Journal of Political Economy*, 2010, *118* (4), 681–722.

Hornbeck, Richard, “The Enduring Impact of the American Dust Bowl: Short- and Long-Run Adjustments to Environmental Catastrophe,” *American Economic Review*, June 2012, *102* (4), 1477–1507.

— and Suresh Naidu, “When the Levee Breaks: Black Migration and Economic Development in the American South,” *American Economic Review*, March 2014, *104* (3), 963–90.

Hsiao, Allan, “Sea Level Rise and Urban Adaptation in Jakarta,” Working Paper 2023.

Kaplan, Greg, Kurt Mitman, and Giovanni L. Violante, “The Housing Boom and Bust: Model Meets Evidence,” *Journal of Political Economy*, 2020, *128* (9), 3285 – 3345.

Kleinman, Benny, Ernest Liu, and Stephen J. Redding, “Dynamic Spatial General Equilibrium,” *Econometrica*, 2023, *91* (2), 385–424.

Kousky, Carolyn and Brett Lingle, “Residential Flood Insurance in Puerto Rico,” Issue Brief, University of Pennsylvania Wharton Risk Management and Decision Processes Center 2018.

— , Erwann O. Michel-Kerjan, and Paul A. Raschky, “Does federal disaster assistance crowd out flood insurance?,” *Journal of Environmental Economics and Management*, 2018, *87*, 150–164.

Krueger, D., K. Mitman, and F. Perri, “Chapter 11 - Macroeconomics and Household Heterogeneity,” in John B. Taylor and Harald Uhlig, eds., *John B. Taylor and Harald Uhlig, eds.*, Vol. 2 of *Handbook of Macroeconomics*, Elsevier, 2016, pp. 843–921.

Leduc, Sylvain and Dan Wilson, “Climate Change and the Geography of the U.S. Economy,” Working Paper 2023-17, Federal Reserve Bank of San Francisco 2023.

Lin, Daniel, "Methods and Assumptions of the CPS ASEC Tax Model," Working Paper, US Census Bureau 2022.

Luttmer, Erzo F. P. and Andrew A. Samwick, "The Welfare Cost of Perceived Policy Uncertainty: Evidence from Social Security," *American Economic Review*, February 2018, *108* (2), 275–307.

McIntosh, Craig, Tito Alegría, Gerardo Ordóñez, and René Zenteno, "The Neighborhood Impacts of Local Infrastructure Investment: Evidence from Urban Mexico," *American Economic Journal: Applied Economics*, July 2018, *10* (3), 263–86.

Meghir, Costas and Luigi Pistaferri, "Income Variance Dynamics and Heterogeneity," *Econometrica*, 2004, *72* (1), 1–32.

Meléndez-Badillo, Jorell, *Puerto Rico: A National History*, Princeton University Press, 2024.

Morales, Juan S., "The impact of internal displacement on destination communities: Evidence from the Colombian conflict," *Journal of Development Economics*, 2018, *131*, 132–150.

Mulder, Philip, "Mismeasuring Risk: The Welfare Effects of Flood Risk Information," Working Paper 2024.

Nakamura, Emi, Jósef Sigurdsson, and Jón Steinsson, "The Gift of Moving: Intergenerational Consequences of a Mobility Shock," *The Review of Economic Studies*, May 2022, *89* (3), 1557–1592.

Nardi, Mariacristina De, "Wealth Inequality and Intergenerational Links," *The Review of Economic Studies*, 07 2004, *71* (3), 743–768.

of Housing, Puerto Rico Department, "CDBG-DR Program Guidelines: Home Repair, Reconstruction, or Relocation Program," Working Paper, Department of Housing, Puerto Rico 2024.

Ostriker, Abigail and Anna Russo, "The Effects of Floodplain Regulation on Housing Markets," Working Paper 2024.

Piazzesi, Monika and Martin Schneider, "Chapter 19 - Housing and Macroeconomics," in John B. Taylor and Harald Uhlig, eds., *Handbook of Macroeconomics*, Vol. 2, Elsevier, 2016, pp. 1547–1640.

Quigley, John, "Interest Rate Variations, Mortgage Prepayments and Household Mobility," *The Review of Economics and Statistics*, 1987, *69* (4), 636–43.

Redding, Stephen J. and Esteban Rossi-Hansberg, "Quantitative Spatial Economics," *Annual Review of Economics*, 2017, *9* (Volume 9, 2017), 21–58.

Santiago-Bartolomei, Raúl, Deepak Lamba-Nieves, and Enrique A. Figueroa, "Tracking Neighborhood Change in Geographies of Opportunity for Post-Disaster Legacy Cities," Working Paper, Lincoln Institute of Land Policy 2022.

Sastry, Narayan and Jesse Gregory, “The Location of Displaced New Orleans Residents in the Year After Hurricane Katrina,” *Demography*, 03 2014, *51* (3), 753–775.

Schachter, Jason and Angelica Menchaca, “New Population Estimates Rely on Monthly Flight Data to Capture Puerto Rico’s Migration Flows,” 2021. Technical Report.

Sheldon, Tamara L. and Crystal Zhan, “The impact of hurricanes and floods on domestic migration,” *Journal of Environmental Economics and Management*, 2022, *115*, 102726.

The New York Times, “Congress Stalls on Disaster Relief Funding After Hurricane Helene,” 2024. Accessed: 2024-10-19.

The Washington Post, “U.S. disaster funding strained by rising costs and climate change,” 2024. Accessed: 2024-10-19.

Tran, Brigitte Roth and Dan Wilson, “The Local Economic Impact of Natural Disasters,” Working Paper 2020-34, Federal Reserve Bank of San Francisco 2023.

Vigdor, Jacob, “The Economic Aftermath of Hurricane Katrina,” *Journal of Economic Perspectives*, December 2008, *22* (4), 135–54.

Wagner, Katherine R. H., “Adaptation and Adverse Selection in Markets for Natural Disaster Insurance,” *American Economic Journal: Economic Policy*, August 2022, *14* (3), 380–421.

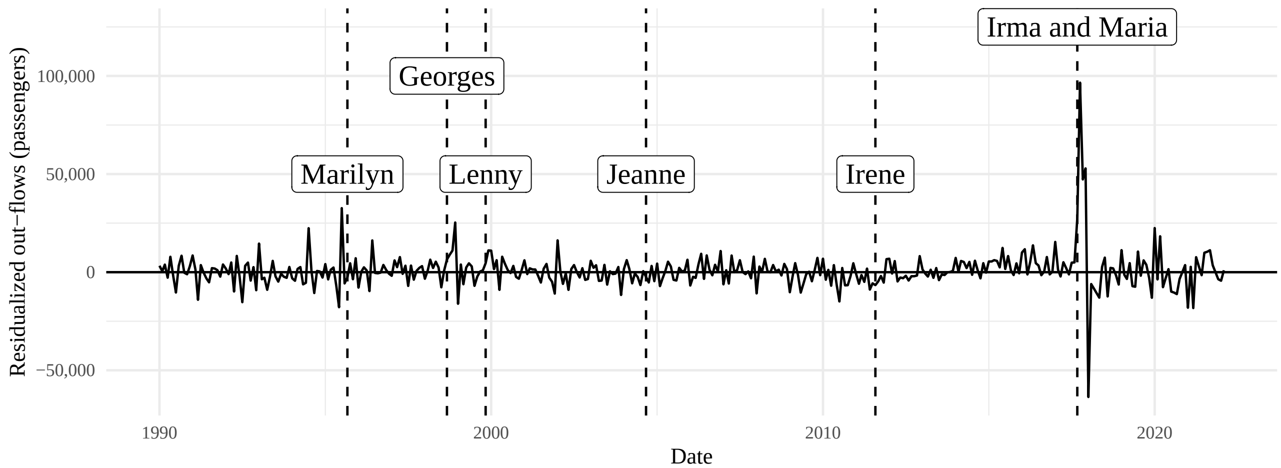
Òscar Jordà, “Estimation and Inference of Impulse Responses by Local Projections,” *American Economic Review*, March 2005, *95* (1), 161–182.

Appendix

Contents

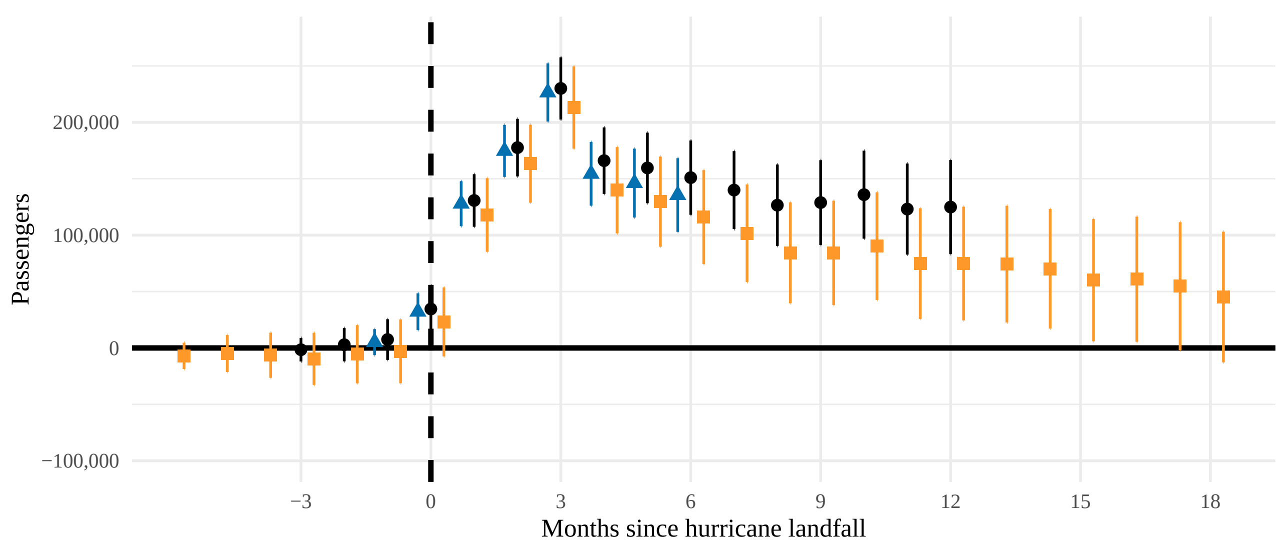
A. Additional Tables and Figures

Figure A1: Residual Passenger Flows



Notes: This figure plots residual migration flows after removing seasonality and a linear time trend. The vertical dashed lines correspond to dates of Hurricanes that made landfall in Puerto Rico.

Figure A2: Migration Response Robustness to Different Leads and Lags



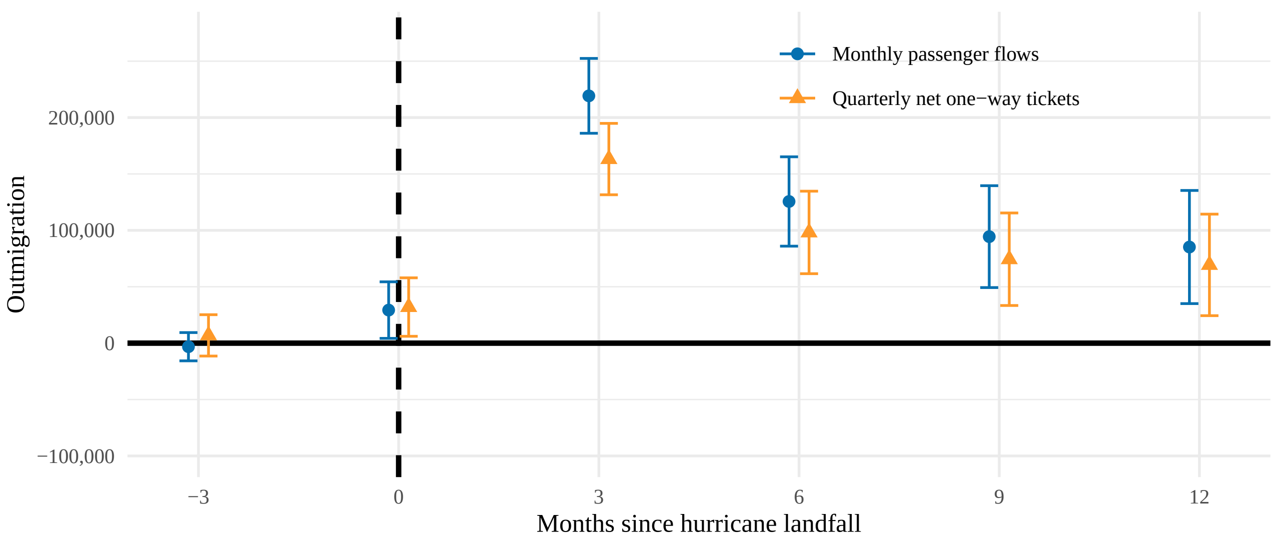
Notes: This figures displays point estimates (shapes) and 95 percent confidence intervals (bars) for the cumulative sum of the β_i coefficients in Equation 1 using different numbers of leads and lags. The black circles denote the baseline model. The blue trianges reflect estimates of a model with fewer leads and lags. The orange squares reflect estimates of a model with additional leads and lags.

Table A1: Migration Elasticity with Respect to Destination PR Population

	Dependent variable:					
	Temporary Migrants			Permanent Migrants		
	(1)	(2)	(3)	(4)	(5)	(6)
PR Population (1,000)	28.602***	27.427***	38.372***	8.699***	6.493***	11.578***
	(1.355)	(1.725)	(3.530)	(0.869)	(1.029)	(2.791)
Non PR Hispanic Population		−0.140	0.029		0.645***	0.231
		(0.301)	(0.208)		(0.180)	(0.165)
Avg January Low		22.218	−15.360		36.543	−24.830
		(83.668)	(51.156)		(49.923)	(40.450)
Avg January High		−9.153	−18.411		−67.763	−19.352
		(76.215)	(46.755)		(45.476)	(36.970)
Avg Rent		2.757**	0.795		0.529	−0.101
		(1.346)	(0.815)		(0.803)	(0.644)
Avg Income		−0.018	0.026		0.009	0.024*
		(0.026)	(0.016)		(0.016)	(0.013)
Avg Airfare		−6.758	−3.743		−2.272	−2.098
		(4.201)	(2.490)		(2.507)	(1.969)
Distance		−0.461	−0.127		−0.413	0.007
		(0.489)	(0.302)		(0.292)	(0.239)
Observations	61	61	58	61	61	58
R^2	0.883	0.904	0.791	0.629	0.737	0.482

Notes: This table presents the corresponding regression to Figure 2b adding additional controls for the non-Puerto Rican Hispanic population in an MSA, The average January low and high temperature, the average rent paid and income earned by individuals born in Puerto Rico living in that MSA as well as the average airfare in 2017Q3 and the distance between the MSA and San Juan, PR. *p<0.1; **p<0.05; ***p<0.01

Figure A3: Comparison of Monthly Passenger Flows to One-Way Ticket Data



Notes: This figures displays point estimates (shapes) and 95 percent confidence intervals (bars) for the cumulative sum of the β_i coefficients in Equation 1. The blue circles show the estimates using the monthly passenger flow data while the orange triangles show the same estimates using one-way ticket data. The coefficients represent out-migration from Puerto Rico to the mainland US after Hurricane Maria.

B. Measuring Migration Using Flight Data

In this appendix, I provide a detailed description of how migration flows are constructed using airline passenger data from the Bureau of Transportation Statistics (BTS). To validate these alternative migration measures, I compare the flight-based estimates of Puerto Rican population changes with corresponding Census data.

B.1 Airline Passenger Data

To measure aggregate net migration between Puerto Rico and the mainland US, I use data on passenger flows by route from the BTS T-100 Airline Passenger Traffic dataset. The T-100 dataset contains data on what is carried on all US airline aircraft between two points for each flight that is advertised and available to the general public. Airlines must report this information to the BTS at a monthly frequency. For example, an observation in the data is that in October 2017, JetBlue transported 15,450 passengers between SJU (San Juan, PR airport) and MCO (Orlando, FL airport). Figure B1a plot the monthly passenger flows between Orlando, FL and San Juan, PR and San Juan, PR and Orlando, FL aggregated across airlines.

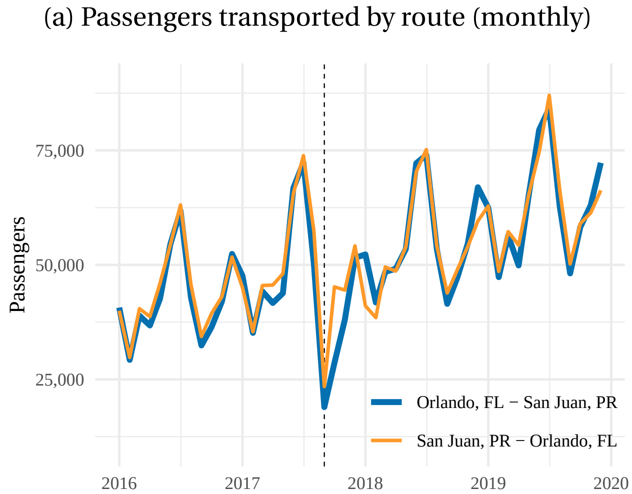
Although the aggregate passenger flow data provides a relatively high frequency measure of air travel to and from PR to a specific airport, the data does not provide any information about the final destinations of passengers. For instance, a passenger who flies from San Juan, PR to Miami, FL and then on to New York, NY would not be properly allocated to their destination in the aggregate passenger flow data. To overcome this limitation, I use detailed ticket-level data from the BTS D1B1 Origin and Destination Survey.[27] This data includes aggregate statistics about itineraries, such as the price and number of passengers, as well as detailed information, such as layovers, allowing me to track passengers to their final destination. Figure B1b plots the quarterly flows of one-way tickets between Orlando, FL and San Juan, PR and San Juan, PR and Orlando, FL aggregated across airlines.

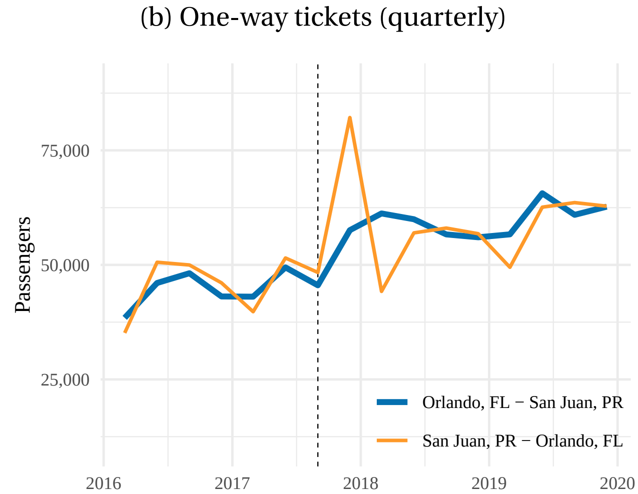
Both these pictures clearly demonstrate that most travel between PR and the mainland US is round-trip. Figure B1a displays nearly equal aggregate passenger flows between Orlando, FL and San Juan, PR, except for the period after Hurricane Maria in 2017. Similarly, although to a lesser extent, figure B1b illustrates that many one-way tickets are likely part of a round-trip. Roughly one-third of the quarterly aggregate passenger flows appear to be on one-way tickets, which suggests that most must have a separately purchased return ticket.

These figures clearly show that there is substantial seasonal variation in passenger travel. For example in the monthly passenger flows it is clear there is a peak in travel in the summer months and over the winter holidays. The quarterly one-way passenger ticket data has similarly large seasonal effects which most travel happening in the second and third quarter of the year. It is crucial to remove the seasonal variation from the data before estimating the migration effects of Hurricane

[27] All large U.S. air carriers must participate in the Origin and Destination Survey. Based on ticket searches, all airlines that fly routes between PR and the mainland US participate. At a quarterly frequency, airlines are required to report a 10% random sample of all tickets

Figure B1: Airline Passenger Flows





Notes: The left panel plots monthly aggregate passenger flows between the San Juan, PR airport and the Orlando, FL airport. The right panel plots quarterly aggregate one-way tickets between the same pair of airports. Flows out of PR are plotted in orange, flows into PR are plotted in blue. The vertical dashed line shows the month/quarter of Hurricane Maria.

Maria. To avoid introducing spurious seasonality, I perform any seasonal adjustment for aggregate migration at the aggregate level instead of seasonally adjusting at the airport pair level. Based on BTS analysis, I focus only on seasonal effects and ignore trading day and holiday effects since they do not affect air-traffic statistics substantially.

B.2 Translating Passenger Flows into Migration Flows

In any given month, there are substantial population flows between PR and the mainland US. To derive migration flows from airline passenger data, I calculate net migration by subtracting gross passenger inflows to Puerto Rico from gross passenger outflows to the mainland US, as illustrated in Figure B2a. Figure B2b displays the resulting net migration measure.[28] Both gross and net flows are quite large. During this period roughly 300,000 people flew into and out of Puerto Rico in a given month (the PR population was roughly 3 million). The large gross passenger flows reflect the fact that Puerto Rico is a popular tourist destination as well as a place where many in the mainland US have family.

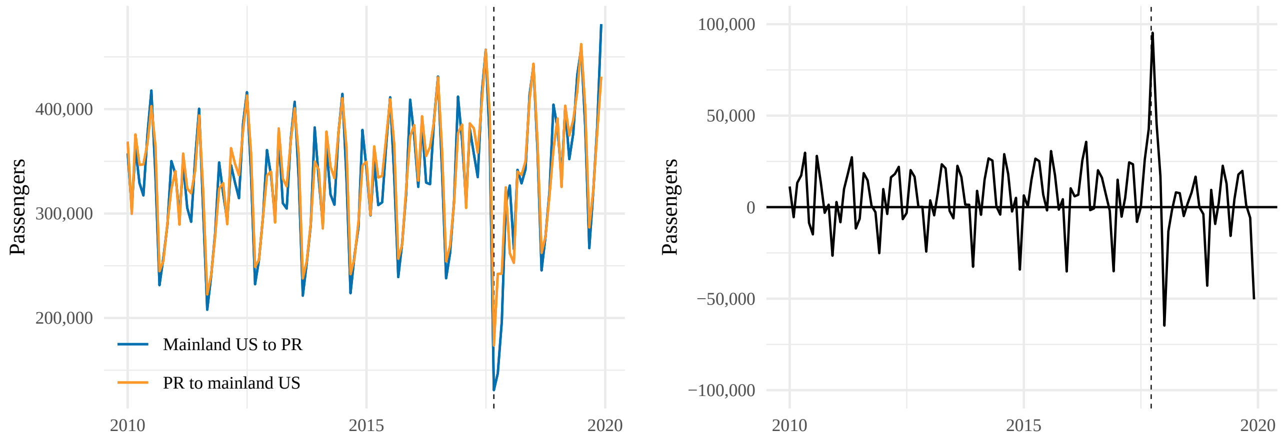
Since 2010, there has been significant net air traffic between PR and the mainland US. Figure B2b plots the monthly net flows from PR to the mainland US from 2010 to 2020. While net passenger flows are naturally smaller than gross flows, they are still quite large ranging from -25,000 to 25,000 people each month in the period leading up to Hurricane Maria. Net flows in most months during

[28] I remove all flights to other US territories such as the US Virgin Islands. There are significant one-way passenger flows between PR and the US VI due to tourists. None of the results presented in the main text are sensitive to the inclusion or exclusion of US VI passengers.

Figure B2: Gross and Net Flows between PR and the Mainland US

(a) Gross Flows between PR and the Mainland US

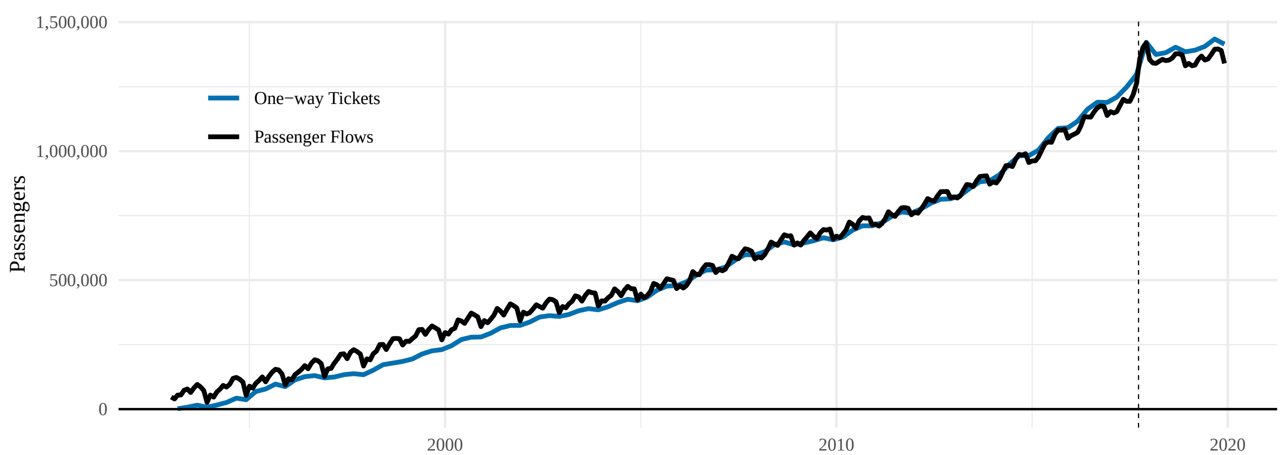
(b) Total Net Outflows to the Mainland US



Notes: The left panel plots monthly gross passenger flows between PR and the mainland US. The right panel plots net flows to the mainland US for the same time period. The vertical dashed line shows the month of Hurricane Maria.

this period are positive indicating that there has been substantial net migration from PR to the mainland US since 2010. Figure B3 plots the estimated net cumulative passenger flows from PR to the mainland US from the beginning of BTS data collection in 1993 until 2020. The figures shows cumulative passengers outflows based on net passenger flows and net one-way tickets. The two lines are nearly identical both before and after Hurricane Maria in 2017. The small differences can likely be attributed to their slightly different frequencies (monthly vs quarterly).

Figure B3: Cumulative Passenger Outflows from PR to the Mainland US



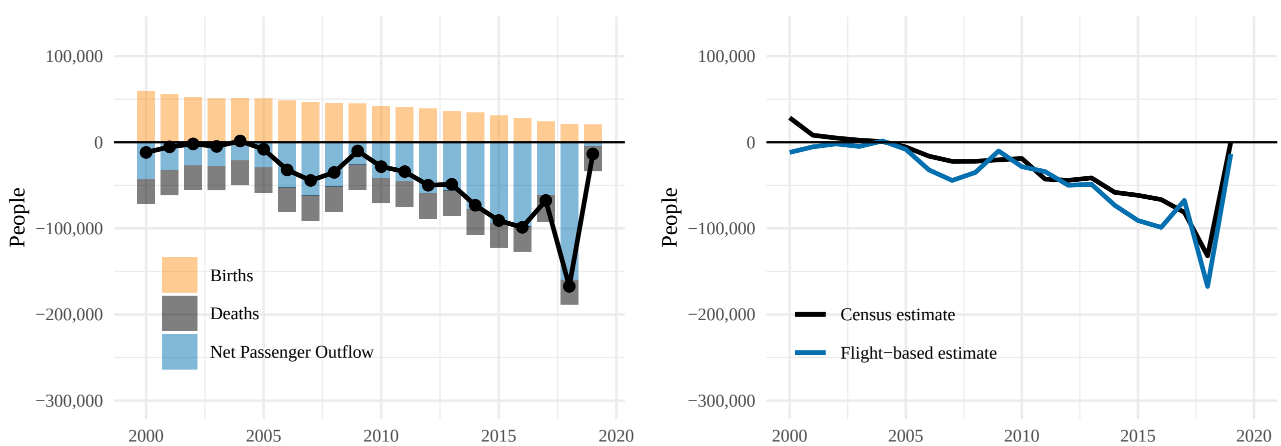
Notes: The figure plots cumulative net monthly passengers flows from PR to the mainland US (in black), and cumulative quarterly net one-way tickets from PR to the mainland US(in blue) from 1993 to 2020.

B.3 Validity of Migration Measure

Net passenger outflows over the past decade suggest sustained out-migration, but it is unclear if airline flows accurately reflect changes in the Puerto Rican population. Cumulative net passenger flows from 2010 and up until Hurricane Maria in September 2017, suggest than over half a million individuals left PR for the mainland US during this period (the 2010 population was 3.7 million). By simple population accounting, the change in the population of Puerto Rico should be births minus deaths and any out-migration. To estimate changes in the population of PR, I combine annual estimates of net passenger outflows from the net monthly passenger flows with data on births and deaths in PR from the National Center for Health Statistics (NCHS). Figure B4a, plots the decomposition of the net population change (black line) between births, deaths, and the net out migration from 2000-2019. Figure B4b plots estimates of annual population changes based on the flight data and from the Census.

Figure B4: Using Airplane Passengers Flows to Estimate Population Changes

(a) Decomposing Population Changes (b) Comparison with Census Estimates



Notes: The left panel decomposes changes in the PR population in a given year between births, deaths, and net out-migration as measured by passenger out-flows. The right panel compares estimates for the change in the PR population constructed using aggregate flight data to measure out-migration with official Census population estimates which are constructed using ACS and PRCS data. Note that for Census population estimation a year is defined as July-June. The Census measure of population thus dramatically understates the amount of temporary migration that occurred in late 2017 and early 2018.

The population estimates constructed from passenger outflows tracks the US Census Bureau's population estimates closely. Census estimates for net migration from Puerto Rico to the mainland US are constructed using the question on where an individual resided last year from the ACS and the Puerto Rican Community Survey (PRCS) [29]. The advantage of the higher frequency flight data is

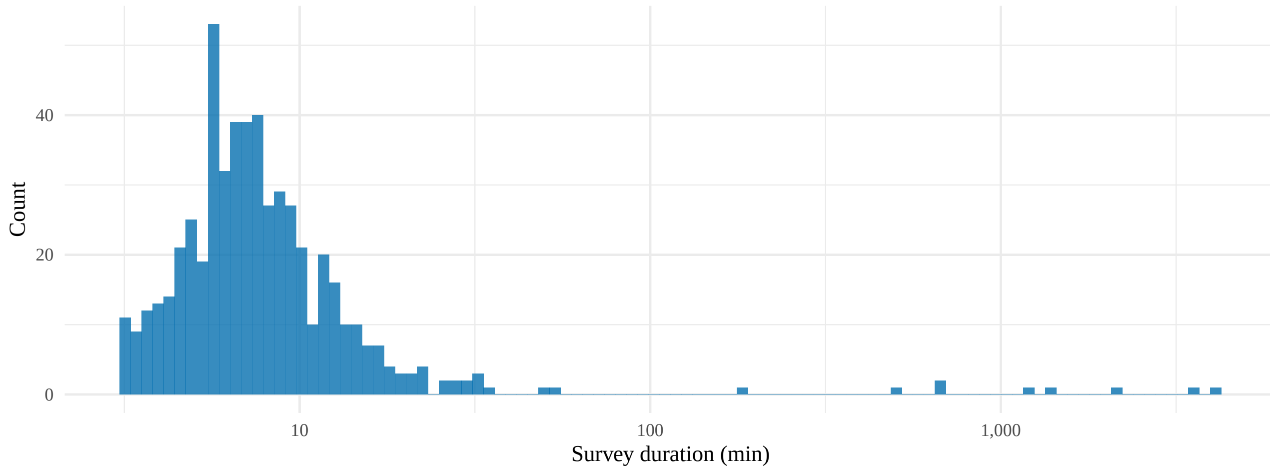
[29] The Census Bureau has used aggregate passenger flow flight data to improve the accuracy of their population estimates to account for population changes due to COVID-19. See Bureau (2021) and Schachter and Menchaca (2021) for more details.

that it allows me to uncover that there was substantial temporary migration in late 2017 and early 2018 immediately after Hurricane Maria.

C. Survey of Puerto Ricans

C.1 Response Quality

Figure C1: Survey Completion Time

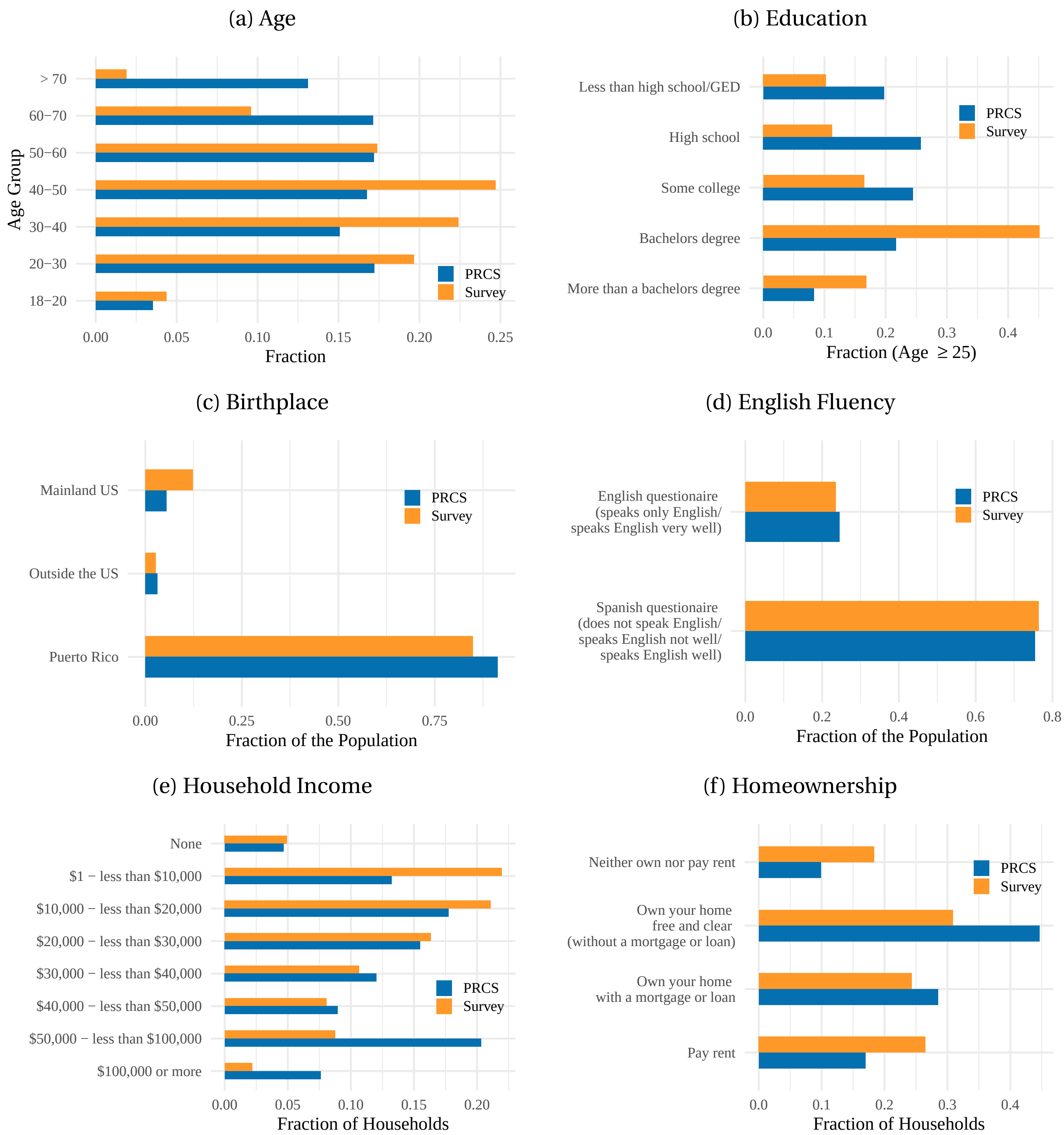


Notes: The figure plots the distribution of survey completion time. The minimum time to complete the survey was 3 minutes. Median time was 7 minutes. 95% of respondents completed the survey in 20 minutes or less. The maximum time was 4,002 minutes (2.8 days).

C.2 Representativeness of Survey Sample

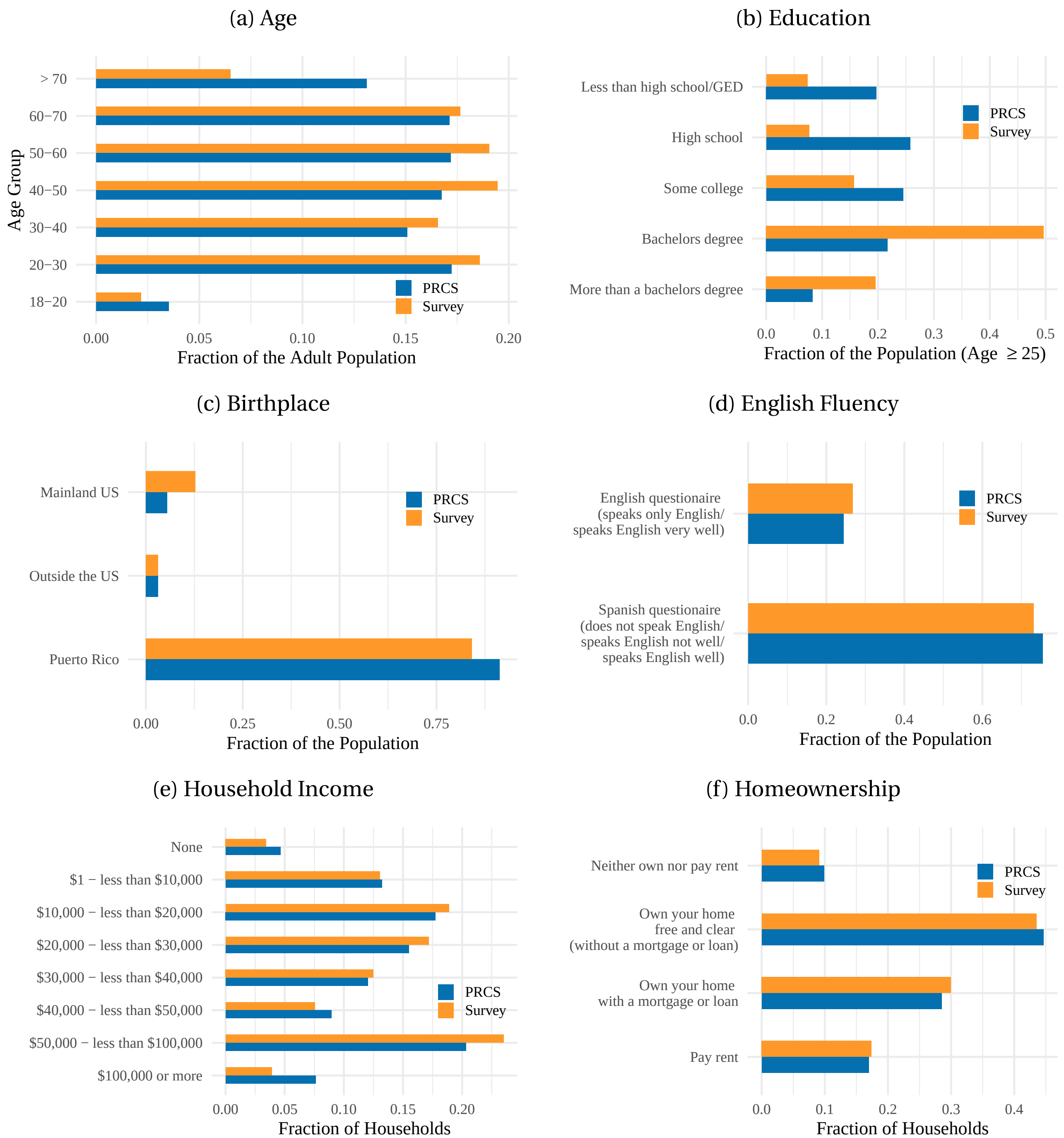
To have confidence in extrapolating the findings from the Survey to the experience of the Puerto Rican population who chose not to migrate permanently to the mainland US after Hurricane Maria, the survey sample must be representative of the income, wealth, migration costs, and preferences of Puerto Rican households. Figure C2 compares raw survey sample demographic, income, and homeownership distributions with the actual population distributions taken from the 2022 PRCS (the most recently released version of the PRCS). Figure C3 plots weighted survey sample distributions.

Figure C2: Raw Survey Sample and PRCS Distributions



Notes: Each panel plots the comparison of the distribution of a variable among online survey respondents with respondents to the 2021 Puerto Rico Community Survey. Panel C2a compares the survey and PRCS age distributions for individuals over age 18. Panel C2b compares the educational attainment of individuals over age 25. Panel C2c compares the birthplace of individuals over age 18. Panel C2d compares the fraction of survey respondents who chose to take the survey in English and Spanish with reported English proficiency in the PRCS. Panel C2e compares household income among survey respondents with binned PRCS household income. Panel C2f compares household ownership status.

Figure C3: Weighted Survey Sample and PRCS Distributions



Notes: Each panel plots the comparison of the distribution of a variable among online survey respondents after applying post stratification weights with respondents to the 2022 Puerto Rico Community Survey. Panel C2a compares the survey and PRCS age distributions for individuals over age 18. Panel C2b compares the educational attainment of individuals over age 25. Panel C2c compares the birthplace of individuals over age 18. Panel C2d compares the fraction of survey respondents who chose to take the survey in English and Spanish with reported English proficiency in the PRCS. Panel C2e compares household income among survey respondents with binned PRCS household income. Panel C2f compares household ownership status.

D. Bellman Equations and Equilibrium

D.1 Household Problems

D.2 Renters

Let $V_{\mathcal{R}}(j, z_t, a_t)$ denote the value function of a household of age j, idiosyncratic productivity z_t, and liquid asset holdings a_t, who starts a period without owning any housing. These households choose between staying in Puerto Rico and migrating to the mainland US:

$$V_{\mathcal{R}}(j, z_t, a_t) = \max \left\{ V_{\mathcal{R}}^{stay}(j, z_t, a_t), V_{\mathcal{R}}^{migrate}(j, z_t, a_t) \right\}, \tag{D1}$$

where I let $\pi_{\mathcal{R}}^{migrate}(j, z_t, a_t) \in \{0, 1\}$ denote the decision to migrate. If the household chooses to stay in PR $\left(\pi_{\mathcal{R}}^{stay} = 1 - \pi_{\mathcal{R}}^{migrate}\right)$, they must choose between renting or owning:

$$V_{\mathcal{R}}^{stay}(j, z_t, a_t, \mathcal{P}) = \max \left\{ V_{\mathcal{R}}^{buy}(j, z_t, a_t, \mathcal{P}, \mathcal{N}) + \epsilon^{buy}, V_{\mathcal{R}}^{rent}(j, z_t, a_t) + \epsilon^{rent} \right\}, \tag{D2}$$

where ϵ^i are iid taste shocks drawn from a Gumbel distribution with shape parameter σ_h. The probability that the household will rent is given by:

$$\pi_{\mathcal{R}}^{rent}(j, z_t, a_t, \mathcal{P}) = \frac{\exp\left[\frac{V_{\mathcal{R}}^{rent}}{\sigma_h}\right]}{\exp\left[\frac{V_{\mathcal{R}}^{rent}}{\sigma_h}\right] + \exp\left[\frac{V_{\mathcal{R}}^{buy}}{\sigma_h}\right]}.$$

Below I describe the decision problem conditional on the renter household's choice to rent, buy, or migrate.

Rent: A household that chooses to rent must choose how much housing to rent, how much to consume, and how much to save:

$$\begin{aligned} V_{\mathcal{R}}^{rent}(j, z_t, a_t) = \max_{c_t, h_t, a_{t+1}} \; & u(c_t, s_t, N_t) + \phi_j \beta E[V_{\mathcal{R}}(j+1, z_{t+1}, a_{t+1})] \\ \text{s.t. } & a_{t+1} = (1+r)a_t + w_t y(j, z_t) - c_t - p_t^r h_t \\ & s_t = f(g_t) h_t, h_t \in H^{\mathcal{R}} \\ & c_t, a_{t+1} \geq 0 \end{aligned} \tag{D3}$$

Buy: Households cannot buy a damaged homes. A household that chooses to buy must choose how much housing to buy, the initial size of their mortgage, how much to consume, and how much to save:

$$V_{\mathcal{R}}^{buy}(\ell, j, z_t, a_t) = \max_{c_t, h_t, b_t, a_{t+1}} u(c_t, s_t, N_t) + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_t, h_t, d_t = 0)] \tag{D4}$$

$$\text{s.t. } a_{t+1} = (1+r)a_t + w_t y(j, z_t) + b_t - c_t - (1 + \kappa + \tau_h) p_t^h h_t + \delta_h p_t^c h_t$$

$$s_t = (1+\omega) f(g_t) h_t, h_t \in H^{\mathcal{O}}$$

$$b_t \leq \psi^{ltv} p_t^h h_t$$

$$c_t, a_{t+1} \geq 0$$

Migrate: The timing of the migration decisions is such that the household observes their iid temporary migration cost m_T at the start of the period and then decided whether or not to migrate. If the households choose to migrate at the start of the period, then at the end of the period, the household observers their iid permanent migration cost and must decided either to return to PR, or to migrate permanently to the mainland US:

$$V_{\mathcal{R}}^{migrate}(j, z_t, a_t, m_t) = \sum_{m_P} \pi(m_P) \left(\pi_{\mathcal{R}}^{temp} V_{\mathcal{R}}^{temp} + (1 - \pi_{\mathcal{R}}^{temp}) V_{\mathcal{R}}^{perm} \right), \tag{D5}$$

where $\pi_{\mathcal{R}}^{temp}(j, z_t, a_t, m_T, m_P \mathcal{P}, \mathcal{N}) \in \{0, 1\}$ is the decision to migrate temporarily conditional on the realization of *both* temporary and permanent migration costs.

If a household chooses to migrate temporarily, they make no additional choices and return to PR at the end of the period:

$$V_{\mathcal{R}}^{temp}(\ell, j, z_t, a_t, m_T, \mathcal{P}, \mathcal{N}) = \bar{u}_m + \phi_j \beta E[V_{\mathcal{R}}(\ell, j+1, z_{t+1}, (1+r)a_t - m_T, \mathcal{P}, \mathcal{N})], \tag{D6}$$

with the constraint that they must be able to finance the migration cost out of start of period assets. If a household chooses to migrate permanently, they make no additional choices and remain in the mainland US at the end of the period:

$$V_{\mathcal{R}}^{perm}(\ell, j, z_t, a_t, m_T, m_P) = \bar{u}_m + \phi_j \beta E[V_{\mathcal{R}}^{US}(j+1, z_{t+1}, (1+r)a_t - m_T - m_P,)], \tag{D7}$$

again subject to the constraint that the household can afford to pay the migration costs out of start of period assets.

D.2.1 Owners

Let $V_{\mathcal{O}}(j, z_t, a_t, b_t, h_t, d_t)$ denote the value function of a household of age j, idiosyncratic productivity z_t, and liquid asset holdings a_t, who owns a house of size h_t, with remaining mortgage balance b_t,and potential damage d_t (as a fraction of house value). These households have the option to keep the house and make mortgage payments, sell their house, or default. If they keep the house they can also decide to migrate temporarily to the mainland US, live in their house in the current condition, self-finance repair their house, or apply for government assistance to repair their house:

$$V_{\mathcal{O}}(j, z_t, a_t, b_t, h_t, d_t) = \max \begin{cases} \text{Default:} & V_{\mathcal{O}}^{default} \\ \text{Sell:} & V_{\mathcal{O}}^{sell} \\ \text{Migrate:} & V_{\mathcal{O}}^{migrate} \\ \text{Hold:} & V_{\mathcal{O}}^{hold} \\ \text{Repair:} & V_{\mathcal{O}}^{repair} \\ \text{Apply:} & V_{\mathcal{O}}^{apply} \end{cases} \tag{D8}$$

Let $\pi_{\mathcal{O}}^{i}(j, z_t, a_t, b_t, h_t, d_t) \in \{0, 1\}$ denote whether or not the households makes choice i. Let $\pi_{\mathcal{O}}^{stay} = \pi_{\mathcal{O}}^{hold} + \pi_{\mathcal{O}}^{repair} + \pi_{\mathcal{O}}^{apply}$. Below, I describe the decision problem conditional on the owner household's choice to default, sell migrate, hold, repair, or apply for assistance.

Default: If an owner defaults, they walk away from their house and their remaining mortgage balance, incur a utility cost $\bar{u}_d$ and are excluded from buying a house for one period. They retain their non-housing wealth and are allowed to migrate temporarily or permanently immediately:

$$V_{\mathcal{O}}^{default}(j, z_t, a_t, b_t, h_t, d_t) = -\bar{u}_d + V_{\mathcal{R}}^{no\,buy}(j, z_t, a_t), \tag{D9}$$

where the value of being a renter who is excluded from buying is simply:

$$V_{\mathcal{R}}^{no\,buy}(j, z_t, a_t) = \max\left\{V_{\mathcal{R}}^{rent}(j, z_t, a_t), V_{\mathcal{R}}^{migrate}(j, z_t, a_t)\right\}. \tag{D10}$$

Sell: If an owner decides to sell their house they immediately become a renter:

$$\begin{aligned} V_{\mathcal{O}}^{sell}(j, z_t, a_t, b_t, h_t, d_t) &= V_{\mathcal{R}}(j, z_t, \tilde{a}_t) \\ \text{s.t. } \tilde{a}_t &= a_t + \frac{1}{1+r}\Big((1-\kappa)(1-d_t)p_t^h h_t - b_t\Big) \\ \tilde{a}_t &\geq 0 \end{aligned} \tag{D11}$$

An owner can only sell if their liquid assets post-sale and paying off any remaining mortgage balance is not negative.

Migrate: If an owner chooses to migrate, they migrate temporarily and make no additional choices. They must continue to make mortgage payments and pay property taxes and maintenance of the undamaged value of their house. The value of being a temporary migrant is given by:

$$\begin{aligned} V_{\mathcal{O}}^{migrate}(j, z_t, a_t, b_t, h_t, d_t) =& \bar{u} + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_{t+1}, h_t, d_t)] \\ \text{s.t. } a_{t+1} &= (1+r)a_t - m_T - h_t(1-d_t)(\tau_h p_t^h + \delta_h p_{\ell,t}^c) - M(j, b_t) \\ b_{t+1} &= (1+r_m)b_t - M(j, b_t) \\ a_{t+1} &\geq 0 \end{aligned} \tag{D12}$$

Hold: A household that chooses to hold onto their house in its current condition must choose how much to consume and how much to save in the liquid asset. The household solves the problem:

$$V_{\mathcal{O}}^{hold}(j, z_t, a_t, b_t, h_t, d_t) = \max_{c_t, a_{t+1}} u(s_t, h_t, N_t) + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_{t+1}, h_t, d_t)] \tag{D13}$$

$$\begin{aligned} \text{s.t. } a_{t+1} &= (1+r)a_t + w_t y(j, z_t) - c_t - h_t(1-d_t)(\tau_h p_t^h + \delta_h p_t^c) - M(j, b_t) \\ b_{t+1} &= (1+r_m)b_t - M(j, b_t) \\ s_t &= (1+\omega) f(g_t)(1-d_t)h_t \\ c_t, a_{t+1} &\geq 0 \end{aligned}$$

Repair: A household that chooses to self-finance the repair their house must choose how much to consume and save. When a household undertakes a repair, they must repair the house fully. The timing of the repair is such that the household must pay the contractor this period but does not get to enjoy living in an undamaged house until the next period. This mimics the assumption of one-period time to build for infrastructure and production capital. The household solves the problem:

$$V_{\mathcal{O}}^{repair}(j, z_t, a_t, b_t, h_t, d_t) = \max_{c_t, a_{t+1}} u(s_t, c_t, N_t) + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_{t+1}, h_t, d_{t+1})] \tag{D14}$$

$$\begin{aligned} \text{s.t. } a_{t+1} &= (1+r)a_t + w_t y(j, z_t) - c_t - \tau_h p_t^h h_t(1-d_t) - p_t^c h_t d_t - M(j, b_t) \\ b_{t+1} &= (1+r_m)b_t - M(j, b_t) \\ s_t &= (1+\omega) f(g_t)(1-d_t)h_t \\ d_{t+1} &= 0 \\ c_t, a_{t+1} &\geq 0 \end{aligned}$$

Apply: A household that chooses to apply for government assistance faces some exogenous probability each period, $\pi_t^{approve}$, that their application will be approved. The value of applying for assistance in period t is given by:

$$V_{\mathcal{O}}^{apply}(j, z_t, a_t, b_t, h_t, d_t) = \pi_t^{approve} V_{\mathcal{O}}^{approved} + (1 - \pi_t^{approve}) V_{\mathcal{O}}^{hold} \tag{D15}$$

If approved, the household receives a transfer equal to the cost of repairing their home up to a cap $t\bar{a}u$ and must repair their home. The household must also choose how much to consume and save:

$$\begin{aligned}
V_{\mathcal{O}}^{approved}(j, z_t, a_t, b_t, h_t, d_t) = \max_{c_t, a_{t+1}} \; & u(s_t, c_t, N_t) + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_{t+1}, h_t, d_{t+1})] \\
\text{s.t. } a_{t+1} &= (1+r)a_t + w_t y(j, z_t) - c_t - \tau_h p_t^h h_t(1-d_t) - \max(0, p_t^c h_t d_t - \bar{\tau}) - M(j, b_t) \\
b_{t+1} &= (1+r_m)b_t - M(j, b_t) \\
s_t &= (1+\omega) f(g_t)(1-d_t)h_t \\
d_{t+1} &= 0 \\
c_t, a_{t+1} &\geq 0
\end{aligned} \tag{D16}$$

If denied, the household must live in their damaged home and can apply again the next period.

Bequests: In the last period of life $j = J$, a homeowner who does not sell its house in the last period pays off any residual mortgage and orders the house to be sold at the beginning of the next period:

$$\begin{aligned}
V_{\mathcal{O}}^{hold}(J, z_t, a_t, b_t, h_t, d_t) = \max_{c_t, a_{t+1}} \; & u(s_t, c_t, N_t) + \beta u(w_{t+1}) \\
\text{s.t. } a_{t+1} &= (1+r)a_t + y(J, z_t) - c_t - h_t(1-d_t)(\tau_h p_t^h + \delta_h p_t^c) - b_t \\
w_{t+1} &= a_{t+1} + (1-\kappa) p_{t+1}^h h_t (1-d_t) \\
s_t &= (1+\omega) f(g_t)(1-d_t)h_t \\
d_{t+1} &= 0 \\
c_t, a_{t+1} &\geq 0
\end{aligned} \tag{D17}$$

D.3 Landlord Problem

A competitive rental sector in each location owns houses and rents then out to households. Rental companies can buy and sell houses frictionlessly. They are subject to the same depreciation cost δ_h and property tax τ_h as homeowners. Rental companies are subject to an additional per-period operating cost, $\psi^{\mathcal{R}}$ for each rental unit. Rental companies make decisions to maximize the present value of current and future dividends:

$$\begin{aligned}
\max_{\phi_s^r, h_s, H_{s+1}} \sum_{s=t}^{\infty} \left(\frac{1}{1+\bar{r}}\right)^{s-t} \Bigg[& \underbrace{(p_s^r - \psi^r - \tau_h)\phi_s^r (H_s + h_s)}_{\text{rented units}} + \underbrace{(1-\phi_s^r)(H_s + h_s) p_s^h}_{\text{units sold}} - \\
& \underbrace{p_s^h h_s}_{\text{units purchased}} - \underbrace{p_s^c (H_{s+1} - (1-\delta_h)\phi_s^r (H_s + h_s))}_{\text{new investment}} \Bigg]
\end{aligned} \tag{D18}$$

The first order condition for the rental firm for the fraction of units to rent or new units to buy is:

$$p_s^r = \psi^r + \tau_h + p_s^h - p_s^c(1-\delta_h)$$

The first order condition for new units gives

$$p_s^c = \frac{1}{1+\bar{r}}\left[(p_{s+1}^r - \phi^r - \tau_h)\phi_{s+1}^r + p_{s+1}^h(1-\phi_{s+1}) - p_{s+1}^c(1-\delta_h)\phi_{s+1}^r\right]$$
$$p_s^c = \frac{p_{s+1}^h}{1+\bar{r}}$$

Combining, we get the user cost formula that determines rents:

$$p_s^r = \psi^r + \tau_h + p_s^h - (1-\delta_h)\frac{p_{s+1}^h}{1+\bar{r}} \tag{D19}$$

The rental company must be indifferent between selling a unit of housing in the current period versus collecting rent, paying the operating cost and property taxes and selling their unit of housing in the next period.

D.4 Firm Problem

Firms pay out any profits each period as a dividend, d_t.

$$\max_{L_s, K_{s+1}} \sum_{s=t}^{\infty}\left(\frac{1}{1+\bar{r}}\right)^{s-t}\left[Y_s - w_s\tilde{L}_s - \tau_G Y_s - p_s^c(K_{s+1} - (1-\delta_K)K_s)\right] \tag{D20}$$

The firm's first order conditions for labor holds period by period:

$$w_s = \alpha_L(1-\tau_G)A(K_s)^{\alpha_K}(L_s)^{\alpha_L - 1}(G_s)^{\alpha_G} \tag{D21}$$

Given one-period time to build the firm's first order condition will not hold in the period of a shock but will apply for all future periods.

$$p_s^c(1+\bar{r}) - p_{s+1}^c(1-\delta_K) = \alpha_K(1-\tau_G)A(K_{s+1})^{\alpha_K - 1}(L_{s+1})^{\alpha_L}(G_{s+1})^{\alpha_G} \tag{D22}$$

Assuming price of capital is constant and equal to 1 the left hand side simplifies to the familiar $\bar{r} + \delta_K$. The firms' optimal capital stock in period $t+1$ is:

$$K_{t+1}^* = \left(\frac{p_t^c(1+\bar{r}) - p_{t+1}^c(1-\delta_K)}{\alpha_K(1-\tau_G)A(L_{t+1})^{\alpha_L}(G_{t+1})^{\alpha_G}}\right)^{\frac{1}{\alpha_K - 1}} \tag{D23}$$

Assuming that capital once installed cannot be destroyed, firm investment in period t is given by:

$$I_t^K = \max\left\{0, K_{t+1}^* - (1-\delta_K)K_t\right\} \tag{D24}$$

D.5 Equilibrium

Define the vector of individual states for renters (non-owners): $\mathbf{x}_\mathcal{R} := (j, z, a) \in \mathbb{X}_\mathcal{R}$ and for owners: $\mathbf{x}_\mathcal{O} := (j, z, a, b, h, d) \in \mathbb{X}_\mathcal{O}$. Let $\theta_j^\mathcal{R}$ and $\theta_j^\mathcal{O}$ be the measure of renter (non-owner) and owner households of age j at the start of period t with $(\theta_\mathcal{R}^j + \theta_\mathcal{O}^j) = x_j$, where x_j is the total fraction of Puerto Ricans in Puerto Rico of age j at the start of the period. Let $\mathbf{\Theta}$ be the distribution over idiosyncratic household states.

Given initial conditions for private capital, infrastructure, and housing stocks $\{K_0, G_0, H_0, \tilde{H}_0\}$ and an initial distribution of household states $\mathbf{\Theta}_0$, an equilibrium is a sequence of prices $\mathcal{P} = \{w_t, p_t^r, p_t^h, p_t^c\}_{t=1}^\infty$, distributions $\{\mathbf{\Theta}\}_{t=1}^\infty$ and allocations $\{K_t, G_t, H_t, \tilde{H}_t\}_{t=1}^\infty$ such that:

1. Households optimize, given a sequence of prices, by solving problems (D3) - (D17) with associated value functions:

$$\left\{V_\mathcal{R}^{rent}, V_\mathcal{R}^{buy}, V_\mathcal{R}^{migrate}, , V_\mathcal{R}^{temp}, V_\mathcal{R}^{perm}, V_\mathcal{O}^{default}, V_\mathcal{O}^{sell}, V_\mathcal{O}^{migrate}, V_\mathcal{O}^{hold}, V_\mathcal{O}^{repair}, V_\mathcal{O}^{apply}\right\}$$

   and decision probabilities

$$\left\{\pi_\mathcal{R}^{rent}, \pi_\mathcal{R}^{migrate}, \pi_\mathcal{R}^{temp}, \pi_\mathcal{O}^{default}, \pi_\mathcal{O}^{sell}, \pi_\mathcal{O}^{migrate}, \pi_\mathcal{O}^{stay}, \pi_\mathcal{O}^{hold}, \pi_\mathcal{O}^{repair}, \pi_\mathcal{O}^{apply}\right\}.$$

2. The labor market in Puerto Rico clears at the wage w_t:

$$\begin{aligned} w_t = \alpha_L (K_t)^{\alpha_K} (G_t)^{\alpha_G} \Bigg(\sum_{j=1}^{J_{ret}} \Bigg[& \int_{\mathbb{X}_\mathcal{R}} \underbrace{\pi_\mathcal{R}^{stay}(\mathbf{x}_\mathcal{R}) y(\mathbf{x}_\mathcal{R}) d\theta_\mathcal{R}^j}_{\text{renters who stay}} + \int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{O}^{stay}(\mathbf{x}_\mathcal{O}) y(\mathbf{x}_\mathcal{O}) d\theta_\mathcal{O}^j}_{\text{owners who stay}} + \\ & \int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{O}^{default}(\mathbf{x}_\mathcal{O}) \pi_\mathcal{R}^{stay}(\mathbf{x}_\mathcal{O}) y(\mathbf{x}_\mathcal{O}) d\theta_\mathcal{O}^j}_{\text{owners who default and stay}} + \\ & \int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{O}^{sell}(\mathbf{x}_\mathcal{O}) \pi_\mathcal{R}^{stay}(\mathbf{x}_\mathcal{O}) y(\mathbf{x}_\mathcal{O}) d\theta_\mathcal{O}^j}_{\text{owners who sell and stay}} \Bigg] \Bigg)^{\alpha_L - 1} \end{aligned} \tag{D25}$$

3. The rental market in Puerto Rico clears at price p_t^r given by (D19) and the equilibrium quantity of rental units satisfies:

$$\tilde{H}_t = \sum_{j=1}^{J}\Bigg[\int_{\mathbb{X}_\mathcal{R}} \underbrace{\pi_\mathcal{R}^{rent}(\mathbf{x}_\mathcal{R})h(\mathbf{x}_\mathcal{R})d\theta_\mathcal{R}^j}_{\text{renters who rent}} + \int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{R}^{sell}(\mathbf{x}_\mathcal{O})\pi_\mathcal{R}^{rent}(\mathbf{x}_\mathcal{O})h(\mathbf{x}_\mathcal{O})d\theta_\mathcal{O}^j}_{\text{owners who sell and rent}} + \int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{O}^{default}(\mathbf{x}_\mathcal{O})\pi_\mathcal{R}^{stay}(\mathbf{x}_\mathcal{O})h(\mathbf{x}_\mathcal{O})d\theta_\mathcal{O}^j}_{\text{owners who default and stay}}\Bigg] \tag{D26}$$

where the left-hand side is the total supply of rental units in period t and the right-hand side is the demand of rental units by households. Demand comes from renters who stay renters, household who sell and become renters, and households who default on their mortgage and do not choose to immediately migrate.

4. The housing market in Puerto Rico clears at price p_t^h and the equilibrium quantity of housing must satisfy:

$$\begin{aligned}
&\sum_{j=1}^{J}\Bigg[\Bigg(\int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{O}^{sell}(\mathbf{x}_\mathcal{O},\mathcal{P})h(\mathbf{x}_\mathcal{O})}_{\text{owners who sell}} + \int_{\mathbb{X}_\mathcal{O}} \underbrace{\pi_\mathcal{O}^{default}(\mathbf{x}_\mathcal{O},\mathcal{P})h(\mathbf{x}_\mathcal{O})}_{\text{owners who default}}\Bigg) d\theta_\mathcal{O}^j\Bigg] + \\
&\sum_{j=1}^{J+1}\Bigg[\int_{\mathbb{X}_\mathcal{O}} \underbrace{\phi_j h(\mathbf{x}_\mathcal{O})}_{\text{bequests}} d\theta_\mathcal{O}^j\Bigg] + \underbrace{I_{t-1}^H}_{\text{new construction}} \\
&= \sum_{j=1}^{J}\Bigg[\int_{\mathbb{X}_\mathcal{R}} \underbrace{\pi_R^{stay}(\mathbf{x}_\mathcal{R},\mathcal{P})\pi_R^{buy}(\mathbf{x}_\mathcal{R},\mathcal{P})h(\mathbf{x}_\mathcal{R},\mathcal{P})}_{\text{renters who stay and buy}} d\theta_\mathcal{R}^j + \\
&\int_{\mathbb{X}_\mathcal{O}} \Bigg(\underbrace{\pi_\mathcal{O}^{sell}(\mathbf{x}_\mathcal{O},\mathcal{P})\pi_\mathcal{O}^{buy}(\mathbf{x}_\mathcal{O},\mathcal{P})h(\mathbf{x}_\mathcal{O},\mathcal{P})}_{\text{owners who sell and buy}} + \underbrace{\pi_\mathcal{O}^{repair}(\mathbf{x}_\mathcal{O},\mathcal{P})h(\mathbf{x}_\mathcal{O})}_{\text{owners who repair}}\Bigg) d\theta_\mathcal{O}^j\Bigg] + \\
&\underbrace{\delta_H H_{t-1}}_{\text{maintanence}} + \underbrace{\Big[\tilde{H}_t - (1-\delta_H)\tilde{H}_{t-1}\Big]}_{\text{new rental units}}
\end{aligned} \tag{D27}$$

The left-hand side represents the total supply of houses to the owner occupied housing market. Total supply equals new units constructed plus units sold by homeowners and foreclosed units and houses sold on the market by households who die. The right-hand side represent total demand for houses to the owner occupied market. Demand comes from new buyers as well as from owners who are making major repairs and maintenance of the existing housing stock and new units purchased by the rental company.

5. The construction sector clears at price p_t^c

$$\underbrace{X_t}_{\text{new construction}} = \underbrace{I_t^K}_{\text{new production capital}} + \underbrace{I_t^G}_{\text{new infrustructure}} + \underbrace{I_t^H}_{\text{new housing units}} \tag{D28}$$

Where new construction is purchased in period t but is available until period $t+1$. I_t^k solves the firms optimization problem D20, and I_t^G balances the local government budget (all revenue must be spent on infrastructure).

D.6 Steady State Characterization

Per-unit construction costs in steady state are simply $p^c = \psi_0$. Since house prices in steady state are given by the steady state construction cost we can write steady state house prices and rents as:

$$p^h = (1+\bar{r})\psi_0 \tag{D29}$$

$$p^r = \psi^r + \tau_h + (\bar{r} + \delta_h)\psi_0 \tag{D30}$$

I choose to normalize the steady state rent $p^r = 1$. The price to rent ratio in steady state is then determined by the marginal construction cost, ψ_0, and the operating cost for landlords, ψ^r.

Given the constant returns to scale production technology, steady state private capital stocks and infrastructure can be expressed as a linear function of the steady state population:

$$G = g_0 L \tag{D31}$$

$$K = k_0 L \tag{D32}$$

where

$$g_0 = \left(\frac{\delta_G}{\tau_G}\right)^{\frac{\alpha_K - 1}{\alpha_L}} \left(\frac{\psi_0}{A}\right)^{\frac{-1}{\alpha_L}} \left(\frac{\bar{r} + \delta_K}{\alpha_K(1-\tau_G)}\right)^{\frac{-\alpha_K}{\alpha_L}}$$

$$k_0 = \left(\frac{\delta_G}{\tau_G}\right)^{\frac{-\alpha_G}{\alpha_L}} \left(\frac{\psi_0}{A}\right)^{\frac{-1}{\alpha_L}} \left(\frac{r + \delta_K}{\alpha_K(1-\tau_G)}\right)^{\frac{-(1-\alpha_G)}{\alpha_L}}$$

The steady state wage is therefore independent of the steady state population size:

$$w = \alpha_L(1-\tau_G)A g_0^{\alpha_G} k_0^{\alpha_K} \tag{D33}$$

I set A such that the steady state wage is normalized to 1.

In steady state it must be that no household chooses to migrate. For renters this means the value of staying given in Equation D2 must be greater than the value of migrating given in Equation D5. This will be true as long as migration costs are sufficiently large and the value of being in the mainland US is sufficiently close to the value of being in PR. For owners this means that the value of one decision in equation D8 must be larger than the value of migrating temporarily.

E. Model Quantification

This section provides a detail discussion of the model quantification specified in section 5.

E.1 Income Process

Data To estimate the deterministic age profile, variance of the persistent component of shocks, and generosity of retirement benefits, I use data on income from both the American Community Survey (ACS) and Puerto Rican Community Survey (PRCS) These data consist of self reported income data covering the period from 2005 to 2016. My main sample consists of household heads between the ages of 20 and 60 who are living either in PR, born in PR or Puerto Rican identifying but living in the mainland US. Individuals are included in the sample if they report positive income and report earnings below $250,000[30].

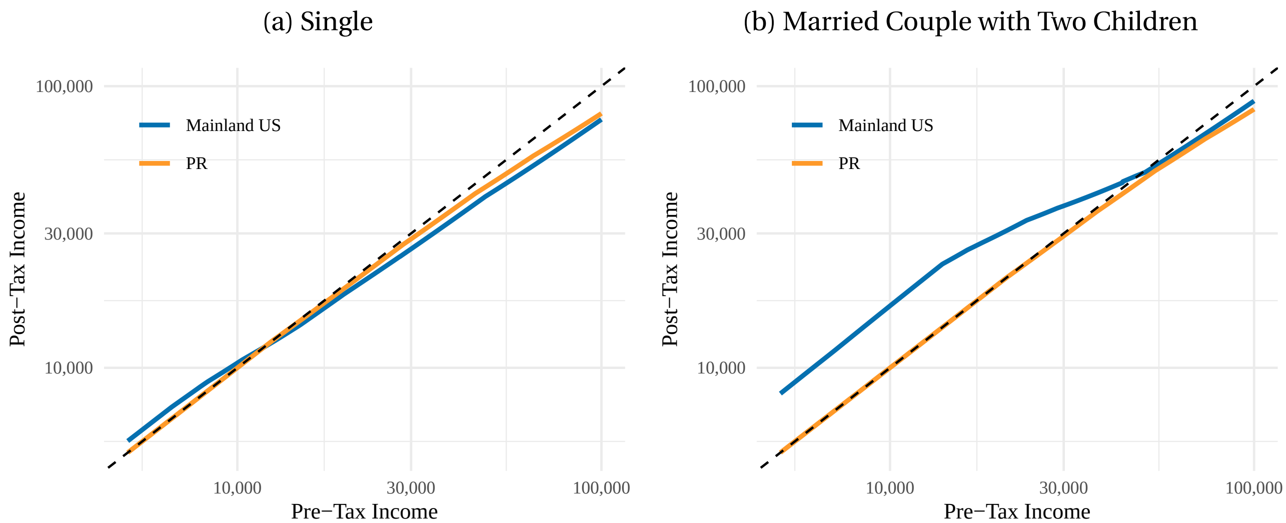
Pre- Versus Post-Tax Income In constructing the relative earnings potential of Puerto Ricans in Puerto Rico and the Mainland US it is crucial to account for differences in taxation. Individuals earning income in Puerto Rico do not pay Federal income taxes, so when quantifying earnings differences between the two locations, it is crucial to account for differences in taxation. To estimate post-tax income in the US, I use the NBER TAXSIM model. The TAXSIM model calculates federal and state income tax liabilities including Federal and state tax credits (see Feenberg and Coutts (1993) for more details). To estimate post-tax income in Puerto Rico, I use information from the Departamento de Hacienda (Treasury Department) of Puerto Rico on personal income tax brackets, exemptions, and potential tax credits during the relevant period.

It is not obvious ex-ante how accounting for taxation will change the post-tax income difference between PR and the mainland US. Although accounting for differences between personal income tax payments in PR and places in the mainland US will lower post-tax income for some types of filers, accounting for the various tax credits available for those who file Federal income tax returns, such as the Earned Income Tax Credit (EITC) and the Child Tax Credit (CTC), will raise post-tax income. Figure E1 illustrates the differences in pre- and post-tax income for a single individual and a family of 4 with two-children if they lived and worked in Puerto Rico versus in New York in 2016. A wealthy single filer would have higher post-tax income living in PR, while a married couple with dependents would have a higher post-tax income if they were living in the US, especially if their pre-tax income makes them eligible for the EITC.

To correctly calculate a household's post-tax income, each household must first be divided into the appropriate tax units. Tax units differ slightly from the Census definition of a household. For example, consider the Census household presented in Table E1. This household consists of a household head, his spouse and two children, his in-laws, and an additional person who is not his relative, though likely a relative of his wife since there are not listed as a separate sub family.

[30]This process works to filter out extreme observations. These screening criteria are similar to those used in prior work such as Abowd and Card (1989), Meghir and Pistaferri (2004) and Guvenen (2007).

Figure E1: Post-tax income in the Mainland US and PR



Notes: Plot shows estimated pre- and post-tax income for a (a) single household and (b) married couple with two children if they live in Puerto Rico versus in mainland US (NY). Post-tax income in the Mainland US is calculated using NBER TAXSIM. Post-tax income in Puerto Rico is calculated using information from the Departamento de Hacienda (Treasury Department) of Puerto Rico on personal income tax brackets, exemptions, and potential tax credits.

This household would file three separate tax returns, 1. the household head, his spouse and two dependents, 2. his in-laws, 3. the non-relative. To systematically define tax units within a Census household and assign dependents, I follow the algorithm used by the Census for defining tax units in the CPS described more detail in Lin (2022)[31].

I use total household income rather than just the income of the household head and any potential spouse

Table E1: Sample Household Division into Tax Units

Relationship (to householder)	Age	Sex	Pre-Tax Income	Tax Unit
Head/Householder	38	M	30,000	a
Spouse	43	F	0	a
Child	8	F	0	a
Child	4	M	0	a
Parent-in-law	69	M	24,000	b
Parent-in-law	64	F	1,500	b
Non-relative	25	M	11,600	c

Notes: Sample Census household. This household consists of a household head, his spouse and two children, his in-laws, and an additional person who is not his relative (though likely a relative of his wife). This household would file three separate tax returns.

The division of households into tax units can have significant implications for estimated

[31] This procedure does not always optimally assign dependents to tax units within a household to maximize ETIC. For example in some cases a if a grandparent claimed a grandchild on their tax return instead of the parent, the post-tax income of the *household* would be larger. The assignment algorithm likely biases downward post-tax income, but is more reliable than using the self reported sub-family information in the Census which is often missing.

post-tax income. If the sample household in Table E1 files their taxes as three tax units then, tax unit a receives a net refund of $2,660, tax unit b owes $333 in taxes, and tax unit c owes $409 in taxes. In total, the post-tax income of the household is $69,019. If instead the entirety of the household income was assigned to the primary tax unit, the household would owe $5,894 in taxes and the post-tax income of the household would be $61,206, a difference of nearly $8,000.

I first examine the average pre and post-tax earnings of individuals born in PR living in the mainland US and PR. I regress log earnings on a full set of age and year dummies as well as additional controls including gender, marital status, and household size for individuals in each location. Figure E2a plots the age dummies together with a polynomial fit for both pre and post-tax income in both locations. Figure E2b plots the ratio of earnings over the life cycle. These figures illustrate that individuals in PR earn less than those working in the mainland US even after accounting for differences in taxes. Income differences are largest for young individuals and decline gradually over the life-cycle. However, accounting for differences in taxation significantly shrinks the income differential.

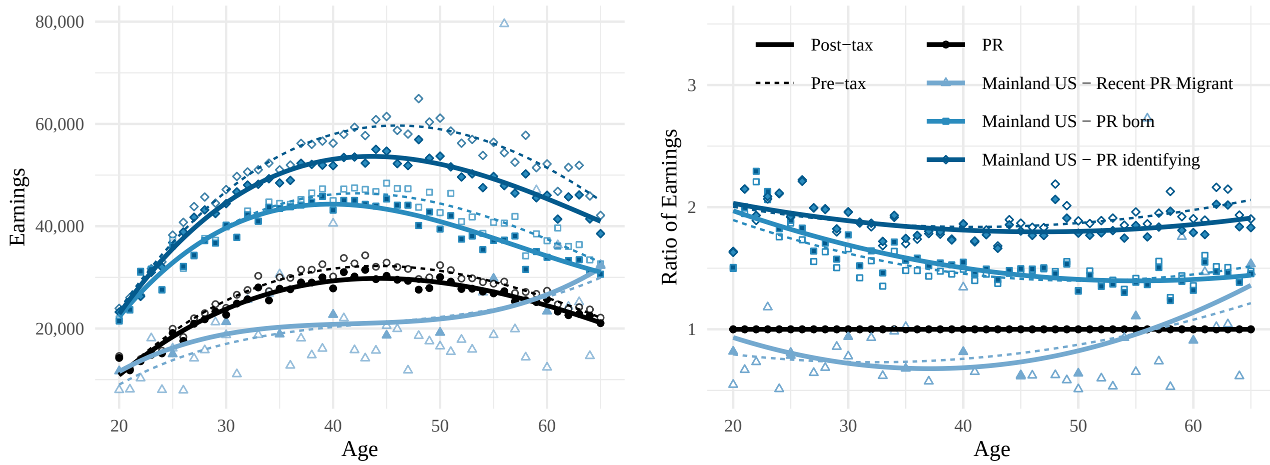
Income of Puerto Ricans in the mainland US versus Puerto Rico The life-cycle profile of earnings in the US and PR differs substantially depending on an individual's education and English fluency. There is an education and English fluency premium in both the mainland US and in PR. However, individuals without a bachelor's degree and who do not speak English working in the mainland US have the highest post-tax earnings relative to their counterparts in PR. Although disparities in income tax credits contribute to these differences, they do not entirely account for the observed variations.

Model Moments Using the sample of household heads and their household post-tax income, I calculate how income depends on age. Following the standard procedure in the literature, I regress log earnings on a full set of age and year dummies as well as a dummy for the sex of the household head. I then fit a third-degree polynomial to the age dummies. Figure E3a plots these age dummies together with the polynomial fit.

To calculate the variance of the persistent income component and the pension replacement rate, I simulate the distribution of working age agents in the model, using a Rouwenhorst approximation of the AR(1) process using a 7-state Markov chain. I then find the parameters that minimize the distance between data and model mean and variance of the income distribution. Figure E3b plots both the model implied income distribution and the distribution in the data.

Figure E2: Life Cycle Earnings Profiles of Puerto Ricans in the US and PR

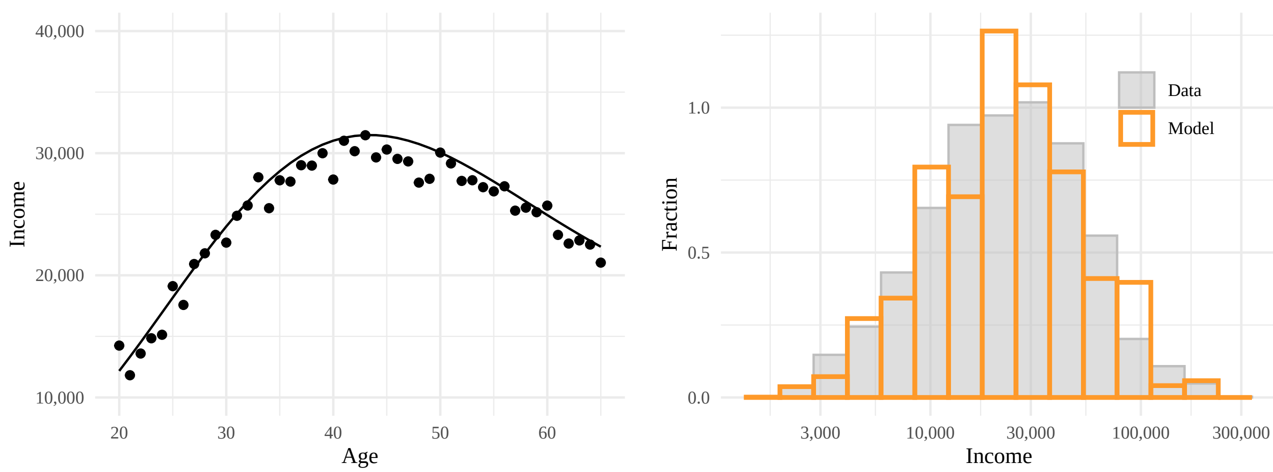
(a) Age Profile (b) Income Ratio



Notes: In the left panel each point corresponds to estimated age-dummies from a regression of log pre or post-tax earnings on a full set of age and year dummies, as well as sex, marital status, and household size dummies. Regressions are estimated independently for Puerto Rican born individuals living in the mainland US and in Puerto Rico. The lines show a second degree polynomial fit to the age dummies. In the right panel, each point corresponds to the estimated ratio of pre or post-tax earnings of a Puerto Rican of a specific age in the mainland US versus PR.

Figure E3: Life-cycle Profile and Income Distribution

(a) Life Cycle Profile (b) Income Distribution



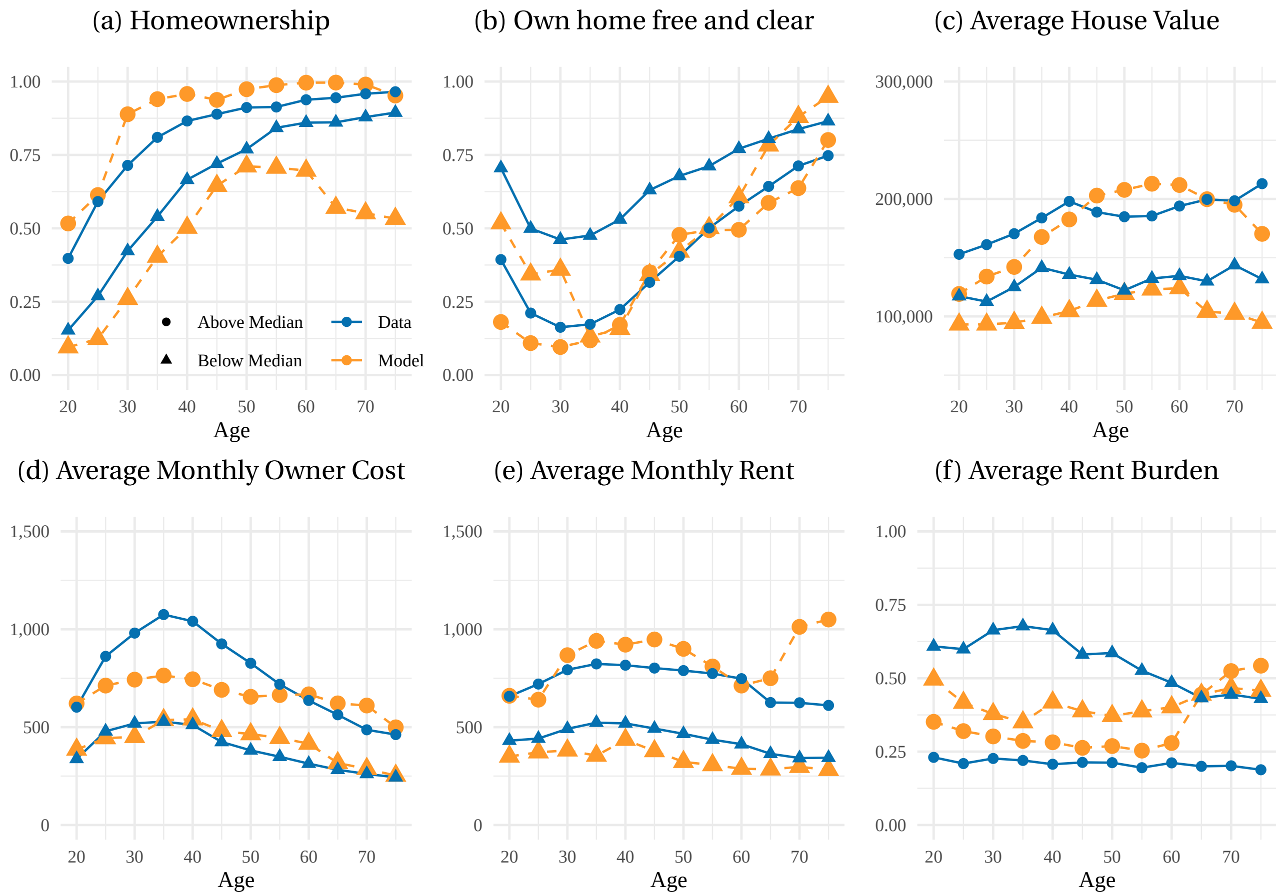
Notes: Estimation based on data from the 2005-2016 PRCS. The left panel shows the age coefficients from a regression of log earnings on a full set of age and year dummies as well as a dummy for the sex of the household head as well as a third-degree polynomial fit. The right panel plots the model implied income distribution against the distribution of post-tax household income in Puerto Rico.

E.2 Steady State Model Fit

Figure E4: Steady State Model and Data Income Profiles

Notes: The figures compare steady state model income profiles for homeownership, the fraction of homeowners who own their home without a mortgage ("free and clear"), average house value, average monthly owner cost, average monthly rent, and average rent burden, with data profiles computed using the 2011-2016 PRCS. The targeted moments plotted here are the fraction of homeowners in the top income quartile and the average house value in the bottom and top income quartile. Since mortgages are amortized over the lifecycle, I define "free and clear" in the model to be greater than 95% home-equity.

Figure E5: Steady State Model and Data Age Income Profiles



Notes: The figures compare steady state model age profiles for above and below median income within a 5-year age bin for homeownership, the fraction of homeowners who own their home without a mortgage ("free and clear"), the average house value, average monthly owner cost, average monthly rent, and average rent burden, with data profiles computed using the 2011-2016 PRCS. Since mortgages are amortized over the lifecycle, I define "free and clear" in the model to be greater than 95% home-equity.