Rebuild or Relocate?
Recovery after Natural Disasters

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Abstract

This paper studies the distributional effects of natural disasters and the impact of post-disaster policies. Using flight and new survey data from Puerto Rico after Hurricane Maria, I document household relocation and rebuilding decisions, highlighting the roles of age, wealth, and housing tenure. 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 face welfare declines from infrastructure destruction and general equilibrium effects. Although rebuilding subsidies are effective at preventing mortgage defaults and alleviating housing shortages, they are not cost-effective. These subsidies are non-transferable, are not guaranteed, and do not provide a payout if the home is sold or foreclosed on, leading damaged homeowners to prefer smaller cash transfers. In contrast, rebuilding infrastructure is more effective, due to complementarities with both housing consumption and production.

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1. Introduction

With increasing government outlays for disaster relief in the United States, there is growing debate about the efficiency of current post-disaster policies. To date, policy has focused on rebuilding, with the federal government providing large transfers to local governments for infrastructure repairs and subsidies to affected homeowners for reconstruction. However, the question remains whether these policies are effective at promoting rebuilding and if they are the best use of limited resources. Rebuilding policies may be beneficial because they directly compensate those most affected and help homeowners avoid forced sales or foreclosures. These policies may also have broader benefits if migration is expensive or community ties are important. However, these transfers are not guaranteed. Payments are often delayed or denied, and are typically conditional on rebuilding, limiting households' flexibility after a disaster. The challenge in evaluating these policies lies in both measuring household responses to disasters and accounting for the complex interactions between policies and household behaviors.

In this paper, I combine microdata on plane tickets and responses to an original household survey with a general equilibrium model to study the distributional effects of natural disasters and assess the impacts of post-disaster policies. First, I document how households cope with natural disasters, using flight traffic data and a new survey of affected households to understand household migration, rebuilding, and mortgage default decisions following Hurricane Maria in Puerto Rico. Second, I develop a rich general equilibrium model of natural disasters, housing, migration, and infrastructure. In the model, households choose how to cope with a shock based on their age, income, wealth, home equity position, house value, property damage, and government policy. Third, I quantify the model using my detailed flight and survey data to discipline key parameters. Finally, I use the model to show that households value current policy below budget cost, and that alternative policy schemes would yield larger welfare improvements.

I begin by using high-frequency flight data to measure the migration response to Hurricane Maria in 2017. Measuring household migration patterns in the immediate aftermath of a natural disaster is challenging due to the sudden and disruptive nature of the shock. The unique setting of Puerto Rico, a US Caribbean territory which can only be reached by air, allows me to use high-frequency flight data to directly measure both temporary and permanent migration responses. I find that 7% of the island's pre-shock population migrated to the mainland US in the first few months after the hurricane. Of these migrants, approximately 43% returned to Puerto Rico, while 57% remained in the mainland US. Although this represents significant disaster-induced migration, the vast majority of Puerto Ricans chose to remain in place.

To better understand post-disaster coping strategies and directly link Hurricane Maria's impacts to household economic decisions, I conducted an original survey of affected individuals. The survey reveals that high migration costs were a significant barrier for most households. I find that households who were unable to migrate responded to the effects of the disaster in other ways. In particular, a significant share of homeowners opted to default on their outstanding mortgage debt. Overall, 5% of households with a mortgage defaulted, with the default rate rising to 20% among those whose homes suffered the most property damage. For those who did not default, the majority were eventually able to make repairs to their homes, though the process was slow. These repairs were funded largely with federal government assistance and out of the household's own savings, as few households were insured.

Motivated by this rich empirical evidence and to better understand the economic effects of natural disaster, I develop a model with realistic features of households' 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, and if they own, whether to default on their mortgage, sell, repair damage, or apply for government assistance. Households can also choose to migrate temporarily or permanently to the mainland US, but 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 crowding 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 effects of disasters and policies in a broad general equilibrium framework.

The model's ability to match observed behavior both before and after Hurricane Maria makes it a powerful 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 reproduce the observed distribution of homeownership, house values, and home equity positions in Puerto Rico. This initial distribution is crucial 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 many of the survey responses directly to key parameters of the model, including migration costs, returns to migration, and preferences for living near other Puerto Ricans. The model is able to match the temporary and permanent migration responses observed in flight data, as well as the cross-section of mortgage defaults captured in the survey data.

With the fully quantified model, I first study the distributional impacts of Hurricane Maria. I find that welfare losses are largest for homeowners with property damage, though renters and undamaged homeowners are also negatively affected. For homeowners with property damage, the disaster is not only a shock to housing consumption but also a wealth shock. For those with mortgages, the damage from the hurricane is also a home equity shock that may lead to default. All households face lower wages due to the destruction of firm capital, infrastructure disruptions that reduce utility from housing, and disaster-induced price movements in the housing market. Because housing supply is inelastic in the immediate aftermath of the storm and relatively few households migrate, house prices and rents rise.

At the time of the disaster, households differ not only in whether they own or rent or whether their home is damaged, but also in their asset positions which shape their response. Among those with damaged homes, the welfare effect of the shock depends on both house size and home equity position. Natural disasters cause fractional damage to houses, for example hurricanes tearing off roofs or flooding that damages the contents of a house. The dollar value of the loss is larger for wealthier households with bigger homes. Mortgage default mitigates some of the losses for households with low home equity, shifting the financial burden onto lenders, while households that own their homes outright must absorb the entire loss. Mortgage default mitigates some of the financial losses for households with low home equity, as they can shift some of the burden while households that own their homes outright must absorb the entire loss. In contrast to a model without household leverage, the option to default generates an imperfect correlation between the wealth and welfare losses from a disaster.

Next, I study the effects of existing post-disaster policies. On average, all households benefit from the current federal policy of transfers for rebuilding infrastructure and rebuilding subsidies for homeowners. These policies reduce average welfare losses by X%, with the largest gains accruing to homeowners with property damage, particularly wealthier households with the largest homes.Rebuilding subsidies, which function as a form of 'in-kind' transfers for lost home equity, reduce default rates from X% to Y% and help alleviate the housing shortage in the immediate aftermath of the hurricane. Transfers for rebuilding local infrastructure speed up the economic recovery, improving the value of living in Puerto Rico, benefiting all households, and reducing permanent migration.

To assess the effectiveness of current policy, I compare government expenditures to the dollar value households place on these interventions. I determine this value by calculating the size of a transfer that would make agents in the model indifferent between a scenario with and without policy. Households value infrastructure rebuilding above cost, reflecting its positive effects on wages and housing consumption. In contrast, households value rebuilding subsidies at only a fraction of their budget cost. Even homeowners with property damage, who are the direct beneficiaries of these subsidies, value them at just \$0.80 for every \$1 spent. Given the significant role of rebuilding subsidies in reducing defaults, mortgage lenders are major beneficiaries. Without these federal transfers to households, their losses would be substantially X

Households undervalue rebuilding subsidies because these transfers are, in effect, a risky and non-transferable asset. Rebuilding subsidies are not guaranteed to payout for households, introducing uninsurable policy risk. Payouts from rebuilding subsidies are often delayed until several years after a disaster, as a result, homeowners must hold onto the damaged property to qualify for the subsidy, as payouts are conditional on staying and rebuilding. The fact that the policy is non-transferable means that homeowners who default or sell without rebuilding receive nothing. This feature makes them particularly poor insurance, they provide no value in bad states of the world where the household needs immediate liquidity and is forced to sell or default.

Alternative policies (still deciding with MM what to highlight here)

- take what we currently spend and give equal cash transfers to households
- Renters and owners without damage get much larger transfer than current policy
- Avg owner with damage prefers cash transfer even though ¡E[payout of subsidy]
- Households prefer subsidy if guaranteed to get it at most 5 years later but still value below budget cost even if guaranteed in period of shock because non-transferable, income effect of

disaster implies some need to default

- \$750 immediate transfer in addition to current policy
- Migration subsidies
- Foreclosure moratorium, allow households to forego mortgage payments and add to debt for several years (extension of existing more short run moratoriums). In effect, they can draw on the liquidity of the house in the immediate aftermath of a storm and make the fact that they have to wait to get a rebuilding transfer less painful.

Related Literature This paper connects to several strands of related literature. First, I contribute to a growing literature examining how disasters affect migration and related outcomes. Prior studies of disaster-induced migration have used annual or decennial census data (**?????**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.[1] Leveraging the unique setting of Hurricane Maria in Puerto Rico, I add to this literature by using relatively high-frequency flight data to reveal that temporary migration is an important coping strategy for many households. Other papers in this literature have studied the effects of disaster related property damage on household finances. These papers generally infer outcomes by linking data on disaster impacts with household outcomes for small geographic units (**????**) By surveying impacted households, I can directly link the effects of the disaster to households' subsequent decisions.

Second, this paper contributes to the literature on general equilibrium effects of natural disasters and disaster policy. Prior research has focused on homeowners' rebuilding decisions (Fu and Gregory, 2019), or long-run adaptation (Fried, 2021; Bilal and Rossi-Hansberg, 2023; Hsiao, 2021; Balboni, 2024; **?**). My framework focuses on the short and long run dynamic effects of natural disasters and policy and addresses both aggregate and idiosyncratic impacts across the entire distribution of households. By directly modeling the interaction between policy and levered housing assets, I show that current non-transferable rebuilding policies distort household migration decisions and generate a form of location 'lock-in' (**????**). As climate-related risks grow, the current focus of policy on rebuilding in place becomes even less efficient, and makes flexible transfers a more effective option.

In typical urban models, where housing is owned by diversified landlords, a natural disaster that destroys capital affects households only indirectly through changes in wages and rents (**??**Hsiao, 2021; Bilal and Rossi-Hansberg, 2023; **?**).[2] However, in Puerto Rico, where homeownership rates are high, and most households hold a large share of their wealth in housing assets, it is crucial to model the direct loss of wealth and home equity through physical damages to owners occupied housing. My model captures both of these effects: the location-as-an-asset effect (Bilal and Rossi-Hansberg, 2021), where all households experience a shock to the stream of payoffs from living in Puerto

[1] 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 (**??**).

[2] New work such as **?** and **?** combine key features of quantitative spatial models with macro-housing models. In my model I have fewer locations but more household choices such as default, rebuilding, and temporary and permanent migration with pecuniary costs not taste shocks.

Rico, lower wages and higher rents, amplified by the destruction of local infrastructure; and the asset-in-a-location effect, where households holding wealth in housing face direct financial losses from physical damage to their homes. Additionally, in spatial models, permanent migration is the sole insurance mechanism households have for coping with local shocks (**???**). In reality, households have other strategies to manage the impact of natural disasters, including temporary migration, drawing down savings, applying for government assistance, rebuilding their damaged homes, selling their homes, and finally mortgage default. Given both the impacts of natural disaster shocks, and the structure of most post-disaster policies, capturing rich household heterogeneity in homeownership and home-equity positions is crucial.

A key contribution of this paper is the use of direct data on expected financial costs of migration and their interaction with households' limited borrowing capacity. While many migration models infer migration costs indirectly to rationalize geographic differences in income (Kennan and Walker, 2011; Bryan and Morten, 2019; **?**), my direct estimates show that pecuniary migration costs are orders of magnitude smaller than standard estimates. In the context of Puerto Rico, pecuniary migration costs are primarily transportation costs, such as plane tickets, and the cost of temporary housing in the mainland US, which must be financed upfront. For poor households, liquidity constraints create a binding barrier to migration, limiting their set of post-disaster choices. I also measure households' expected real returns to migration to the mainland US directly from survey responses, capturing not only potential wage gains but also higher housing costs. Using model-informed survey questions, I also quantify non-pecuniary costs of migration, such as the value households place on living near other members of their community (**??**).

My model builds on heterogeneous agent, incomplete market models that incorporate portfolio choice with housing, that are consistent with micro data on the distribution of homeownership and wealth (Favilukis et al., 2017; Kaplan et al., 2020; Guren et al., 2021; Greenwald and Guren, 2021). These models were largely developed to study changes in credit conditions and house price movements during the Great Recession. In contrast to financial crises, natural disasters directly affect homeowners' wealth by damaging property and mortgage collateral, as well as indirectly through fluctuations in house prices. Additionally, natural disasters are one of the few instances where the U.S. government provides large-scale transfers to compensate for uninsured home-equity losses. Although many models of the Great Recession incorporate strategic default, where negative equity triggers mortgage default, recent studies find limited evidence of such behavior outside of crises (**??**). In my setting, I find direct evidence of strategic default, with default rates ten times higher for households experiencing severe damage, representing a large home equity shock (20%), compared to those with minor damage, which entails a smaller equity shock (2%).

In my model, I abstract from natural disaster insurance since very few households in Puerto Rico were insured before Hurricane Maria (**?**). However, my findings on how households value government rebuilding subsidies offer valuable insights into the puzzlingly low uptake of disaster insurance in exposed housing markets (**??**Wagner, 2022; **?**; **?**). 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 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, low take-up, (**?**, **?**).

The remainder of the paper is organized as follows. Section 2 provides additional details on the setting of Puerto Rico and Hurricane Maria, describes the flight and survey data and documents household rebuilding and relocation behavior. Section 3 develops a model of natural disasters with housing, migration, and infrastructure. Section 4 discusses the quantification of the model. Section 5 studies the distributions effects of natural disasters and the role of current policy while Section 6 studies the effects of alternative post disaster policies. Section 7 concludes.

2. Post-Disaster Relation and Rebuilding Choices

2.1 Setting: 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 migration restrictions. Puerto Rico is an unincorporated Caribbean territory of the United States. Puerto Ricans are US citizens and therefore face no legal restrictions on migration to, or employment in, the mainland US.[3] In the aftermath of Hurricane Maria, the mainland U.S. was the primary destination for displaced Puerto Ricans, because of the large diaspora population and the island's small foreign-born population.[4]

Second, the island's geography, combined with the magnitude of Hurricane Maria's destruction, allows for precise measurement of migration. Puerto Rico is located over 1,000 miles from the coast of Florida, and all travel between PR and the mainland US in the modern era takes place via air plane. The only passenger vessels operating between Puerto Rico and the mainland U.S. are 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. Even five months after the storm, a quarter of the population remained in the dark without electricity.[5] Given the distance, any household seeking to escape the widespread

[3] The U.S. acquired Puerto Rico in 1898 at the end of the Spanish-American War. In 1901, the US Supreme Court case allowed the colonization of conquered territories including Puerto Rico, the Philippines, and Guam. Birthright citizenship was established for Puerto Ricans under the 1917 Jones Act of Puerto Rico. While part of the US, Puerto Rican is "foreign in a domestic sense" (1901 Downes v. Bidwell) as an unincorporated territory instead of as a state. This classification has continuing implication for taxation, federal transfer programs, and electoral representation. Most Puerto Rican residents are exempt from paying federal income taxes, but as a consequence, are ineligible for many transfers such as the Earned Income Tax Credit, the Child Tax Credit, and Supplemental Security Income, while residing in Puerto Rico. Puerto Rican residents are eligible for Social Security and Medicare and have local implementations of Medicaid and SNAP. Since the early 20th century, there has been steady migration to the mainland US mainly driven by better economic opportunities (**?**). Consequently, the Puerto Rican diaspora community in the mainland US today comprises a significant share of all Puerto Ricans. As of the 2021 American Community Survey and Puerto Rican Community Survey, there were 5.8 million self-identifying Puerto Ricans living in the mainland US and 3.2 million in Puerto Rico.

[4] Migration to destinations outside the US not an important margin in this setting (see Figure **??** for more details).

[5] The official death toll in Puerto Rico from the Hurricane Maria as of December 2017, stood at 64. Other studies estimate close to 5,000 people died as a result of the direct effects of Hurricane Maria or due indirect effects such as

devastation in the aftermath of Hurricane Maria had to travel by plane.

2.2 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.[6] 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 **??** 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.[7] I also included questions on post-disaster migration

disruptions in medical care (see Kishore et al. (2018) for details). These mortality estimates make Hurricane Maria the most deadly US hurricane since 1900.

[6] 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.

[7] 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.

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 **??**, 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.

2.3 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) :

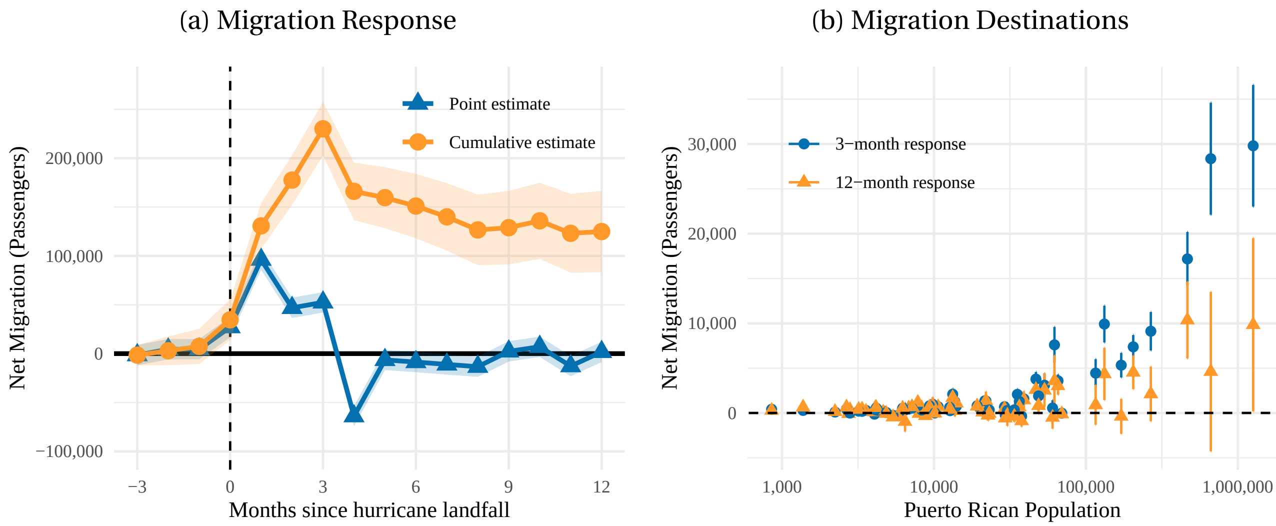
$$y_t = \sum_{i=-3}^{12} \beta_i H_{t-i} + \mu_{m(t)} + \tau t + \epsilon_t \quad (1)$$

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 8 below plots these point estimates as well as the cumulative estimates for net out-migration.[8] 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

[8]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).

Rico migrated to the mainland US, while in the long run, 4% of the pre-Maria population migrated permanently to the mainland US. [9]

Figure 1: 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.

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 1b, 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.[10] 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 **??**.

[9]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.

[10]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 (**?**) 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).

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 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 2a presents the cumulative distribution function (CDF) of expected temporary and permanent migration costs, while Figure 2b plots the CDF of these costs as a fraction of income and wealth. The mean expected cost of temporary

Table 1: Demographic Characteristics of Migrants

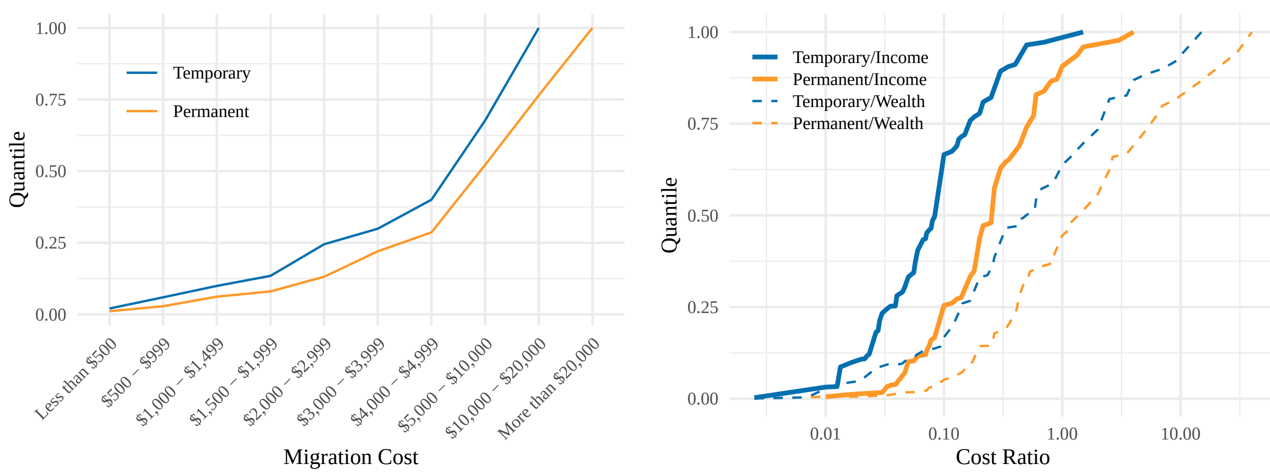
	Dependent variable:		
	Temporary Migrant		Permanent Migrant
	(1)	(2)	(3)
Severe Damage	0.081***	0.082***	
	(0.018)	(0.018)	
Moderate Damage	0.022	0.022	
	(0.014)	(0.014)	
Homeowner	−0.008	−0.008	0.013
	(0.016)	(0.016)	(0.004)
Age	0.004*	0.004*	−0.012***
	(0.002)	(0.002)	(0.0002)
Age^2	−0.0001*	−0.00005*	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

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.[11] 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.

Figure 2: Pecuniary Migration Cost Distributions

(a) CDF of Migration Costs (b) CDF Migration Costs Ratio



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.

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 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 (see **??** for more details).[12]

[11] 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?*

[12] Additionally, none of the respondents, who were living in Puerto Rico at the time of the survey, believed that the

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 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.[13]

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

present value of higher real wages in the mainland U.S. outweighs the costs of migration. In Section **??** I discuss how households perceive the benefits of moving to the mainland US in more detail. In general though, very few households percieve *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

[13] I also ask about the inverse, how many households hosted family members or friends after the hurricane. ADD NUMBERS

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

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.

3. 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.

3.1 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:

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

where $u_j(c_t, s_t, N_{\ell,t})$ is the flow utility for the household during their life and $v^{beq}(a_J)$ is the utility from bequests, as in **?**. 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[14]. 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.

[14]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.

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.

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.[15]

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 **??**.[16]

[15] My survey of Puerto Rican households after Hurricane Maria shows that those who earlier access to reliable electricity 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.

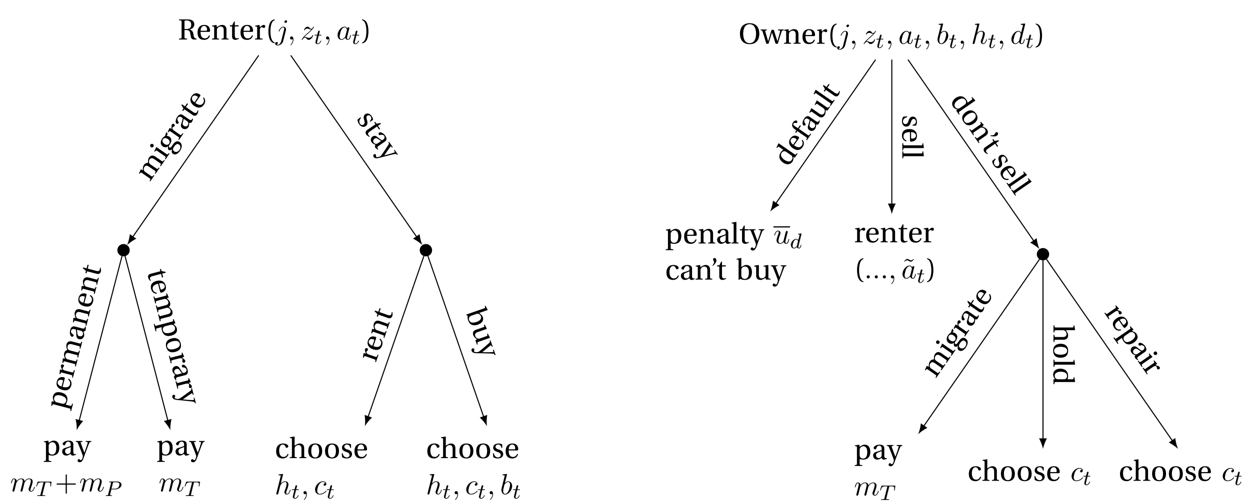
[16] In the model I abstract from Home Equity Lines of Credit (HELOC) since very few households report using bank lending to finance repairs following Hurricane Maria.

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 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 ($m_T + m_P \geq m_T$).

3.2 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 3. Appendix D.1 contains the detailed Bellman equations.

Figure 3: 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.

3.3 Financial Sector

Mortgages and liquid assets are issued by risk-neutral foreign agents with deep pockets. In the event of a household default, the lender absorbs the loss, calculated as $p_t^h h_t(1-d_t) - b_t$.

3.4 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.

3.5 Production

There is one homogeneous tradable non-durable consumption good whose price is normalized to one. Competitive firms in Puerto Rio 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.

3.6 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 $t+1$.

3.7 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: $I_t^G = \tau_G Y_t / p_t^c$.

3.8 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.

3.9 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 **??** 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.

3.10 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 effect 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 migrating 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.

4. 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 that the extent of property damage and potential for mortgage default are so important in the data, I try to accurately capture the distribution of homeownership, home equity positions, and house values prior to Hurricane Maria. In the second step, I estimate the remains parameters that can only be identified from the model's transition dynamics under the current post-disaster policy regime. These are the parameters that govern household decisions on migration, rebuilding, and default following Hurricane Maria. 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.

4.1 Initial Steady State

I assume in the initial steady state that there is no migration and no mortgage default. I defer discussion of the parameters governing this behavior until section 4.3.

Limited data on household wealth in Puerto Rico before the shock. Rely on Census data. Information on homeownership and household self-reported house values. Coarse measure of home-equity either has a mortgage or doesn't additional data on income, rents, owner costs.

Table 3 summarizes the jointly estimate parameters and data moments.

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 and set the initial age distribution to exactly match the age distribution of households in the 2016 PRCS, the year before Hurricane Maria.

Preferences I set the parameter γ which governs both the household's risk aversion and intertemporal elasticity of substitution to 1.5 as in **??**. The household consumption equivalence scales, e_j are OECD based and calculated to account for the average household composition by age in the 2011-2016 PRCS. I estimate the discount factor, $\beta = X$ to match the fraction of households over age 75 who own their home "free and clear" in the Census. In the model since mortgages are amortized over the remaining life of an agent, I define the model counter part of "free and clear" as those having greater than 95% equity in their home. The bequest motive, $\nu = X$, governs household saving behavior in retirement. I estimate that this bequest motive is very strong because such a large share of older households own a house with little mortgage debt.

The weight on housing services, η, is identified from the average rent burden (rent as a share of household income). In a static model, with Cobb-Douglas utility without a savings margin, η would be exactly the average household expenditure share on rent. With a savings, a down payment constraint, taste shocks for owning versus renting, and a finite set of house sizes, the mapping is no longer exact. I estimate that the weight on housing services, $\eta = 0.4$. This estimate is somewhat higher than estimates for cities in the mainland US (see **??**), 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 the same unit of housing. I calibrate the utility benefit of ownership $\omega = 1.015$ to match the aggregate homeownership rate in PR. 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 $\sigma_h = X$. Finally I parameterize the role of per-capita government infrastructure in

Income I estimate the deterministic age profile of the income process using post-tax household income from the 2011-2016 PRCS. In the absence of panel data on Puerto Rican household income, I assume an annual persistence of 0.97 similar to estimates for US households based on panel data (**?**, **?**). I calibrate the standard deviation of innovations, and the pension replacement rate to match the variance of the income distribution in PR prior to Hurricane Maria. Appendix E.1 provides additional details on the estimation of the income process.

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 $\iota = 1.33$ as in **??**. Together, these imply a mortgage rate of $r_m = 4.66\%$ consistent with financial conditions in Puerto Rico pre-hurricane. Following **??**, the maximum loan to value allowed at origination is $\psi^{ltv} = 0.85$.

Housing I set the depreciation rate of housing, $\delta_h = 0.02$, following the BEA and set the property tax rate, $\tau_h = 0.01$, the average rate in Puerto Rico. The transaction cost of buying and selling in the model is $\kappa = 0.05$. In 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. The price to rent ratio determines the relative cost of buying and renting which young households are particularly sensitive to when deciding to buy or rent. 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 \$200/month. I pin down the spacing of the rental grid to match the average rent in the top quartile of the income distribution. The minimum size available to own is pinned down by the average house value in the bottom quartile of the income distribution, while the spacing of the owner occupied grid is pinned down by house values in the top quartile of the income distribution. Of course 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 calibrated jointly.

Production I set the infrastructure factors share, α_G , and local government tax rate, τ_G, equal to 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. The implied private capital to labor ratio is **X**, which is slightly lower than standard values for the US overall. Following the BEA, I set the depreciation rate for private and government capital (structures) as $\delta_K = \delta_G = 0.02$.

4.2 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 important for household's exposure to a natural disaster shock. Figure 4 compares

Table 3: Internally Estimated Steady State Parameters

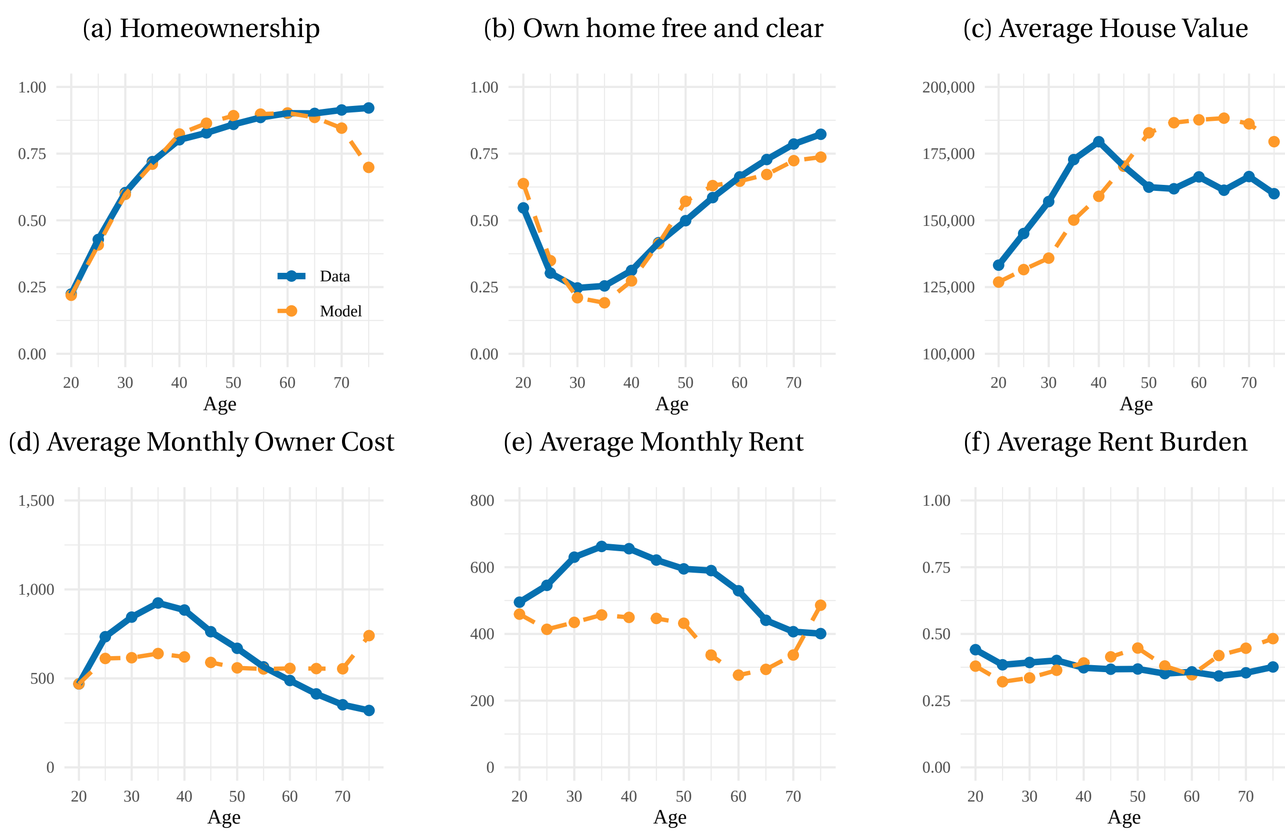
Parameter	**Value**	**Target Moment**	**Data**	**Model**
Preferences				
Housing services weight η	0.4	Average rent burden	0.38	0.38
Utility from owning ω	1.09	Homeownership rate	0.82	0.80
Bequest motive ν	20	Homeownership rate >75	0.92	0.84
Homeownership taste shocks σ_h	0.001	Homeownership rate top 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

model and data age profiles for homeownership, fraction that own their home outright, and average house value. Some of these moments are explicit targets but most are not. Although homeownership for the young and the old are target moments, the model is able to match the profile over the whole lifecycle.

Similar, I explicitly target the fraction of households over age 75 who own their home free and clear but the model also is able to match features over the life cycle: the fact that the share starts out relatively high falls and then rises again. Finally, the model is able to successfully match the fact that younger households own less valuable, smaller homes and that his number goes up over the lifecycle.

The model is also able to match homeownership, free and clear, and average house value across the the income distribution. Slightly too many wealthy households own their home free and clear. If the spacing of the homeownership grid was larger, i.e. there were larger homes to buy, then the fraction of wealthy individuals who own free and clear would be smaller, but this would mean that the average house value among high income individuals would be too high.

Figure 4: 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") and the average house value 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.

4.3 Post-Shock Equilibrium

Returns to Migration

- survey questions to get the real returns to migration

> 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?

> 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?

- Higher income: post-tax income data and survey responses agree. People expect to earn on average 36% more if they were to move to the Mainland US.
- Higher housing costs: self reported rents and owners costs distribution and survey responses agree. People expect to pay twice as much for housing. Price differences are persistent even controlling for size of house(number of rooms), age of structure, and dummies for high cost of living areas such as New York City. Results can be found in an appendix
- Matches roughly with differences in income in ACS/PRCS data [17].

Pecuniary Migration Costs

- Survey question on temporary and permanent migration costs
- Temporary migration costs and permanent migration costs
- Correlation of costs

Non-pecuniary Migration Costs

- remaining free parameter = utility in the period of migration
- Homophily preferences
  - Minimize distance between the answers people give in the survey and the answers that someone in the steady state of the model would give with the same states
  - Resulting values $\theta_0 = 0.0069$, $\theta_1 = 0.18$
  - Magnitude means that if we move from the current equilibrium with Puerto Ricans spread across locations to one where all Puerto Ricans are concentrated in one location (holding all else fixed) the average households would gain $X

[17] It is especially important in this setting to account for taxation since Puerto Rican households typically do not pay Federal income tax or receive social benefits distributed through the tax code. It is not a trivial process to compute household post-tax income, as many households contain multiple tax units. More details can be found in Appendix ??

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?

- What fraction of the population are never moovers? Individuals for who have a very strong preference for the place of Puerto Rico, independent of the people.

Based on results of prior work, it is also possible that some individuals have a very strong attachment to living in Puerto Rico independent of other Puerto Ricans. To estimate the size of the group of individuals with these preferences I ask the following sequences of questions.

Consider the following hypothetical situations, in each situation think carefully about how likely would you be to move to the mainland US.

1. If all your friends and family in Puerto Rico moved to the mainland US
   (a) I would definitely move to the mainland US in this situation
   (b) Very likely
   (c) Somewhat likely
   (d) Not very likely
   (e) There is no chance that I would move to the mainland US in this situation
2. If all your friends and family in Puerto Rico moved to the mainland US and you were guaranteed to find a good job in the mainland US
3. If all your friends and family in Puerto Rico moved to the mainland US, you were guaranteed to find a good job in the mainland US, and you could sell any property you own such as house for 10% more than you paid

The fraction that respond "There is no chance that I would move to the mainland US in this situation" to the third scenario where all of their social network has moved, they are guaranteed a job, and there are no frictions from selling their local assets identifies the population of "never movers." Question 1 in this sequence also provides and over-identification check on the homophily preference parameters. These questions are sequenced in this way to be able to identify and remove from the estimation individuals who did not understand the question.

Construction sector congestion The strength of the congestion force in the construction section ψ^1 is estimated to match the fraction

Cost of default

Table 4: Internally Estimated Post Shock Parameters

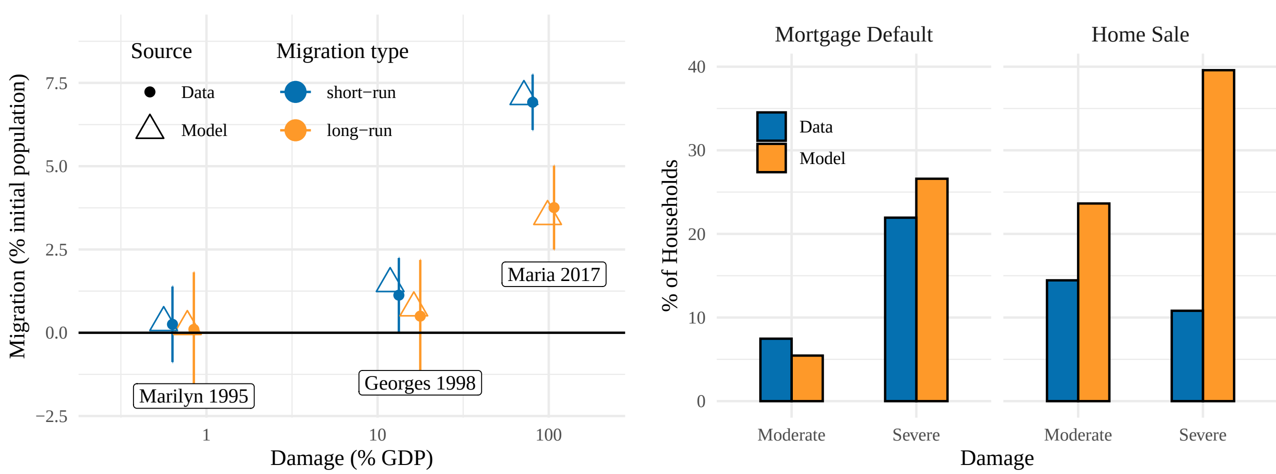
Parameter	Value	Target Moment	Data	Model
Utility cost of default u_d		Aggregate default rate	0.05	
Utility in period of migration renter $u_{\mathcal{R}}$		Permanent migration rate	0.04	
Utility in period of migration owner $u_{\mathcal{O}}$		Homeowner share of temporary migrants	0.80	
Construction section adjustment cost ψ_1		Share repairing with government assistance	0.04	
Construction section adjustment cost ψ_1		Date 0 House Price Growth	0.04	

- The disutility from mortgage defaults y is chosen to target an equilibrium foreclosure rate of 0.5%, which was the average rate in the United States during the late 1990s. The calibrated value implies an average consumption-equivalent loss of roughly 30
- Aggregate foreclosure rate in the US at the height of the Great Recession was roughly 2.25% per year. Foreclosure rates peaked in Florida on 2011 above 12% and in Nevada above 8% **?**.

4.3.1 Model Fit

Figure 5

(a) Migration Response to Hurricanes (b) Default and Sales



Notes:

4.4 Homophily Preferences

I use a sequence of revealed preference survey questions to elicit Puerto Rican households' preferences for living near other Puerto Ricans. Respondents are presented with a sequence of questions asking how they would trade-off additional income with living in a city with relatively more Puerto Ricans. An example survey question is presented below.

> Imagine that you have decided to move to the mainland US permanently and are choosing where to live. I will provide some information about pairs of hypothetical cities and then ask you to choose between them. This will help researchers understand what factors are important to you when choosing where to live.
>
> | City A | City B |
> |---|---|
> | Expected earnings: \$50,000/year | Expected earnings: \$45,000/year |
> | Number of Puerto Ricans: 5,000 | Number of Puerto Ricans: 10,000 |
>
> 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.
>
> 1. Which city would you choose? A or B?
> 2. How much *more* would you have to earn to choose the other city?

This is a question that agents in my model can also answer. Given the additional demographic and wealth data I collect in my survey, I can exactly match respondents to a state in my model (age, income, non-housing wealth). I will then use simulated method of moments and minimize the distance between model implied answers and actual survey responses to identify the average scale (θ_0) and returns to scale (θ_1) homophily preference parameters.

4.5 Migration Costs

I disciple the pecuniary costs of migration using direct survey evidence. I assume that temporary migration costs are idiosyncratic since demographics have very little explanatory power. I also assume that temporary and permanent migration costs are independent draws. Recall the the timing of migration in the model is such that if I household migrates temporarily they pay a cost m_T and if they migrate permanently they pay a cost $m_T + m_P$. In the survey data, temporary and permanent migration costs are correlated (Pearson coefficient 0.63). However the appears to be a common component to both the temporary and permanent migration costs. Permanent migration costs net of an individuals expected temporary migration costs are uncorrelated (Pearson coefficient 0.09). I assume that the cost follow a Gumbel distribution and estimate the location and shape parameters by maximum likelihood.

4.6 Current Post Disaster Re-building Regime

I model the current post disaster policy region in two parts. The first part of post disaster policy is transfers to the local government, which are immediately invested in the local infrastructure. I model these transfers as equal sums disbursed over a 10 year horizon equal to the value of the damaged government infrastructure at the time of the shock.

The second part of post disaster policy is transfers to rebuild damages owner-occupied housing. This is an non-transferable claim that owners at the time of the shock get. In other words if they sell their house, the buyer does not inherit this potential transfer from the federal government. And in fact I restrict home sales in my model to sales of undamaged housing. For an owner household there is some probability that is increasing the damage of their house $p(d_t)$ that tomorrow they will receive this bailout and wake up with an undamaged home. I assume these bailouts only occur for the first 10 years after the shock. I construct the probabilities $p(d_t)$ to match the fraction of survey respondents who are owners with a certain damage level who have rebuilt by the date of the survey and report receiving government assistance to rebuild.

4.7 SMM Estimation

Figure **??** below shows the results of a very rough quantification and the ability of the model to match data targets such as the age-homeownership profile, the age- value profile, and age-rent profile.

4.8 Model Evaluation

As a rest of the model's quantification, I will evaluate its fit for a set of non-targeted data moments that are important for households exposure to hurricane shocks. I will show the the model matches (1) the fraction of households who own their home free and clear across the age distribution, (2) the left tail of the asset distribution, (3) the cross section of migration, and (4) features of the distribution of recent migrants from Puerto Rico to the mainland US.

Hurricanes must exceed a minimum size threshold to induce migration from Puerto Rico to the Mainland US. I repeat the same estimation exercise for all large hurricanes that have effected Puerto Rico since the start of the BTS data in the 1990s.[18] Figure **??** plots the temporary (3-month) and permanent (12-month) migration response as a fraction of the pre-shock population of Puerto Rico on the y-axis and the estimated physical damages of the hurricane as a fraction of Puerto Rican GDP in the prior year on the x-axis. For all hurricanes, the temporary migration response is weakly larger than the permanent migration response. The migration response to Hurricane Georges in 1998, the next largest hurricane after Maria to strike Puerto Rico, was considerably smaller and only marginally statistically significant. Hurricanes of lesser magnitude generated no measurable migration outflows to the Mainland US.

The left panel plots the estimated 3-month and 12-month cumulative out-migration response to prior large hurricanes as a function of the estimated physical damages. The migration response is shown as a fraction of pre-hurricane population. Physical damage estimates come from NOAA and are plotted as a fraction of GDP in the year prior to the hurricane.

Table 3 summarizes the jointly estimated steady state parameters and corresponding data moments. Parameters are listed with the data targets they affect most quantitatively.[19]

[18] More details on the metrics here since there are overlapping event windows

[19] I identify which data targets model parameters affect most quantitatively, following **??**, I simulate the steady state

model 10,000 times for different parameter sets and compute the corresponding data moments in the model. I then use a random forest to develop a prediction algorithm for the model parameters as a function of model moments. Finally, I identify the variable importance of a moment for parameter identification by comparing the performance for the estimated model with and without the variable. I then use the most important moment for each parameter as the targets. Finally I use the predicted parameter values based on the true data moments as the starting value for the SMM algorithm.

5. Current Post-Disaster Policy

- Baseline what happens to prices.
  - Period 0 need prices that clear markets given fixed supply of housing
  - After prices determined by FOC of landlord and construction firm (why prices move in lockstep)
  - Interpretation of rent increase in relation to survey evidence on how hh size distribution changed. Mean household size increased by 34% from 3.87 to 5.19 people. Implies rent per unit of housing per person went up 20%.
  - What does simple Cobb Douglas imply should happen if housing supply declines by 25%? Rents need to go up by 25%.

Discussion of table 1

- Start with the first two columns of Table 5 which compare the effects of a Hurricane Maria where the current policy is in place of rebuilding subsidies for damaged owners and transfers to the local government to rebuild infrastructure (Baseline) with the effects of Hurricane Maria in a world where the federal government provided no transfers (No Policy).

- Current policy is very effective at preventing default. Default rate is 5 times higher when the current policy is not in place. Nearly three-quarters of all households with severe damage default. The default rate jumps more dramatically for households with minor damage from (1.3% to 25.7%)

- Similarly, current policy is also very effective at the households who experienced the damage form the disaster to repair their houses. This is especially true for households with severe damage, without the policy only 4% would repair their house. The alternative at least through the lens of the model is that they would sell or default on their damaged home and the landlords would undertake the cost of repairs before selling them.

- Without the policy, there would have been much more migration after Hurricane Maria. By investing in rebuilding Puerto Rico, the policy encourages more people stay in Puerto Rico (6.3 versus 3.1% permanent out-migration). Without the policy the conditions in Puerto Rico are worse for longer and there is also therefore more temporary migration.

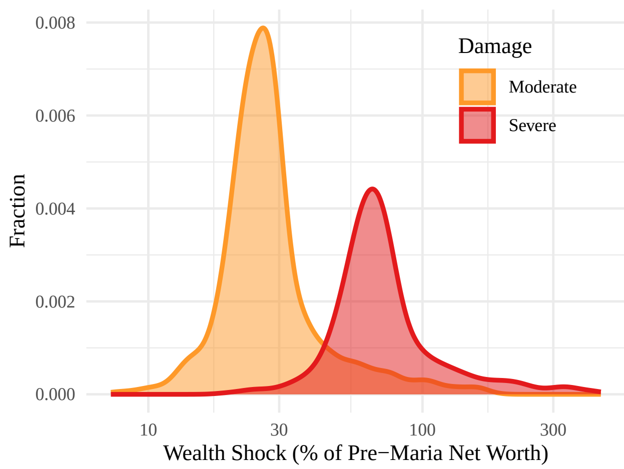
- The welfare effects of a hurricane are significant. Here I report the consumption equivalent welfare loss relative the steady state. These numbers can be interpreted as the amount of consumption that a household would be willing to give up for the rest of their life to avoid living through Hurricane Maria. The consumption equivalent welfare loss without any government policy is 17% . These numbers are even larger for homeowners with damage, 28% . At first glance, it may be surprising that owners with a mortgage have smaller welfare losses (18%) than those without (23%), but this is because owners without a mortgage experience the full wealth shock of a natural disaster, whereas those with a mortgage can default and walk away, though at a cost.[20]

- Undamaged owners (11%) and renters (9%) experience large negative welfare losses. Talk through wage effects, price impacts.

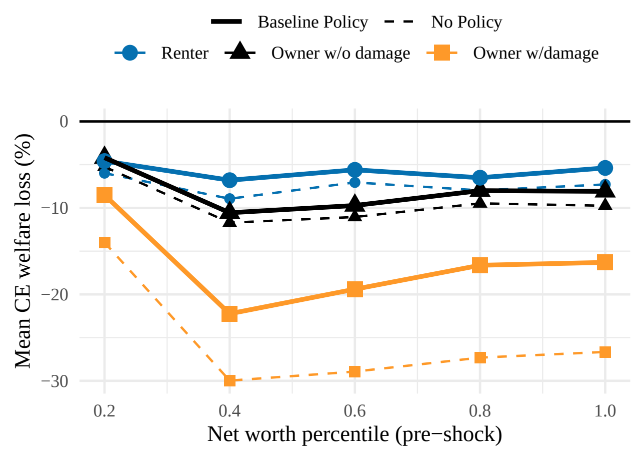
- What happends

Figure 6: Baseline

(a) Wealth Shock



(b) Welfare Shock



Notes:

[20] Discuss welfare cost of default not being that large in the model. This implies relatively large losses to the lender

Table 5: Current Policy

	Baseline	No Policy	Only Infrastructure Rebuilding	Only Rebuilding Subsidies
Mortgage Default				
Aggregate	6.1	30.5	27.3	7.2
Moderate Damage (31%)	1.3	25.7	25	2.2
Severe Damage (18%)	23.3	71.6	64.3	26.4
Repair				
Moderate Damage	86.7	44.9	47.9	86.3
Severe Damage	57.4	3.9	3.8	58.5
Migration				
Total	6.8	12	9.8	8.2
Permanent	3.1	6.3	4.3	4.4
Temporary	3.7	5.6	5.5	3.8
Owner Temporary	1.8	3.1	3.1	1.9
Welfare - CE				
Average	-12.5	-17.2	-15.7	-14.4
Owner (80%)	-13.9	-19.3	-17.8	-16.0
Owner with Damage (48%)	-18.9	-28.3	-27.2	-20.9
Undamaged Owner (52%)	-9.27	-10.8	-8.91	-11.3
Owner with Mortgage (72%)	-12.5	-17.8	-16.3	-14.6
Owner w/o Mortgage (28%)	-17.6	-23.2	-21.6	-19.6
Renter (20%)	-7.26	-8.87	-7.76	-8.48

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 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 shock. Rows 6-11 report numbers related to migration in the period of the shock. Total migration, is the fraction of households initially in PR who choose to migrate either temporarily in period 0. Total labor units it the fraction of effective labor units these households represent. The next two rows break out total migration by type, either temporary or permanent migration. Owner temporary is defined as the fraction of households who were initially owners who choose to migrate while still retaining ownership of their home. Sell house and leave is defined as the fraction of households who were initially owners who choose to sell their house or default and migrate permanently. Rows 12-19 report both money metric (MM) and consumption equivalent (CE) welfare on average and broken out by homeownership and damage. The final rows report the present value at the date of the hurricane of the cost of the policy in effect per household initially in Puerto Rico.

Table 6: Household Valuation of Current Policy

	Baseline	Only Infrastructure	Only Subsidies	No Risk	No Delay
Welfare Gain Relative to No Policy					
Average	\$26,700	\$8,760	\$14,800	\$28,600	\$41,900
Owner (80%)	\$32,700	\$10,300	\$18,500	\$35,000	\$51,600
Owner with Damage (48%)	\$56,300	\$7,760	\$41,800	\$60,600	\$95,600
Undamaged Owner (52%)	\$10,600	\$12,800	-\$3,410	\$11,100	\$10,500
Owner with Mortgage (72%)	\$33,700	\$10,600	\$18,900	\$35,600	\$50,900
Owner w/o Mortgage (28%)	\$33,700	\$10,600	\$18,900	\$35,600	\$50,900
Renter (20%)	\$3,430	\$2,630	\$455	\$3,550	\$4,220
Cost Per Household					
Rebuilding Subsidy	\$50,300	\$ 0	\$ 0		
Infrastructure	\$ 6,130	\$ 0	\$ 6,130		

Notes:

- First, what does current policy do relative to no post-disaster government intervention? (first two columns of Table 5).
  - Effective at preventing defaults. Without the policy, model predicts defaults rates that would be **X** times higher.
  - Is this a reasonable default rate in the model counterfactual? 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, there was effectively no policy in effect 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.[21] The foreclosure rates in the model are not annual but rather among household who initial had mortgage debt what fraction *ever* defaulted.
  - We don't observe this world so how can we know?
    - what matters here is elasticity of default with respect to government policy
    - what is PV of policy to households? can roughly get from difference in money metric utility between baseline and no policy. Get elasticity of default rate with respect to transfer?
$$\frac{\%\Delta\text{default}}{\%\Delta\text{MM owner with mortgage}}$$
  - Paying people to rebuild their homes, also leads to a much higher higher rebuilding rate especially among homeowners with severe damage (**X**% vs. **X**%). After the shock, homeowners with damage can do one of three things in the long run: repair, sell, or default. Without rebuilding subsidies, homeowners with high damage mostly choose to default (**X**%) instead of repair because either, they cannot afford the financial cost of repair $p_t^c h_t d_t$, or the utility cost of paying for the repair exceeds the utility penalty of default u_d and cost for being forced to rent for one period, at the much higher rents after the hurricane (see Figure 7 below).[22] This effect is less pronounced for households with only minor damage, since their out of pocket costs of repair are much lower.
  - ADD POLICY FUNCTION PICTURES FOR BASELINE + NO POLICY SHOWING HOW POLICY CHANGES DECISIONS
  - The policy does not have a large effect of aggregate migration in the period of the shock (**X**% vs. **X**%). However, the policy changes the composition of migrants. The rate of permanent migration is **X**pp lower in terms of people and **X**%pp lower in terms of labor.
  - Is this a big effect? What is big and small in terms of migration (ASK MELANIE)
    - Potential benchmark dust bowl Rick Hornbeck paper? "7 percent of 1935 Plains residents had, by 1940, moved to a county more than 200 miles away"

[21] Sources: S&P CoreLogic Case-Shiller FL-Miami Home Price Index, **?**
[22] Something about HELOCs here?

    * Mariel boat-lift was roughly same # of people but smaller as a fraction of the population: 125,000 people (1.3% of population)
    * Out migration from Greece during the economic crisis? 2010-2018 796,000 emigrated. Population in 2010 roughly 11 million.
  - We don't observe this world so how can we know?
    * what matters here is elasticity of migration with respect to government policy
    * what is PV of policy to households? can roughly get from difference in money metric utility between baseline and no policy for renter.

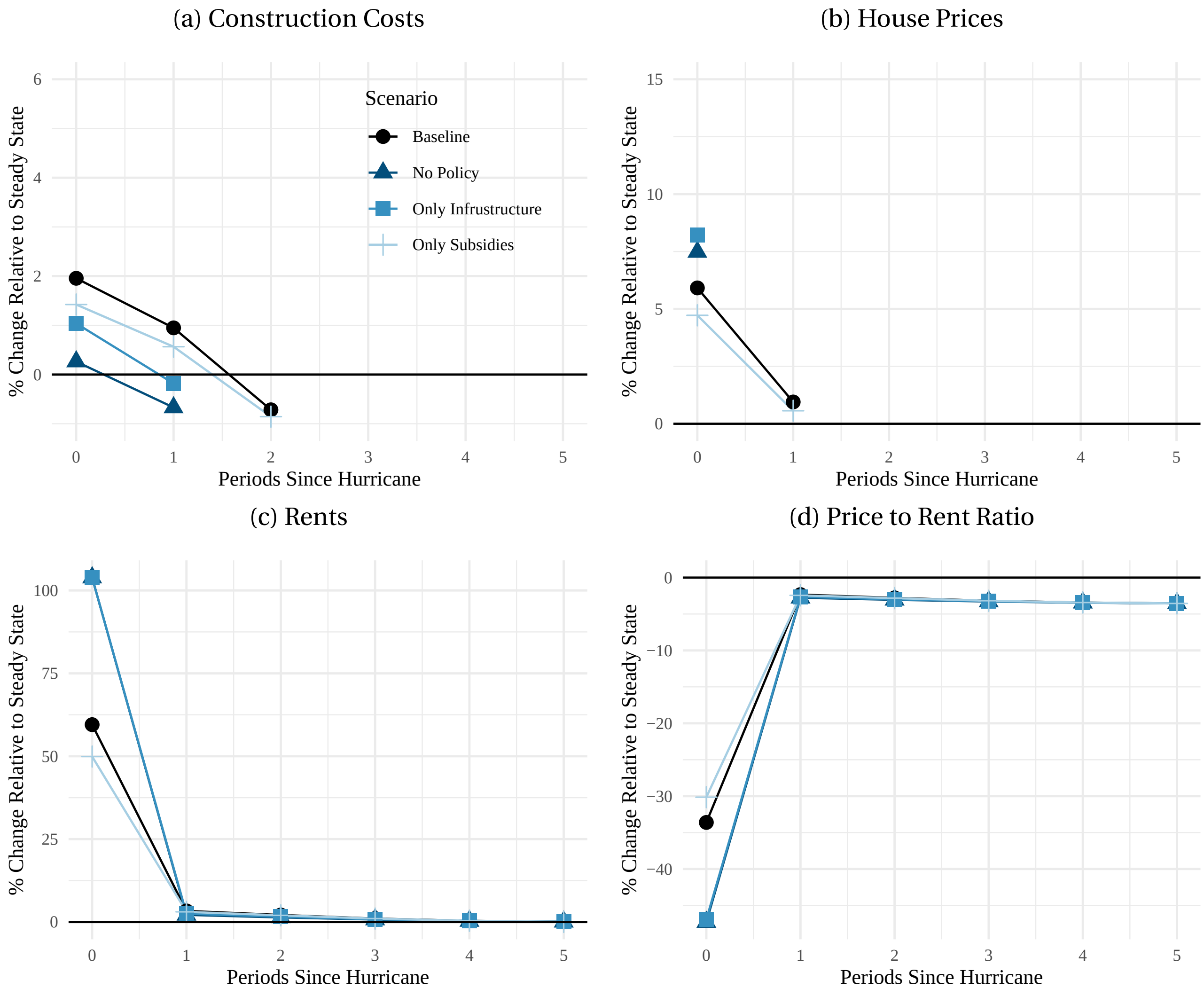
$$\frac{\%\Delta\text{migration}}{\%\Delta\text{MM renter}}$$

    * How does this compare to migration cost?
  - Biggest "winners" homeowners with severe damage, less home equity
    * How to show?

- Only Infrastructure Rebuilding
  - How much faster does infrastructure get rebuilt relative to baseline? How does this translate to wages, housing services?
  - Default rate nearly identical to world with no policy. Sensible, rebuilding in infrastructure does not have any direct effect on home equity. Only effects would be through prices.
  - Repair rate slightly higher for those with minor damage due to complementarity between housing and infrastructure.
  - Even with rebuilding subsidies owners value rebuilding infrastructure due to complementarity
  - Huge rent increase relative to baseline. Driven by the much higher default rate, these households *must* rent for one period after they default.

- Rebuilding subsidies
  - Without subsidy many more owner households sell or default
  - Drives up rent especially and house prices somewhat
  - Many households especially those with minor damage would make repairs anyway
  - Most of the impact on renters is through higher date 0 rents

Figure 7: Housing Market Price Movements



Notes:

Figure 8: Migration Heterogeneity

Notes:

- Shutting down migration
  - Everyone in PR has to live somewhere
  - Prices must rise much more to reduce housing demand
  - Default slightly lower since remaining value of damaged home worth more
- Absent government infrastructure
  - Situation in PR less dire both due to wage path + housing services
  -
- Something unique about this setting is that wages and house prices are higher in the Mainland US relative to PR. What happens if we remove this channel
  - Only households who face 0 additional cost to permanent migration stay
  - Why more temporary migration?
- What does agglomeration (homophily) do?
  - Raises the value of moving to the mainland US slightly (which is a bit strange but there are actually more Puerto Ricans in the Mainland US than in PR)
  - Imposes a small externality on those who remain in Puerto Rico
  - Could also re-estimate the model here and change the utility cost of migration?
- What does congestion in the construction sector do?

Table 7: Model Counterfactuals

	Baseline	No Migration $m_T = \infty$	No Infrastructure $\alpha_G = 0, f(g) = 1$	No Complementary $f(g) = 1$	No Differences $w_{us} = w_{pr}, p^r_{us} = p^r_{pr}$	No Agglomeration $\theta_0 = \theta_1 = 0$	Elastic Supply
Date 0 Price Change							
Construction Cost	6.05	6.77	7.33	6.26	6.85	6.16	0.00
Rent	28.3	91.9	27.0	22.5	40.5	30.4	33.3
House Price	8.56	15.6	9.63	8.18	10.5	8.87	3.36
Wages	-7.43	-9.40	-3.43	-7.87	-7.81	-7.50	-7.77
Mortgage Default							
Aggregate	5.8	5.81	4.3	5.39	5.09	5.6	9.01
Severe Damage	30.8	36.9	24.7	28.1	30.8	30.4	34.9
Minor Damage	0.751	0.195	0.723	0.751	0.361	0.5	1.39
Repair							
Minor Damage	94.9	94.9	94.5	94.6	95	94.9	95.2
Severe Damage	48.6	48.5	49.3	50.3	44.9	47.7	52.2
Migration							
Total	10.42	0	7.68	8.09	9.04	10.39	9.64
Effective Labor	0.893	0	0.69	0.796	0.267	0.799	0.662
Permanent	3.45	0	1.89	2.24	0.37	3.29	2.97
Temporary	6.97	0	5.79	5.85	8.67	7.1	6.67
Owner Temporary	3.32	0	3.32	3.35	3.49	3.42	2.98
Sell and Leave	0.38	0	0.0886	0.127	0.468	0.253	0.177
Welfare - CE							
Average	-7.12	-9.44	-4.37	-5.04	-12.9	-11.7	-5.96
Owner with Damage	-8.67	-10.5	-5.7	-6.42	-14.8	-13.8	-7.37
Undamaged Owner	-5.72	-6.97	-2.94	-3.7	-11.9	-11	-4.6
Owner with Mortgage	-7.11	-8.68	-4.14	-4.94	-13.4	-12.4	-5.76
$<$50% Home Equity	-4.55	-6.13	-1.54	-2.68	-11.9	-11	-2.66
Renter	-3.99	-8.72	-1.88	-2.33	-8.16	-6.45	-3.14

Table 8: Alternative Post-Disaster Policies

	Baseline	No Policy	Cash Transfer $48,830
Date 0 Price Change			
Construction Cost	4.83	3.91	4.43
Rent	57	88.3	137.0
House Price	8.64	10.0	14.0
Wages	-7.94	-7.34	-6.31
Mortgage Default			
Aggregate	6.14	30.5	23.7
Minor Damage	1.32	25.7	24.5
Severe Damage	23.3	71.6	58.4
Repair			
Minor Damage	86.7	44.9	59.7
Severe Damage	57.4	3.87	18.8
Migration			
Total	6.81	11.97	12.31
Permanent	3.13	6.35	3.81
Temporary	3.68	5.62	8.5
Owner Temporary	1.75	3.06	5.02
Welfare - CE			
Average	-12.5	-17.2	-0.172
Owner with Damage	-18.9	-28.3	-15.2
Undamaged Owner	-9.27	-10.8	1.16
Owner with Mortgage	-12.5	-17.8	-5.82
Renter	-6.35	-7.94	26.6

- Give everyone a cash transfer = average cost of baseline policy
  - Not enough of a cash transfer to those with damaged housing to prevent default
  - Almost no permanent migration (why?)
  - Much more temporary migration, households can afford (though not as much as implied by survey answers though policy environment is different)
  - Prices rise absurdly high initially, everyone is richer and therefore demand more housing on top of other forces pushing up rents and house prices absent policy
  - renters now richer want to buy
  - what happens in simple Cobb-Douglas Case?

– N_0 people, wage w, housing stock H_0, expenditure share η

$$N_0 \underbrace{\frac{\eta w_0}{p^r}}_{\text{housing per person}} = H_0$$

$$\frac{N_0 \eta w_0}{H_0} = p^r$$

– What does \$80,000 translate to in terms of pre-shock income on average? Roughly doubling $\rightarrow$ initial rent = 1 so change ≈ 100. In welfare terms?

$$u = (h^{\eta} c^{1-\eta})^{1-\gamma}$$
$$\text{s.t.} w = c + p^r h$$

$$c = (\eta/(p^r))^{\eta}((1-\eta)w)^{1-\eta}$$
$$c_{transfer} = (\eta 2w/(2p^r))^{\eta}((1-\eta)2w)^{1-\eta}$$
$$c_{transfer} = 2^{1-\eta} c_0$$

– but what about g in housing services? More cash = more rebuilding = high construction costs = less rebuilding by private firm = lower output = lower g than without cash transfers.

- Subsidize the cost of migration (do a version with current policy but reduce construction benefit enough to cover migration cost so total cost $\approx$ the same?
- Other ideas given that I can now explore the mix of these four policies?

6. Alternative Post-Disaster Policies

I use the quantified model to study the distributional effects of current government post-disaster policy relative to no government intervention post-disaster. I also study other post disaster policies such as migration subsidies and targeted buyouts. The model is also useful for exploring the impacts of an ex-ante policy, a location specific property tax such as an insurance mandate.

6.1 No Government Intervention

Mortgage default: Absent government intervention after a natural disaster, many households default on their mortgage. Figure **??** shows default decisions for different parts of the state space. Within each subplot, orange regions show where the household finds it optimal to default. Dashed lines show the "underwater" line, that is the mortgage balance where after the disaster the household no longer has positive home equity. The columns show the decision rule for different house values and the rows show the decision rule for different possible amounts of damage. From this figure it is clear to see that default probability is increasing in damage amount and house value. Another feature to note is that given a household is underwater it is not automatic that they will choose to default. If the utility cost of default is sufficiently large, households will sufficient non-housing wealth would rather accept the loss of assets.

Default probability is also increasing in age. Figure **??** plots the age cut-off above which a household would default for different house values and non-housing wealth. If older households have lower future earnings and therefore less time to recoup their disaster losses they are the most likely to default.

Current government policy helps move many households from the orange region to the blue region. By transferring the financial losses from lenders to the government, current policy improves the welfare of households by sparing them the costs of default.

Migration: Absent government intervention, migration by renters will be unambiguously larger. The path for wages will be lower and so the present discounted value of staying in Puerto Rico will be lower than in the scenario where the government intervenes to rebuild after a natural disaster.

6.2 Migration Subsidies

I intend to explore additional counterfactuals where instead of allocating the entire budget of post-disaster spending to rebuilding, the government allocated a fraction to subsidize migration. Figure **??** plots the value function for various post disaster choices a renter or owner household can make (these values are computed absent any policy intervention). How does post-disaster policy change the value of choices a household can make? For renters, rebuilding changes the value of staying while migration subsidies increase the value of both temporary and permanent migration. I assume that the government cannot discriminate between temporary and permanent migration when implementing the subsidy. Given that renter households can migrate either temporarily or permanent, it is not obvious how much additional *permanent* migration migration subsidies generate. However, the welfare gains from increase the number of temporary migrants may be quite large.

6.3 Targeted Buyouts

The final post disaster policy I plan to analyze are targeted buyouts of damaged homes. This policy already exists though at a very scale. The basic idea is that the government offers a contract to households where the household receives some money and the government destroys the house. My model is well suited to analyze how many households would take buyout offers of difference sizes, and to understand what households would do after they are bought out. Would they use the funds to buy another house in Puerto Rico or migrate?

6.4 Location Specific Property Taxes

Although my model does not incorporate aggregate risk or anticipation of natural disasters it is a useful tool for analyzing what would happen to the Puerto Rican housing market if a property insurance mandate was implemented. Do households switch from owning to renting? If the insurance premium (property tax) is sufficiently large to cover expected damages does it induce out-migration?

7. Conclusion

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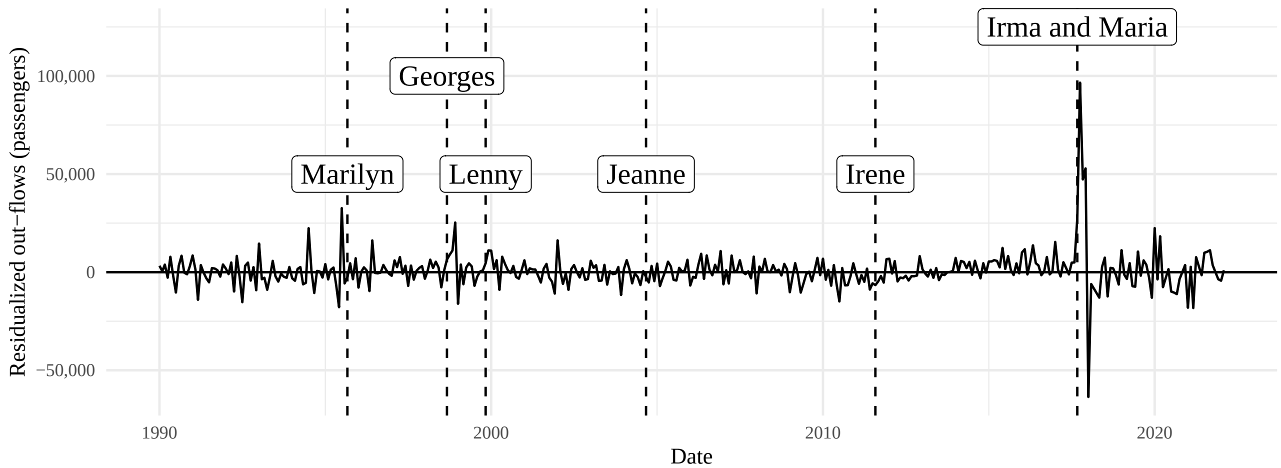
Appendix

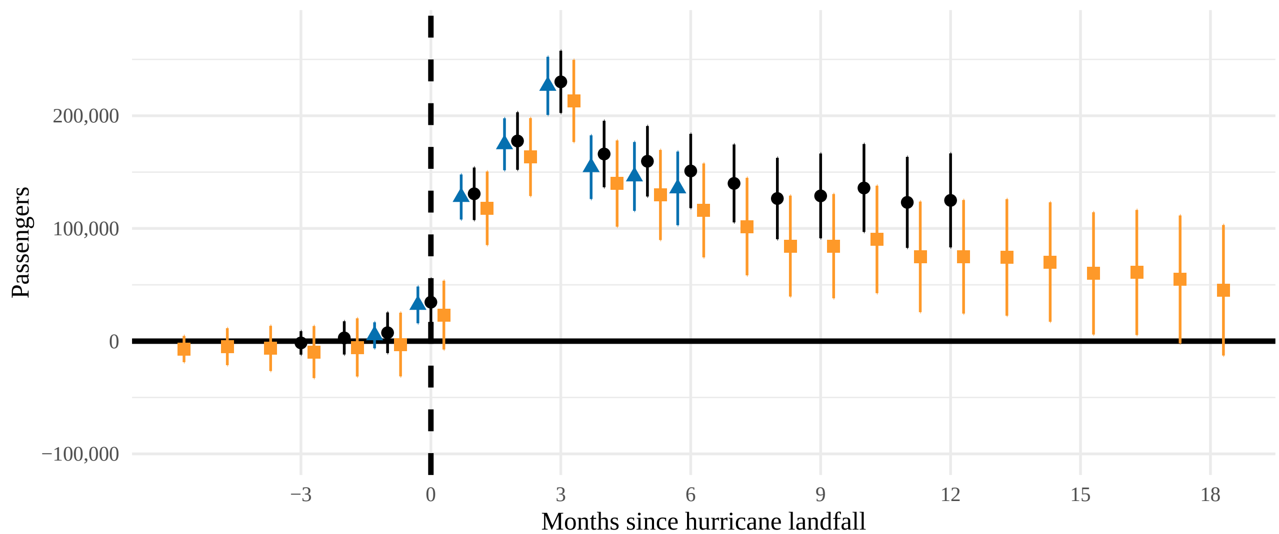
A. Additional Tables and Figures

Figure A1: Residual Passenger Flows



Notes: This figure plots individualized migration flows. These are the residuals of regressing net passenger out-flows from PR to the mainland US on decade and month fixed effects and a linear time trend. Month fixed effects and the time trend are allowed to vary by decade. The vertical dashed lines correspond to dates of large Hurricanes listed in Table A2.

Figure A2: Migration Response Robustness to Different Leads and Lags

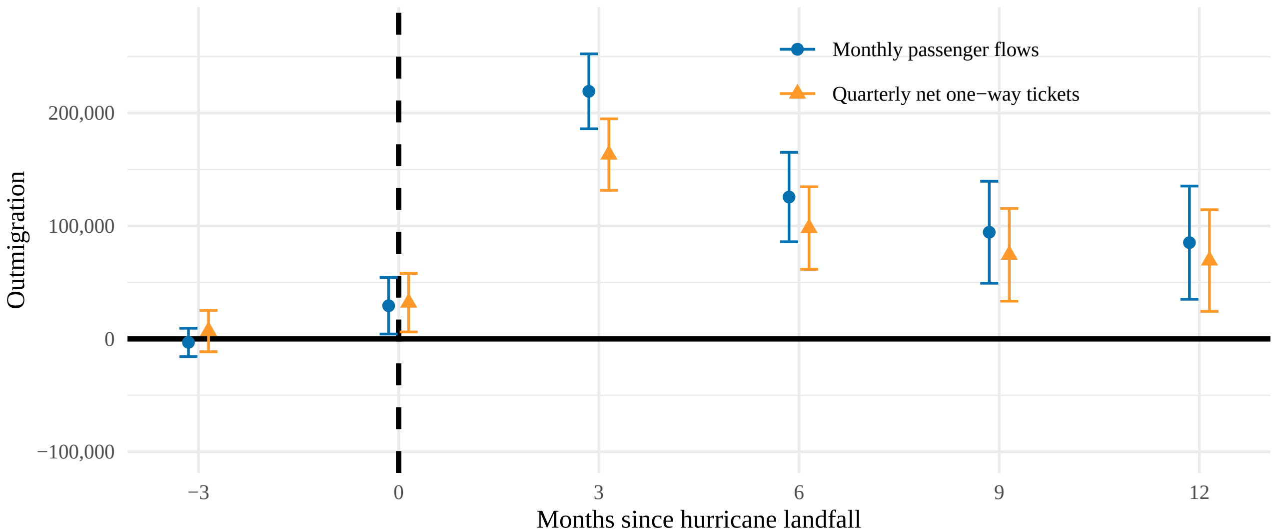


Notes:

Table A1: Migration Elasticity with Respect to Destination PR Population

	Dependent variable:					
	Temporary			Permanent		
	(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
Note:						*p<0.1; **p<0.05; ***p<0.01

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



Notes:

Table A2: Major PR Hurricanes since 1990

Hurricane	Date	Estimated Damages
Marilyn	September 15, 1995	\$300 million
Georges	September 20, 1998	\$8 billion
Lenny	November 17, 1999	\$80 million
Jeanne	September 15, 2004	\$170 million
Irene	August 21, 2011	\$500 million
Irma	September 5, 2017	\$1 billion
Maria	September 19, 2017	\$90 billion

Notes: This table reports Puerto Rican hurricane events since 1995 with over 0.1% in estimated damages as a fraction of contemporary GDP. Estimated damages reported here excludes estimates of crop damages when possible and is focused on approximating damages to structures, roads, and utilities. Estimated damages come from NOAA reports on individual hurricanes.

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.[23] 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.

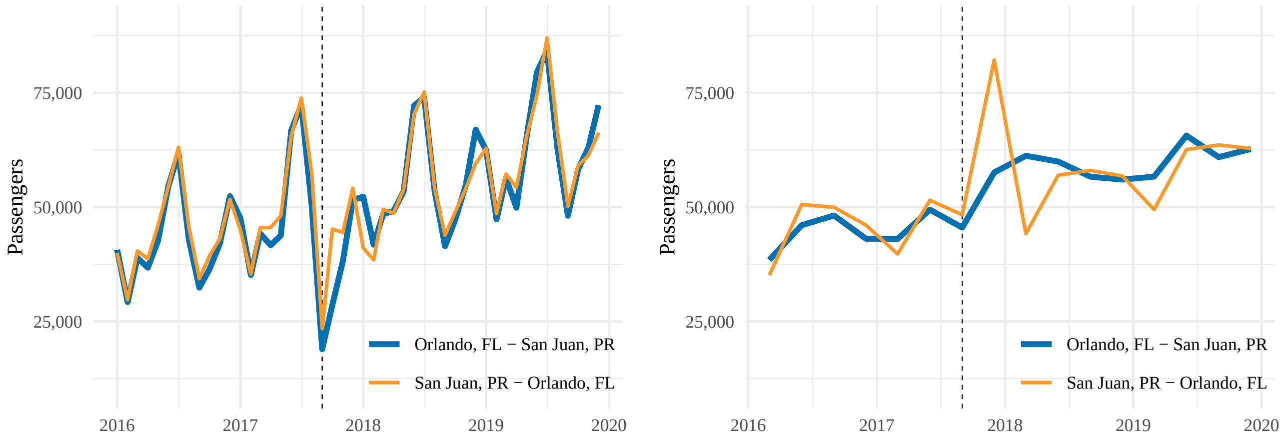
Both these pictures clearly demonstrate that most travel between PR and the mainland US is round-trip. Figure B1a displays nearly equal aggregate passenger flows between Orlando, FL and San Juan, PR, except for the period after Hurricane Maria in 2017. Similarly, although to a lesser extent, figure B1b 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 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

[23] 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

(a) Passengers transported by route (monthly) (b) One-way tickets (quarterly)



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.

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.[24] 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.

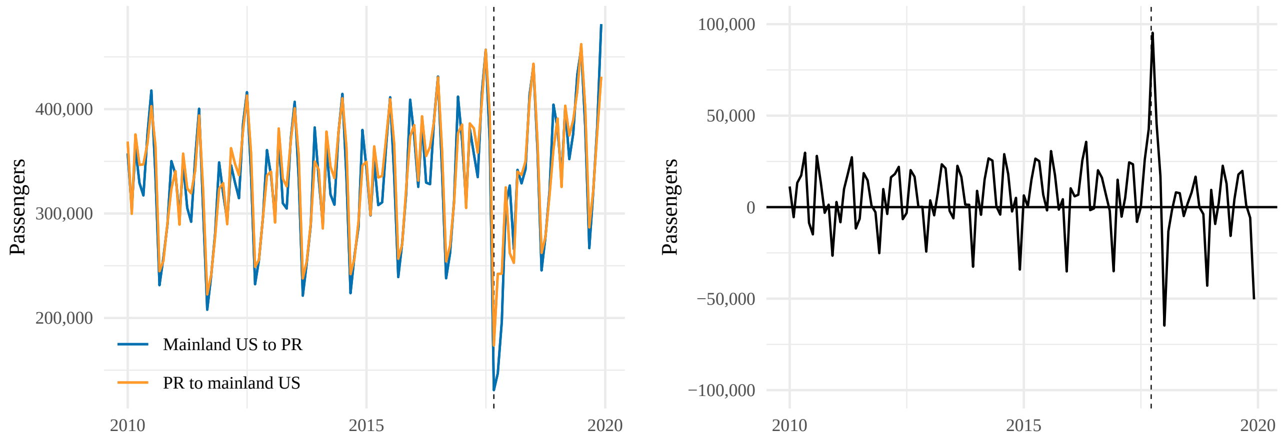
Since 2010, there has been significant net air traffic between PR and the mainland US. Figure B2b plots the monthly net flows from PR to the mainland US from 2010 to 2020. While net passenger flows are naturally smaller than gross flows, they are still quite large ranging from -25,000 to 25,000 people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

[24] 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

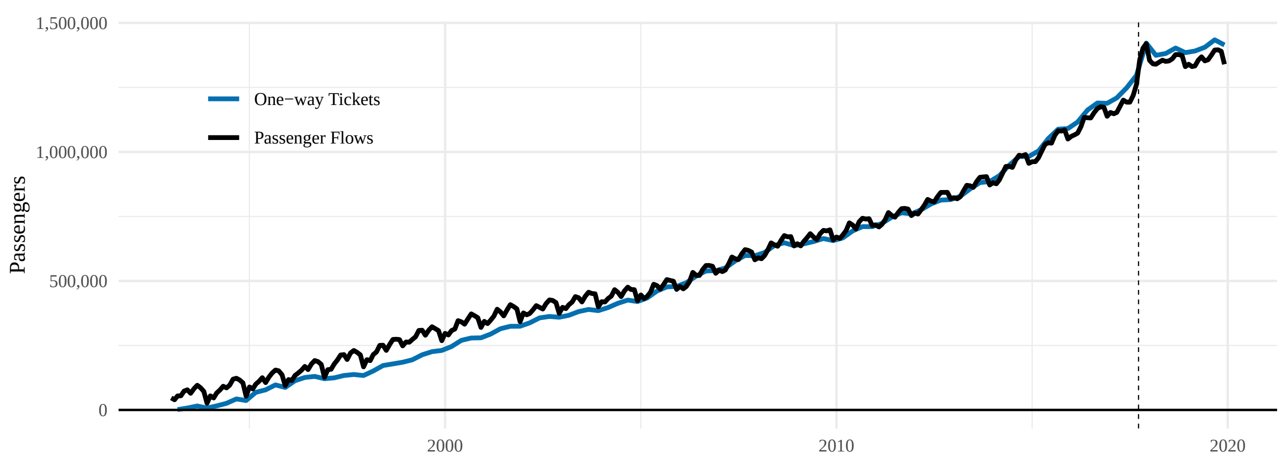
(b) Total Net Outflows to the Mainland US



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.

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



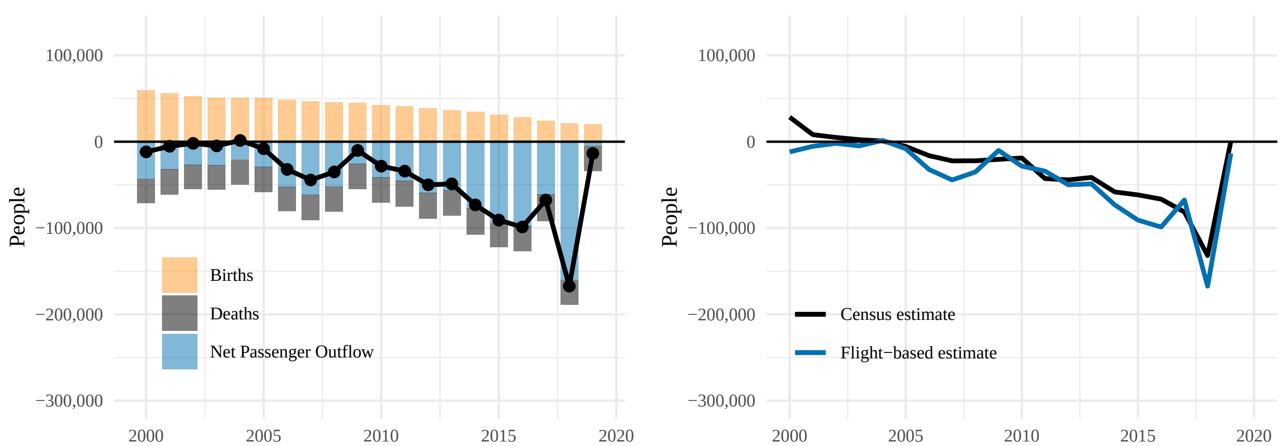
Notes: The figure plots cumulative net monthly passengers flows from PR to the mainland US (in black), and cumulative quarterly net one-way tickets from PR to the mainland US(in blue) from 1993 to 2020.

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.

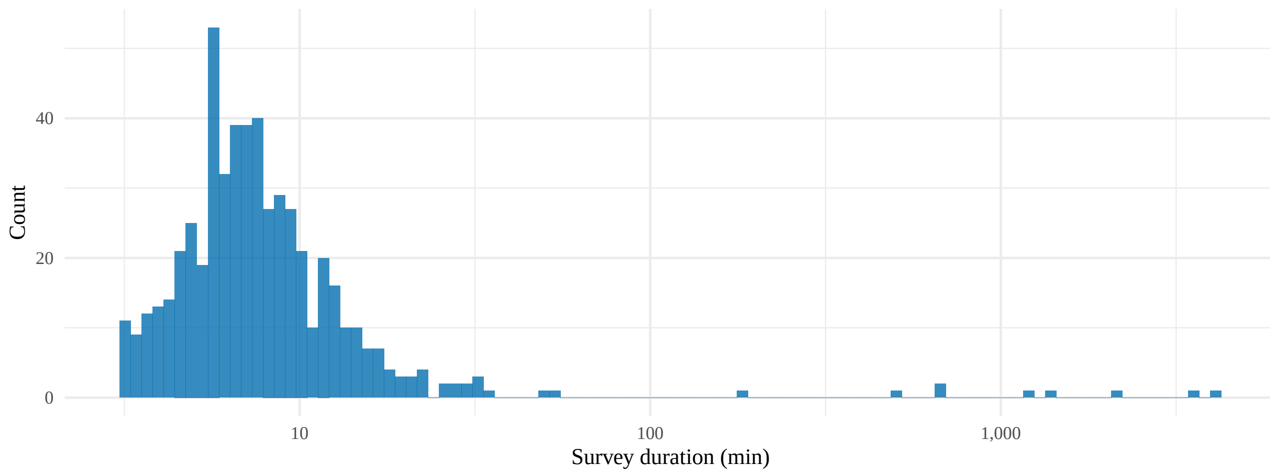
The population estimates constructed from passenger outflows tracks the US Census Bureau's population estimates closely. Census estimates for net migration from Puerto Rico to the mainland US are constructed using the question on where an individual resided last year from the ACS and the Puerto Rican Community Survey (PRCS) [25]. The advantage of the higher frequency flight data is that it allows me to uncover that there was substantial temporary migration in late 2017 and early 2018 immediately after Hurricane Maria.

[25]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 **??** and **??** for more details.

C. Survey of Puerto Ricans

C.1 Response Quality

Figure C1: Survey Completion Time

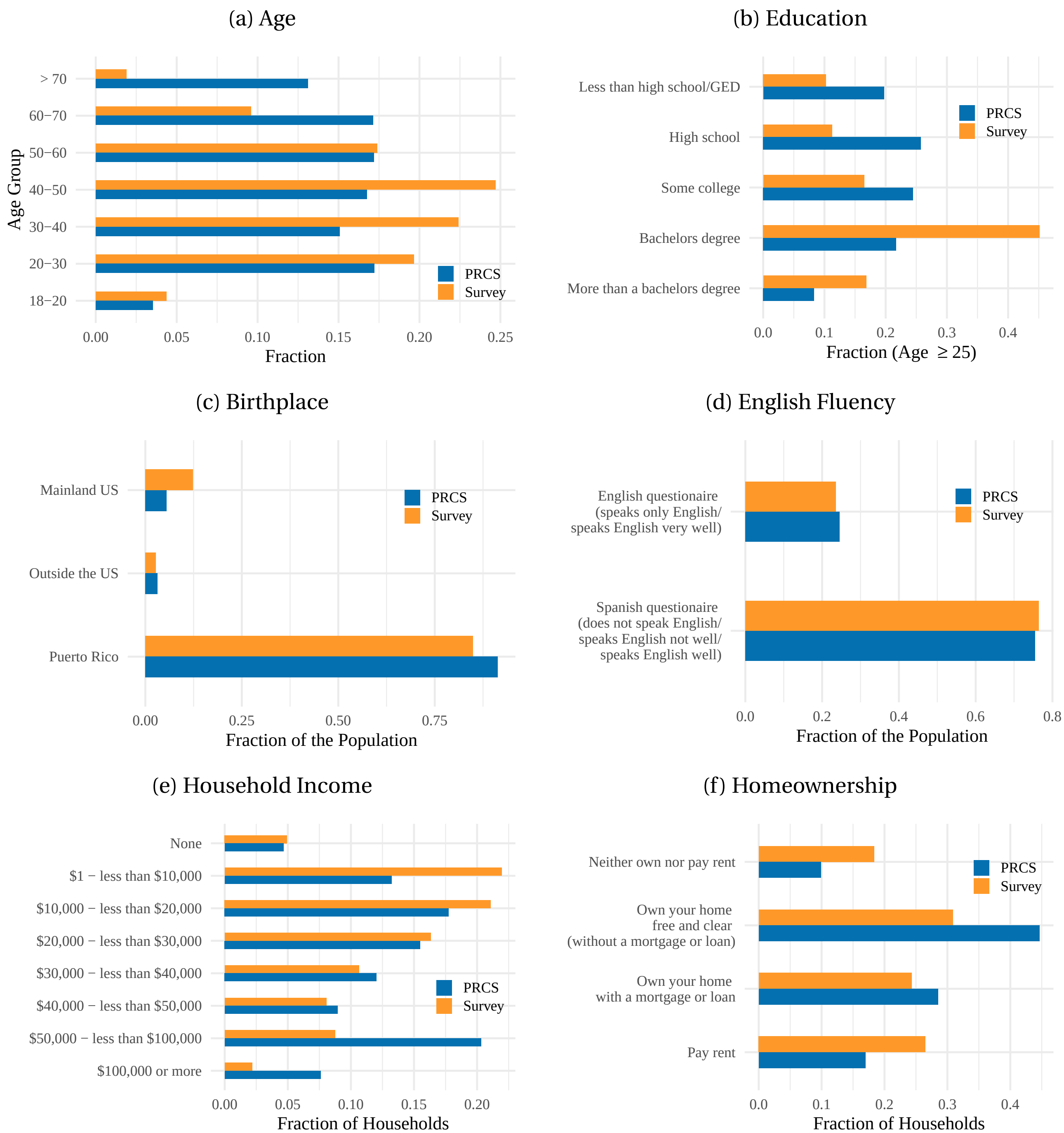


Notes: The figure plots the distribution of survey completion time. The minimum time to complete the survey was 3 minutes. Median time was 7 minutes. 95% of respondents completed the survey in 20 minutes or less. The maximum time was 4,002 minutes (2.8 days).

C.2 Representativeness of Survey Sample

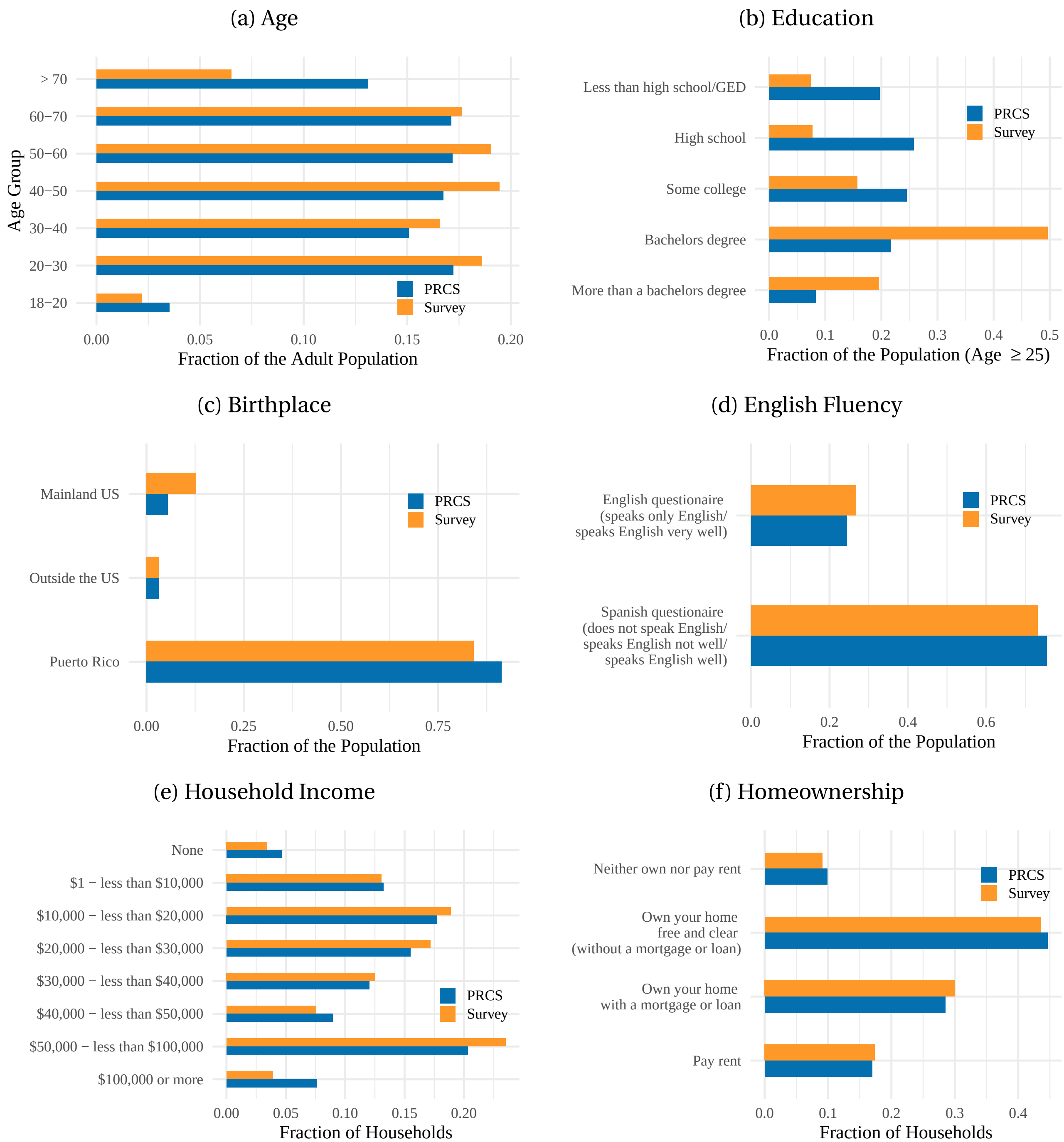
To have confidence in extrapolating the findings from the Survey to the experience of the Puerto Rican population who chose not to migrate permanently to the mainland US after Hurricane Maria, the survey sample must be representative of the income, wealth, migration costs, and preferences of Puerto Rican 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:

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

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.

Bequests:

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:

$$V_{\mathcal{O}}^{hold}(j, z_t, a_t, b_t, h_t, d_t) = \max_{c_t, a_{t+1}} u(s_t, h_t, N_t) + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_{t+1}, h_t, d_t)] \tag{D13}$$
$$\text{s.t. } a_{t+1} = (1+r)a_t + w_t y(j, z_t) - c_t - h_t(1-d_t)(\tau_h p_t^h + \delta_h p_t^c) - M(j, b_t)$$
$$b_{t+1} = (1+r_m)b_t - M(j, b_t)$$
$$s_t = (1+\omega)f(g_t)(1-d_t)h_t$$
$$c_t, a_{t+1} \geq 0$$

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:

$$V_{\mathcal{O}}^{repair}(j, z_t, a_t, b_t, h_t, d_t) = \max_{c_t, a_{t+1}} u(s_t, c_t, N_t) + \phi_j \beta E[V_{\mathcal{O}}(j+1, z_{t+1}, a_{t+1}, b_{t+1}, h_t, d_{t+1})] \tag{D14}$$
$$\text{s.t. } a_{t+1} = (1+r)a_t + w_t y(j, z_t) - c_t - \tau_h p_t^h h_t(1-d_t) - p_t^c h_t d_t - M(j, b_t)$$
$$b_{t+1} = (1+r_m)b_t - M(j, b_t)$$
$$s_t = (1+\omega)f(g_t)(1-d_t)h_t$$
$$d_{t+1} = 0$$
$$c_t, a_{t+1} \geq 0$$

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:

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

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

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

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.

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

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 $\boldsymbol{\Theta}$ 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 $\boldsymbol{\Theta}_0$, an equilibrium is a sequence of prices $\mathcal{P} = \{w_t, p_t^r, p_t^h, p_t^c\}_{t=1}^{\infty}$, distributions $\{\boldsymbol{\Theta}\}_{t=1}^{\infty}$ 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:

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

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:

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

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 qunatification specified in section **??**. Table E1 presents all models and parameter values.

Table E1: Parameter Values

Parameter	Description	Value	Source
Preferences			
β	Discount factor	0.98	internally estimated (see Table 3)
γ	Inverse EIS	1.5	Gourinchas and Parker (2002)
η	Housing services weight		internally estimated (see Table 3)
ν	Bequest motive	0.50	internally estimated (see Table 3)
u_d	Default penalty		internally estimated (see Table 4)
θ_0	Homophily scale		see Section 4.3
θ_1	Homophily returns to scale		see Section 4.3
Income			
χ_j	Deterministic life-cycle profile		see Appendix E
σ_y^2	Variance of productivity shocks		see Appendix E
ρ	Persistence of shocks	0.975	Heathcote, Storesletten, Violante (2010)
$\bar{y}$	Pension replacement rate	0.5	Munnell-Soto (2005)
Migration Costs			
m_T	Temporary migration costs	{}	see Section 4.3
m_P	Permanent migration costs	{}	see Section 4.3
$\bar{u}_{\mathcal{O}}$	migration utility renter		internally estimated (see Table 4)
$\bar{u}_{\mathcal{R}}$	migration utility owner		internally estimated (see Table 4)
Financial Assets			
r	Risk free rate	0.035	
ι	Intermediation wedge	0.33	**??**
Housing			
ω	Benefit from ownership	1.015	**??**
κ_{buy}	Transaction cost home purchase	0.025	
κ_{sell}	Transaction cost home sale	0.075	
δ_h	Housing depreciation rate	0.02	BEA
τ_h	Property tax rate	0.01	property tax rate in PR
$\psi^{\mathcal{R}}$	Per unit rental operating cost		internally estimated (see Table 3)
$\mathcal{H}^{\mathcal{R}}$	Rental house sizes		internally estimated (see Table 3)
$\mathcal{H}^{\mathcal{O}}$	Owner-occupied house sizes		internally estimated (see Table 3)
Production			
α_L	Labor Factor Share	0.62	
α_K	Capital Factor Share	0.31	
α_G	Infrastructure Factor Share	0.015	State and Local Tax Revenue GDP Share
δ_K	Capital depreciation rate	0.02	BEA
δ_G	Government infrastructure depreciation rate	0.02	BEA
Construction			
ψ_0	Capital supply scale		internally estimated (see Table 3)
ψ_1	Capital supply elasticity		internally estimated (see Table 4)
Mainland US			
w_{us}	Wage in Mainland US	1.5	
p^r_{us}	Rent in Mainland US	2	

E.1 Income Process

This section provides a detailed discussion of the estimation of the income process that is specified in Section E7.

E.1.1 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[26].

E.1.2 Pre- Versus Post-Tax Income

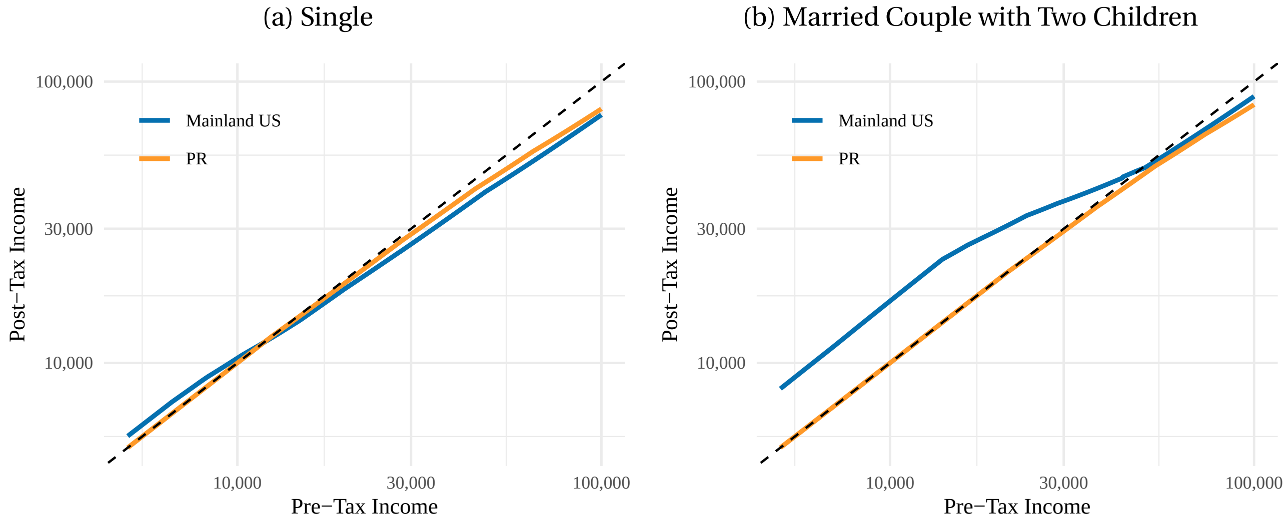
In constructing the relative earnings potential of Puerto Ricans in Puerto Rico and the Mainland US it is crucial to account for differences in taxation. Individuals earning income in Puerto Rico do not pay Federal income taxes, so when quantifying earnings differences between the two locations, it is 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 **?** 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 E2. 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.

[26]This process works to filter out extreme observations. These screening criteria are similar to those used in prior work such as **?**, **?** and **?**.

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 **?**[27].

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

The division of households into tax units can have significant implications for estimated post-tax income. If the sample household in Table E2 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.

E.1.3 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, (e.g., Deaton and Paxson, 1994) 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 E2a plots these age dummies together with the polynomial fit.

[27]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.

Table E2: 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.

To calculate the variance of the persistent income component, 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.

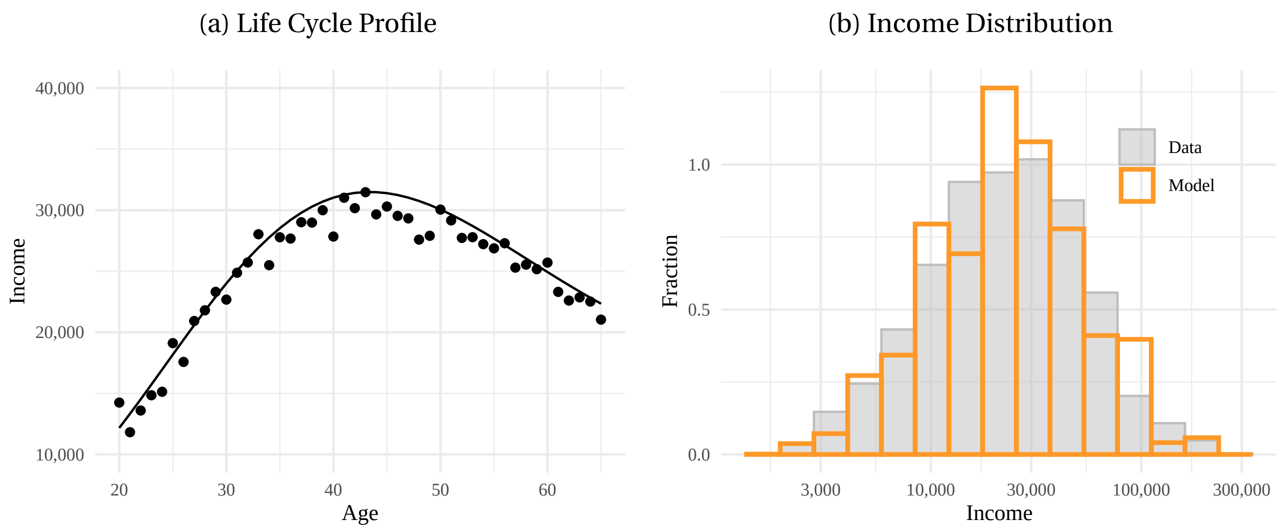
- minimize distance between data + model income distribution mean, variance, median
- pins down model income profile intercept, variance of shocks, pension replacement rate
- since age profile already decline substantially from peak at age 45 by age 65 implied pension replacement rate is quite high
- 6.0587534 0.5339734 0.8984520

Figure E2b shows a comparison of the model implied income distribution and the distribution in the data.

Table E3

	Dependent variable:
	estimate
age	0.197***
	(0.017)
age2	−0.003***
	(0.0004)
age3	0.00002***
	(0.00000)
Constant	6.932***
	(0.215)
Observations	92
R^2	0.928
Adjusted R^2	0.925
Residual Std. Error	0.057 (df = 88)
F Statistic	375.933*** (df = 3; 88)
Note:	*p<0.1; **p<0.05; ***p<0.01

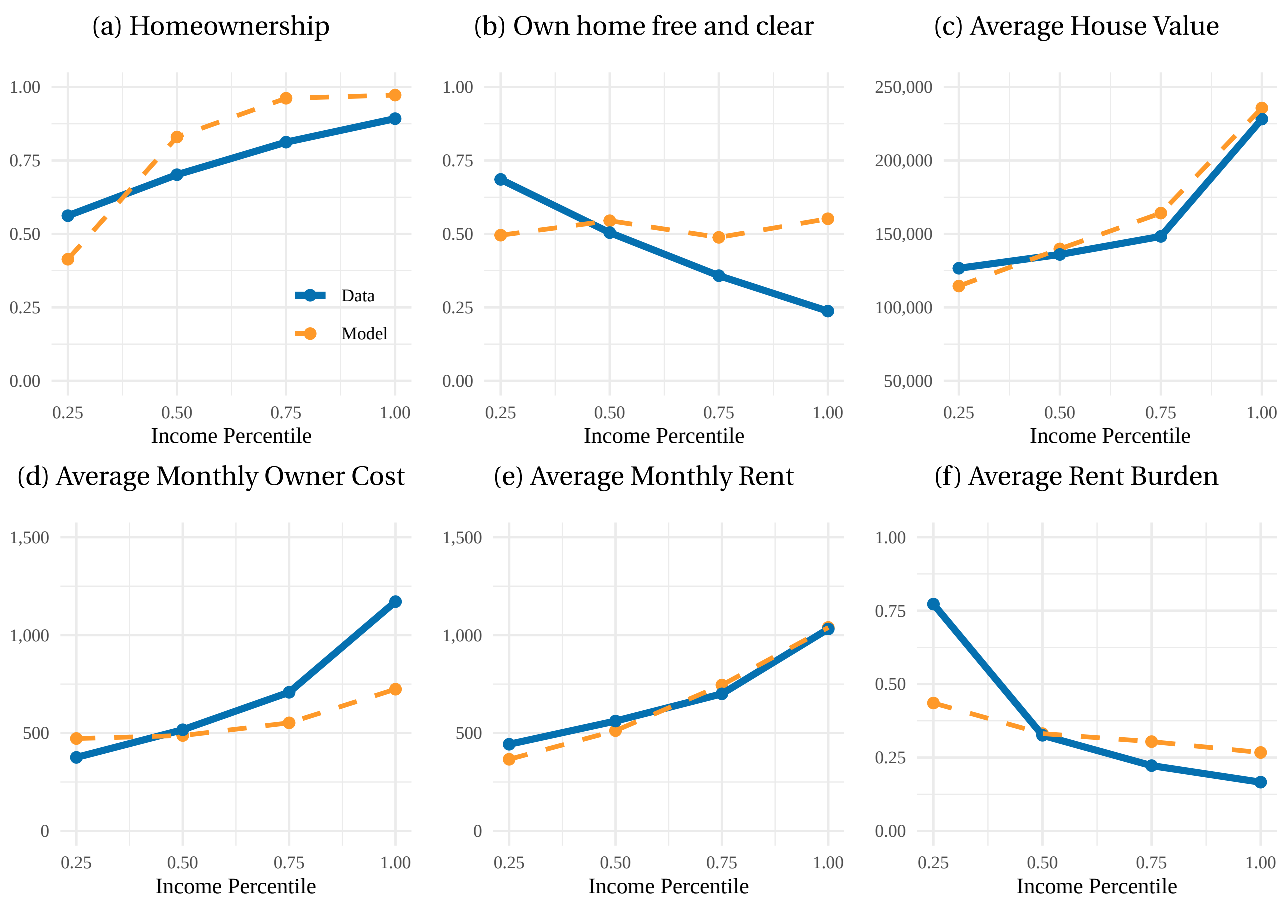
Figure E2: Life-cycle Profile and Income Distribution



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.

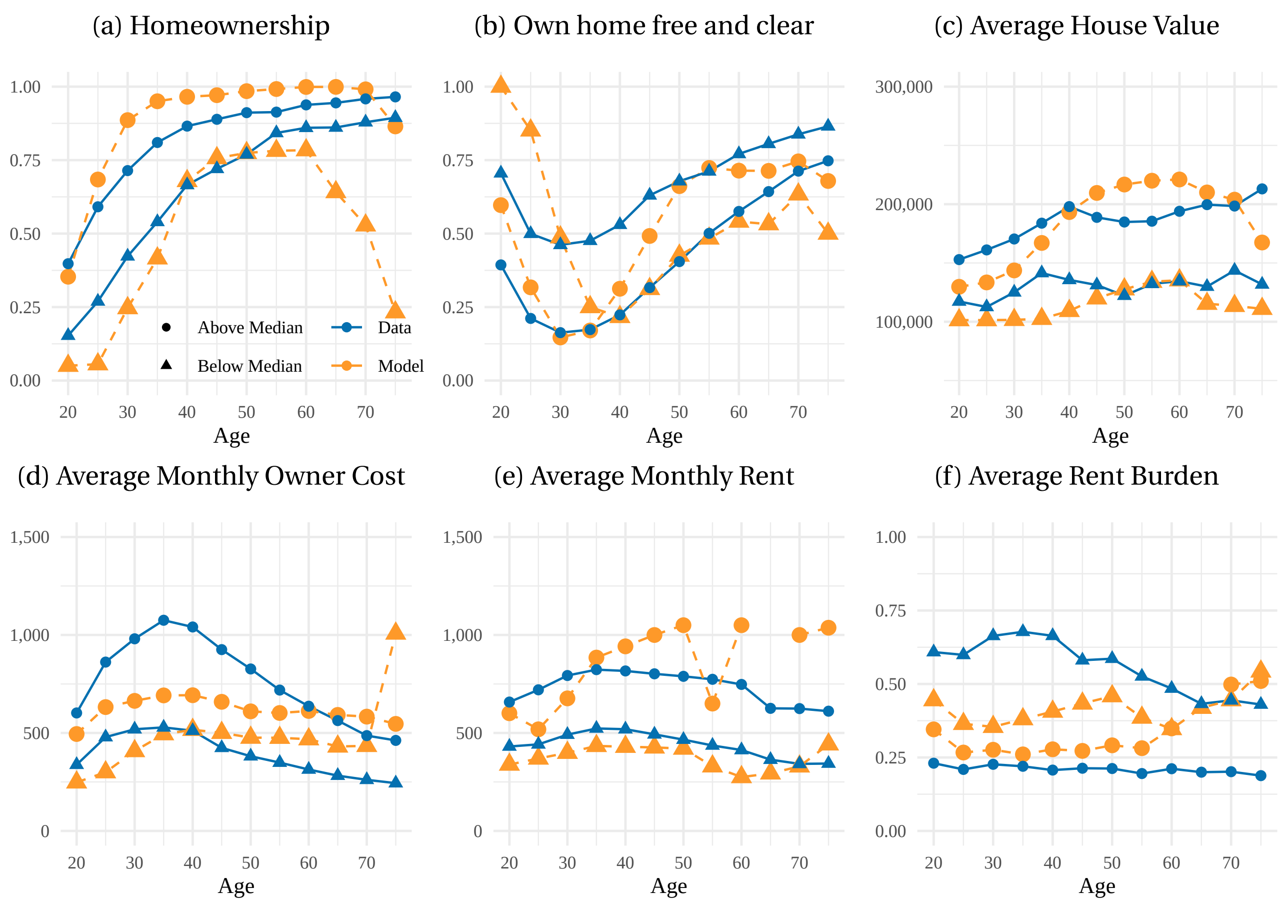
E.2 Steady State Model Fit

Figure E3: Steady State Model and Data Income Profiles



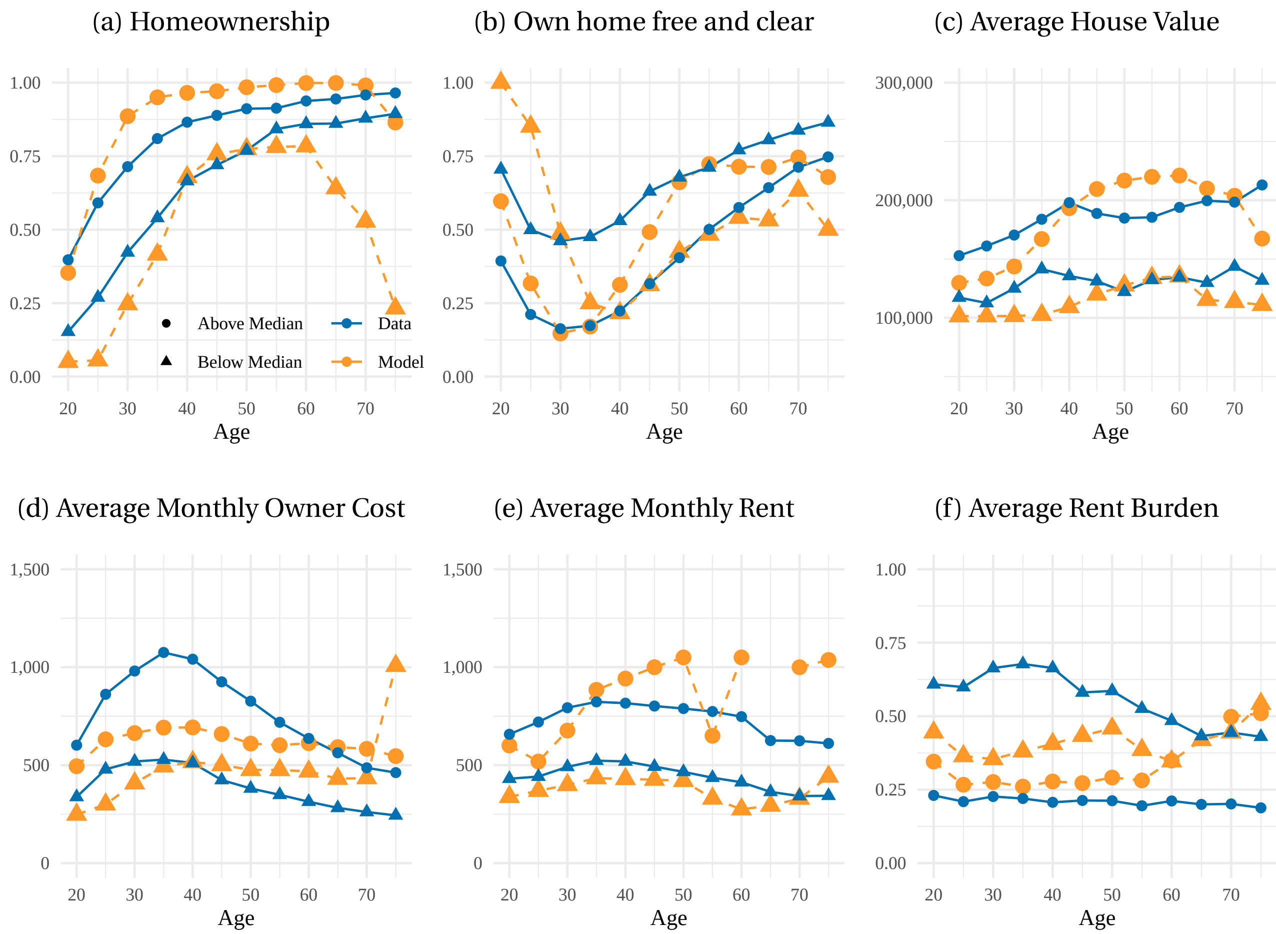
Notes: The figures compare steady state model income profiles for homeownership, the fraction of homeowners who own their home without a mortgage ("free and clear") and the average house value with data profiles computed using the 2011-2016 PRCS. The targeted moments plotted here are the fraction of 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 E4: Steady State Model and Data Age 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") and the average house value 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: Moments Across the Age-Income Distribution



Notes:

E.3 Migration Costs

This section provides a detailed discussion of the estimation of temporary and permanent migration costs in Section E7.

E.3.1 Data

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.*

(a) Less than $500
(b) $500 - $999
(c) $1,000 - $1,499
(d) $1,500 - $1,999
(e) $2,000 - $2,999
(f) $3,000 - $3,999
(g) $4,000 - $4,999
(h) $5,000 - $10,000
(i) More than $10,000
(j) Don't know

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*

(a) Less than $500
(b) $500 - $999
(c) $1,000 - $1,499
(d) $1,500 - $1,999
(e) $2,000 - $2,999
(f) $3,000 - $3,999
(g) $4,000 - $4,999
(h) $5,000 - $10,000
(i) $10,000 - $20,000
(j) More than $20,000
(k) Don't know

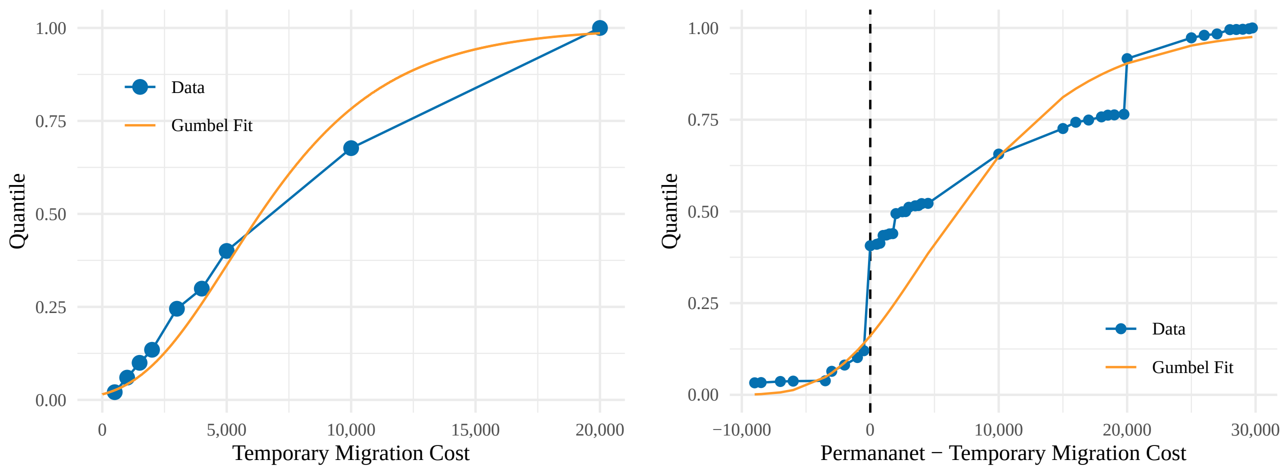
E.3.2 Temporary and Permanent Migration Costs

Table E4: Correlation of Migration Costs

	Permanent	Temporary	Difference
Permanent	1.00	0.60	0.86
Temporary	0.60	1.00	0.11
Difference	0.86	0.11	1.00

Figure E6: Migration Costs

(a) Temporary Migration Cost (b) Permanent Migration Cost



Notes: The left panel plots the joint distribution of household reported temporary and permanent migration costs. The left 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.

Table E5

type	parameter	value
Temporary	Location	5055
Temporary	Shape	3516
Permanent	Location	4172
Permanent	Shape	6922

E.4 Returns to Migration

This section provides a detailed discussion of the estimation of the wage premium in the Mainland US as well as the higher housing costs in Section E7.

E.4.1 Data

To estimate the wage premium in the Mainland US relative to Puerto Rico, I use the same sample of post tax income of household heads used for the income process estimation (described in Section E7). I supplement these data with information from the survey of households currently living in Puerto Rico. In the survey I asked households the following question about the income they expect to earn if they were to move from Puerto Rico 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?*
>
> (a) Less than I earn now
> (b) The same as I earn now
> (c) Up to $500 more per year
> (d) Up to $1,000 more per year
> (e) Up to $2,000 more per year
> (f) Up to $5,000 more per year
> (g) Up to $10,000 more per year
> (h) More than $10,000 more per year
> (i) Don't know

I combine the responses to this question with additional information about current earnings, age, and education of the respondent.

To estimate the difference in housing costs between the Mainland US relative to Puerto Rico, I use self-reported rents and owner costs from the ACS and PRCS as well as information from the survey of households currently living in Puerto Rico. In the survey I asked households the following question about how much they expect to pay in housing costs if they were to move from Puerto Rico to the Mainland US:

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?*

(a) Less than I pay now

(b) The same as I pay now

(c) Up to \$100 more per month

(d) Up to \$250 more per month

(e) Up to \$500 more per month

(f) Up to \$1,000 more per month

(g) Up to \$5,000 more per month

(h) More than \$5,000 more per month

(i) Don't know

I combine the responses to this question with additional information about current housing tenure and other household characteristics of the respondent.

E.4.2 Wage Premium

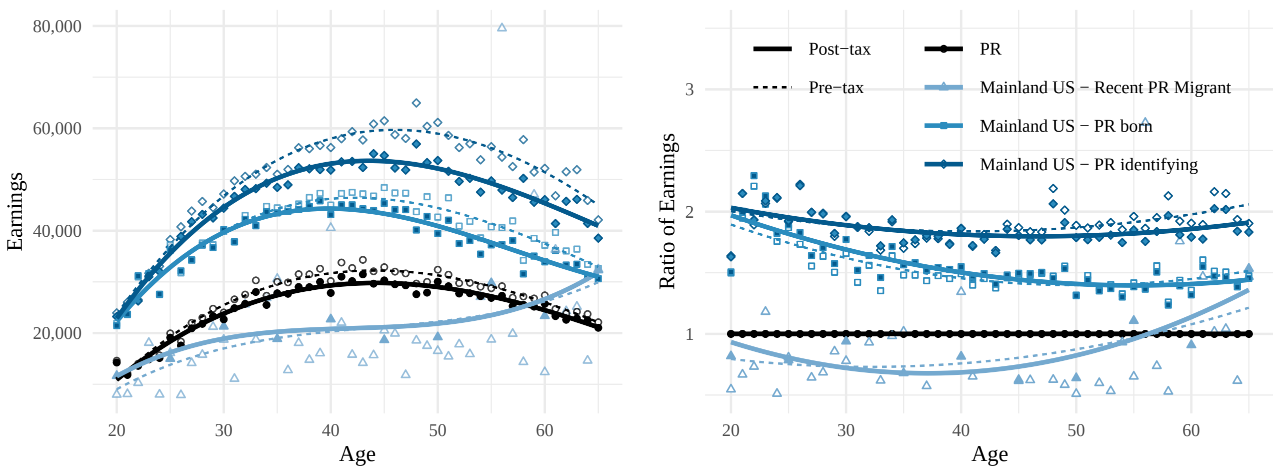
I first examine the average pre and post-tax earnings of individuals born in PR living in the mainland US and PR. I regress log earnings on a full set of age and year dummies as well as additional controls including gender, marital status, and household size for individuals in each location. Figure E7 plots the age dummies together with a polynomial fit for both pre and post-tax income in both locations. Figure E7 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.

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.

I allocate heads of tax units in the ACS and PRCS sample to three human capital groups using information on the highest grade completed: "Less than high school" (those without a high school diploma), "High school" (those with a High-School diploma, but without a college degree), and "College" (those with at least a bachelor's degree). An individual is classified as married if they are cohabiting with a spouse (or if two individuals classified as "parents" in relation to the household head are living together etc.). Finally, I use an individual's self reported English fluency to classify them as "Does not speak English", "Speaks English, but not well" (self assessment of speaking English but not well), or "Speaks English well" (self assessment of speaking English well, very well, or only speaking English).

Figure E7: Life Cycle Earnings Profiles of Puerto Ricans in the US and PR

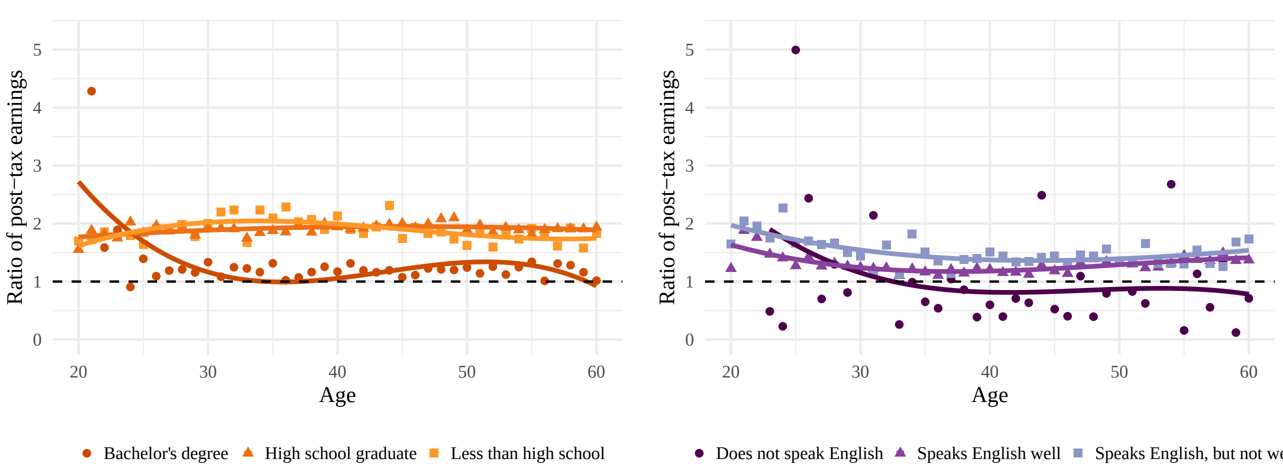
(a) Age Profile (b) Income Ratio



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 E8: Ratio of Life Cycle Earnings Profiles of Puerto Ricans in the US and PR

(a) Ratio of Earnings by Education (b) Ratio of Earnings by English Fluency

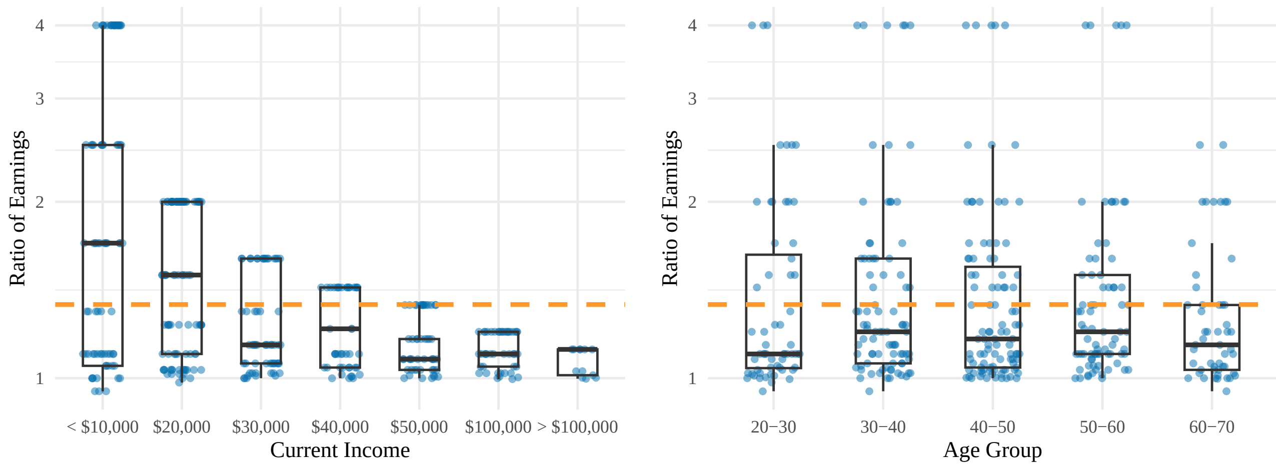


Notes:

Figure E9: Distribution of Expected Income Gains Relative to Current Income

(a) By Current Income

(b) By Age

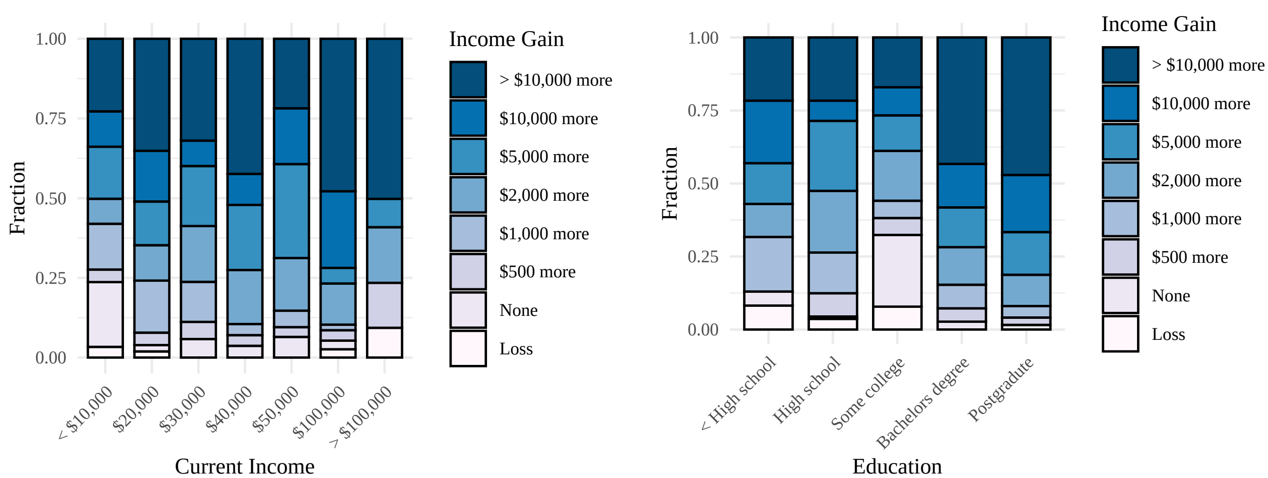


Notes:

Figure E10: Distribution of Expected Income Gains

(a) By Current Income

(b) By Educational Attainment



Notes:

E.4.3 Higher housing costs

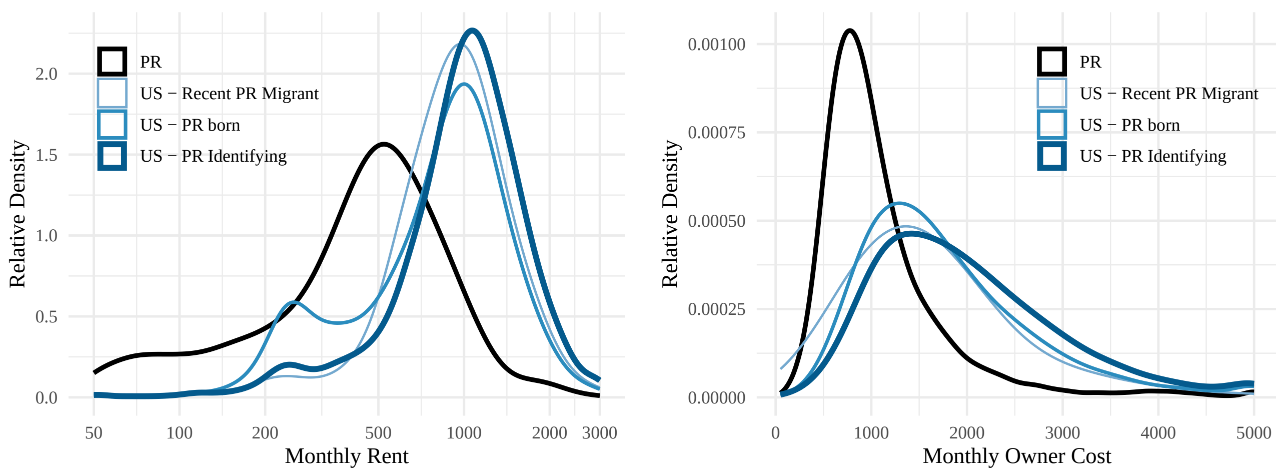
This section discusses the estimation of the relative cost of housing for Puerto Ricans living in the mainland US and in PR used in section E7. The relative cost of housing is crucial for determining the real consumption differentials between Puerto Ricans living in the US and in PR.

Data on rents and owner costs comes from both the American Community Survey (ACS) and Puerto Rican Community Survey (PRCS). Owner costs are defined as the sum of payments for mortgages, real estate taxes, property insurance, utilities, and any HOA fees. Rents are similarly defined as the sum of contract rent and any utilities. My sample consists of households living in the mainland US containing at least one individual born in Puerto Rico living and all households living in Puerto Rico.

Housing costs are much higher for Puerto Ricans in the mainland US than in Puerto Rico. Median rents in the mainland US are more than twice what they are in Puerto Rico. Median owners' costs in the mainland US are more than four times what they are in Puerto Rico. Although it is challenging to measure accurately, it does not appear that the differences in housing costs are driven by differences in the quantity or quality of housing. Figure E7 plots the distribution of rents and owner costs across the two locations by the number of rooms reported in the residence. The large differences in housing costs are present across the quantity distribution.

Figure E11: Cost of Housing in the US and PR

(a) Rent Distribution (b) Owner Cost Distribution



Notes:

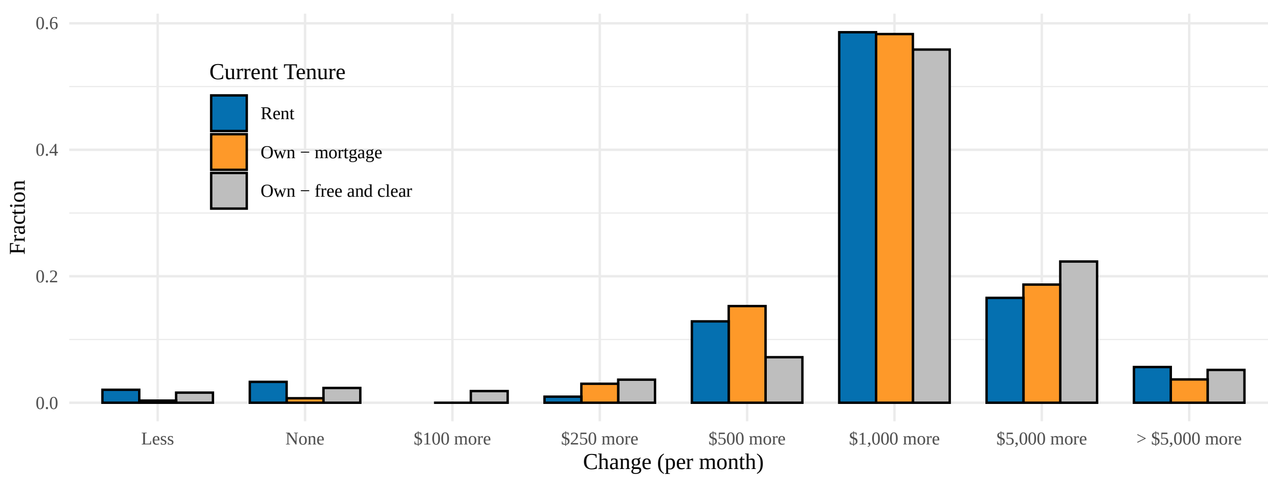
There do not appear to be substantial quality differences between housing of a similar size in PR and the mainland US. One natural measure of quality is the number of rooms per person. Households in PR live in less crowded housing than Puerto Rican households in the mainland US. Among renters, the median number of rooms per person in PR is 2, while the median number of rooms per person in the mainland US is 0.6. Among owners, the median number of rooms per person in PR is 2.5, while the median number of rooms per person in the mainland US is 2.

Table E6: Housing Costs

	Dependent variable:		
	log(Rent)	log(Owner Cost)	
		Free and Clear	Mortgage
	(1)	(2)	(3)
Mainland US	0.722	0.722	0.375
	(0.019)	(0.024)	(0.016)
House Size	0.137	0.089	0.058
	(0.004)	(0.002)	(0.003)
Mainland US × House Size	−0.038	0.014	−0.014
	(0.004)	(0.004)	(0.003)
Demographic Controls	✓	✓	✓
House Characteristic Controls	✓	✓	✓
Observations	95,180	64,019	67,436
R^2	0.350	0.451	0.447

Notes:

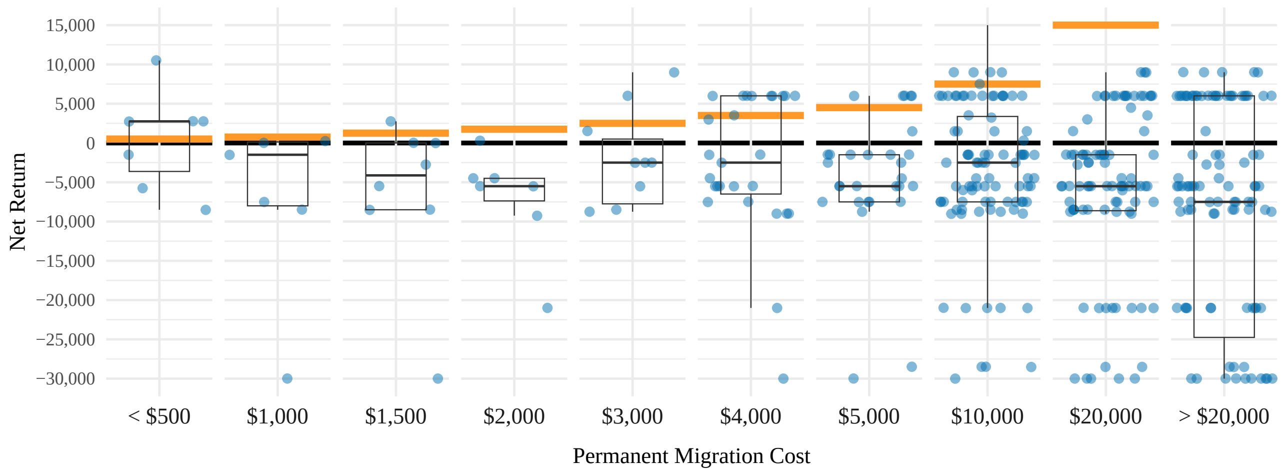
Figure E12: Expected Change in Housing Cost by Moving to Mainland US



Notes:

E.4.4 Net Returns

Figure E13: Net Annual Return to Migration by Expected Migration Cost



Notes:

Table E7

type	answer	Income	Housing Costs
Ever lived in Mainland US	No	7005.74	1557.6
Ever lived in Mainland US	Yes	7669.71	1050.4
Family in Mainland US	No	4644.25	1855.08
Family in Mainland US	Yes	7523.49	1280.82