## Overview

The code in this replication package constructs the calibration targets in Table 3 of the paper using Matlab and Stata. It calculates the externally calibrated parameters in Table 1 of the paper using Stata and Microsoft Excel. It reproduces the regression results in Table 4 and in online Appendix Tables B.2 and B.3 using Stata. It reproduces all model output in all the remaining Tables and Figure 2 of the paper using C and Matlab. The full code is computationally intensive to run. The archive includes data and model output at intermediate steps for the replicator who does not have the resources to re-run the code from scratch.

## Data Availability and Provenance Statements

### Statement about Rights

* I certify that the author of the manuscript has legitimate access to and permission to use the data used in this manuscript.

### Summary of Availability

* All data **are** publicly available.

### Details on each data source

* Data on National Income and Product Accounts were downloaded from the U.S. Bureau of Economic Analysis, <https://apps.bea.gov>.
  + Tables 1.1, 1.5, 5.1, 3.1ESI (BEA 2019a,b,c,d,e,f) are included as part of this archive in /data/raw\_data/macro\_targets.xlsx.
  + Tables 1.1 and 1.3 (BEA 2019a,g) are included as part of this archive in /data/raw\_data/depreciation.xlsx
  + Table 1.1.5 (BEA 2020) is included as part of this archive in /data/raw\_data/gdp.xlsx
  + Tables CA1 and CAGDP2 (BEA 2019h,i) are included as part of this archive in /data/raw\_data/gdp\_data/.
* All FEMA data were retrieved from the OpenFEMA API in 2019. The OpenFEMA API can be accessed here: <https://www.fema.gov/about/reports-and-data/openfema>. The data include the following disclaimer: “This product uses the Federal Emergency Management Agency’s OpenFEMA API, but is not endorsed by FEMA. The Federal Government or FEMA cannot vouch for the data or analyses derived from these data after the data have been retrieved from the Agency’s website(s)”. I describe the data sets below.
  + Data on Presidential Disaster Declarations (FEMA 2019a) are included as part of this archive in /data/raw\_data/DisasterDeclarationSummaries.xlsx.
  + Data on Individuals and Homeowners Program assistance (FEMA 2019b,c) are included as part of this archive in /data/raw\_data/HousingAssistanceOwners.xlsx and /data/raw\_data/HousingAssistanceRenters.xlsx.
  + Data on Individual and Households assistance for Flood Damage (FEMA 2019d) are included as part of this archive in /data/raw\_data/IADataset\_IHPFloods.xlsx.
  + Data on Public Assistance (FEMA 2019e,f) are included as part of this archive in /data/raw\_data/PublicAssistanceApplicants.xlsx and /data/raw\_data/PublicAssistanceFundedPorjectDetails.xlsx.
  + Data on Hazard Mitigation Assistance (FEMA 2019g) are included as part of this archive in /data/raw\_data/HazardMitigationAssistanceProjects.xlsx.
  + Data on NFIP policy holders (FEMA 2019h) are included as part of this archive in /data/raw\_data/NFIP.
* Data on insured losses were collected from the Insurance Information Institute (III, 2019). The data can be downloaded from <https://www.iii.org/graph-archive/96537>. A copy of the collected data is included as part of this archive in /data/raw\_data/iii\_losses\_coverage.xlsx.
* Data on average income of homeowners and renters are from the US Census Current Population Survey (CPS 2019). I use Table PINC-01 for years 2004-2018. To download the data, go to <https://www.census.gov/data/tables/time-series/demo/income-poverty/cps-pinc/pinc-01.2012.html>, click on the desired year, and click on the All Races excel file under the headings Total Work Experience, Both Sexes. The collected data for years 2004-2018 is included as part of this archive in /data/raw\_data/owner\_Renter\_income.xlsx.
* Best track data on cyclone storm tracks is from the HURDAT2 data base (Landsea, et al. 2013), available for download from <https://www.nhc.noaa.gov/data/>. The extended best track data set RAMMB (2019) is available to download from <https://rammb2.cira.colostate.edu/research/tropical-cyclones/tc_extended_best_track_dataset/>. Copies of both data sets are included as part of this archive in /data/raw\_data/cyclones/.
* Data on NCEI storm damage (NCEI 2021) were collected from <https://www.ncdc.noaa.gov/billions/events/US/2014-2018>. The collected data is included as part of this archive in /data/raw\_data/NCE\_raw.xlsx. The mapping between disaster numbers and disaster names is based on the CBO (2019) and the description and location of the disaster.
* Data on the GDP deflator (BEA 2019j) were accessed from the Federal Reserve Bank of St. Louis (FRED), <https://fred.stlouisfed.org/series/GDPDEF>. A copy of the data is included as part of this archive in /data/raw/GDPDEF.xlsx.
* County-level climate projections for extreme precipitation events are from the fourth National Climate Assessment (NCA 2017), downloaded from <https://scenarios.globalchange.gov/loca-viewer/>. Use the dropdown menu to choose “Annual Number of days >2 inches” and “Annual Maximum 1-Day Precipitation.” Download the resulting data for the late 21st century. A copy of the data is included in this archive in /data/raw\_data/pr2.xlsx and /data/raw\_data/prmax1day.xlsx.
* Data on household size, number of homeowners and renters and the quarterly workforce indicators are from the US Census (Census 2019a,b,c). Copies of the data are included as part of the archive in the folders /data/raw\_data/HH\_size/, /data/raw\_data/home\_ownership\_rate/,and/data/raw\_data/QWI.
* Data on the civil works budget for the U.S. army corps (USACE 2018) were retrieved from <https://usace.contentdm.oclc.org/digital/collection/p16021coll6/id/43>. A copy of the budget reports are included in the archive in /data/raw\_data/USACE.
* U.S. county shape files (NOAA 2018) were downloaded from <http://www.nws.noaa.gov/geodata/catalog/county/html/county.html> on January 10, 2018. Copies of the data are included as part of the archive in /data/raw\_data/ c\_11au16.shp and /data/raw\_data/c\_03mar20.shp.

## Dataset list

#### Raw data (all files are provided in /data/raw\_data and are publically available)

|  |  |  |
| --- | --- | --- |
| Data file | Source | Notes |
| /gdp\_data  depreciation.xlsx  macro\_targets.xlsx  gdp.xlsx  GDPDEF.xlsx  DisasterDeclarationsSummaries.xlsx  HazardMitigationAssistanceProjects.xlsx  HousingAssistanceOwners.xlsx  HousingAssistanceRenters.xlsx  IADataset\_IHPFloods.xlsx  PublicAssistanceApplicants.xlsx  PAApplicantsFundedProjectDetails.xlsx  /NFIP  iii\_losses\_coverage.xlsx  NCE\_raw.xlsx  pr2in.xlsx  prmax1day.xlsx  /HH\_size  /home\_ownership\_rate  /QWI  city\_pop\_2000\_2010.xlsx  owner\_Renter\_income.xlsx  cbo\_supp.xlsx  /USACE  c\_03mr20.shp  c\_11au16.shp | BEA  BEA  BEA  BEA  FRED  FEMA  FEMA  FEMA  FEMA  FEMA  FEMA  FEMA  FEMA  III.org  NCEI  globalchange.gov  globalchange.gov  Census  Census  Census  Census  Census  CBO (2019)  USACE  NOAA  NOAA | County GDP, population, and personal income  Tables 1.1 and 1.3  Tables 1.1. 1.1.5, 3.1ESI, 1.5, 5.1,2.3.5  Table 1.1.5  Table DPO4  Table B25008  Quarterly workforce indicators  Mapping between cities and counties  County shape files  County shape files |  |
|  |  |  |  |

#### Cleaning (all files are provided in data/cleaning and were created manually by the author)

|  |  |
| --- | --- |
| Data file | Notes |
| city\_county\_2.dta  city\_county\_corrections2.xlsx  city\_spelling\_corrections.dta | Lists cities, counties, and states  Lists cities, counties, and states  Corrects spelling of cities in PA data |
| Counties\_trans\_jan2019.dta  county\_lat\_lon.xlsx | Lists cities, counties, and states  Lists lat lon coordinates of county centroids |
| state\_trans.dta  storm\_name\_trans.dta  usdb.dta | State names and abbreviations  Fips, year, storm name, storm id  County shapefiles for Figure 1 in .dta format |

#### Derived data (all files are provided in data/derived and can be reproduced by /data/do\_files/clean/clean\_master.do)

|  |  |
| --- | --- |
| Data file | Notes |
| cbo.dta  county\_policies4.dta  county\_pop\_gdp.dta | Aid, number of approved applicants, for events in CBO (2019)  NFIP policies by county, month, and homeownership status  County population, personal income, and GDP |
| deflator.dta  distribution.dta | US GDP deflator  County, region, storm probability |
| fema\_1.dta  hma.dta  ihp\_1.dta  ihp\_2.dta  ihp\_full.dta  ncei.dta  nfip\_policies4.dta  number\_trans.dta  pa\_1.dta  pa\_2.dta  pdd\_indicators.dta  regions.dta  usace.dta  usgdp.dta | Fips, aid, storm characteristics  Year, hazard mitigation grants  IHP aid, aggregated by Fips, year, PDD  IHP aid, aggregated, by PDD, year  IHP aid, disaggregated  PDD number and NCEI damage  Fraction of renters and homeowners with flood insurance, by county, month  Year, state, storm name, PDD title, PDD number  PA aid, by Fips, year, PDD  PA aid, aggregated by PDD, year  List of county, year, quarters with PDDs  Fips, state, region  USACE adaptation expenditures by year  US GDP |

## Computational requirements

### Software Requirements

* Stata (code was last run with version 16)
* Matlab (code was run with Matlab Release R2020b)
* GCC compiler: 7.5.0

### Memory and Runtime Requirements

#### Summary

Approximate time needed to process the raw data on a standard (2017) laptop computer: 10-60 minutes.

Approximate time needed to process the model output on a standard (2017) laptop computer: 10-60 minutes.

It is not feasible to solve the model on a standard (2017) laptop computer, as described below.

#### Details

The C-code to solve the model was last run in parallel on an 88-core Linux server with 128 GB of ram. It takes approximately 4 hours to solve the model for the baseline experiment. The code to process the model results and the raw data was run on a 4-core windows laptop.

## Description of programs/code

#### Data cleaning

It is necessary to first process the cyclone data, to calculate the maximum sustained wind speed for every county-cyclone pair. After this is processed, the rest of the data can be cleaned to generate all of the data sets in /data/derived/.

* Cyclones
  + Stata program /data/cyclones/HURDAT.do cleans the cyclone storm track data.
  + Stata program /data/cyclones/cyclone\_list.do creates a list of all counties that experience each cyclone.
  + Matlab program /data/cyclones/cyclone\_wind\_8.m uses the cleaned storm track data to determine the maximum sustained wind speed for every county-cyclone pair. It stores these results in cyclone\_wind\_19.xlsx.
* All other data
  + Programs in data/do\_files/clean/ will clean all of the raw data referenced above. Program/do\_files/clean/clean\_master.do runs all of the cleaning programs in the necessary order. The code stores the processed (derived) data sets in /data/derived/.

#### Programs to compute regression results and model targets

These programs can all be run using the data sets provided in /data/derived/. It is not necessary to run the cleaning programs to reproduce these data sets first.

* Program /data/do\_files/map.do will produce the map in Figure 1 of the paper.
* Program /data/do\_files/validation.do runs the regression for Table 4 of the paper.
* Program /data/do\_files/agg\_mom.do produces the aggregate moments related to FEMA aid in Table 3 of the paper, the summary statistics reported in online Appendix Table B.1, the values in online Appendix Table B.4, the storm probabilities reported in Table 1, the ratio of GDP across regions reported in Section 4, and the fraction of households that received the maximum grant reported in footnote 17.
* Program /data/do\_files/psi.do calculates the ratio of disaster aid to damage, reported in Table 3 of the paper. Additionally, it runs the regressions for online Appendix Tables B.2 and B.3 and calculates the fraction of events with NCEI reported damage data.
* Program /data/do\_files/qwi.do runs the regression reported in footnote 10 of the paper.
* Program /data/precip.do computes the projected changes in extreme precipitation for the extreme-precipitation method of modeling climate change.
* All calibration targets in Table 3 that are not produced by the above Stata code and all parameter values in Table 1 that are not taken from the literature are computed directly from the raw data in the excel spreadsheets: /data/raw\_data/macro\_targets.xlsx, /data/raw\_data/iii\_losses\_coverage.xlsx and /data/raw\_data/owner\_Renter\_income.xlsx.

#### Model solution

Programs in /c\_programs compute the model solution in C and store the results in /c\_programs/results\_1109.

* /c\_programs/shell.c: runs model for the baseline and counterfactual experiments. Lines 75-84 are flags to determine the model experiment.
* /c\_programs/solveModel.c solves the firm and household optimization problems, computes aggregate quantities.
* /c\_programs/err\_hrahrp.c computes the first order condition for the rental-housing firm’s optimization problem
* /c\_programs/err\_lb.c computes lower bound on the initial guess for the final good firm’s optimization problem.
* /c\_programs/err\_kakp.c computes the first order condition for the final-good firm’s optimization problem
* /c\_programs/value\_function\_loop.c uses value function iteration to solve the household’s optimization problem.
* /c\_programs/nelder.c and /c\_programs/nelder\_nr.c calls the Nelder-Mead optimization routine from Numerical Recipes (Press et al. 1988) as part of the optimization step in /c\_programs/value\_function\_loop.c.
* /c\_programs/cond\_v.c computes the continuation value conditional on the realization of the shock.
* /c\_programs/ucont.c computes u + beta\*E(v) as part of the value function iteration. Uses cubic splines to interpolate the continuation value for off-grid points.
* /c\_programs/sim\_peeps.c uses approximate aggregation to construct the distribution of households across the state space.
* /c\_programs/save\_results.c saves model results as .dat files to be processed in Matlab.
* /c\_programs/moments.c computes model values of the calibration targets in the model.
* The following routines in /c\_programs/ are taken directly from Numerical Recipes (Press et al. 1988). They are modified slightly to fit the context of the specific problem. The names of the routines correspond to the names in Press et al. 1988.
  + amoeba.c, amoeba\_nr.c amoeba\_r.c amotry.c amotry\_nr.c amotry\_r.c, golden.c, rtbis.c, splie2.c, splin2.c, spline.c, and splint.c

#### Process model output

Programs in folder /process\_output process .dat files produced by the C code and create Figure 2 and Tables 1-3 and 5-14 in the main paper and Tables C.1 and C.2 in the online Appendix.

* Program /process\_output/readc.m processes all model results from C data files.
* Program /process\_output/elasticity.m calculates the damage-probability and the aid-probability elasticities in the model, reported in Section 4 of the paper.
* Program /process\_output/tables.m produces Figure 2 and Tables 1-3 and 5-14 in the main paper and Tables C.1 and C.2 in the online Appendix. Output files are called names that should be easy to correlate with the titles of the tables in the paper (see chart below).
* Program /process\_output/income\_shocks.m computes the Markov transition matrix for income shocks, reported in online Appendix B.5. Calls rouwen.m (Lkhagvasuren, 2005) to implement the Rouwenhorst discretization method. The Markov transition matrix is hard-coded into /c\_programs/shell.c.

#### Miscellaneous

* Program /cyclones/county\_cyclones\_1.m computes the fraction of counties that experience a category 1 or higher cyclone that have a PDD (reported on page 23 of the paper).

## Instructions for replicators

The archive has the file structure necessary to run the code including the empty folders: /data/output, /data/temp, /process\_output/figures and /process\_output/tables.

#### To replicate calibration targets and regression output

1. Edit all program files to adjust the default path.
2. Clean cyclone data: run in the following order:
   * /data/cyclones/HURDAT.do,
   * /data/cyclones/cyclone\_list.do
   * /data/cyclones/cyclone\_wind\_8.m
3. Clean remaining data: run data/do\_files/clean/clean\_master.do
4. Produce calibration targets and regression results. These programs can be run in any order.

* /data/do\_files/agg\_mom.do and /data/do\_files/psi.do reproduce the calibration targets related to FEMA aid in Table 3, the summary statistics reported in online Appendix Table B.1, the values in online Appendix Table B.4, the storm probabilities reported in Table 1, the ratio of GDP across regions reported in Section 4, and the fraction of households that received the maximum grant reported in footnote 17.
* /data/do\_files/psi.do reproduces the regressions in online Appendix Tables B.2 and B.3.
* /data/do\_files/validation.do reproduces the regression for Table 4.
* /data/do\_files/qwi.do reproduces the regression for footnote 10.
* /data/do\_files/map.do reproduces Figure 1.
* /data/do\_files/precip.do constructs the changes in probability and severity for the extreme-precipitation method for modeling climate change.
* /data/cyclones/county\_cyclones\_1.m computes the fraction of counties that experience a category 1 or higher cyclone that have a PDD (reported on page 23 of the paper).

Note that steps 2 and 3 can be skipped if the replicator wishes to start from the derived data files (included as part of this archive) instead of the raw data.

#### To replicate the model solution

1. Edit all programs to adjust the default path.
2. Set the flags in line 75-80 of /c\_programs/shell.c to run the desired experiment (e.g., the baseline, climate change, changes in federal policy, etc.). The notes in the code indicate which flag corresponds to which experiment.
3. Compile the C code using the provided makefile and run the resulting executable.
4. Adjust the exper\_vec1 and exper\_vec2 in /process\_output/readc.m to the relevant experiments. Run /process\_output/readc.m. This will generate all the aggregate quantities for the particular experiment discussed in the paper.

Note steps 2 and 3 can be skipped if the replicator wishes to start from the c\_program output included as part of this archive in /c\_programs/results\_1109.

## List of tables and programs

The provided code reproduces all numbers, tables, and figures in the paper.

|  |  |  |  |
| --- | --- | --- | --- |
| Figure/Table # | Program | Line Number | Output file |
| Table 1 | process\_output/tables.m | 20 | params\_direct.tex |
| Table 2 | process\_output/tables.m | 50 | params\_mom.tex |
| Table 3 | process\_output/tables.m | 88 | targets.tex |
| Table 4 | data/do\_files/validation.do |  |  |
| Table 5 | process\_output/tables.m | 173 | baseline\_agg.tex |
| Table 6  Table 7  Table 8  Table 9  Table 10  Table 11  Table 12  Table 13  Table 14  Table B.1  Table B.2  Table B.3  Table B.4  Table C.1  Table C.2  Figure 1  Figure 2 | process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  process\_output/tables.m  data/do\_files/agg\_mom.do  data/do\_files/psi.do  data/do\_files/psi.do  data/do\_files/agg\_mom.do  process\_output/tables.m  process\_output/tables.m  data/do\_files/map.do  process\_output/tables.m | 209  234  269  299  341  379  463  415  556  188  100  101  77  125  149  99  496 | adaptive\_capacity.tex  quintiles.tex  federal\_policy.tex  fed\_welfare.tex  climate\_params.tex  adaptation\_capital.tex  adapt\_cc.tex  welfare\_cc.tex  welfare\_ccnr.tex  income\_quintile.tex  wealth\_quintile.tex  map.eps  D\_45.eps, D\_85.eps |

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