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Modelling exposure and vulnerability to disaster risk: A dynamic household level approach

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No theoretical framework able to replicate all empirical findings in the literature so far.

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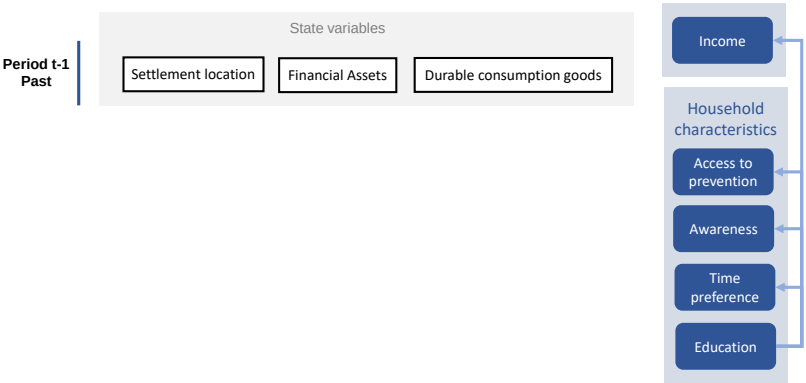
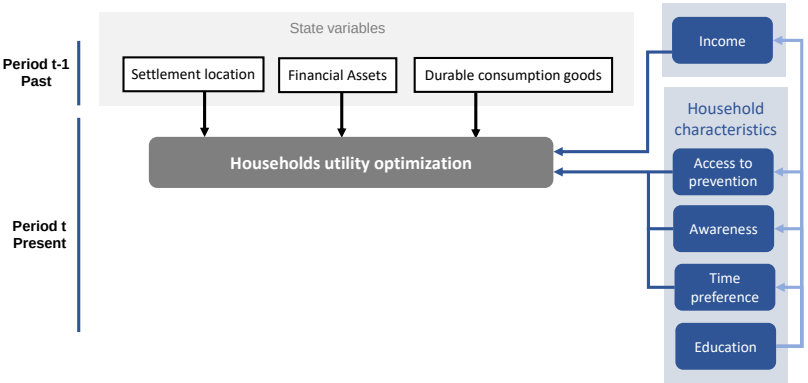
- A theoretical model deriving the behavioural patterns directly from individual preferences can
  - deliver more consistent results and predictions.
  - provide some explanation for behavioural patterns.

Model

Model


Period t-1
Past
State variables
Settlement location
Financial Assets
Durable consumption goods
Income
Household characteristics
Access to prevention
Awareness
Time preference
Education

Model


State variables
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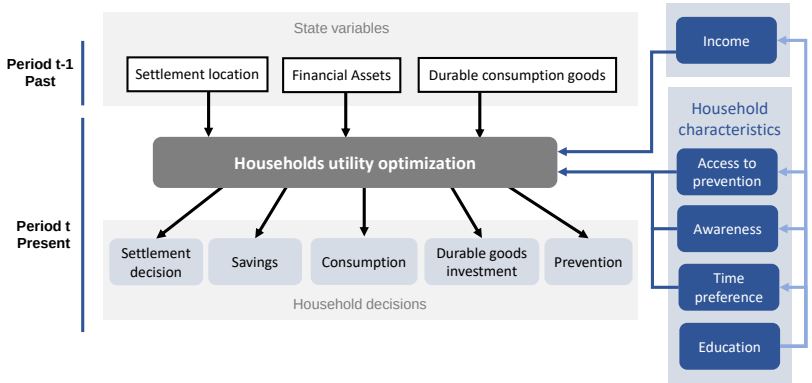
State variables
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Savings
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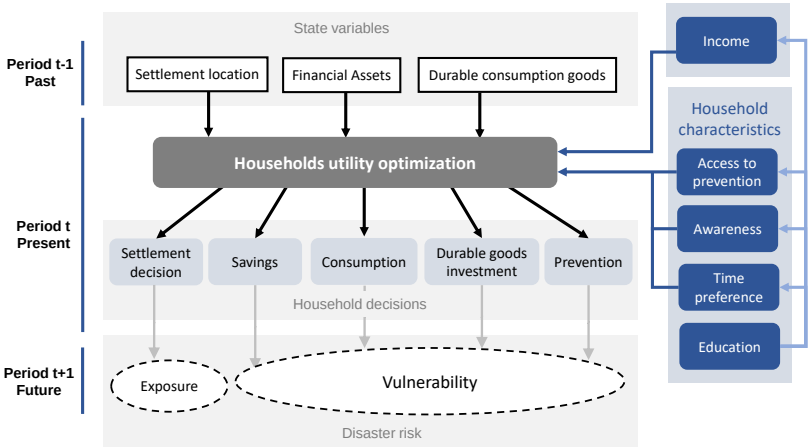
State variables
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Financial Assets
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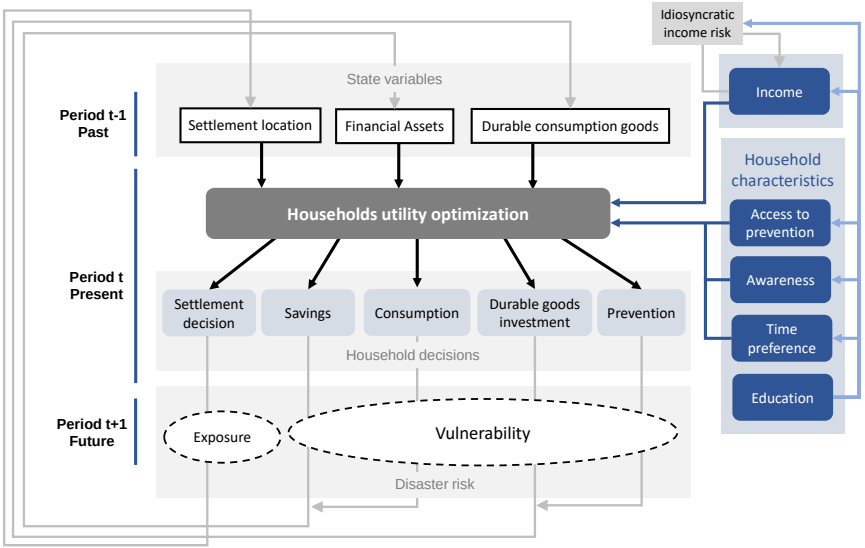
Settlement decision
Savings
Consumption
Durable goods investment
Prevention
Household decisions
Period t+1
Future
Exposure
Vulnerability
Disaster risk
Income
Household characteristics
Access to prevention
Awareness
Time preference
Education

Model


Idiosyncratic income risk
State variables
Period t-1 Past
Settlement location
Financial Assets
Durable consumption goods
Income
Household characteristics
Households utility optimization
Access to prevention
Awareness
Time preference
Education
Period t Present
Settlement decision
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Main interactions and trade-offs

Less exposed settlement location $E \downarrow$

- Lower probability of being struck by natural disaster.
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Disaster Experience $D = 1$

- Durable consumption goods get destroyed.
- Share of working income in following period is lost.

Mathematical Formulation

$$\max_{\substack{c_t, w_t, I_t, E_{t+1}, P_{t+1}, \\ t \in \{1,2,\ldots\}}} \mathbb{E}_{\mathcal{N},\mathcal{D},\mathcal{Y}} \left[\sum_{t=1}^{\infty} \left(\frac{1}{1+\rho_h} \right)^t u(c_t, W_{t+1}) \right]$$

$$S_{t+1} = y_t^h \cdot (1 - \Delta^y D_t) + (1 + r_t) S_t - c_t - p^w(w_t) - p^P(E_{t+1}, W_{t+1}, P_{t+1}, h) - p^E(E_{t+1})$$

$$W_{t+1} = (1-\delta)(1 - \Delta^W I_t)(1 - (1 - P_t) D_t) W_t + w_t$$

$$(E_{t+1} - E_t)(1 - I_t) = 0$$

$$\mathcal{N} \sim \begin{cases} \mathbb{P}[N_t = 1] = H_t \\ \mathbb{P}[N_t = 0] = 1 - H_t \end{cases}$$

$$\mathcal{D} \sim \begin{cases} \mathbb{P}[D_t = 1] = a_{t-1}^h E_t H_t \\ \mathbb{P}[D_t = 0] = 1 - a_{t-1}^h E_t H_t \end{cases}$$

- c_t ... consumption
- W_t ... durable consumption goods
- S_t ... financial assets
- E_t ... exposure level ($\in [0,1]$)
- D_t ... disaster experience ($\in [0,1]$)
- P_t ... prevention level ($\in [0,1]$)
- I_t ... relocation decision ($\in [0,1]$)
- y_t ... income realisation

Mathematical Formulation

To keep it short: In the model households

- obtain utility from period consumption and durable consumption goods;
- take the effects of their decisions on exposure and vulnerability into account;
- maximize their long-run expected utility.

Bellman Formulation

$V(E, S, W, y, D)$ is the value-function depending on the state variables.
$\Longrightarrow$ Impact of location decision becomes more apparent:

$$V(E_t, S_t, W_t, y_t, D_t) = \max_{\substack{E_{t+1}, S_{t+1}, \\ W_{t+1}, P_{t+1}, \\ I_t, c_t, w_t}} \left\{ u(c_t, W_{t+1}) + \frac{1}{1+\rho} \Big[a_t E_{t+1} H_{t+1} \cdot \mathbb{E}_{\mathcal{Y}} V(E_{t+1}, S_{t+1}, W_{t+1} P_{t+1}, \mathcal{Y}, D_{t+1} = 1) + \right.$$

$$\left. + (1 - a_t E_{t+1} H_{t+1}) \cdot \mathbb{E}_{\mathcal{Y}} V(E_{t+1}, S_{t+1}, W_{t+1}, \mathcal{Y}, D_{t+1} = 0) \Big] \right\}$$

$$S_{t+1} = y_t \cdot (1 - \Delta^y D_t) + (1 + r_t) S_t - c_t -$$
$$- p^w(w_t) - p^P(E_{t+1}, W_{t+1}, P_{t+1}) - p^E(E_{t+1})$$

$$W_{t+1} = (1 - \delta)(1 - \Delta^W I_t) W_t + w_t$$

$$0 = (E_{t+1} - E_t) \cdot (1 - I_t)$$

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Analytical results Overview

Analytical results for the FOC are limited:

- Depend on intricate expectation operator.

$$u_c(t)\left[p_W^P(t+1)+(p^w)'(t)\right]=u_W(t)+$$
$$+\frac{1-\delta}{1+\rho}\mathbb{E}_t\left\{u_c(t+1)(p^w)'(t+1)(1-\Delta^W I_{t+1})(1-(1-P_{t+1})D_{t+1})\right\}$$

- Depend on derivatives of unknown value function.

$$u_c(t)\left[p_W^P(t+1)+(p^w)'(t)\right]=u_W(t)+$$
$$+\frac{1}{1+\rho}\Big[aEH\cdot P\cdot\mathbb{E}_{\mathcal{Y}}\frac{\partial V}{\partial W}(E,S,W\cdot P,\mathcal{Y},1)+(1-aEH)\cdot\mathbb{E}_{\mathcal{Y}}\frac{\partial V}{\partial W}(E,S,W,\mathcal{Y},0)\Big]$$

Numerical Results

Numerical results overview

Solving the mathematical model numerically we derive two main results:

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- The long-run equilibrium distributions across the state variables (derived from Monte-Carlo-Simulations).

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  - for every possible scenario the household can potentially be in.
- The long-run equilibrium distributions across the state variables (derived from Monte-Carlo-Simulations).

We derive these results for different combinations of the household characteristics

- Prevention access (low, mid, high)
- Awareness (low, mid, high)
- Time preference (low, mid, high)
- Education (5 different educational levels)

which results in 135 different types of households.

Calibration Data

We generate a synthetic population replicating the main results found in empirical data.

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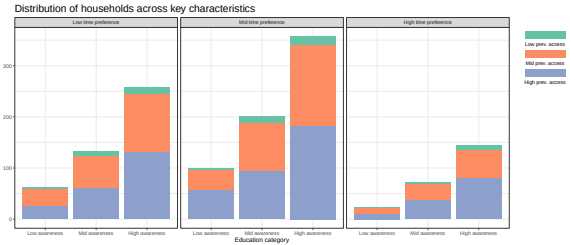
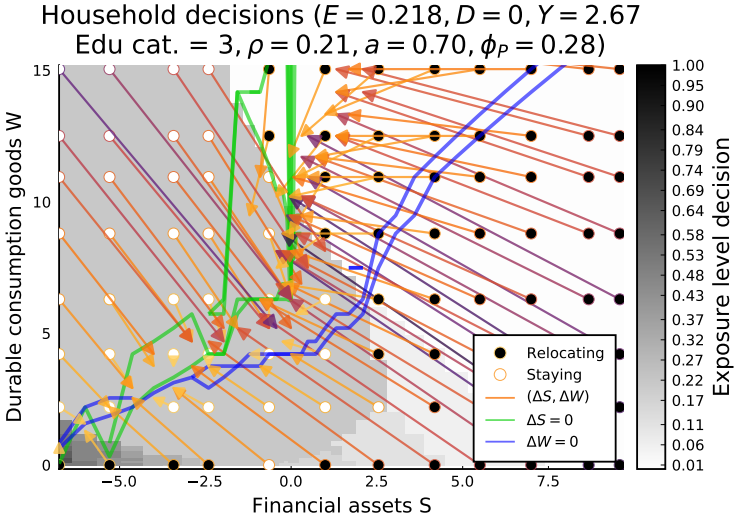
We use data from the Thailand-Vietnam Socio-Economic Panel (TVSEP) to calibrate the model with respect to

- the functional forms and parameters used in the model;
- the distribution of households across the different household characteristics.



Optimal household decisions



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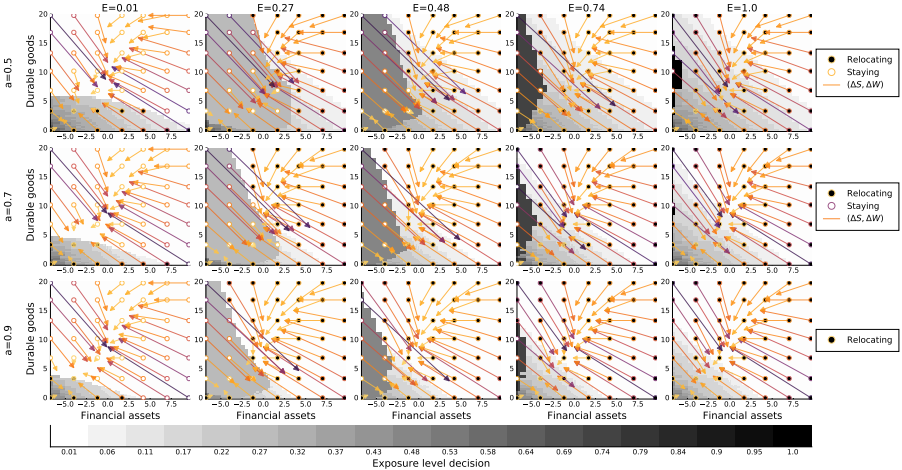
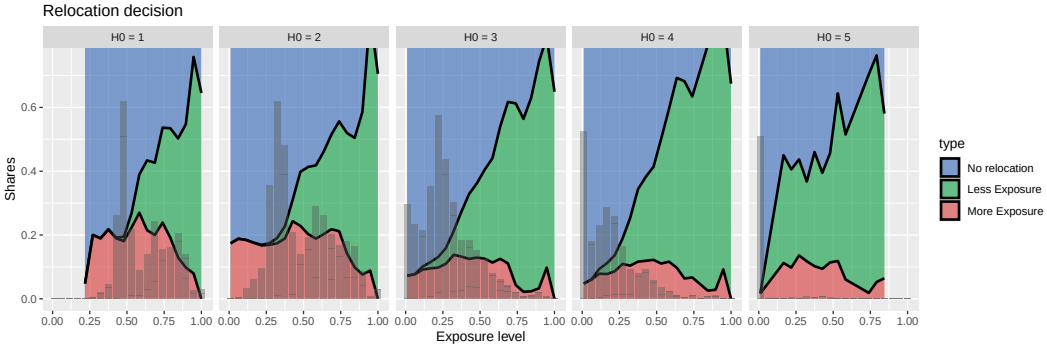
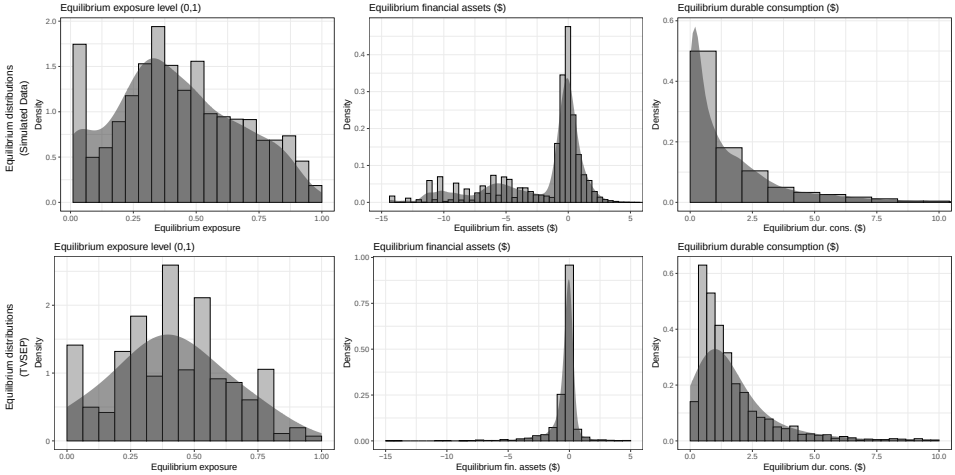


Optimal household decisions

Optimal relocation decision depending on current settlement location.



Equilibrium long-run distributions



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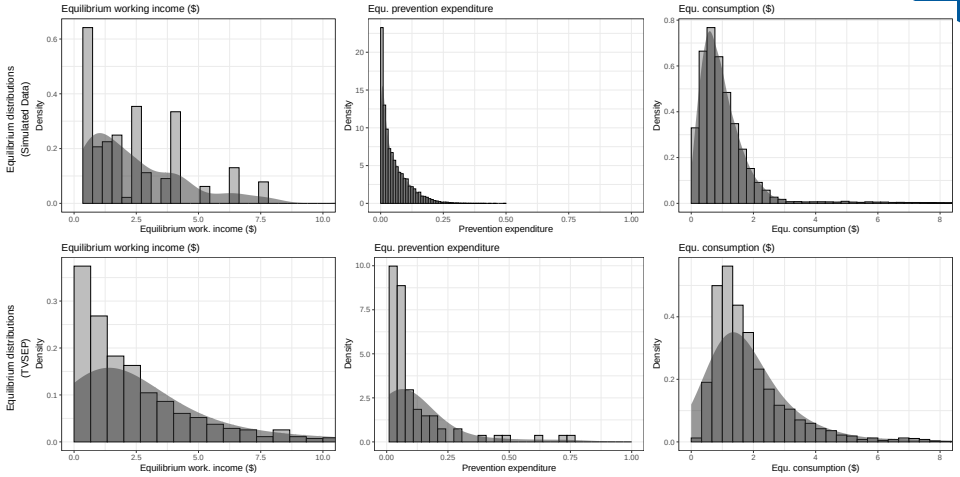

Policy Interventions

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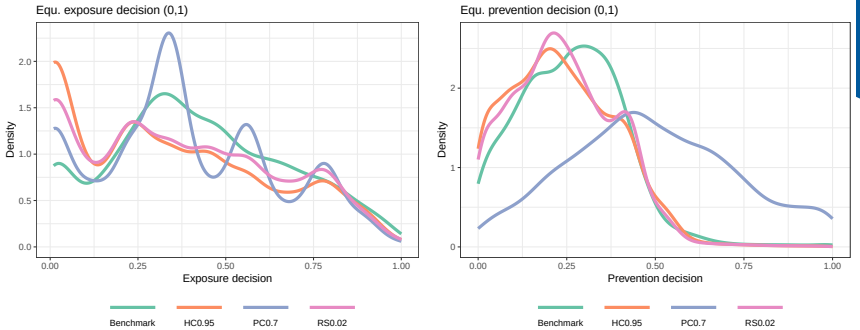
- Relocation subsidy $\rightarrow$ Reduce losses from relocation to *RS*.
- Prevention subsidy $\rightarrow$ Reduce prevention cost by factor *PS*.


Equ. exposure decision (0,1)
Density
Exposure decision
Equ. prevention decision (0,1)
Density
Prevention decision
Benchmark
HC0.95
PC0.7
RS0.02
Benchmark
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PC0.7
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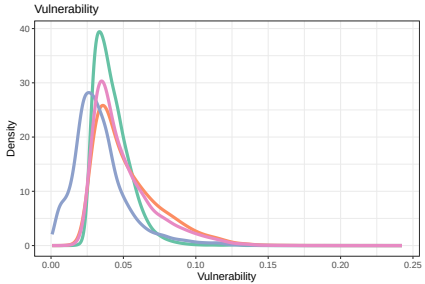
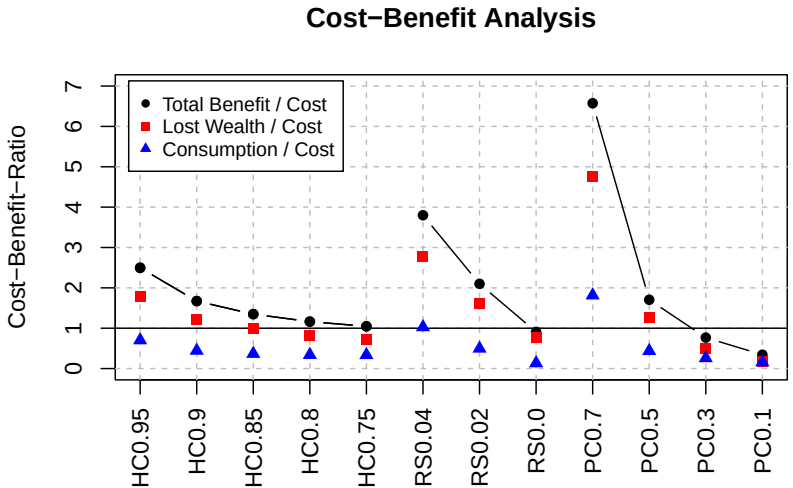

Vulnerability
Density
Vulnerability

Cost-Benefit Analysis



Things to do!

- Analyse other possible policy interventions, which change the household characteristics:
  - Awareness campaign
  - Education program
  - Improving access to prevention

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- Analyse which groups benefit the most and which the least from different policy interventions.
- Assess how policy interventions change the household behaviour.
- Assess the benefits of modelling approach compared to econometric approach.

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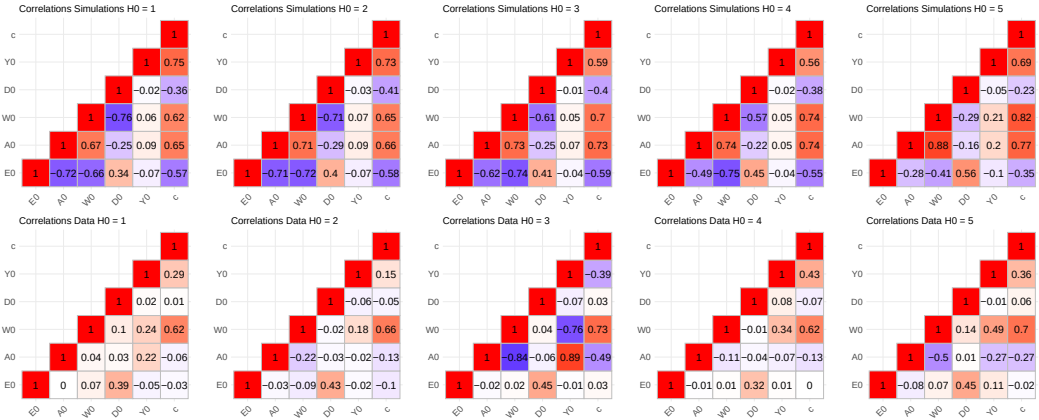
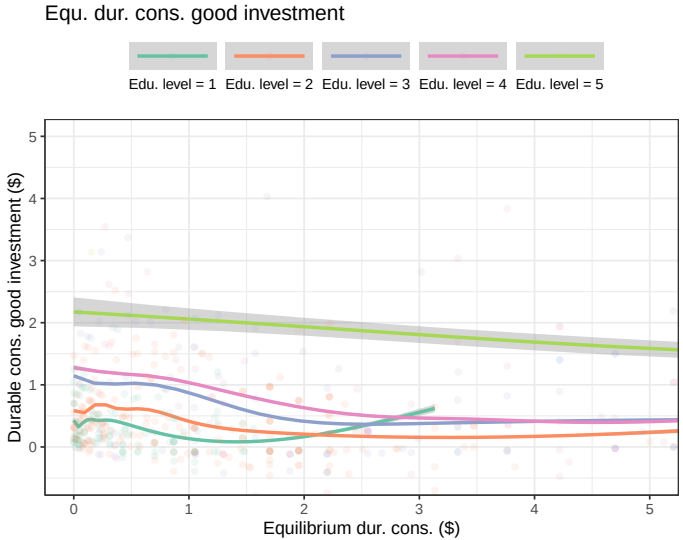
Correlations within stationary distributions

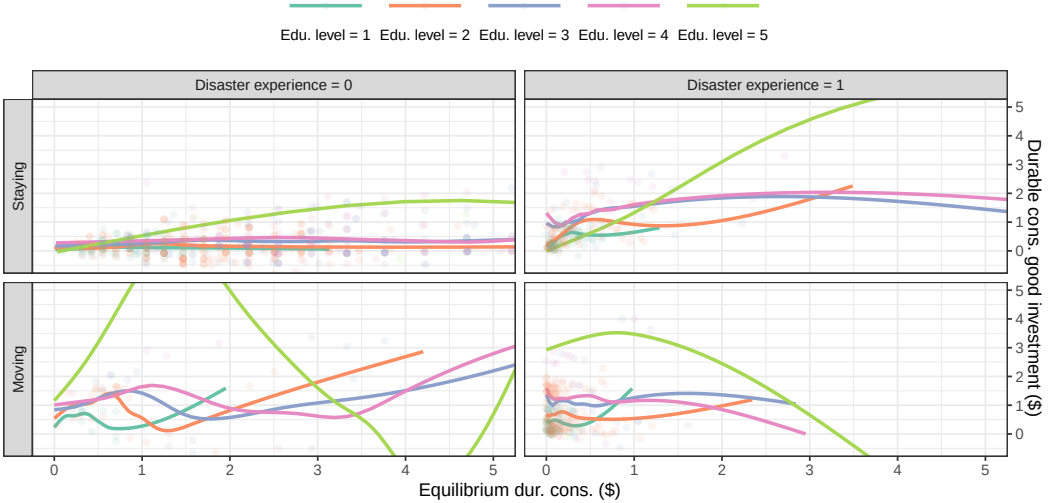


Optimal investment decision



Optimal investment decision

Equ. dur. cons. good investment



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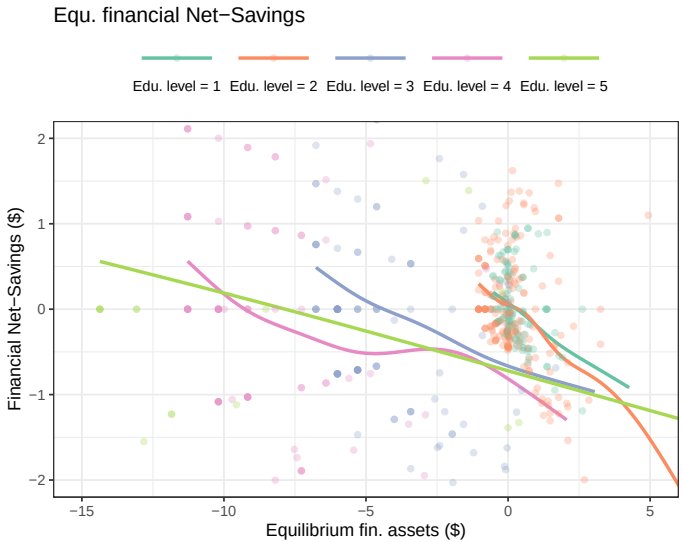

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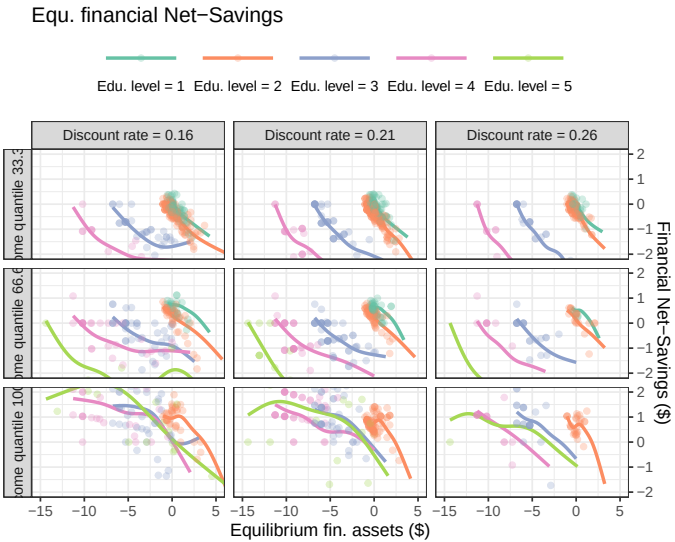

Optimal household decisions

	Dependent variable:					
	Relocation	Exp. Dec.	Savings	Dur. Cons. invest.	Cons.	Prevention
Curr. Exp.	−0.578	1.906	0.646	0.197	−0.169	0.276
Curr. Assets	−0.296	−0.077	−0.251	0.226	0.113	−0.036
Curr. Dur. Cons.	−0.968	−0.232	0.054	−0.182	0.125	0.023
Curr. Income	0.203	−0.233	0.364	0.416	0.181	−0.007
Dis. Exp.	1.216	0.109	−0.392	0.318	−0.035	−0.005
Edu. Class 2	0.173	−0.089	−0.220	0.105	0.075	0.095
Edu. Class 3	−1.514	−0.456	−1.855	1.046	0.615	0.063
Edu. Class 4	−2.794	−0.788	−3.316	1.919	1.024	0.102
Edu. Class 5	−3.194	−0.978	−5.484	3.257	1.792	0.386
Mid Awareness	−0.133	−0.177	0.051	−0.065	−0.037	0.643
High Awareness	−0.303	−0.309	0.078	−0.113	−0.083	1.369
Mid Prev. Access	−0.484	0.013	−0.010	−0.006	−0.001	0.665
High Prev. Access	−0.753	0.041	−0.011	−0.008	0.003	0.985
Mid Time Disc.	0.016	0.010	−0.192	0.087	0.102	0.061
High Time Disc.	0.028	0.022	−0.287	0.131	0.151	0.122
Constant	−0.144	−0.103	−0.492	−0.501	0.289	−3.066

Optimal household decisions

	Dependent variable:									
	Relocation		Exposure Decision		Fin. Net-Savings		Dur. Cons. Good invest.		Consumption	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Curr. Exp.	0.003	−0.578	2.202	1.906	1.277	0.646	−0.122	0.197	−0.329	−0.16
Curr. Assets	−0.045	−0.296	−0.019	−0.077	0.020	−0.251	0.067	0.226	0.027	0.11
Curr. Dur. Cons.	−1.132	−0.968	−0.260	−0.232	−0.114	0.054	−0.080	−0.182	0.180	0.12
Curr. Income	0.199	0.203	−0.235	−0.233	0.343	0.364	0.429	0.416	0.189	0.18
Dis. Exp.	1.015	1.216	0.080	0.109	−0.573	−0.392	0.428	0.318	0.025	−0.03
Edu. Class 2		0.173		−0.089		−0.220		0.105		0.07
Edu. Class 3		−1.514		−0.456		−1.855		1.046		0.61
Edu. Class 4		−2.794		−0.788		−3.316		1.919		1.02
Edu. Class 5		−3.194		−0.978		−5.484		3.257		1.79
Mid Awareness		−0.133		−0.177		0.051		−0.065		−0.03
High Awareness		−0.303		−0.309		0.078		−0.113		−0.08
Mid Prev. Access		−0.484		0.013		−0.010		−0.006		−0.00
High Prev. Access		−0.753		0.041		−0.011		−0.008		0.00
Mid Time Disc.		0.016		0.010+		−0.192		0.087		0.10
High Time Disc.		0.028		0.022		−0.287		0.131		0.15
Constant	−0.949	−0.144	−0.487	−0.103	−0.901	−0.492	−0.394	−0.501	0.387	0.28

Risk, Exposure and Vulnerability

Disaster Risk = Hazard $\times$ Exposure $\times$ Vulnerability

- Hazard: Exogenous from the household perspective.
- Exposure E: What is the probability of the household being affected in case a natural disaster occurs. $\Longrightarrow$ Exposure variable in the model.
- Vulnerability Vul: How strongly is a household affected in case it gets hit by natural disaster. $\Longrightarrow$

$$Vul := \frac{\mathbb{E}_{\mathcal{Y}}[V(E, S, W, \mathcal{Y}, D = 0)] - \mathbb{E}_{\mathcal{Y}}[V(E, S, W, \mathcal{Y}, D = 1)]}{\mathbb{E}_{\mathcal{Y}}[V(E, S, W, \mathcal{Y}, D = 0)] - \underline{V}}$$

- Risk R: Combination of Vulnerability and Exposure in our framework.

$$R = E \times Vul$$

Risk, Exposure and Vulnerability

	Equilibrium Values					
	Exposure		Vulnerability		Disaster Risk	
	(1)	(2)	(3)	(4)	(5)	(6)
Edu. Class = 2	-0.500^{***}	-0.529^{***}	0.043^{***}	0.025^{***}	-0.210^{***}	-0.194^{***}
	(0.003)	(0.003)	(0.001)	(0.001)	(0.002)	(0.002)
Edu. Class = 3	-1.448^{***}	-1.426^{***}	0.145^{***}	0.140^{***}	-0.730^{***}	-0.505^{***}
	(0.004)	(0.004)	(0.001)	(0.001)	(0.003)	(0.003)
Edu. Class = 4	-1.938^{***}	-1.880^{***}	0.220^{***}	0.225^{***}	-1.065^{***}	-0.702^{***}
	(0.005)	(0.005)	(0.001)	(0.001)	(0.004)	(0.003)
Edu. Class = 5	-3.745^{***}	-3.577^{***}	0.208^{***}	0.236^{***}	-2.644^{***}	-1.914^{***}
	(0.015)	(0.015)	(0.002)	(0.002)	(0.015)	(0.012)
Mid Awareness		-0.389^{***}		-0.127^{***}		-0.338^{***}
		(0.004)		(0.001)		(0.002)
High Awareness		-0.660^{***}		-0.312^{***}		-0.680^{***}
		(0.004)		(0.001)		(0.002)
Mid Prev. Acc.		-0.006		-0.088^{***}		-0.082^{***}
		(0.005)		(0.001)		(0.003)
High Prev. Acc.		0.025^{***}		-0.157^{***}		-0.121^{***}
		(0.005)		(0.001)		(0.003)
Mid Disc. Rate		0.116^{***}		-0.023^{***}		0.052^{***}
		(0.003)		(0.001)		(0.002)
High Disc. Rate		0.192^{***}		-0.042^{***}		0.089^{***}
		(0.004)		(0.001)		(0.002)
Income		-0.035^{***}		-0.006^{***}		-0.151^{***}
		(0.001)		(0.0002)		(0.001)
Constant	0.468^{***}	0.934^{***}	-4.266^{***}	-3.902^{***}	-4.752^{***}	-4.022^{***}
	(0.003)	(0.007)	(0.001)	(0.002)	(0.002)	(0.004)