Modelling disaster risk: Assessing the impact of education on risk behaviour

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Motivation

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Large body of empirical literature on the impacts of education on different aspects of household disaster risk. E.g. better educated households on average

- react faster to disaster shocks (Muttarak and Lutz, 2014)
- are better prepared for potential disasters (Muttarak and Pothisiri, 2013; Baker et al., 2011; Thieken et al., 2007).
- are more aware of risk level of current settlement (Peters et al., 2006).
- reside in less exposed areas (Wamsler et al., 2012).

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Goal of this paper is to close this gap: Develop theoretical household model incorporating the most relevant aspect of behaviour with respect to disaster risk.

But why do we need a theoretical model, if we have the empirical findings:

- Behavioural patterns found in empirical data are conditional on the setting they are collected in.
- The patterns might not hold under different regimes, e.g.
  - in counterfactual scenarios
  - after policy interventions

  as this can affect the set of strategies and constraints the households face in their decision making.
- A theoretical model deriving the behavioural patterns directly from individual preferences can
  - deliver more consistent results and predictions.
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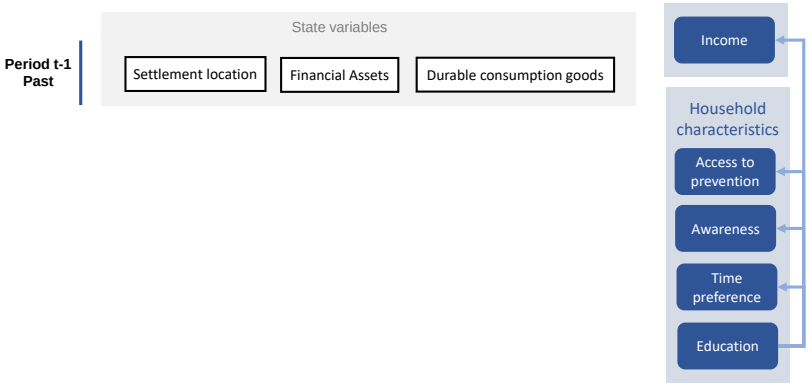
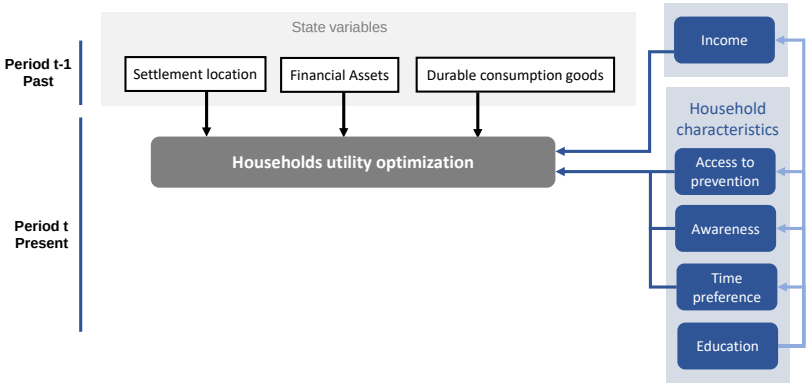

Period t-1
Past
State variables
Settlement location
Financial Assets
Durable consumption goods
Income
Household characteristics
Access to prevention
Awareness
Time preference
Education

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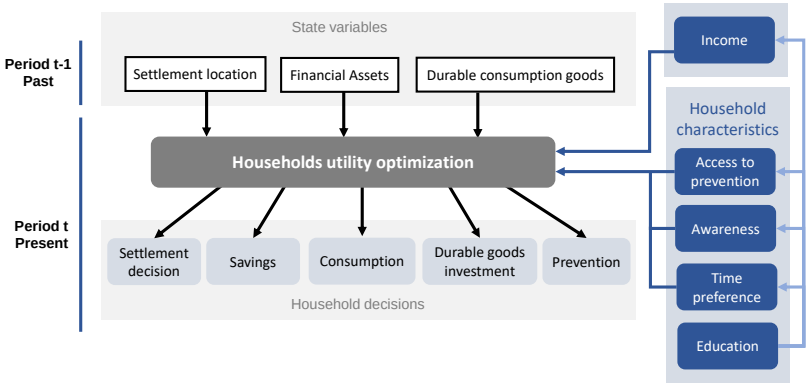
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Durable consumption goods
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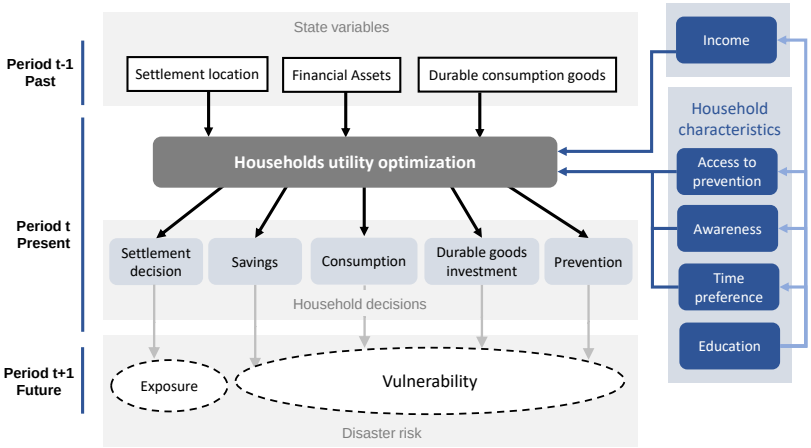
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Disaster risk
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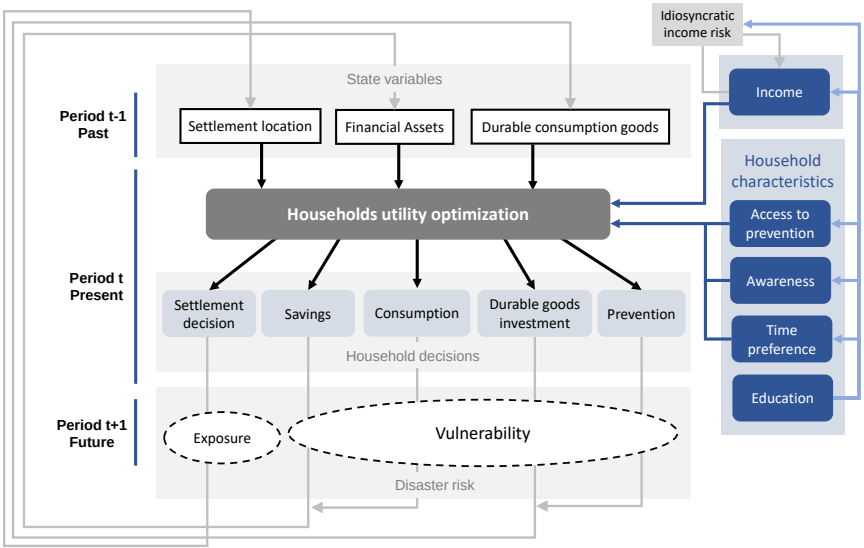
Idiosyncratic income risk
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Period t-1 Past
Settlement location
Financial Assets
Durable consumption goods
Income
Household characteristics
Households utility optimization
Access to prevention
Awareness
Time preference
Education
Period t Present
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Main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

Less exposed settlement location $E \downarrow$

- Lower probability of being struck by natural disaster.
- More expensive.

Settlement relocation $I = 1$

- Allows change in the exposure level of settlement.
- Negative impact on durable consumption goods.

Higher prevention efforts $P \uparrow$

- Less durable consumption goods get destroyed in case of disaster.
- Lead to higher financial costs.
- no impact if HH is not affected by disaster.

Disaster Experience $D = 1$

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

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Mathematical Formulation

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

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

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

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

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

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

- 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.

Numerical Results

Numerical results overview

Solving the mathematical model numerically we derive two main results:

- The decision rules for households, which contain
  - the optimal decisions of a household
  - 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.

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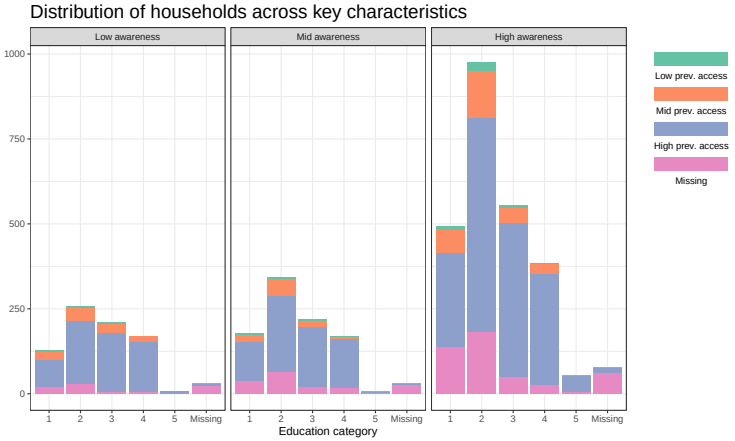
Calibration Data

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

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.



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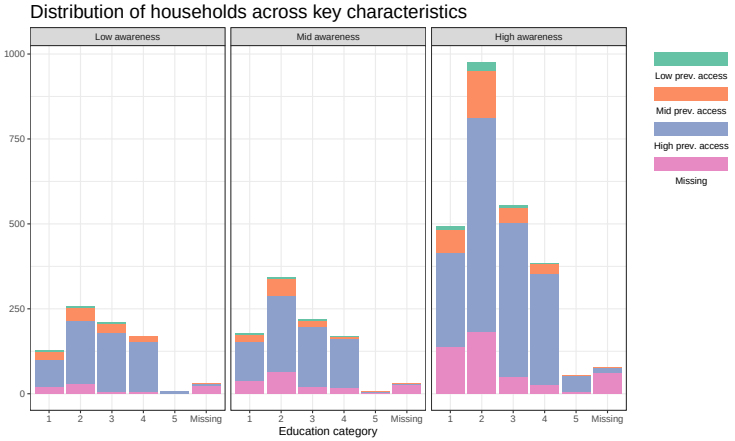
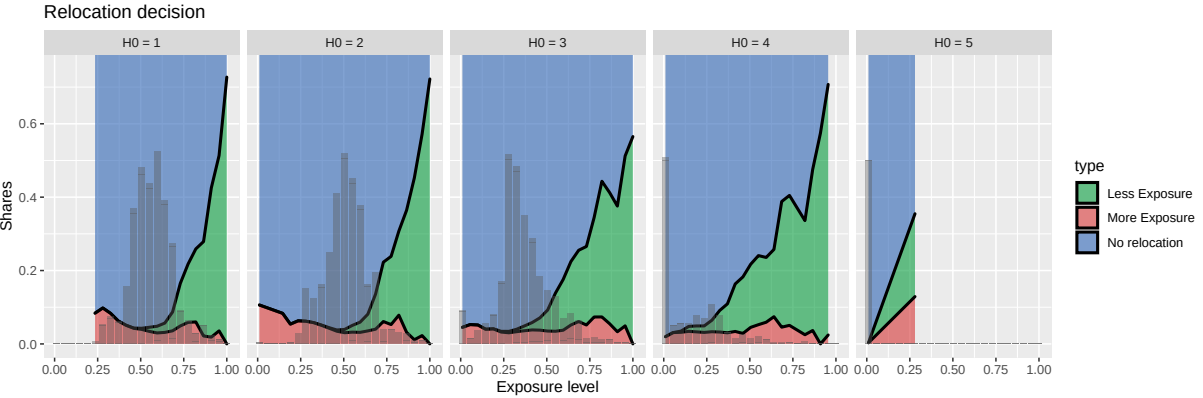


Optimal household decisions

Optimal relocation decision depending on current settlement location.



Exposure, Vulnerability and Risk

	Equilibrium Values					
	Exposure		Vulnerability		Disaster Risk	
	(1)	(2)	(3)	(4)	(5)	(6)
Edu. Class = 2	-0.201^{***}	-0.162^{***}	-0.140^{***}	-0.070^{***}	-0.221^{***}	-0.109^{***}
	(0.003)	(0.003)	(0.003)	(0.003)	(0.005)	(0.004)
Edu. Class = 3	-0.806^{***}	-0.775^{***}	-0.478^{***}	-0.257^{***}	-0.820^{***}	-0.493^{***}
	(0.003)	(0.003)	(0.003)	(0.003)	(0.006)	(0.005)
Edu. Class = 4	-1.965^{***}	-1.889^{***}	-0.778^{***}	-0.320^{***}	-1.783^{***}	-1.111^{***}
	(0.004)	(0.004)	(0.004)	(0.004)	(0.009)	(0.008)
Edu. Class = 5	-4.557^{***}	-4.148^{***}	-1.624^{***}	-0.320^{***}	-5.261^{***}	-3.287^{***}
	(0.030)	(0.029)	(0.017)	(0.014)	(0.159)	(0.125)
Mid Awareness		-0.258^{***}		-0.142^{***}		-0.258^{***}
		(0.003)		(0.003)		(0.004)
High Awareness		-0.455^{***}		-0.262^{***}		-0.471^{***}
		(0.002)		(0.002)		(0.004)
Mid Prev. Access		0.088^{***}		-0.125^{***}		-0.084^{***}
		(0.007)		(0.006)		(0.010)
High Prev. Access		0.182^{***}		-0.198^{***}		-0.117^{***}
		(0.006)		(0.006)		(0.010)
Mid Disc. Rate		0.176^{***}		0.072^{***}		0.157^{***}
		(0.003)		(0.003)		(0.006)
High Disc. Rate		0.255^{***}		0.132^{***}		0.251^{***}
		(0.004)		(0.004)		(0.006)
Income		-0.047^{***}		-0.308^{***}		-0.520^{***}
		(0.001)		(0.001)		(0.002)
Constant	0.263^{***}	0.285^{***}	-3.453^{***}	-2.849^{***}	-3.936^{***}	-3.146^{***}
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Edu. Class = 4	-1.965^{***}	-1.889^{***}	-0.778^{***}	-0.320^{***}	-1.783^{***}	-1.111^{***}
	(0.004)	(0.004)	(0.004)	(0.004)	(0.009)	(0.008)
Edu. Class = 5	-4.557^{***}	-4.148^{***}	-1.624^{***}	-0.320^{***}	-5.261^{***}	-3.287^{***}
	(0.030)	(0.029)	(0.017)	(0.014)	(0.159)	(0.125)
Mid Awareness		-0.258^{***}		-0.142^{***}		-0.258^{***}
		(0.003)		(0.003)		(0.004)
High Awareness		-0.455^{***}		-0.262^{***}		-0.471^{***}
		(0.002)		(0.002)		(0.004)
Mid Prev. Access		0.088^{***}		-0.125^{***}		-0.084^{***}
		(0.007)		(0.006)		(0.010)
High Prev. Access		0.182^{***}		-0.198^{***}		-0.117^{***}
		(0.006)		(0.006)		(0.010)
Mid Disc. Rate		0.176^{***}		0.072^{***}		0.157^{***}
		(0.003)		(0.003)		(0.006)
High Disc. Rate		0.255^{***}		0.132^{***}		0.251^{***}
		(0.004)		(0.004)		(0.006)
Income		-0.047^{***}		-0.308^{***}		-0.520^{***}
		(0.001)		(0.001)		(0.002)
Constant	0.263^{***}	0.285^{***}	-3.453^{***}	-2.849^{***}	-3.936^{***}	-3.146^{***}
	(0.002)	(0.008)	(0.002)	(0.007)	(0.004)	(0.012)

What can we use the model for?

Since the model is able reproduce the empirical data fairly well, it allows us to

- assess the impacts of parameter changes by analysing counterfactual scenarios;
- predict the effects of policy interventions
  - in the short term (immediate reactions of households);
  - in the long term (new equilibrium distributions);

Potential policy interventions to be investigated:

- Awareness program
- Prevention subsidization program
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Modelling disaster risk: Assessing the impact of education on risk behaviour

Michael Freiberger[1] Roman Hoffmann[2] Alexia Prskawetz[3]

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[3]Institute for Statistics and Mathematical Methods in Economics, TU Wien

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Stochastic 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

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:

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

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

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

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

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

- c_t ... consumption
- W_t ... durable consumption goods
- S_t ... financial assets
- E_t ... exposure level ($\in [0, 1]$)
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Analytical results Overview

Analytical results for the FOC are limited:

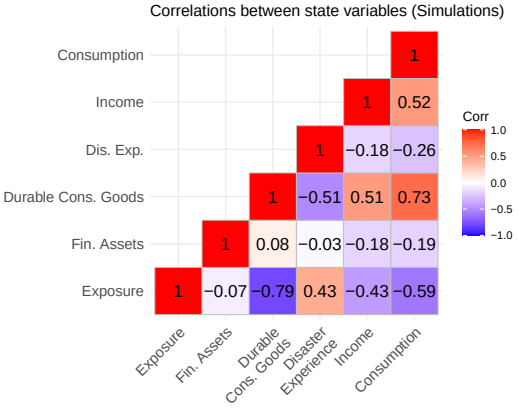
- Depend on intricate expectation operator.

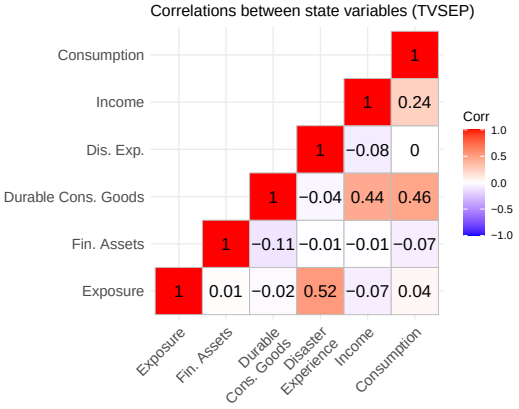
$$u_c(t)\left[p_W^P(t+1)+(p^w)'(t)\right]=u_W(t)+$$
$$+\frac{1-\delta}{1+\rho}\mathbb{E}_t\left\{u_c(t+1)(p^w)'(t+1)(1-\Delta^W I_{t+1})(1-(1-P_{t+1})D_{t+1})\right\}$$

- Depend on derivatives of unknown value function.

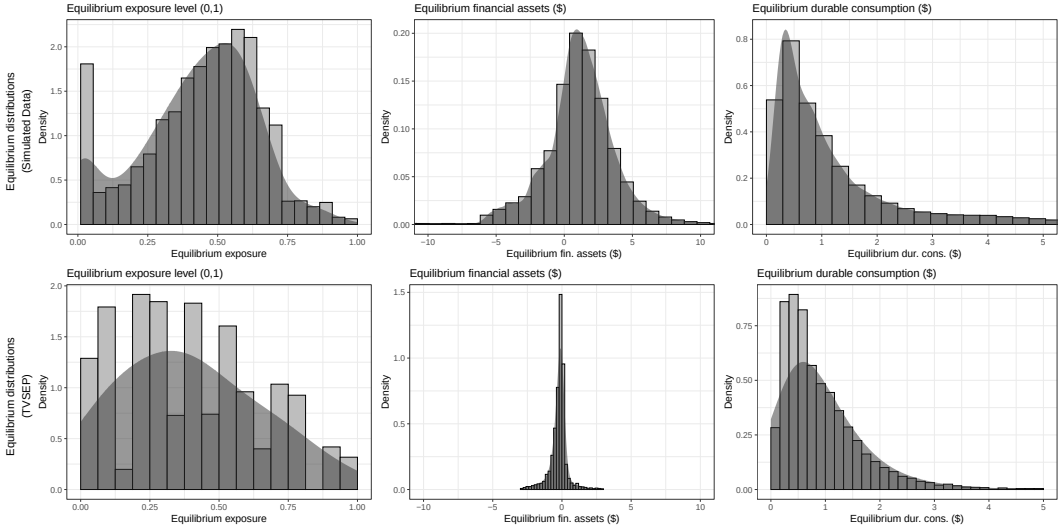
$$u_c(t)\left[p_W^P(t+1)+(p^w)'(t)\right]=u_W(t)+$$
$$+\frac{1}{1+\rho}\Big[aEH\cdot P\cdot\mathbb{E}_{\mathcal{Y}}\frac{\partial V}{\partial W}(E,S,W\cdot P,\mathcal{Y},1)+(1-aEH)\cdot\mathbb{E}_{\mathcal{Y}}\frac{\partial V}{\partial W}(E,S,W,\mathcal{Y},0)\Big]$$

Correlations within stationary distributions

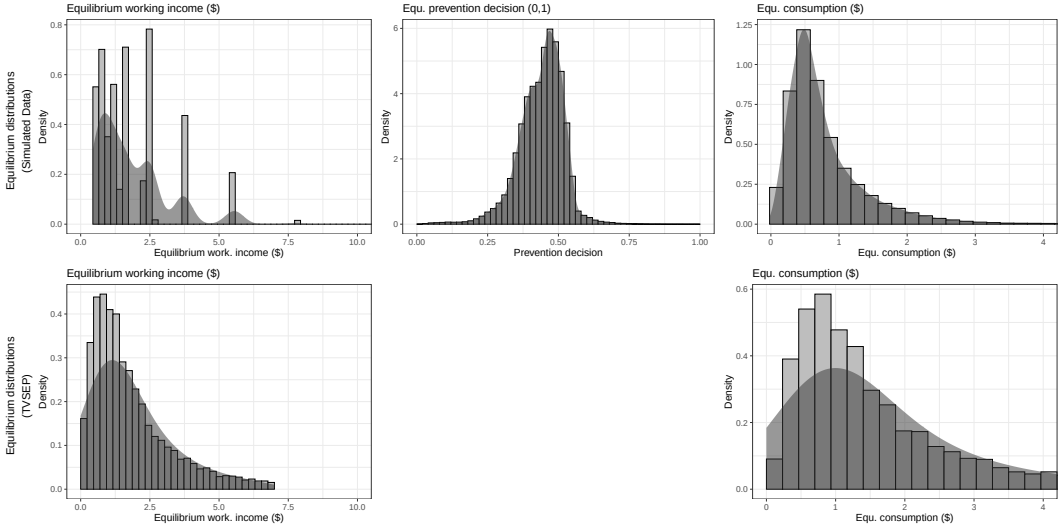




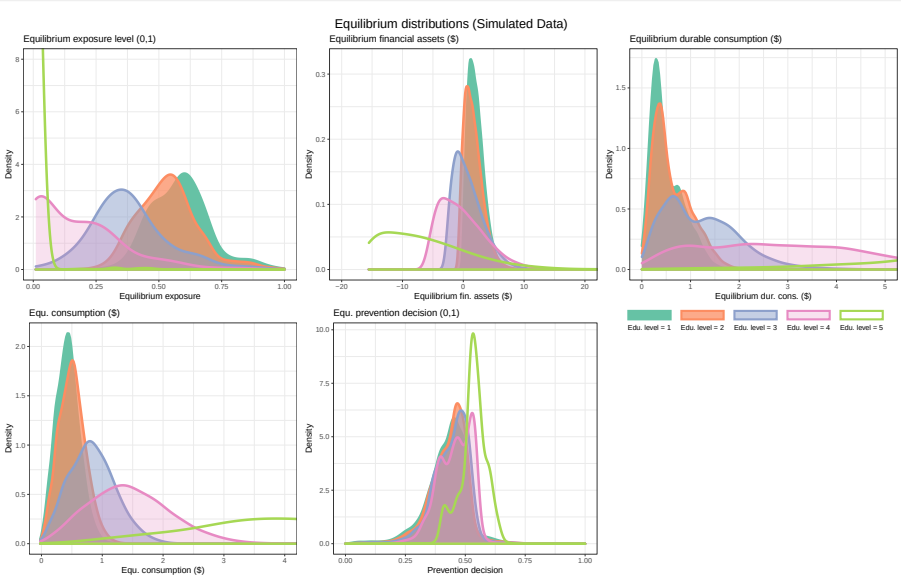
Equilibrium long-run distributions



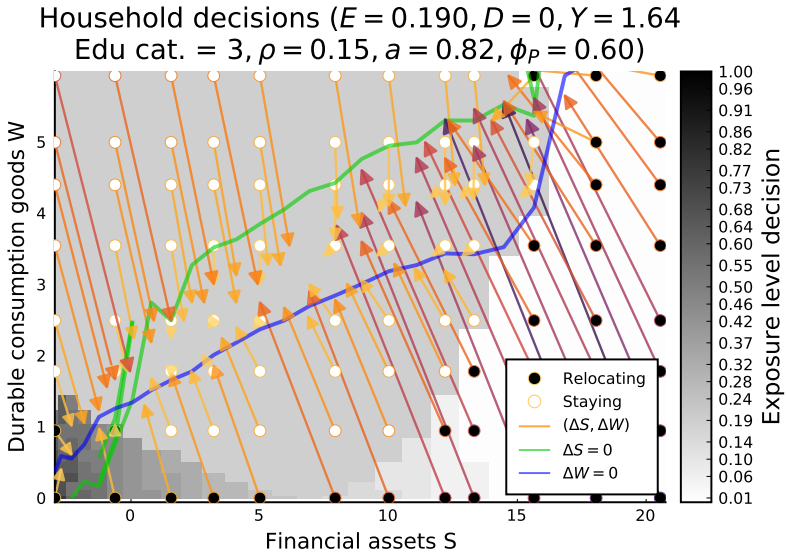
Equilibrium long-run distributions



Equilibrium long-run distributions depending on education

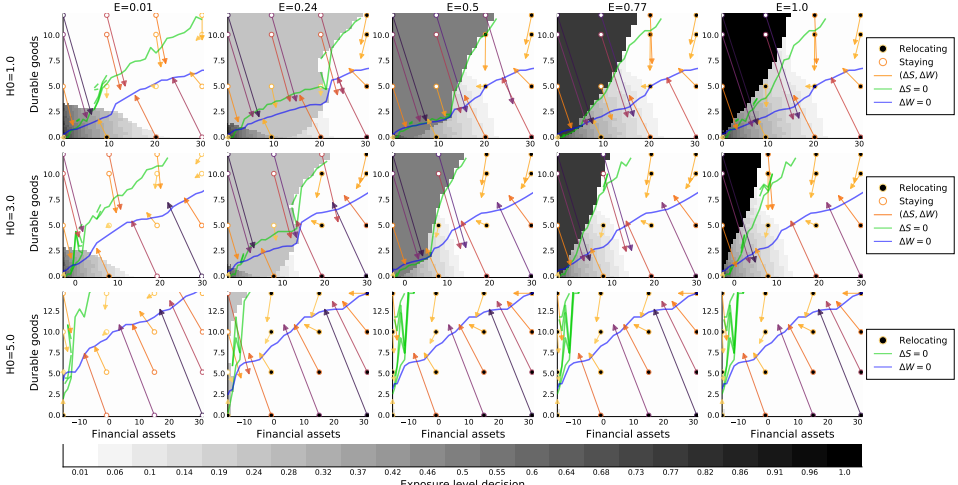


Policy Functions

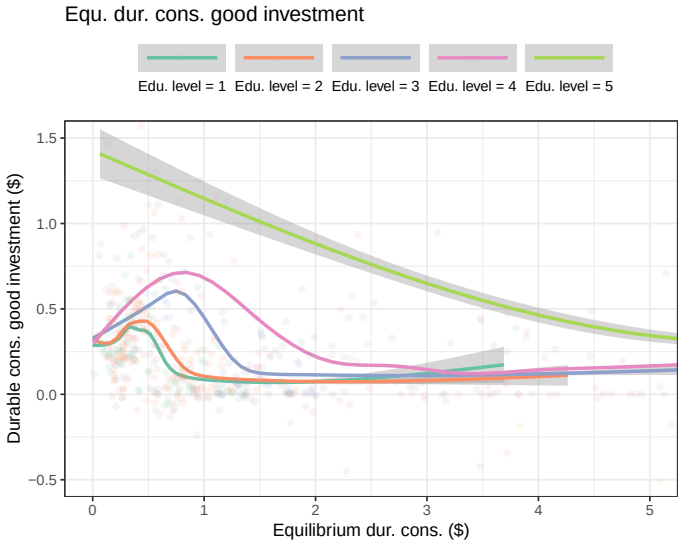


Policy Functions

Household decisions
(D = 0, Y = 1.64, $\rho = 0.15$, a = 0.82, $\phi_P = 0.60$)

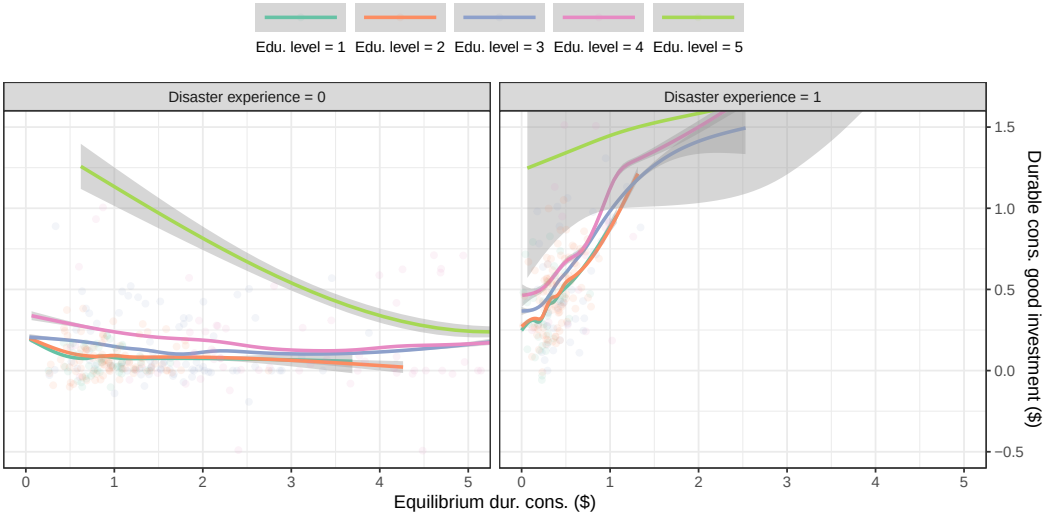


Optimal investment decision



Optimal investment decision

Equ. dur. cons. good investment



Optimal household decisions

	Dependent variable:									
	Relocation		Exposure Decision		Savings		Consumption		Prevention	
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Exposure	−0.690	0.183	3.151	3.153	1.149	0.914	0.081	0.111	−0.175	0.152
Fin. Assets	−0.198	−0.042	0.003	0.024	0.024	−0.121	0.034	0.125	−0.006	−0.001
Dur. Cons. goods	−1.634	−2.024	−0.442	−0.507	−0.283	0.161	0.385	0.096	0.036	0.031
Income	0.305	0.267	−0.072	−0.080	0.590	0.638	0.190	0.160	−0.001	0.001
Dis. Exp.	1.215	0.987	−0.213	−0.254	−0.769	−0.483	0.135	−0.051	0.057	0.054
Edu. Class = 2		0.117		0.023		−0.177		0.116		0.027
Edu. Class = 3		0.687		0.128		−0.683		0.431		0.076
Edu. Class = 4		1.553		0.168		−1.596		0.923		0.143
Edu. Class = 5		2.474		0.573		−5.258		3.463		0.213
Mid Awareness		0.039		−0.059		0.045		−0.019		0.254
High Awareness		0.094		−0.102		0.082		−0.036		0.503
Mid Prev. Acc.		−0.505		0.064		−0.029		0.040		0.485
High Prev. Acc.		−0.673		0.119		−0.047		0.065		0.735
Mid Disc. Rate		0.068		0.039		−0.133		0.100		0.011
High Disc. Rate		0.138		0.052		−0.188		0.134		0.029
Constant	−2.354	−2.345	−1.039	−1.111	−0.897	−0.690	0.047	−0.167	−0.240	−1.484

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.

$$R = E \times Vul$$