The Interaction between Financial and Physical Adaptation to Climate Change

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Research Question

Analysis of the interaction between financial and physical adaptation in the presence of externalities and moral hazard.

$\Rightarrow$ Which influence has the insurance premium design on the optimal physical adaptation strategy and how is the optimal adaptation strategy affected by climate change, risk-externalities and moral hazard?

Risk-Externalities

Physical adaptation measures may have externalities on other individuals.

Examples:

- Wildfire protection
- Landslide protection
- Flood protection

Model

Single-period, non-cooperative principal-agent model in which the insurer (principal) and the insured (agents) are players.

Players are rational and risk-neutral and are exposed to the risk of climate change.

For the following analysis, let

- $y > 0$: initial income
- $l > 0$: potential loss, with $l < y$
- $p > 0$: probability of loss l

Financial and Physical Adaptation

Physical Adaptation:

- $a_i \geq 0$: physical adaptation level,
  with $\frac{\partial p_i}{\partial a_i} < 0$, $\frac{\partial^2 p_i}{(\partial a_i)^2} > 0$, $\frac{\partial l_i}{\partial a_i} < 0$ and $\frac{\partial^2 l_i}{(\partial a_i)^2} > 0$.
- $c(a) \geq 0$: cost of physical adaptation,
  with $\frac{\partial c_i}{\partial a_i} > 0$ and $\frac{\partial^2 c_i}{(\partial a_i)^2} > 0$.

Financial Adaptation:

- $\pi > 0$: insurance premium to completely cover losses l
- $0 \leq \gamma \leq 1$: insured share of loss l

Environmental Quality

Environmental Quality:

- Q: environmental Quality
  (GHG concentration in the atmosphere $\uparrow \Rightarrow Q \downarrow$),
  with $\frac{\partial p_i}{\partial Q} < 0$ and $\frac{\partial l_i}{\partial Q} < 0$

Climate change does not change the cost of adaptation but the efficiency:

$$\frac{\partial c_i}{\partial Q} = 0, \quad \frac{\partial^2 p_i}{\partial a_i \partial Q} \geq 0 \quad \text{and} \quad \frac{\partial^2 l_i}{\partial a_i \partial Q} \geq 0.$$

Risk-Externalities

Physical adaptation may have positive externalities on other individuals, i.e.

$$\frac{\partial p_i}{\partial a_{-i}} < 0, \quad \frac{\partial^2 p_i}{\partial a_i \partial a_{-i}} > 0, \quad \frac{\partial l_i}{\partial a_{-i}} < 0, \quad \text{and} \quad \frac{\partial^2 l_i}{\partial a_i \partial a_{-i}} > 0.$$

Maximization Problem

Summing up, agent *i* faces the following problem to maximize his expected net income

$$a_i^*(a_{-i}) \in \arg\max_{a_i} E(NI_i) = p_i(y_i - (1-\gamma_i)l_i) + (1-p_i)y_i - \gamma_i\pi_i - c_i$$

with $c_i = c_i(a_i)$, $l_i = l_i(a_i, a_{-i}, Q)$ and $p_i = p_i(a_i, a_{-i}, Q)$.

Complete Information

Insurer can ask for risk-dependent premiums. Actuarially fair premium $\pi_i = p_i l_i$.

Maximization constraint:

$$a_i^*(a_{-i}) \in \arg\max_{a_i} E(NI_i) \quad = \quad y_i - p_i l_i - c_i$$

with $c_i = c_i(a_i)$, $l_i = l_i(a_i, a_{-i}, Q)$ and $p_i = p_i(a_i, a_{-i}, Q)$.

FOC:

$$\frac{\partial p_i}{\partial a_i} l_i + p_i \frac{\partial l_i}{\partial a_i} + \frac{\partial c_i}{\partial a_i} = 0$$

Complete Information

Symmetric pure-strategy Nash equilibria for two agents *i* and *j*

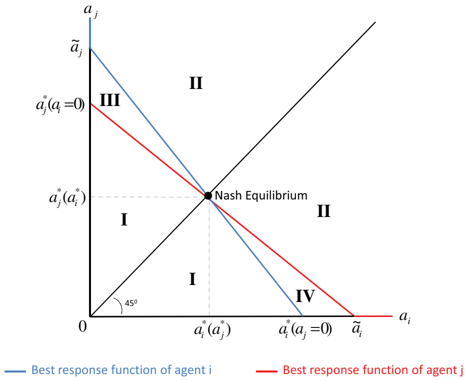

Figure: Best physical adaptation response functions of agent *i* and agent *j*.

Comparative Statics

Physical adaptation of other agents decreases physical adaptation of agent i:

$$\frac{da_i}{da_{-i}} = -\frac{p_i^{a_i,a_{-i}} l_i + p_i l_i^{a_i,a_{-i}} + p_i^{a_i} l_i^{a_{-i}} + p_i^{a_{-i}} l_i^{a_i}}{p_i^{a_i,a_i} l_i + p_i l_i^{a_i,a_i} + 2 p_i^{a_i} l_i^{a_i} + c_i^{a_i,a_i}} < 0$$

Assuming that own physical adaptation has a stronger impact on own risk exposure than physical adaptation of others

$$\frac{da_i}{da_{-i}} \in [-1, 0]$$

Climate change increases optimal physical adaptation of agent i:

$$\frac{da_i}{dQ} = -\frac{p_i^{a_i,Q} l_i + p_i l_i^{a_i,Q} + p_i^{a_i} l_i^{Q} + p_i^{Q} l_i^{a_i}}{p_i^{a_i,a_i} l_i + p_i l_i^{a_i,a_i} + 2 p_i^{a_i} l_i^{a_i} + c_i^{a_i,a_i}} < 0$$

Asymmetric Information

Maximization problem:

$$a_i^*(a_{-i}) \in \arg\max_{a_i} E(NI_i) = y_i - p_i(1-\gamma_i)l_i - \gamma_i\pi_i - c_i$$

with $c_i = c_i(a_i)$, $l_i = l_i(a_i, a_{-i}, Q)$, $p_i = p_i(a_i, a_{-i}, Q)$ and $\pi_i = \pi_i(Q)$.

FOC:

$$-(1-\gamma_i)\left(\frac{\partial p_i}{\partial a_i} l_i + p_i \frac{\partial l_i}{\partial a_i}\right) - \frac{\partial c_i}{\partial a_i} = 0$$

$\gamma = 0$: individually efficient adaptation
$\gamma = 1$: no physical adaptation (moral hazard)

Comparative Statics

Financial adaptation crowds out physical adaptation:

$$\frac{da_i}{d\gamma_i} = \frac{p_i^{a_i} l_i + p_i l_i^{a_i}}{(1-\gamma_i)(p_i^{a_i,a_i} l_i + p_i l_i^{a_i,a_i} + 2p_i^{a_i} l_i^{a_i}) + c_i^{a_i,a_i}} < 0$$

Physical adaptation of other agents decreases physical adaptation of agent i:

$$\frac{da_i}{da_{-i}} = -\frac{(1-\gamma_i)(p_i^{a_i,a_{-i}} l_i + p_i l_i^{a_i,a_{-i}} + p_i^{a_{-i}} l_i^{a_i} + p_i^{a_i} l_i^{a_{-i}})}{(1-\gamma_i)(p_i^{a_i,a_i} l_i + p_i l_i^{a_i,a_i} + 2p_i^{a_i} l_i^{a_i}) + c_i^{a_i,a_i}} < 0$$

Comparative Statics

Climate change increases optimal physical adaptation of agent i:

$$\frac{da_i}{dQ} = -\frac{(1-\gamma_i)(p_i^{a_i,Q} l_i + p_i l_i^{a_i,Q} + p_i^Q l_i^{a_i} + p_i^{a_i} l_i^Q)}{(1-\gamma_i)(p_i^{a_i,a_i} l_i + p_i l_i^{a_i,a_i} + 2p_i^{a_i} l_i^{a_i}) + c_i^{a_i,a_i}} < 0$$

Climate change increases the demand for insurance coverage:

$$\frac{d\gamma_i}{dQ} = \frac{(1-\gamma_i)(p_i^{a_i,Q} l_i + p_i l_i^{a_i,Q} + p_i^Q l_i^{a_i} + p_i^{a_i} l_i^Q)}{p_i^{a_i} l_i + p_i l_i^{a_i}} < 0$$

Conclusion

- Under risk-dependent premiums, financial adaptation is never a substitute to physical adaptation. Individuals choose the individually efficient physical adaptation level which is not socially efficient when externalities exist.
- Under risk-independent premiums, financial adaptation crowds out physical adaptation. Moral hazard and adverse selection increase insurance premiums to a inefficiently high level, so that individuals are better off without financial adaptation in the long term.
- Climate change leads individuals to do more physical adaptation. Under risk-independent premiums, climate change will simultaneously lead to an increased demand for insurance protection, which decreases the incentives for physical adaptation.

Thank you for your attention!

Why should insurance companies care about physical adaptation?

The alleviation of impacts of climate change by physical adaptation measures is essential for the insurance industry to

- preserve the insurability and affordability of insurance coverage
- maintain the feasibility of risk assessment
- preserve the financial stability of insurance companies

Complete Information, Cooperative Case

Maximization constraint for a situation with two agents (i and j)

$$a_i^*(a_j) \in \arg\max_{a_i} E(NI_i) + E(NI_j) \quad = \quad y_i - p_i l_i - c_i + y_j - p_j l_j - c_j$$

with $c_i = c_i(a_i)$, $c_j = c_j(a_j)$, $l_i = l_i(a_i, a_j, Q)$, $l_j = l_j(a_i, a_j, Q)$, $p_i = p_i(a_i, a_j, Q)$ and $p_j = p_j(a_i, a_j, Q)$.

FOC:

$$\left(\frac{\partial p_i}{\partial a_i} + \frac{\partial p_i}{\partial a_j}\right) l_i + p_i \left(\frac{\partial l_i}{\partial a_i} + \frac{\partial l_i}{\partial a_j}\right) + \frac{\partial c_i}{\partial a_i} = 0 \qquad (1)$$

Financial Adaptation

An agent purchases total insurance coverage if the following condition holds

$$\begin{aligned} NI_T &\geq NI_N \\ \pi &\leq p_i^* l_i^* + c_i^* \end{aligned} \tag{2}$$

with $c_i^* = c_i(a_i^*(\lambda_i = 0))$, $l_i^* = l_i(a_i^*(\lambda_i = 0), a_{-i}^*, Q)$, $p_i = p_i(a_i^*(\lambda_i = 0), a_{-i}^*, Q)$, $a_{-i}^* = a_{-i}(a_{-i}^*(\lambda_i = 0))$ and $a_i^*(\lambda_i = 0) = a_i(a_{-i}^*)$ for $a_i^*(\lambda_i = 0)$, the equilibrium value of physical adaptation which maximizes agent i's expected net income without insurance protection for a given state of the global climate Q.

But even with the lowest cost-covering premium condition (2) does never hold.