Preventive Investments Through Climate Insurance Market Design

Vimal Balasubramaniam Ananya Goyal Jan Knoepfle*

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Extended Abstract

Traditional climate insurance providers mitigate local non-diversifiable risks through reinsurance, debt contracts, and, at times, public-private partnerships with state actors. Primary insurers rely heavily on reinsurers, who provide global geographic diversification, thereby transferring risks to the most appropriate financial institutions. Catastrophe (cat) bonds have also been used by reinsurers to manage extreme weather risks. Joint initiatives such as the *Flood Re* scheme in the U.K. and the National Flood Insurance Program in the U.S. help alleviate natural catastrophe (natcat) risks downstream for households and firms. Multilateral agencies such as the World Bank occasionally act as intermediaries to facilitate risk-transfer solutions. However, none of these mechanisms effectively incentivize preventive investment strategies at the downstream level, and some may even reduce incentives, making them temporary solutions to an increasingly severe global challenge.

While insurance companies primarily focus on financial instruments to reduce their exposure to locally non-diversifiable risks, preventive investments that decrease the impact of natural catastrophes are often a socially efficient way to manage climate-related losses. Such investments include broader commitments to climate adaptation infrastructure—typically considered a domain of public finance, which is often constrained and competes with other pressing socio-economic priorities.

*Balasubramaniam: Queen Mary University of London and CEPR. v.balasubramaniam@qmul.ac.uk. Goyal: Queen Mary University of London. a.goyal@qmul.ac.uk. Knoepfle: Queen Mary University of London. j.knoepfle@qmul.ac.uk.

This paper presents a model of preventive investment by primary insurers that cover climate risk. We examine how natcat insurers choose to invest in public preventive measures when incentivized by the secondary market of reinsurers. These investments—such as flood dykes and dams—are local public goods that primarily support climate adaptation and mitigation. As such, they are subject to classic constraints in the provision of public goods, including coordination failures and non-excludability. In competitive insurance markets, firms under-invest in these measures since they cannot fully internalize the benefits. Even when such investments would profitably reduce risk, our initial results already shown in Goyal (2024) suggest that insurers in competitive markets do not supply efficient preventive public goods.

A commonly assumed role of the state in this context is the public provision of preventive investments. However, the localized nature of natcat risks complicates the state's ability to efficiently target disaster-prone areas. Beyond informational challenges, political economy considerations further hinder optimal allocation decisions across geographic regions. Insurers have private information on these risks, but lack the incentive to report truthfully and may overstate the benefits of mitigation investments. The classic Vickrey-Clarke-Groves mechanism (Vickrey, 1961; Clarke, 1971; Groves, 1973) fails to provide incentive for truthful reports when valuations are interdependent; further the complex and potentially large transfers in a VCG mechanism may violate budget or other political constraints.

We analyze the role of reinsurers in addressing these challenges and examine how the availability of preventive investment technologies influences primary insurers' incentives to diversify risk. Reinsurance contracts that are contingent on such investments can incentivize natcat insurers to internalize the benefits of these investments while mitigating free-riding by other natcat insurers in the region. However, these contracts introduce additional frictions: the classic principal-agent problem leads to moral hazard. Due to the ability to transfer risk through reinsurance, natcat insurers may engage in excessive risk-taking by reducing preventive investments. In response, reinsurers invest in costly monitoring of these investments. Our results indicate that an effective contract design is feasible—particularly when a primary insurer that invests in preventive measures receives a guaranteed payoff with full reinsurance while deterring entry by new insurers attempting to free-ride on regional investments.

In the following sections, we present our early results in further detail. We aim to have a full draft of the paper completed next few months and hope to present a more developed version at the symposium.

1 Model

We present an incentive model with primary and secondary markets of natural catastrophe insurance in the presence of a preventive investment technology and locally non-diversifiable disaster risk. These preventive investments have non-excludable benefits by reducing the expected loss from a natural catastrophe. The incumbent primary insurers in the market have better information on localized risks and risk mitigation benefits of the investments than other agents. They also have access to reinsurance contracts to diversify the risk across other regions. Reinsurers reduce the risk exposure of primary insurers, which leads to moral hazard as it disincentivize preventive investments by primary insurers. Hence, the reinsurers write suitable contracts to incentivize and monitor investments and internalize the benefits through reduction in reinsurance premia. We adapt the classical model of financial intermediation with monitoring in Holmstrom and Tirole (1997) and Holmstrom (1982) to model the natcat insurance with information frictions and preventive investments.

Thus, this simplified model has the following agents:

- Primary market of insurance: This market faces non-diversifiable risk and incumbents have more information about the localized risk and risk-mitigation by preventive investment. Insurance firms compete in insurance prices and their investments have a non-excludable reduction in disaster risk of the region, i.e. a positive externality to other firms. They can also buy a reinsurance contract which offers reduces the cost of reinsurance for an increase in preventive investment.

- Secondary market of insurance: Reinsurers write contracts to incentive preventive investments. These investments are verifiable at a cost to the reinsurer, which we model as a monitoring cost. We assume there is a monopolist reinsurer in the market, which we relax later to study the effect of competition in the reinsurance market.

- Potential entrants: These entrants have less information than incumbents and do not observe the private contracts between the primary and secondary insurers. However, they observe the prices charged by primary insurers and the preventive investments, which they use to update the perceived risk of a disaster.

Let the probability of a natural catastrophe be p. If the natcat shock is realized, it results in a loss of $\theta(C)$ where the quantum of loss is a decreasing function of the preventive investment C. The insurer underwrites policies worth $s \times d(P)$, where s is the

share of insurer i in the market and $d(P)$ is the demand for insurance at a price P. The insurer is risk-averse with a generalized mean-variance preference $u(\cdot)$ as in Schoch (2017) and decides on buying reinsurance contract $R \times \theta(C)$ where $R \in [0, 1]$ for a reinsurance premia α under the contract $\{\alpha(C), R(C), C\}$. Note that C is a continuous variable here to reflect varying intensity of climate resilience investments. It is bounded below by 0 and above by $\bar{C}$, which is the highest possible level of investment such that if a natural catastrophe occurs, the quantum of loss is zero, i.e., $\theta(\bar{C}) = 0$. Say the cost of producing C is linear and for simplicity, is C.

The monopolist reinsurer offers the following contract: reinsurance rate R to invest C for a premia α. To incentivize the investment, the reinsurer writes a contract where the reinsurance premia is a decreasing function of preventive investment C. The primary insurer can choose between this contract or no reinsurance (with free choice of C). There is however an ex-post moral hazard because the natcat insurers have a low incentive to invest in (public) preventive investments after buying reinsurance. Even though these are physical investments and are verifiable, the usual result of no moral hazard with fully-contractible effort may not hold here because of the additional externality concern: Even if the contract includes a clause that payments are contingent on the preventive investment, the natcat insurer may not optimally invest unless competition is also limited or are monitored.

Thus, the reinsurer anticipates this and engages in costly monitoring of the investments. The reinsurer faces a monitoring cost of M to verify C, which is increasing in C. Let there be N incumbent insurers in the market with a share s_i of the total demand at market premium P. Offered the reinsurance contract $\{C, R(C), \alpha(C)\}$, the primary insurer i solves the optimization problem:

$$U(P_i; s_i, p, \{C, R(C), \alpha(C)\}) = \max_{C_i, P_i} pu\left[(P_i - (1 - R_i(C_i))\theta(C_i + C_{-i}) - \alpha(C_i))\, s_i d(P_i) - C_i\right] \tag{1}$$

$$+ (1 - p)u\left[(P_i - \alpha(C_i))\, s_i d(P_i) - C_i\right] \tag{2}$$

where $\theta(.)$ is the quantum of loss and it depends on the preventive investments by all insurers in a risk-region pair, $C_i + C_{-i}$.

The monopolist risk-neutral reinsurer has the payoff:

$$\Pi(C,R,\alpha) = \sum_i \Big[p[\alpha(C_i)s_i d(P) - R(C_i)\tilde{\theta}(C)s_i d(P)] + (1-p)[\alpha(C_i)s_i d(P)] - M(C_i)\Big]$$
$$= \sum_i \Big[\Big[\alpha(C_i) - pR(C_i)\tilde{\theta}(C)\Big] s_i d(P) - M(C_i)\Big]$$

where $C_i + C_{-i} = C$ and P is the equilibrium insurance price. The secondary insurer does not know the true expected loss $p\theta$ for a unit of insurance, but a less precise signal $p\tilde{\theta}$.

Say the contract offered by reinsurer is $\{C_1, R_1, \alpha_1\}$. The incentive compatibility constraint for the natcat insurer to choose this over no contract $\{0,0,0\}$ is:

$$U(P_i; s, p, \{C_1, R_1, \alpha_1\}) \geq U(P_i; s_i, p, \{0,0,0\})$$
$$\implies pu\left[(P_i - (1-R_1)\theta(C_i + C_{-i}) - \alpha_1)\, s_i d(P_i) - C_1\right] + (1-p)u\left[(P_i - \alpha_1)\, sd(P_i) - C_1\right] \geq$$
$$pu\left[(P_i - \theta(C_{-i})s_i d(P_i)\right] + (1-p)u\left[P_i s_i d(P_i)\right]$$

This incentive compatibility condition ensures no competition: A potential entrant who does not invest and wants to free-ride will not get any reinsurance and would only find it profitable to either buy the optimal reinsurance contract or not enter the market. This provides a limit to competition in primary insurance industry through the market mechanism; this is necessary for any provision of the public good C in the local risk-region.

If the monitoring cost $M = 0$, then the reinsurer would like the highest possible level of C. This is $\bar{C}$ where $\theta(\bar{C}) = 0$.

$$U(P_i; s, p, \{\bar{C}, R, \alpha\}) > U(P_i; s, p, \{0,0,0\})$$
$$\implies pu\left[(P_i - (1-R)0 - \alpha)\, sd(P_i) - \bar{C}\right] + (1-p)u\left[(P_i - \alpha)\, sd(P_i) - \bar{C}\right] >$$
$$pu\left[(P_i - \theta(C_{-i} sd(P_i)\right] + (1-p)u\left[P_i sd(P_i)\right]$$
$$\implies pu\left[(P_i - \alpha)\, sd(P_i) - \bar{C}\right] + (1-p)u\left[(P_i - \alpha)\, sd(P_i) - \bar{C}\right] >$$
$$pu\left[(P_i - \theta(C_{-i} sd(P_i)\right] + (1-p)u\left[P_i sd(P_i)\right]$$

Thus, the incentive compatibility constraint for $\bar{C}$ is:

$$u\left[(P_i-\alpha)\,sd(P_i)-\bar{C}\right] > pu\left[(P_i-\theta(C_{-i}))sd(P_i)\right]+(1-p)u\left[P_i sd(P_i)\right]$$

for any choice of R offered.

However, reinsurer will not offer this contract because if they do, there is no entry deterrence. Potential entrant i gets the certain payoff of $u\left[P_i sd(P_i)\right]$ if someone accepts the contract $\{\bar{C}, R, \alpha\}$.

This utility with $\bar{C}$ is the same if the contract had full reinsurance ($R = 1$) instead. The primary insurer receives

$$\begin{aligned} U(P_i;\{C,1,\alpha\},s_i,p) =& pu\left[(P_i-(1-1)\theta(C_i+C_{-i})-\alpha)\,s_i d(P_i)-C_i\right] && (3)\\ &+(1-p)u\left[(P_i-\alpha)\,s_i d(P_i)-C_i\right] && (4)\\ =& u[(P_i-\alpha)\,s_i d(P_i)-C_i] && (5)\end{aligned}$$

Thus, the primary insurer gets a certain payoff with full reinsurance as well as with $\bar{C}$, but full reinsurance preserves entry deterrence.

2 Diversification vs. Reinsurance With Preventive Investments

Reinsurance changes the incentives to invest because primary insurers do not internalize the benefits of risk mitigation.

For example, consider a natcat insurer who sells insurance claims Q_j for the price P_j in region-risk pair j. They also buy reinsurance in the secondary market which pays out $R(Q_j)$ for a charge of $\alpha R(Q_j)$. They can also invest in preventive technology C_j which reduces claims payout $\theta(C_j)$ in j for a cost of $F(C_j)$. They have some mean-variance preference u.

$$u(\Pi) = u\left[(P_j-\theta(C_j))\,Q_j - F(C_j) + R(Q_j) - \alpha R(Q_j)\right] \tag{6}$$

We focus on the range of C_j where the investment is efficient, i.e., $u(-\theta'(C_j)Q_j - F'(C_j)) > 0$. If the reinsurance premia α does not account for the level of preventive investment, then with full insurance $R(Q_j) = \theta(C_j)Q_j$,

$$u(\Pi) = P_j Q_j - R(Q_j) - F(C_j) + R(Q_j) - \alpha R(Q_j)$$
$$\implies C_j^* = 0$$

In other words, a risk-neutral firm with full reinsurance that cannot internalize the benefit of preventive investment has no incentive to invest (with or without competition).

Naturally, this is different from the case of full diversification across many risk-region pairs because at the margin, the primary insurer will still have the incentive to invest in a specific risk-region j if the investment is efficient.

$$u(\Pi) = u\left[\Sigma_{j \in N} \left(P_j - \theta(C_j)\right) Q_j - F(C_j)\right] \tag{7}$$

If $\theta_j'(C_j) > F'(C_j)$, then a (monopoly) natcat insurer will invest (keeping aside competition concerns), even if N is large.

3 Why Does Public Provision Fail?

We began by assuming that primary insurers have an information advantage about the risk-region compared to any potential entrant or the state. When the government does not know the level of efficient investment – and the regions they are meant to invest in – successful public provision is non-trivial. For instance, eliciting this information from primary insurers so as to enable efficient investment as in Vickrey (1961), Clarke (1971), and Groves (1973) (VCG) may be one option. However, truthful elicitation is difficult under the VCG mechanism because valuations from different primary insurers are likely inter-dependent, and the complex transfer rules are potentially impractical in low-capability contexts. As shown earlier, primary insurers have strong incentives to maximize state investments into preventive measures that are potentially not socially optimal. Furthermore, considering the (limited) extent of competition in primary insurance industry around the world, the potential for collusion to misreport among natcat insurers could also hinder efficient public good provision. Finally, the political economy considerations also motivate us to find a non-state mechanism that improves investments into preventive infrastructure and climate resilience in the world.

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