Global Earth Observation - Benefit Estimation: Now, Next and Emerging

GEOBENE

Assessing the economic, social and enviromental benefits of the GEO domains

Will GEO Work? – An Economist View

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We use a game-theoretical approach to model a global partnership in building global earth observation system. Our analysis of possible equilibrium solutions shows that only in the case of similar economies we will observe cooperation behavior (when all invest into global system) and otherwise we will observe free-riding. However uncertainty in environmental risks valuing can provide a strong incentive for free-riders to cooperate.

MODELING FRAMEWORK

- Aggregated macroeconomic model of a society under the threat of extreme events (catastrophes)
- **GEOSS**: Preventive measures to increase society's welfare
- **Global Partnership**: "Investment Game" in multi-society world

MODEL

We consider a stylized neoclassical model of the development of an economy affected by random natural hazards (treated as suggested in [1]).

Capital stock dynamics: $K_{i+1} = ((1-\delta)K_i + I_{i+1}) \cdot D_{i+1}, \quad i = 0,1,\ldots,\infty$

Here K_i is the capital stock, δ is a capital depreciation rate, I_i is investment, and D_i is an extreme event (random variable).

Production output $Y_{i+1} = \alpha K_i$ in period 0 is divided between investment I_1, consumption C_1, and investment z in the development of prevention measures, $Y_1 = I_1 + C_1 + z$; at all other periods ($i>1$) output is divided between investment and consumption, $Y_{i+1} = I_{i+1} + C_{i+1}$

Extreme event occurs with probability q_i causing the loss of fraction d of the capital stock

$$D_i = \begin{cases} 1-d, & \text{with probability } q_i \\ 1, & \text{with probability } 1-q_i \end{cases}$$

Probability q_i endogenously depends on the preventive measures z:

$$q_i = \frac{q_0}{1+\kappa z}, \quad i = 1,2,\ldots$$

Here q_0 is the probability of disasters without any preventive measures, and κ is a given positive coefficient characterizing the efficiency of investment.

Social planner chooses consumption level in order to **maximize** the economy's utility, expected value of the **social welfare** (ρ is a positive social discount rate):

$$W(z) = \max_{C_i} E\left(\sum_{i=0}^{\infty} (1+\rho)^{-1} \log C_i\right),$$

Proposition 1 ([2]). *For every* $z \in [0, \alpha K_0)$ *, the optimization problem has the unique solution*

$$W(z) = \log(1-s_0) + \tfrac{1}{\rho}\log\big((1-\delta)K_0 + s_0(\alpha K_0 - z)\big)$$
$$+ \log(\alpha K_0 - z) + \tfrac{1}{\rho}\log\rho + \tfrac{1+\rho}{\rho^2}\log\rho\left(\tfrac{\alpha+1-\delta}{1+\rho}\right)$$

where

$$s_0 = \begin{cases} \frac{\alpha K_0 - z - \rho(1-\delta)K_0}{(\alpha K_0 - z)(1+\rho)} & \text{if } z < (\alpha + \rho\delta - \rho)K_0, \\ 0 & \text{otherwise} \end{cases}$$

Optimal investment z in prevention measures

$$\text{Maximize } W(z) \text{ over all } z \in [0, \alpha K_0).$$

Proposition 2. *Optimal investment problem has the unique solution z*. If*

$$\kappa K_0 \left| q_0 \log(1-d) \right| \le \frac{\rho(1+\rho)}{1+\alpha-\delta},$$

then z=0, otherwise z* is positive (for exact formula see ([2]).*

Corollary. Economy refrains from investing in the prevention measures if its ability to cope with natural hazards (κK_0) is low, or the measure of danger, caused by natural hazards ($\left|q_0 \log(1-d)\right|$) is not high enough.

INVESTMENT GAME

- Two independent economies both under the threat of natural disasters
- Each of the economies can make an investment (z^1, z^2) in common prevention measures aimed at mitigating the impact of natural hazards on both economies
- Each economy is subject the same dynamics as in the previous section but with its own set of parameters (indicating by corresponding indexes).

Effect of joint investments is achieved by the modification of the rule how probability of the occurrence of natural hazards changes after the implementation of prevention measures

$$q_i = \frac{q_0}{1+\kappa^1 z^1 + \kappa^2 z^2}, \quad i = 1,2,\ldots$$

Each economy is maximizing its own welfare

$$\text{Maximize } W_1(z^1, z^2) \text{ over all } z^1 \in [0, \alpha^1 K_0^1).$$
$$\text{Maximize } W_2(z^1, z^2) \text{ over all } z^2 \in [0, \alpha^2 K_0^2).$$

This is a non-zero-sum game and we can characterize its equilibriums:

Proposition 3. *Investment game problem always has a unique Nash equilibrium solution (z^{1*},z^{2*}).*

It can be shown that in the context of perfect knowledge about model's parameters the case when both economies invest ($z^{i*}>0$) into preventing measures (we call this **cooperative behavior**) happens only among similar economies. Figure 1 shows the example how narrow is the *"cooperation zone"* (economies' initial capitals must belong to the black area to reveal the cooperative behavior).

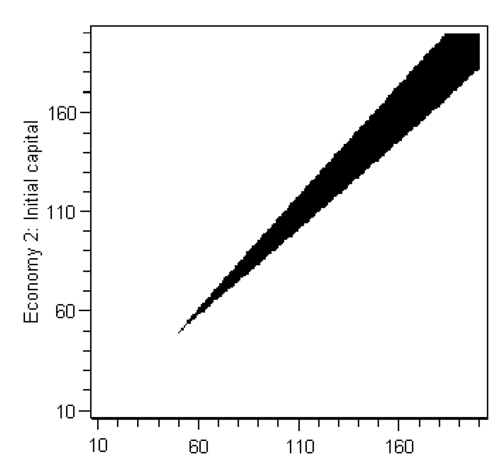

Figure 1.

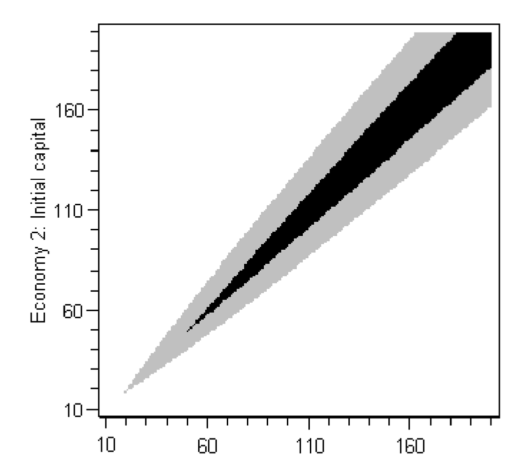

Figure 2.

However if we take into account uncertainties naturally existing in the model (parameters like probability of natural disasters, q_0 and their impact on capital stock, d) we found that for some of previously non-cooperative economies there will appear additional cooperative solutions. Figure 2 shows that 10% uncertainty in the probability (q_0) of occurring of natural disaster leads to the increasing of "cooperation zone" of Figure 1 more than twice. Grey area on the figure describes the economies where cooperation becomes an option.

CONCLUSIONS

- Emergence of a joint GEOSS infrastructure as a Global Partnership is unlikely to materialize basing only on economical interests:
  - "Rich" always pays in its own interest;
  - Involving "Poor" only under special cases;
  - Free-rider problem to establish global infrastructure;
- Uncertainty in risk valuing provides an incentive for cooperation;
- Arising non-uniqueness of equilibrium solutions leads to necessity of additional negotiations between countries to set appropriate investments level.

[1] Z. Chladna, E. Moltchanova, and M. Obersteiner, "Prevention of Surprise", in: S. Albeverio, V. Jentsch, H. Kantz (Eds.), Extreme Events in Nature and Society, Springer, vol. 352, pp. 295–318, 2006.
[2] A. Kryazhimskiy, M. Obersteiner, and A. Smirnov, "Infinite-horizon dynamic programming and application to management of economies effected by random hazards ", Appl. Math. Comput., 205, pp. 609–620, (doi:10.1016/j.amc.2008. 05.042), 2008.

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