How to Design Public-Private Partnerships in a Changing World? (When Infrastructure Becomes a Really "Hot" Topic.)

David Martimort (*EHESS, PSE*)
and
Stéphane Straub (*TSE, Arqade and Idei*)

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Introduction

- Climate change raises unprecedented challenges for large investments in infrastructure (sectors with Long-Lived Capital Stock: Power plants, 30-40 years; energy distribution networks, water and transportation infra, 30-100 years).
- Growing uncertainty in future climate makes it difficult for agents to base long-term decisions on standard models assigning reliable probabilities to different scenario (Weitzman, 2009; Hallegate, 2009).
- Situation especially pressing in LDCs: greater need for investment in LLKS and expectation that impact of climate change will be stronger (WDR, 2010).

Introduction

- Large and growing uncertainty on future values of environmental parameters: e.g., IPCC (2007) projects rises in temperature between 1.1 and 6.4$\circ$C over 21st century.
- Difficult to pinpoint even proba distribution for future outcomes; disastrous collapses possible.
- Extreme climatic events: link between growing aggregate uncertainty and local impacts. Ex: (Kunreuther & Michel-Kerjan, 2009): insurers' losses from natural catastrophes (hurricanes) since 1990 been greater than in entire previous history of insurance

Introduction

- Climate change related hazards are especially relevant for infrastructure:
  - Acceleration in rate of climate change: long-lived invts will have to cope with larger range of climatic conditions.
  - nature of infra invts: sensitivity to precipitations, rivers and glacial runoffs, drought and floods (water collection and distribution networks), extreme temperatures (roads, bridges, energy plants and distribution networks).
  - Urbanization in LDCs: sensitivity to local events.
  - Transition to technologies that mitigate impact of infra on climate change also likely to increase costs: for first time in mankind’s history, current change in energy technological mix away from fossil fuels implies shift towards less energy-efficient sources

Introduction

- Some evidence of a link between anthropogenic GHG concentration and local extreme events (heat waves, floodings and precipitations). (Stott et al., 2004, Pall et al., 2011, Min et al., 2011).
- However, uncovering the exact channels and providing precise future projections appear to be beyond current scientific possibilities.

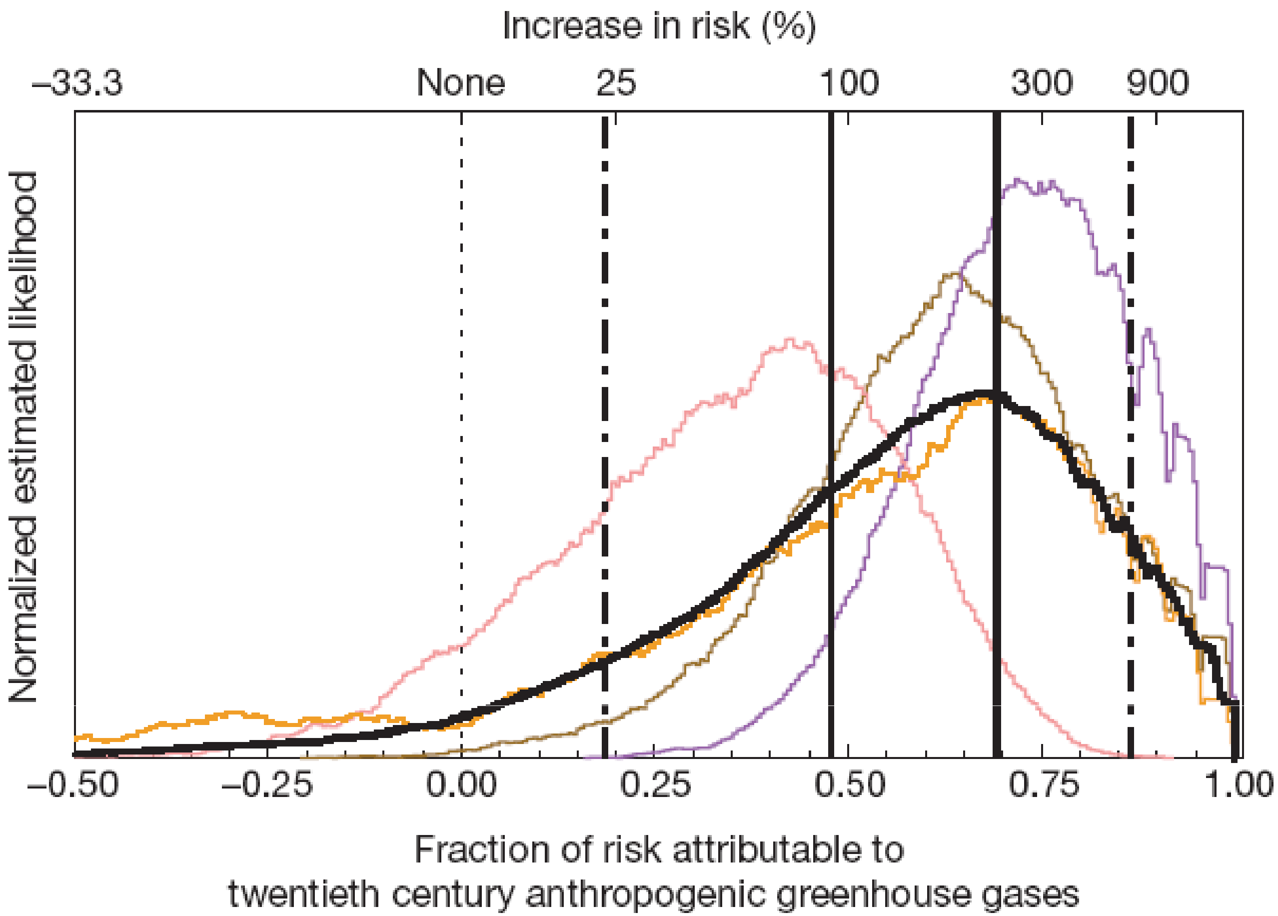

Figure 4 | Attributable risk of severe daily river runoff for England and Wales autumn 2000. Histograms (smoothed) of the fraction of risk of severe synthetic runoff in the A2000 climate that is attributable to twentieth-century anthropogenic greenhouse gas emissions. Each coloured histogram shows this fraction of attributable risk (FAR) with respect to one of four A2000N climate estimates in Fig. 3 (with corresponding colours). The aggregate histogram (black) represents the FAR relative to the full A2000N climate, with the dot-dashed (solid) pair of vertical lines marking 10th and 90th (33rd and 66th) percentiles. Top axis is equivalent increase in risk.

Introduction

- Need to assess effects on proximate climatic manifestations and physical environment for infrastructure equipments: Piao et al. (Nature, 2010):

  "...notwithstanding the clear warming that has occurred in China in recent decades, current understanding does not allow a clear assessment of the impact of anthropogenic climate change on China's water resources and agriculture...". "...one cannot rule out the possibility of strong negative climate change impacts on food production, even though the most optimistic scenario provides a net increase."

Introduction

- Paper asks two main questions:

1. How is suitability of standard PPP model affected by dramatic increase in uncertainty, potentially coupled irreversibility and learning.
2. What does this imply in terms of technological choices for long-lived projects: degree of flexibility of technologies that trade off lower future adaptation costs against larger upfront investments.

Introduction

- Uncertainty + irreversibility (learning on shock at t=2) create an option value of waiting (Arrow & Fisher, 74, Henry, 74, Dixit & Pindyck, 94).
- Implies under-investment in period 1.
- Bulk of our analysis consists in studying how these incentives for flexibility are modified when agency issues are taken into account.
- Main issue for principal: how to counteract this by tailoring contract properly: optimal shape of (t_1, t_2)?

The Model

- Consider a partnership or concession contract between a government ("principal") and a private firm ("agent") for the provision of public service (e.g., transportation, telecommunication, energy, water, sanitation).
- Relationship lasts over 2 periods:
  - Initial investment at date $T = 1$
  - Additional investment at date $T = 2$.
- For most of paper, relationship between the principal and his agent run by long-term contract covering both periods.

The Model

Technology and Uncertainty

- 1^{st} stage: agent designs infrastructure. Social value is S_0, but can become S_0+S if successful.
- Project successful with proba e_1 if agent exerts non-monetary effort e_1 (altern: e_1 is a non-verifiable investment), with cost $\psi(e1)$ ($\psi(0)=0$, $\psi'>0$, $\psi''>0$, $\psi'''>0$, $\psi'(0)=0$, $\psi'(1)=+\infty$). Optimal effort $\in [0,1]$, i.e., is proba of success.
- Second stage: project only remains successful and yields extra benefit S if agent exerts non-monetary effort e_2, with cost $\psi(e_2)$.

The Model

Technology and Uncertainty

- Complementarity between 1st and 2nd stage investments creates irreversibility: one cannot disinvest once initial infrastructure has been set up. Only possibility is to maintain assets:

$$e_2 \geq e_1. \qquad (1)$$

⇒ Intertemporal technological constraint.

The Model

Technology and Uncertainty

- 2nd period proba of success is θe_2 if effort e_2 .
- θ can be interpreted as a productivity shock linked to climate change. Distributed on interval $[0, \bar{\theta}]$ according to a cdf $F(.)$ with everywhere positive and atomless density $f(.) = F'(.)$.
- $\theta = 0$: no possible increase in social value in 2nd period, i.e., climate change has extreme detrimental impact on welfare.

The Model

Technology and Uncertainty

- $E_\theta(.) = 1$: "average" proba of success constant, no "intertemporal productivity drift" over time.
- There is ex ante uncertainty on realization of productivity shock θ although it is known at time of choosing 2^{nd} period effort.
- Together with irreversibility constraint (1), this will justify adopting flexible technologies at earlier stage even without agency.

The Model

Contracts

- Agent' efforts are non-verifiable.
- Agent is protected by limited liability (no profit loss), so incentives can only be given with rewards in case of good performances, i.e., when *S* has realized.
- We will be interested in design of intertemporal contracts that limit amount of agent's limited liability rent.
- We denote by $\boldsymbol{(t_1; t_2)}$ a long-term contract that specifies a profile of payments to the firm following good performances in each period.

The Model

Preferences

- δ the discount factor common to all players.
- Intertemporal payoff of the principal (2):

$$V(t_1, t_2, e_1, e_2(\cdot)) = e_1(S - t_1) + \delta E_\theta(\theta e_2(\theta, e_1, t_2))(S - t_2).$$

- Intertemporal profit (liability rent) of agent (3):

$$U(t_1, t_2) = \max_{e_1} \left\{ e_1 t_1 - \psi(e_1) + \delta E_\theta \left(\max_{e_2 \geq e_1} \theta e_2 t_2 - \psi(e_2) \right) \right\}$$

with

$$e_2(\theta, e_1, t_2) = \arg\max_{e_2 \geq e_1} \theta e_2 t_2 - \psi(e_2)$$

Solving the Model: Benchmark

- Government itself invest in both periods (equiv. to case of verifiable agents' efforts that can be contracted upon ex ante).
- If shock θ unknown at time of making 2nd period investment, optimal efforts same in both periods

$$e^u{}_1 = e^u{}_2 = e^u = \varphi(S)$$

where $\boldsymbol{\varphi} = \psi'^{-1}$.

Solving the Model: Benchmark

- If shock θ known at date $T = 2$:

$$e_2(\theta S, e_1) = max\{\varphi(\theta S), e_1\} \qquad (5)$$

- 2^{nd} period investment constrained by 1^{st} period commitment only if θ low enough: $\theta \leq \theta^* = \frac{\psi'(e^1)}{S}$
- Principal has positive option value of waiting till θ gets known to invest more in 2^{nd} period. To gain flexibility over wider region of possible realizations for θ, he reduces 1^{st} period effort.
- Optimizing yields (6):

$$\psi'(e_1^i(\delta)) = S\left(1 - \delta \int_0^{\frac{\psi'(e_1^i(\delta))}{S}} F(\theta)d\theta\right) \Rightarrow e_1^i(\delta) < e^u$$

Agency and Flexibility

- Building and operating tasks delegated to agent. Maximization of (3) yield 2nd period IC:

$$e_2(\theta t_2, e_1) = max\{\varphi(\theta t_2), e_1\}. \qquad (9)$$

- Technological constraint binding for θ low enough: agent would like to disinvest but (1) precludes this.
- As a result, we expect agent to underinvest in the first-period to keep more flexibility ex post.

Long-term Contracts

- Inserting expression of $e_2(\theta t_2, e_1)$ in (3):

$$U(t_1, t_2) = \max_{e_1} e_1 t_1 - \psi(e_1) + \delta \left(\int_0^{\frac{\psi'(e_1)}{t_2}} (\theta e_1 t_2 - \psi(e_1)) f(\theta) d\theta + \int_{\frac{\psi'(e_1)}{t_2}}^{\bar{\theta}} R(\varphi(\theta t_2)) f(\theta) d\theta \right)$$

- Optimizing w.r.t. to e_1 yields 1st period IC constraint (10)

$$\psi'(e_1) = t_1 - \delta t_2 \int_0^{\frac{\psi'(e_1)}{t_2}} F(\theta) d\theta.$$

- Similar to (6), equal for $t_1 = t_2 = S$.

Long-term Contracts

- Better long-term contracts can be designed, by:

1. Diminishing rewards for good performances to better extract agent's liability rent (choose $t = t_1 = t_2 < S$): stationary contracts.
2. Fine-tuning power of incentives over time (choose $(t_1; t_2)$ such that $t_2 = \gamma t_1$): non-stationary contracts.

Stationary Contracts

- Prop 1: (δ small enough) Optimal per-period reward $t^s(\delta)$ is downward distorted below first-best:

$$S = t^s(\delta) + \frac{\Phi(t^s(\delta), \delta)}{\frac{\partial \Phi}{\partial t}(t^s(\delta), \delta)} > t^s(\delta)$$

- It induces less effort than when principal invests:

- Distortion depends on inverse elasticity of effort supply (t^0 reward of myopic agent, cares only about t_1, $\delta = 0$):

$t^s(\delta) \leq t^0$ *(resp.* $\geq$*)* $\Leftrightarrow$ $d/dx[x\varphi'(x)/\varphi(x)] \leq 0$ *(resp.* ≥ 0*)*

Stationary Contracts

- Intuition: 2 effects.
  - *First-period effect*: when δ increases, flexibility becomes more attractive and θ^* decreases. This makes an increase in the stationary reward t less attractive in first-period. Agent's incentives for first-period investment are now countered by the flexibility motives.
  - *Second-period effect*: increasing t more attractive as δ increases because raises probability of success for all favorable productivity shocks θ for which earlier commitments no longer bind.
  - When elasticity of effort supply decreasing, the agent's effort less responsive to rewards when the marginal returns on effort is higher (on upper tail of distribution of θ). The first-period effect dominates and the optimal stationary reward is lower than with myopic players.

Non-Stationary Contracts

- Fine-tuning (t_1; $t_2 = \gamma t_1$).
- Denote $\zeta(\delta,\gamma)$ unique solution in $(0, \gamma^{-1})$ for:

$$\zeta(\delta, \gamma) = \frac{1}{\gamma} - \delta \int_0^{\zeta(\delta,\gamma)} F(\theta) d\theta$$

- Interval $[0, \zeta(\delta,\gamma)]$ set of possible productivity shocks where agent does not add new investment, with $\zeta(\delta,\gamma)$ decreasing in γ.

Non-Stationary Contracts

- Prop 2: optimal long-term contract ($t^*_1(\delta)$, $t^*_2(\delta) = \gamma^*(\delta)t^*_1(\delta)$) in presence of agent's motives for flexibility is such that, when δ is small enough:

$$t_2^*(\delta) \geq t_1^*(\delta) \Leftrightarrow \frac{d}{dx}\left(\frac{x\varphi'(x)}{\varphi(x)}\right) \leq 0.$$

- Prop states conditions under which increasing (resp. decreasing) profile of rewards is preferred by principal: Inverse elasticity of effort supply must be increasing (technological assumption)

Non-Stationary Contracts

- Intuition:
  - when elasticity of labor supply is decreasing and contracts are stationary, principal reduces the per-period reward more than in case of myopic behavior: first-period effect dominates.
  - When non-stationary contracts feasible, principal plays on rewards profile to affect separately first-and second-period effects. Lowering first-period reward, first-period effect is diminished without touching on the second period one and this is the dominant directions for the distortions.
  - When elasticity of labor supply is instead increasing, optimal contracting calls on the contrary for a decreasing profile of rewards.

Non-Stationary Contracts

- Corollary 1: with increasing profile of rewards, optimal long-term contract $(t^*_1(\delta), t^*_2(\delta) = \gamma^*(\delta)t^*_1(\delta))$ leaves more flexibility to the agent than what he has when contracts are stationary:

$$\zeta(\delta, \gamma^*(\delta)) \leq \zeta(\delta, 1) \Leftrightarrow \frac{d}{dx}\left(\frac{x\varphi'(x)}{\varphi(x)}\right) \leq 0.$$

- When principal finds it more attractive to use increasing profile of rewards, it is less likely that agent gets stuck by his initial commitment than with stationary contracts. This is the reverse when a decreasing rewards profile is optimal.

Extension: Endogenous technology

- When designing infrastructure, contracting parties may choose among continuum of technologies with ≠ degrees of exposure to climatic hazards.
- Ex: water company invest in safer extraction technologies to limit subsequent contamination risk; road concessionaire may include in project design features that reduce exposure to floods and heavy precipitations.

Extension 2: Endogenous technology

- Technologies indexed by parameter α that characterizes level of exposure to productivity shock θ. Adopting an α-technology costs $C(\alpha)$ (with $C(0) = C'(0) = 0$, $C'(\alpha) \geq 0$ and $C''(\alpha) > 0$).
- Support of $F(\cdot|\alpha)$ independent of α and $F_{\alpha}(\theta|\alpha) \leq 0$ (resp. ≥ 0) for any $\theta \in [0, 1)$ (resp. $\in (1, \bar{\theta})$): $F(\cdot|\alpha_1)$ is a mean-preserving spread transformation of $F(\cdot|\alpha_2)$ whenever $\alpha_1 < \alpha_2$.
- Lower (less costly) α-technology implies more uncertainty on θ around mean. Instead, investing more ex ante, contracting parties make sure that random productivity shocks is closer to that mean.

Extension 2: Endogenous technology

- <u>Prop 4</u>: (δ small enough) It is optimal to invest in a α-technology that reduces uncertainty. Moreover, there exists $k > 0$ such that the following first-order Taylor approximation holds:

$$C'(\alpha(\delta)) \approx k\delta(S - t^0).$$

- Always optimal to invest in technologies that insulate from fluctuations in productivity shocks. Doing so, principal does not need to keep as much flexibility by reducing his first-period investment. This in turn brings optimal stationary rewards closer to that obtained with myopic agents (but these would never invest).

Conclusion

- How does climate-related uncertainty affect long-term infrastructure PPPs?
- Classical underinvestment effect with irreversible investments under uncertainty exacerbated by agency relationship.
- Principal can play with contracting features (lowering reward; adjusting intertemporal slope) to limit agent's excessive incentives for flexibility.
- When elasticity of effort supply decreasing, rent extraction-efficiency trade-off tilted towards the former, translating into a lower level of rewards and calling for increasing profile over time.

Conclusion

- We conjecture that this is more likely for water and energy production PPPs than for energy distribution, transport and local public good.
- Stress on long-run viability of these PPPs?
- Always optimal to invest in technologies that insulate from fluctuations in productivity shocks.
- Open questions:
  - how is this affected by limits on commitment;
  - how do environmental and policy uncertainty interact to shape investments in new technologies in sectors such as energy (where hope is placed on development of green technologies to face environmental challenges).

Solving the Model: Benchmark

- Threshold below which no further 2nd period effort is made ($e_2(\theta S, e_1) = e_1$ when $\theta \leq \zeta(\delta,1)$) is less than the average shock:

$$\zeta(\delta,1) < 1 = E_\theta(\theta)\ . \qquad (7)$$

where $\zeta(\delta,1)$ is unique solution in (0,1) to (8):

$$\zeta(\delta,1) = 1 - \delta \int_0^{\zeta(\delta,1)} F(\theta)d\theta$$

- Then optimality condition writes:

$$e^i{}_1(\delta) = \boldsymbol{\varphi}(\zeta(\delta,1)S) < \boldsymbol{\varphi}(S).$$