HUMBOLDT-UNIVERSITÄT ZU BERLIN

Adapting long-lived infrastructure to uncertain climate change

Adaptation Futures 2016

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Motivation

- How adapt the design of long-lived infrastructure to climate change?
- Shall robustness be increased in light of
    1. irreversibility of the design for a long time
    2. uncertainty about climate change rate
    3. speed of climate change?

- Competing objectives
    1. Plan for a long life-time
    2. Fit design to climatic conditions

➢What are the consequences for the planned infrastructure life-time?

Why does it matter?

- Analysis of a frequent decision problem where bad decisions incur substantial costs
- For both private and public investors
- For public regulators
  - Infrastructures frequently natural monopolies, thus regulated
  - Standard regulatory regimes: regulator estimates ‘used and useful’ investment in order to avoid ‘gold plating’
  - ➢What economic infrastructure life-times should be accounted for in the ‘regulatory asset base’?

Literature

- General considerations on how to adapt long-lived assets to uncertain climate change (Callaway 2004, Hallegatte 2009)
- Relevance for infrastructure regulation (Pechan 2014)
  - ➢More on institutional dimensions: Matteo Roggero’s special session (program p. 157, SC 9.11, Thu 13:45-15:30)
- Applications of stochastic dynamic control / real options theory (generally: Dixit & Pindyck 1994; similar considerations in other fields, e.g. Alvarez & Dixit 2013)
- Similar approaches in the economics of adaptation (Fisher & Rubio 1997, de Bruin & Ansink 2011, van der Pol et al. 2015)

➢Our contribution: consideration of irreversible adaptation decision with stochastic dynamic control

Stylized analysis as a stopping problem

Decision structure

1. Irreversibly decide on the long-term design, then start the investment
2. Irreversibly decide to actually end ('stop') life-time at some time (considering expected forgone benefits in light of uncertain climate change)
3. Climate evolves according to a stochastic process

Step 2

$$h(x_0, a, \mu, \sigma) = \; max_T \; E \int_0^T \overbrace{\pi(x,a)e^{-rt}}^{\text{discounted flow of benefits}} dt$$

$$s.t.\; dx = \mu x dx + \sigma x dz$$

Yields expected stopping time $T^*(x_0, a, \mu, \sigma)$ according to stopping rule $x = x^*$

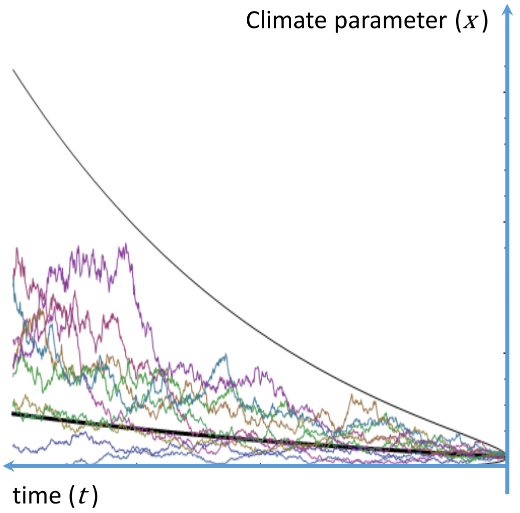
Step 1

$$max_a \; h(x_0, a, \mu, \sigma) - cost(a)$$

Yields optimal design $a^*(x_0, \mu, \sigma)$ and planned life-time $T^{**}(x_0, \mu, \sigma) = T^* \; (x_0, a^*, \mu, \sigma)$

x	climate parameter
a	infrastructure design
μ	speed of clim. ch.
σ	uncertainty of clim. ch.
t	time
r	discount rate

Stylized analysis, ctd.



Questions and trade-offs

- Designing more “bunker houses” or more “paper houses” in light of climate change?

- Increase robustness (and planned life-time)?
  - Obtain benefits for a longer time under unfavorable climate
- Decrease robustness (and planned life-time)?
  - Obtain a better fit to changing climate during life-time
  - Remain more flexible if new information about climate change appears

Decomposing the effects

$$\frac{dT^{**}}{d\mu} = \underset{(-)}{\partial_\mu T^*(x_0, a^*, \mu)} + \underset{(+)}{\partial_a T^*(x_0, a^*, \mu)} \cdot \underset{(?)}{\frac{da^*}{d\mu}}$$

$$\frac{dT^{**}}{d\sigma} = \underset{(+)}{\partial_\sigma T^*(x_0, a^*, \sigma)} + \underset{(+)}{\partial_a T^*(x_0, a^*, \sigma)} \cdot \underset{(?)}{\frac{da^*}{d\sigma}}$$

- Ceteris paribus effects
  - Faster change rate: shorter expected life-time, generally unclear effect on optimal design
  - More uncertainty: longer expected life-time, generally unclear effect on optimal design
  - More robust design: longer expected life-time

  Overall effect: ambiguous, i.e. it depends on detailed empirical parameters

A more specific example

$$max_a\ h(x_0, a, \mu, \sigma) - c \cdot a$$
$$h(x_0, a, \mu, \sigma) = max_T\ E \int_0^T \left(1 - \frac{a}{x}\right) e^{-rt} dt$$

Solution procedure:

- Deriving the value function h from solving the second order ODE
$$\frac{1}{2}\sigma^2 x^2 h'' + \mu x h' - rh + \left(1 - \frac{a}{x}\right) = 0$$
- Stopping rule $x^*(a, \mu, \sigma)$ characterized by:
  - Value matching condition $h(x^*, a, \mu, \sigma) = 0$, smooth pasting condition $h_x(x^*, a, \mu, \sigma) = 0$
- Optimal design a^* fulfills $h_a(x_0, a^*, \mu, \sigma) = 0$, planned life-time is
$$T^{**}(x_0, \mu, \sigma) = E\ min\ \ \{t | x(t) = x^*(a^*, \mu, \sigma)\}$$

Results

Current infrastructure	Update of climate change expectations		Optimal adjustment	
Planned life-time (T**)	Speed (μ)	Uncertainty (σ)	Robustness (a)	Planned life-time (T**)
Relatively short (below some T_1)	---	up	raise	raise
	up	---	decrease	decrease
Relatively long (above some T_2)	---	up	decrease	(?)
	up	---	increase	(?)

Conclusions

- Adaptation decisions on long-lived infrastructure are not easy
- It can be beneficial (for particularly long-lived infrastructure)
  to design infractructure less robustly under climate change!
- Testing for specific conditions requires empirical estimates and solving higher-order differential equations numerically

- Approach rests on climate change uncertainty being adequately represented by a stochastic process…
- … otherwise, infrastructure adaptation would require new ways to deal with decisions involving uncertainty and speed of change

Thank you for your attention

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