The Min-max Regret and the Max Expected Utility Strategies for the Climate Policy Evaluations under Uncertainties by the expansion of Integrated Assessment Model MARIA

As a Part of "Integrated Research on the Development of Global Climate Risk Management Strategies" Project

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1. Introduction

Various “uncertainties” in the climate decision making
-> key barrier against policy agreement

- Impacts of climate changes
- Uneven societal distribution of cost and benefits
- Deployment strategy of technology options, etc.

Existing method – basically focusing on expected utility, however

- “Extreme (tipping) Event” : low probability and high risk
- Long tail risk

Shutdown of thermohaline circulation (THC), collapse of west antarctic ice sheet, the collapse of Greenland ice sheet, methane outburst, increase of hurricane and cyclones, etc.

Decision based on maximum expected utility (MxU) would not be preferable.

-> Alternative method : minimum regret strategy (MnR)

"Extreme (tipping) Event" : low probability and high risk

- Nuclear power : high technological potential but low societal acceptance, at least in Japan.
After March 11, 2012, Gigantic earthquake followed by nuclear station accident, people in Japan seriously consider the "unexpected outcomes".

- CCS and geo-engineering : large possibility to mitigate the global warming, but regrettable when warming damage is low.

- Other possible tipping events: - shutdown of thermohaline circulation (THC), collapse of west antarctic ice sheet, the collapse of Greenland ice sheet, methane outburst, increase of hurricane and cyclones, etc.

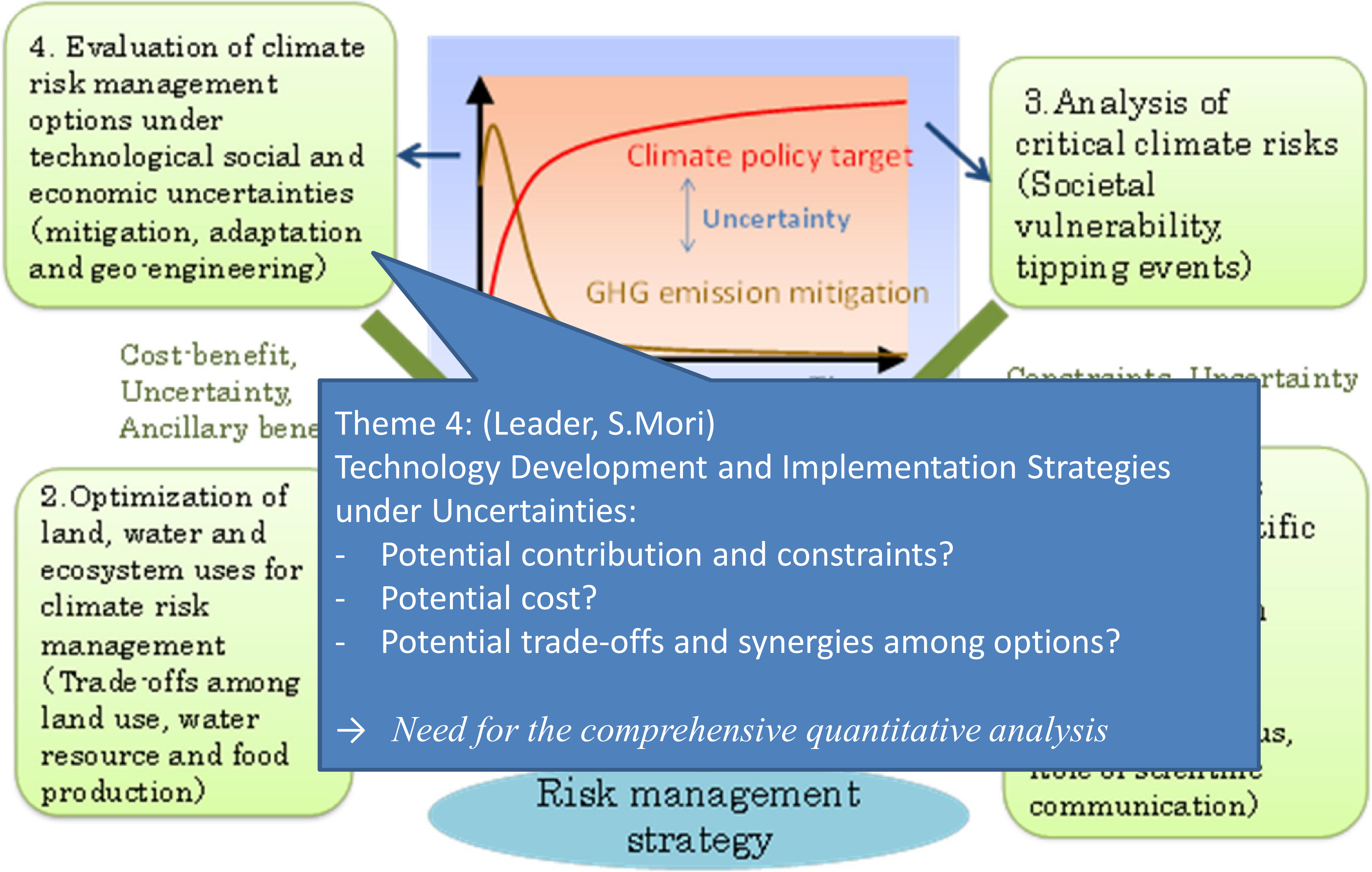
Decision based on maximum expected utility (MxU) would not be applicable.
-> Alternative method : minimum regret strategy (MnR)

Research Background: Risk Management against Climate Change

ICA-RUS - Integrated Research on the Development of Global Climate Risk Management Strategies – is going on in Japan

- Supported by Ministry of Environment Japan
  Project leader: Dr.Seita Emori (National Institute of Environmental Studies)

- Including five research categories:
  (1) Synthesis on global climate risk management strategies
  (2) Optimization of land, water and ecosystem uses for climate risk management
  (3) Analysis of critical climate risks
  (4) **Evaluation of climate risk management options under technological social and economic uncertainties**
  (5) Interactions between scientific and social rationalities in climate risk management



Theme 4: (Leader, S.Mori)
Technology Development and Implementation Strategies under Uncertainties:

- Potential contribution and constraints?
- Potential cost?
- Potential trade-offs and synergies among options?

→ *Need for the comprehensive quantitative analysis*

Structure of the Integrated Research on the Development of Global Climate Risk Management Strategies Project

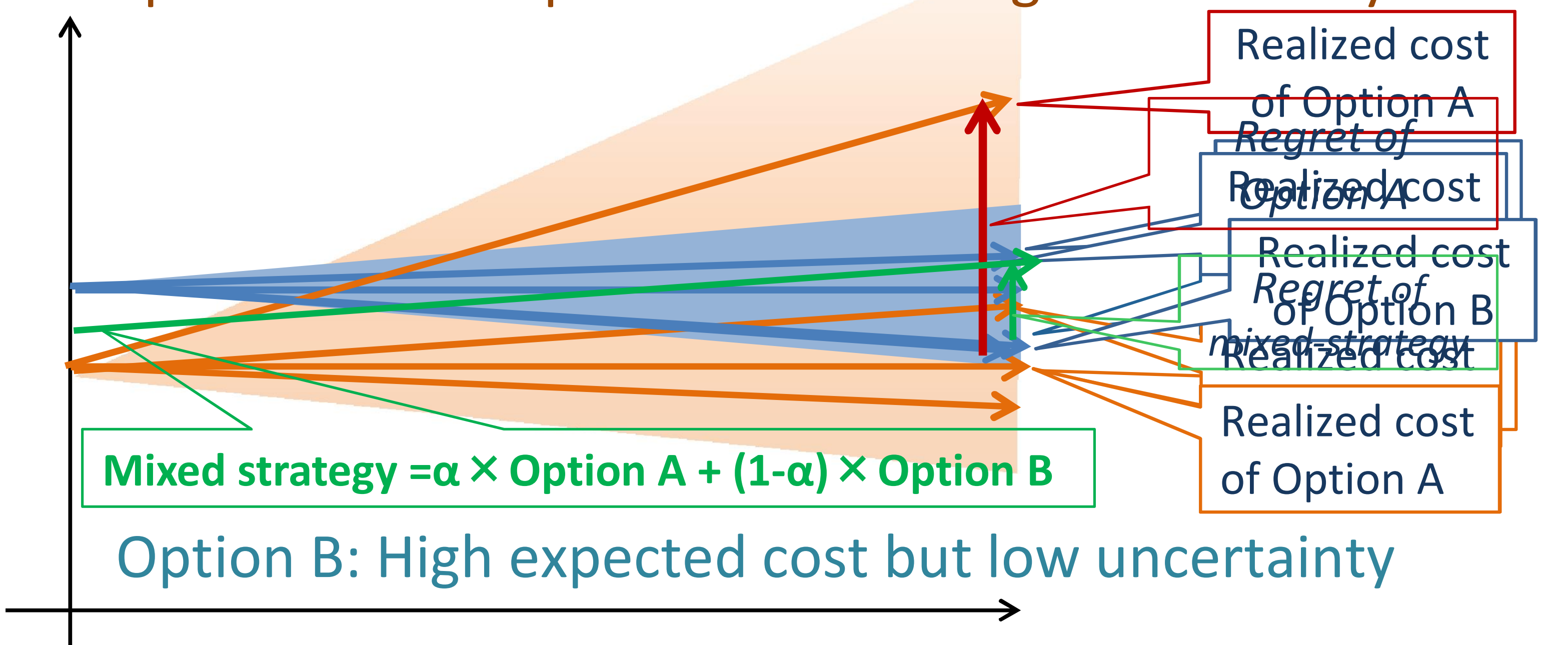
2. Maximum Expected Utility vs. Minimum Regret - example

Optimum fuel mix of

P_1(Kerosene): low expected price but large uncertainty

P_2(Coal based DME): high expected price but small uncertainty

Option A: Low expected cost but high uncertainty



Option B can be better than Option A in a few cases.

Expected cost strategy always chooses Option A only.
-> *how about risk*? **Mixed-strategy focusing on regret**

2. Maximum Expected Utility vs. Minimum Regret – example-2

Optimum fuel mix of

P_1(Kerosene): low expected price but large uncertainty

P_2(Coal based DME): high expected price but small uncertainty

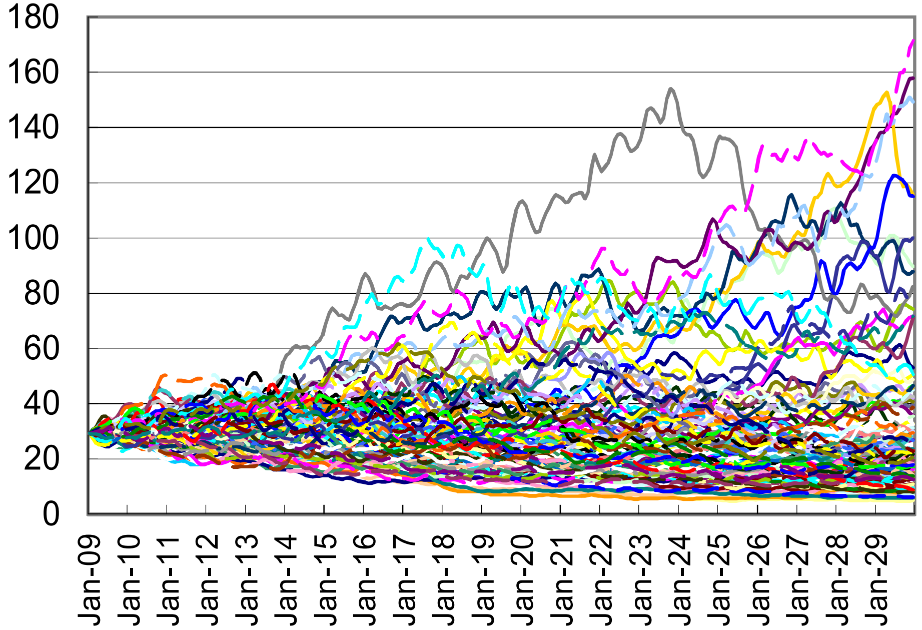


Figure 1 Kerosine price in ¥/ktoe

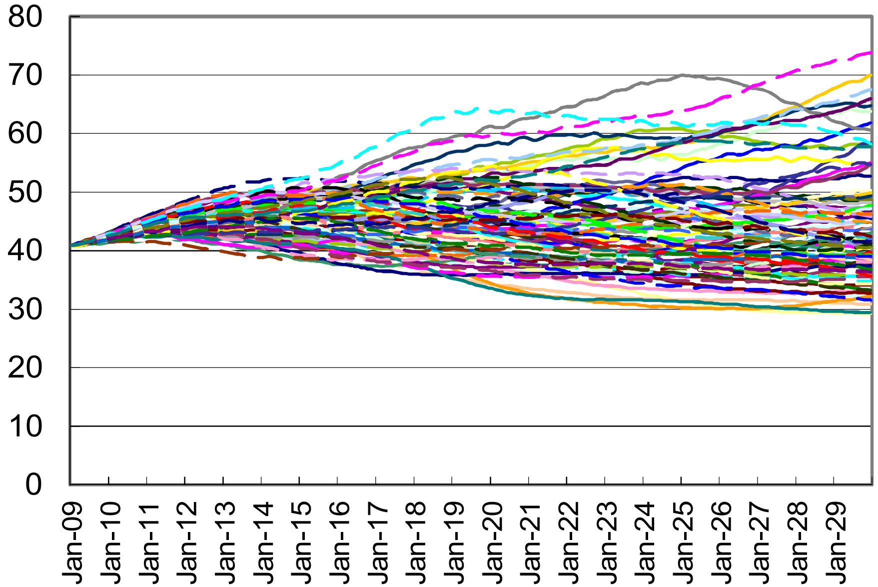


Figure 2 DME price in ¥/ktoe

Optimum fuel mix $$P^*(t;\omega) = \alpha(t)P_1(t;\omega) + (1 - \alpha(t))P_2(t;\omega)$$

Kerosene is always fully selected when the expected value is employed.

2. Maximum Expected Utility vs. Minimum Regret – *cont.*

Minimizing the regret of strategy $\alpha(t)$ in the n-th trial

$$\mathrm{Regret}(\alpha(t)) = \max\left\{P^*(t;n) - P_1(t;n),\ P^*(t;n) - P_2(t;n)\right\}$$

Formulation

$$\min.\ \sum_n w(n) \sum_t \left\{P\_UP_1(t;n)^{\theta} + P\_UP_2(t;n)^{\theta}\right\}^{1/\theta}$$

→ Minkowski generalized distance

$$P^*(t;n) - P_1(t;n) = P\_UP_1(t,n) - P\_LO_1(t,n)$$

$$P^*(t;n) - P_2(t;n) = P\_UP_2(t,n) - P\_LO_2(t,n)$$

$\theta \to \infty$ the above converges to the min-max strategy.

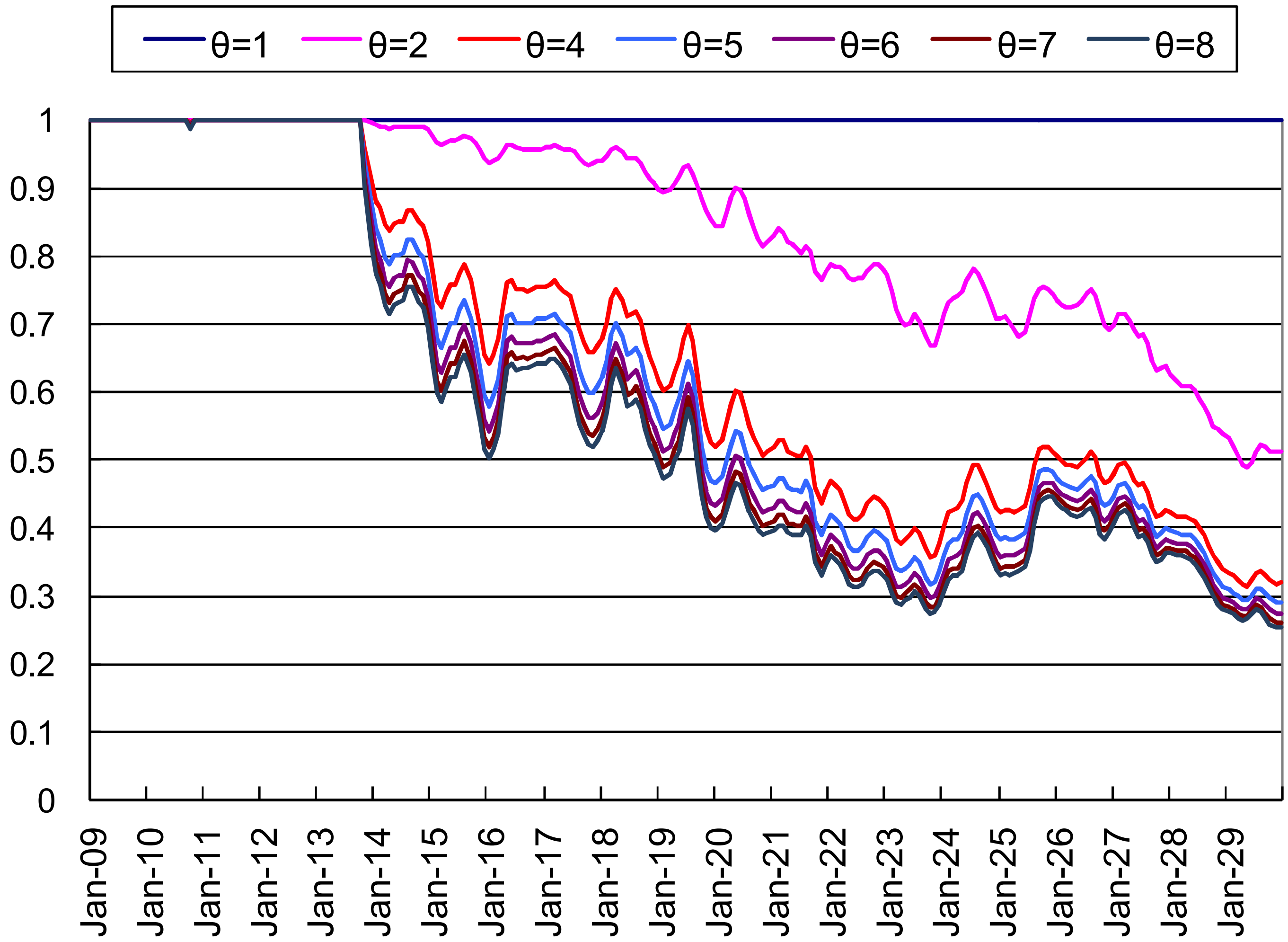


Figure 3 Optimal fuel mix weights $\alpha^*(t)$ corresponding to the θ changes

→ Share of synthetic fuel DME increases with larger ϑ while no DME was employed under MxU strategy.

3. Extension of MARIA for the regret based assessment

MARIA (Multiregional Approach for Resource and Industry Allocation)
- an inter-temporal optimization model integrating top-down macroeconomic activity and bottom-up technology flows

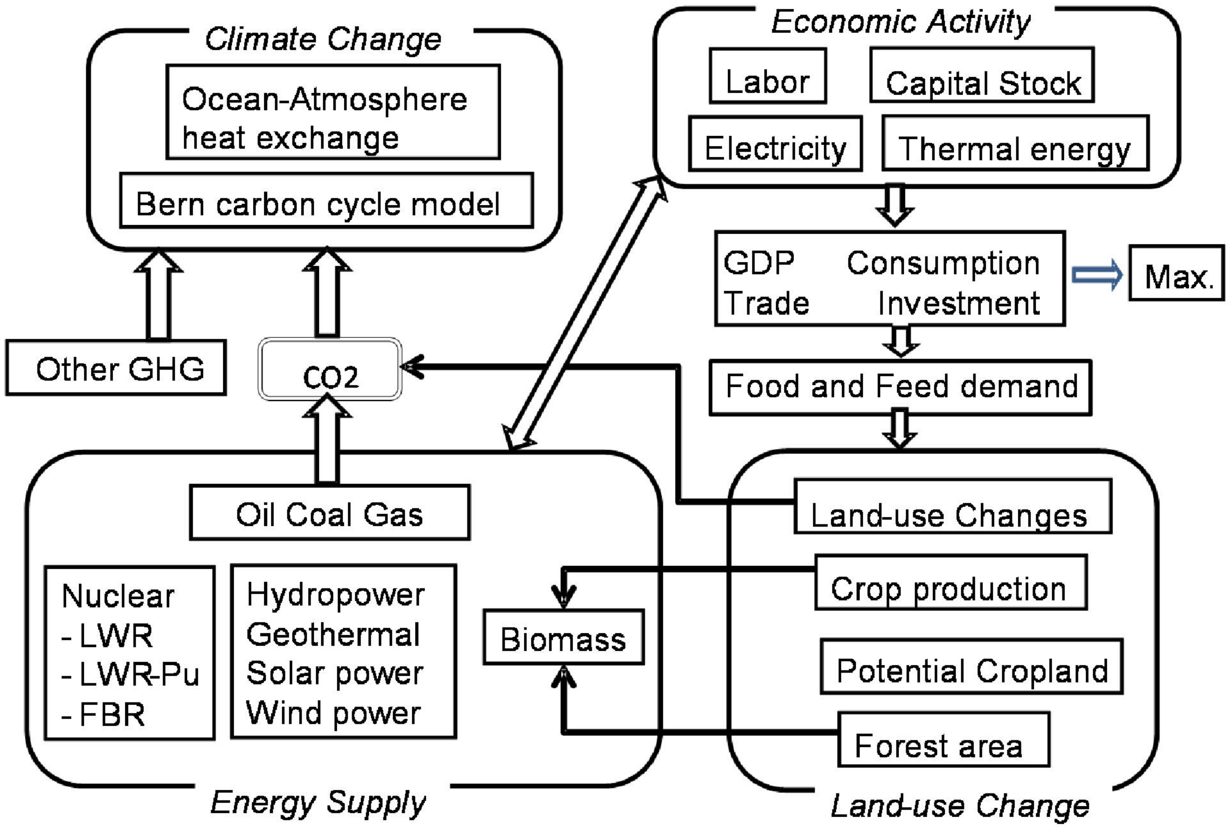


Figure 4 Structure of MARIA model

3-2. Future Uncertain Scenarios

Uncertainty: 12 scenarios on loss of GDP when the global atmospheric temperature rises 3.0 Celsius degree from the pre-industry level

Scenario-1	0.6% - 0.9%	
Scenario-2	1.2% - 1.8%	<- reference case
Scenario-3	1.8% - 2.7%	
Scenario-4	2.4% - 3.6%	
Scenario-5	3.0% - 4.5%	
Scenario-6	3.6% - 5.4%	
Scenario-7	4.2% - 6.3%	
Scenario-8	4.8% - 7.2%	
Scenario-9	5.4% - 8.1%	
Scenario-10	6.0% - 9.0%	
Scenario-11	12% - 18%	
Scenario-12	18% - 27%	

→ *Conventional Min.-Max regret strategy refers only Scenario-1 and Scenario-12, two extreme cases.*

4. Formulation – conventional Min-max approach

Objective function f(SCN) : discounted present value of utility under scenario SCN. Optimum solution under SCN is $f^*(SCN)$.

$$f^*(SCN) = \max. \sum_h \sum_t (1+r)^{-t} L_{h,t} \ln\left(\frac{C_{h,t}(SCN)}{L_{h,t}}\right)$$

X*(SCN) -- Optimal solution of control variables under scenario SCN

Regret of strategy $X^*(SCN)$ under the realized scenario scn' is

$$f^*(SCN \mid scn') = \max_X f\left(scn';\ X(t;scn') = X^*(t;SCN)\right)$$

$$\therefore \quad Regret(SCN \mid scn') = f^*(scn') - f^*(SCN \mid scn')$$

- Min-Max regret solution is basically determined by the **extreme assumption regardless of the plausibility**.
- Optimal "policy mix" cannot be generated.

4-2. Formulation – generalized distance approach

$$\mathrm{Regret}[X(t)\,|\,SCN] = f^*\left(X^*(t;SCN)\right) - f^*\left(X(t)\right) = D\_UP\left(X(t)\,|\,SCN\right) - D\_DN\left(X(t)\,|\,SCN\right)$$

(single stage decision) $$\min_{X(t)} \left\{\sum_{SCN} P(SCN) \times (1-d)^t \times D\_DN\left(X(t)\,|\,SCN\right)^\theta \right\}^{1/\theta}$$

P(SCN) denotes occurrence probability of scenario SCN

Expansion – ATL multi-stage decision approach

$$X(m,t) = X^0(t) \qquad \text{for} \quad t \le T$$ m: future bifurcation possibilities

(multi stage decision) $$\min_{X(m,t)} \sum_m \left\{\sum_{SCN} P(SCN,m) \sum_t (1-d)^t \times D\_DN\left(X(m,t)\,|\,SCN\right)^\theta \right\}^{1/\theta}$$

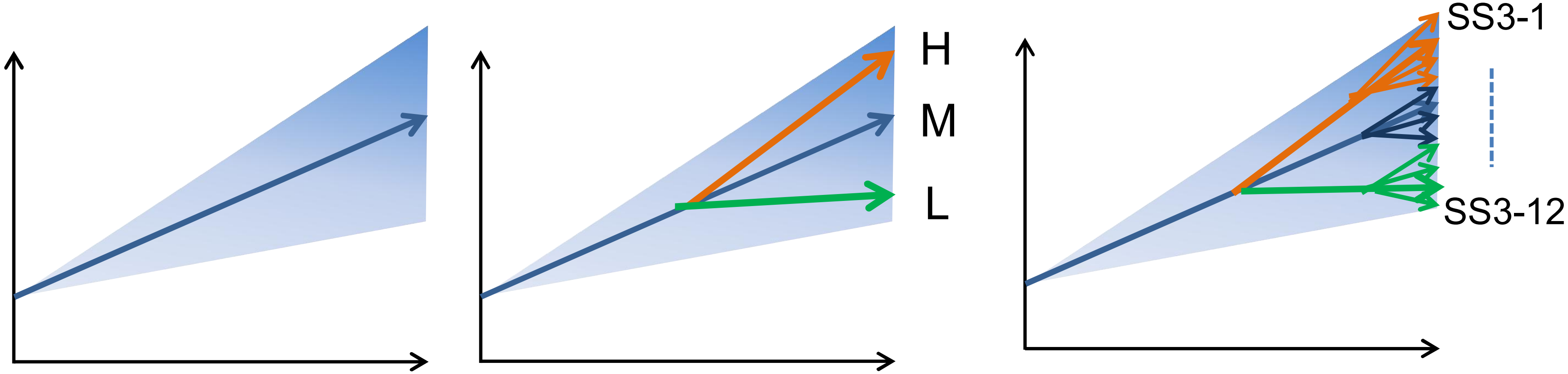
Existing MxU formulation

(single stage decision) $$\max \sum_{SCN} P(SCN) \sum_t (1-d)^t f\left(X(t|SCN)\right)$$

(multi stage decision) $$\max \sum_{SCN} \sum_m P(SCN,m) \sum_t (1-d)^t f\left(X(m,t|SCN)\right)$$

4-3. Decision Strategy under Future Uncertainties

A: Three decision stages



Single stage decision: under 12 scenarios (SS1)

Two stage decision: 3 decisions under 12 scenarios (SS2)

Three stage decision 3 decisions then 12 decisions (SS3)

B: Two decision basis

MxU: Maximizing expected utility

MnR: Minizing regret in generalized distance

5. Simulation Results

5-1 perfect information

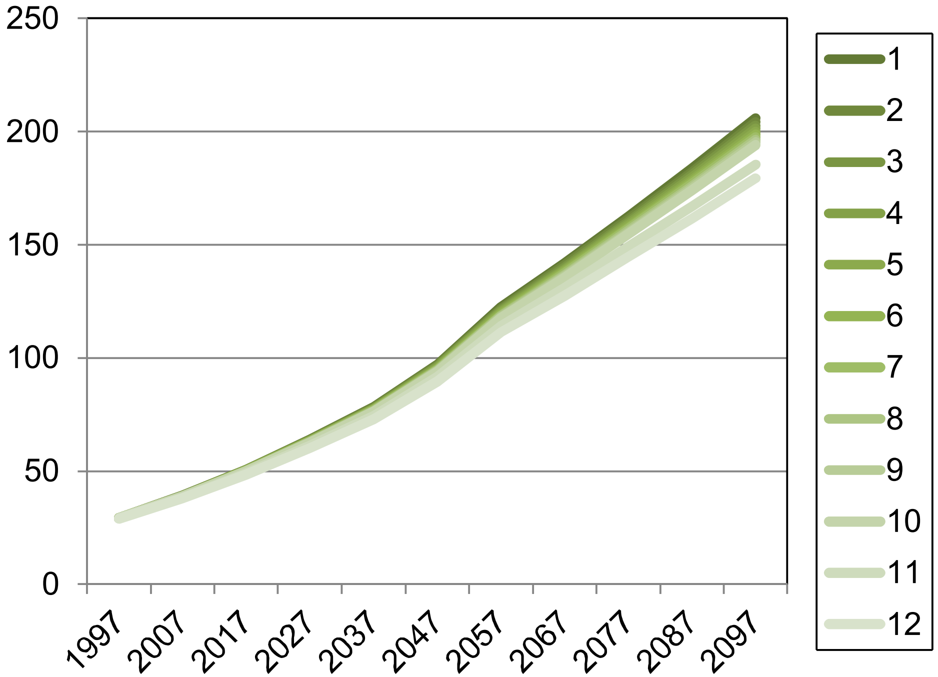


Figure 5 GDP without uncertainty in trillion US dollars

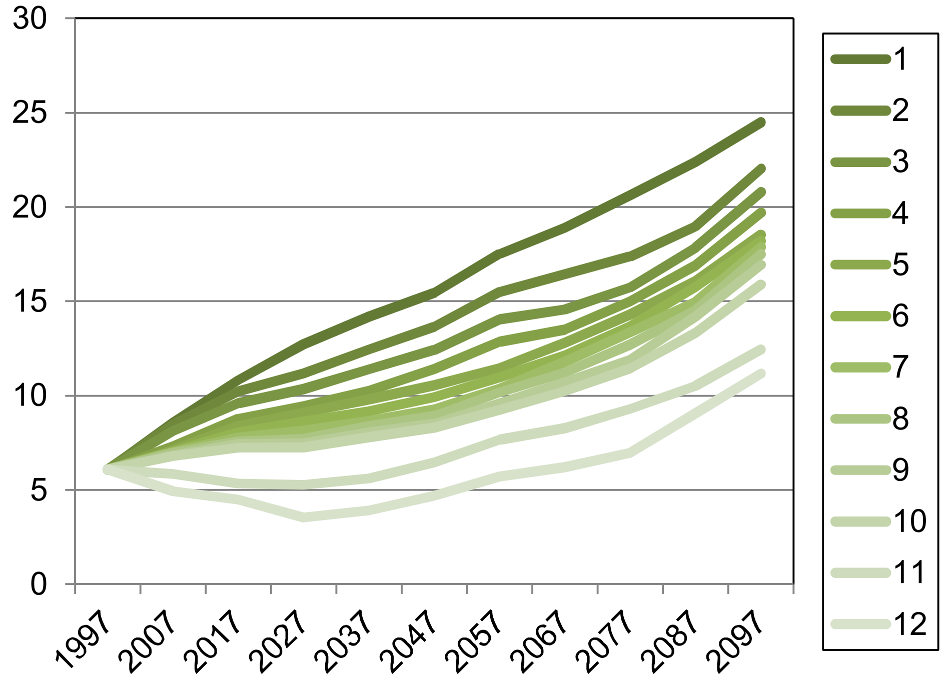
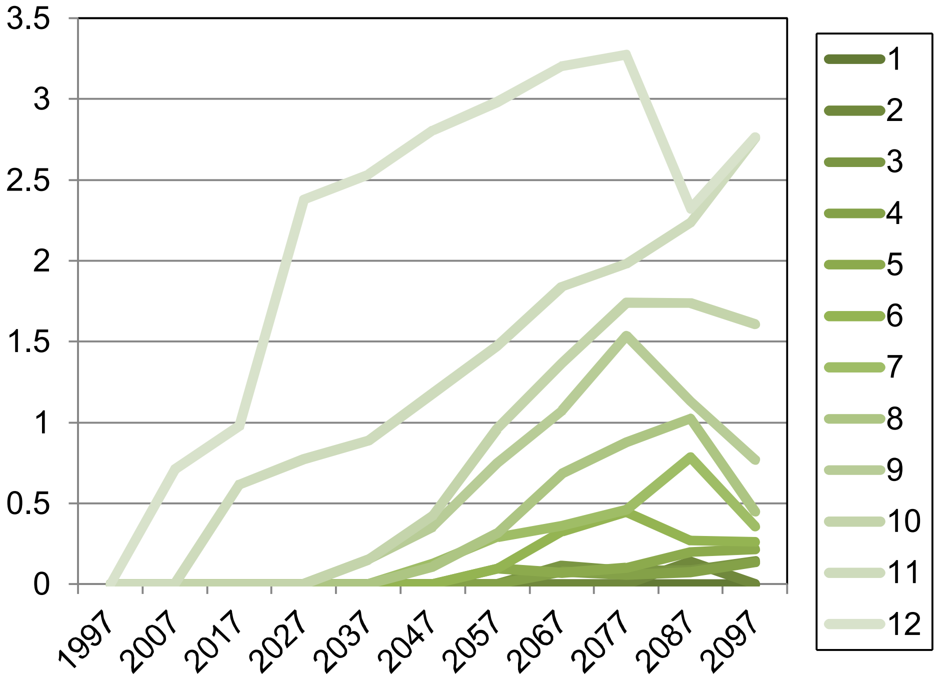


Figure 6 CO_2 emission without uncertainty in Gt-C (L-m and L-h overlap each other.)

- In the perfect information cases, carbon control strategies bifurcate broadly.
- Under future uncertainties, how the policy maker(s) can select single emission path?

5. Simulation Results

5-1 perfect information -2



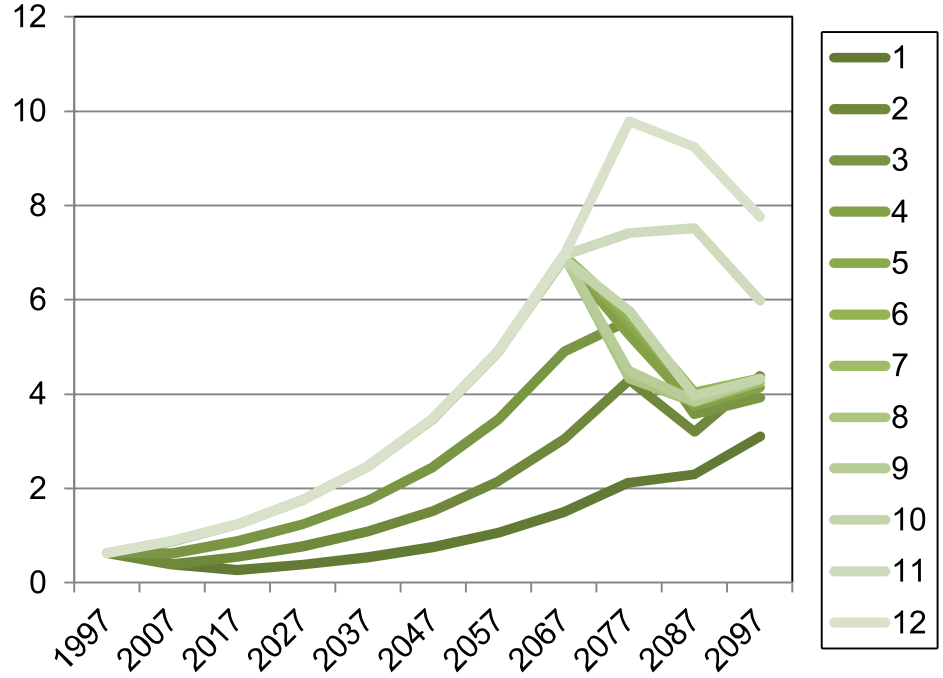


Figure 7 CCS implementation without uncertainty in Gt-C

Figure 8 Nuclear power implementation without uncertainty in GTOE

- Optimal CCS implementation also distributes broadly.
- When and how much CCS should be implemented under non-repeatble and irreversible situation?

5. Simulation Results

5-1 perfect information -3

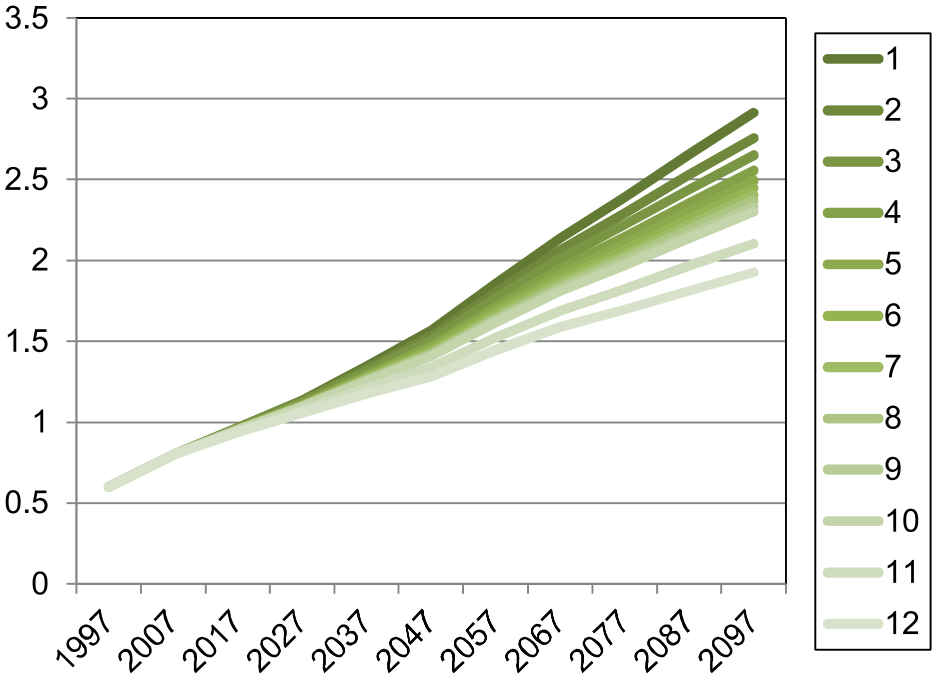


Figure 7 Atmospheric temperature rise in degree

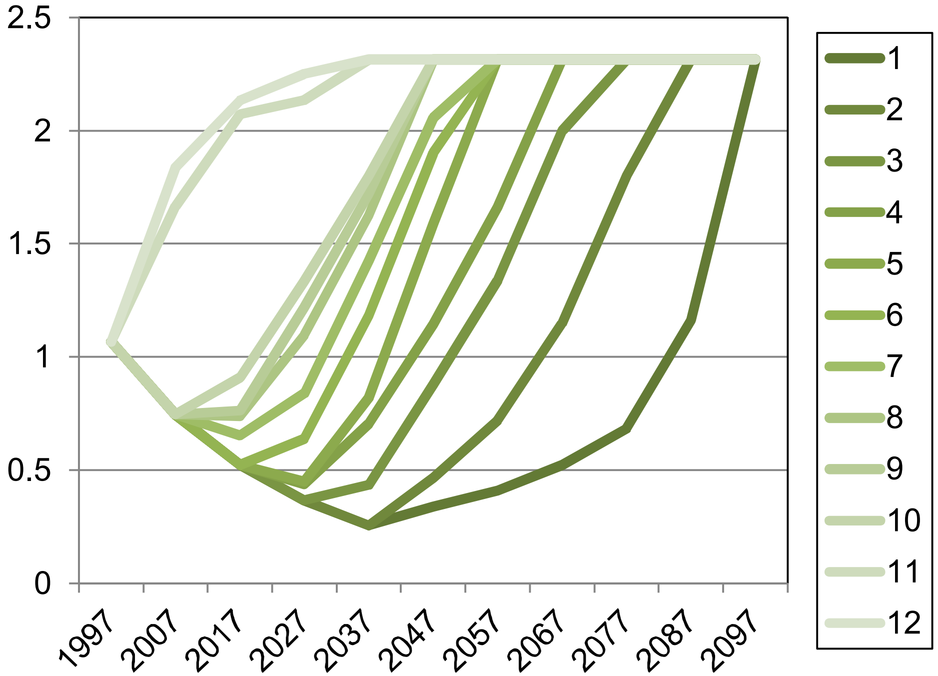


Figure 8 Biomass power implementation in GTOE

- Biomass energy increases earlier as the climate damage costs increase due to the high costs assumptions.

5. Simulation Results

5-2 Decision making under uncertainty: MnR vs.MxU and Single stage vs. Multi stage

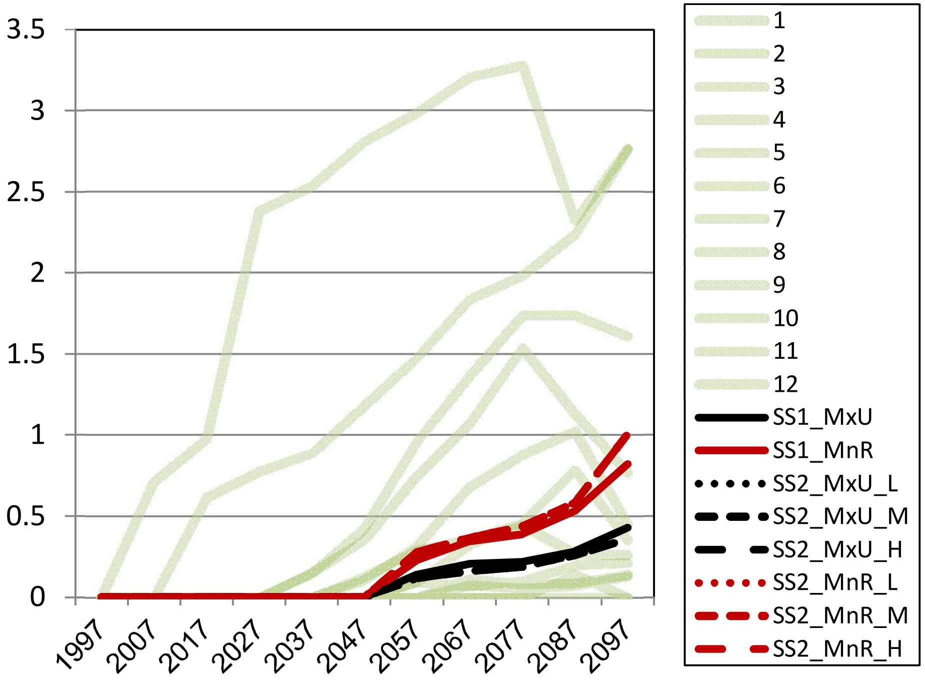


Figure 10 CCS implementation paths of the maximum expected utility (MxU) and minimum regret (MnR) in the single stage decision (SS1)and the two stage decision (SS2)

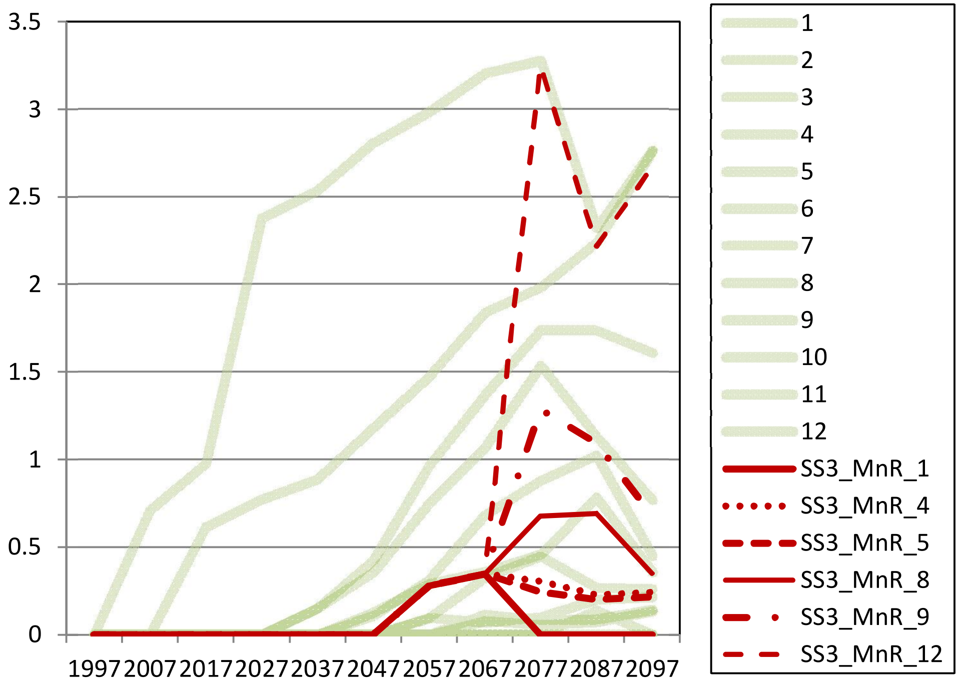


Figure 11 CCS implementation paths of the maximum expected utility (MxU) and minimum regret (MnR) in the three stage ecision (SS3)

- CCS implementation pathways appear differenmtly between MxU and MnR.
- CCS is implemented moderately comparing with perfect information cases.

5. Simulation Results

5-2 Decision making under uncertainty: -2

MnR vs.MxU and Single stage vs. Multi stage

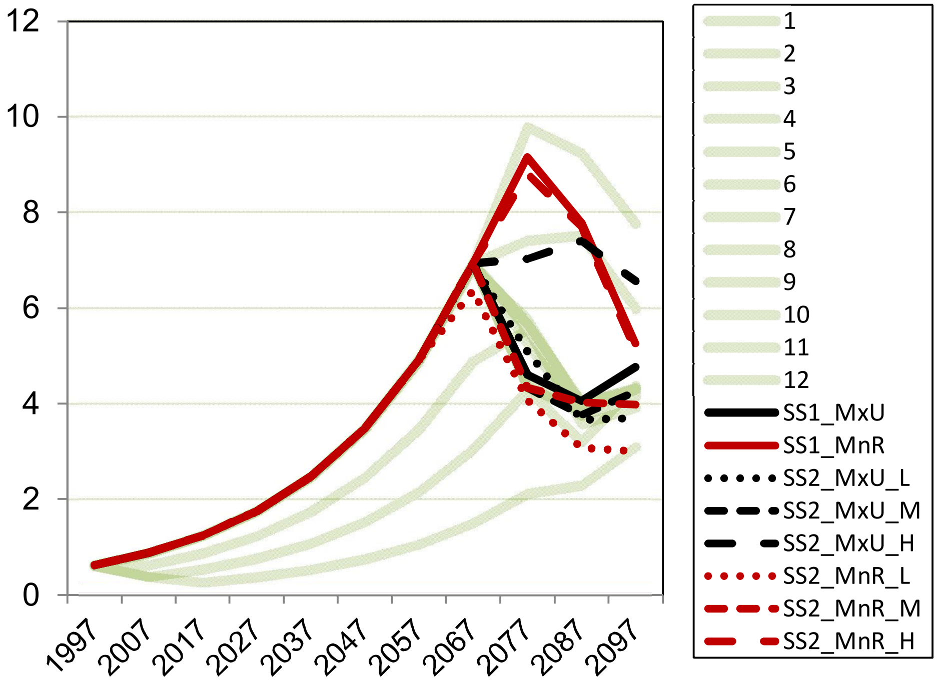


Figure 12 Nuclear implementation paths of the maximum expected utility (MxU) and minimum regret (MnR) in the single stage decision (SS1)and the two stage decision (SS2)

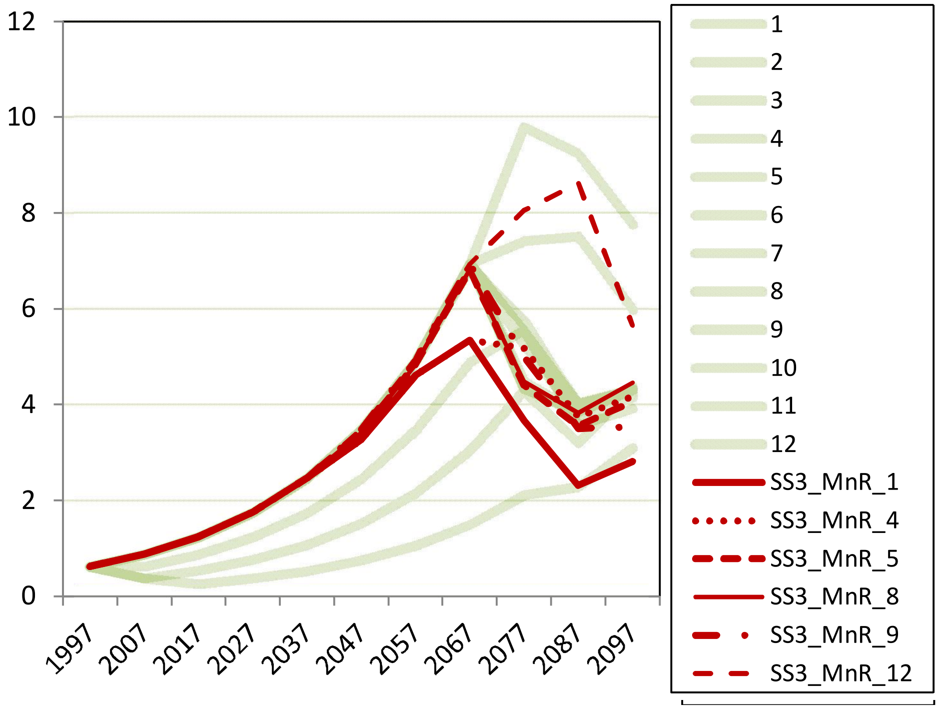


Figure 13 Nuclear implementation paths of the maximum expected utility (MxU) and minimum regret (MnR) in the three stage ecision (SS3)

- Nuclear power pathways are not so different between MxU and MnR.
- Uncertainty consideration tends to implement nuclear power.

5. Simulation Results

5-2 Decision making under uncertainty: -3

MnR vs.MxU and Single stage vs. Multi stage

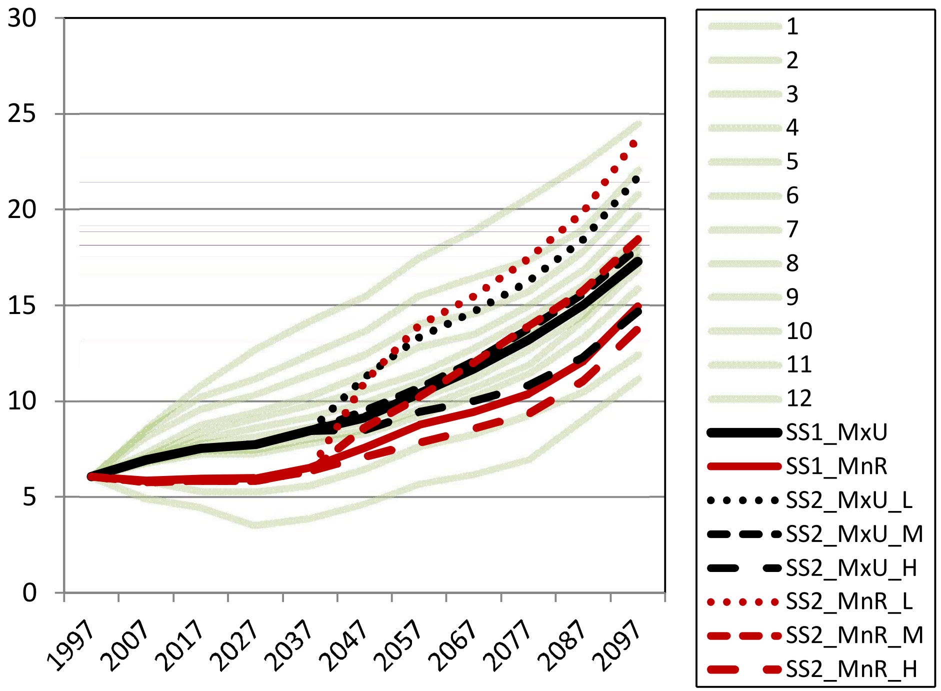


Figure 14 CO2 emission paths of the maximum expected utility (MxU) and minimum regret (MnR) in the single stage decision (SS1)and the two stage decision (SS2)

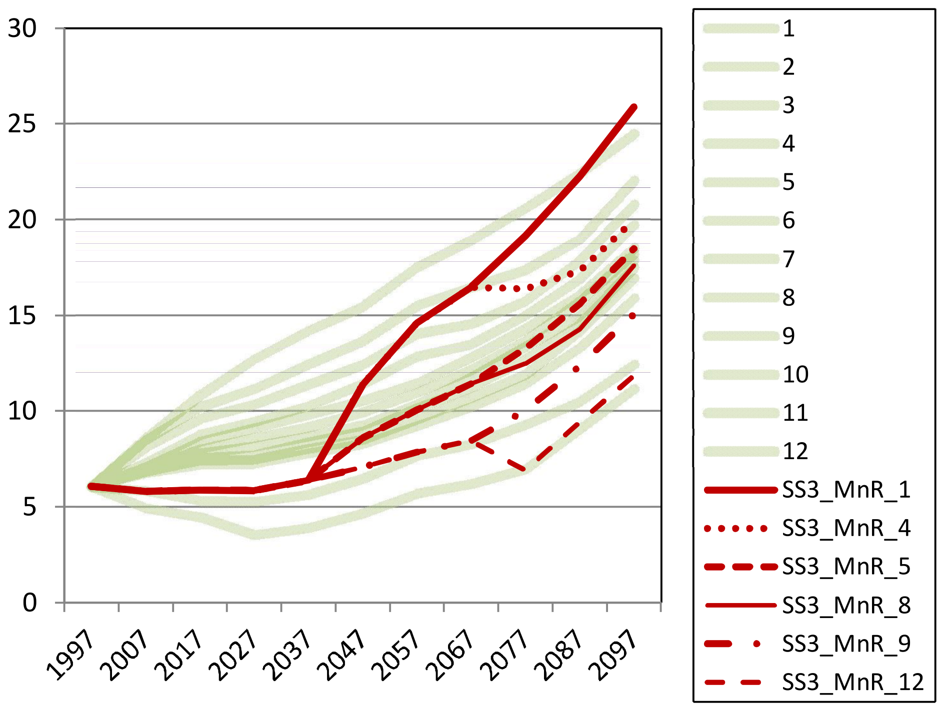


Figure 15 CO2 emission paths of the maximum expected utility (MxU) and minimum regret (MnR) in the three stage ecision (SS3)

CO2 emission pathways in MnR are apparently lower than MxU cases.

5. Simulation Results

5-2 Decision making under uncertainty: -4

MnR vs.MxU and Single stage vs. Multi stage

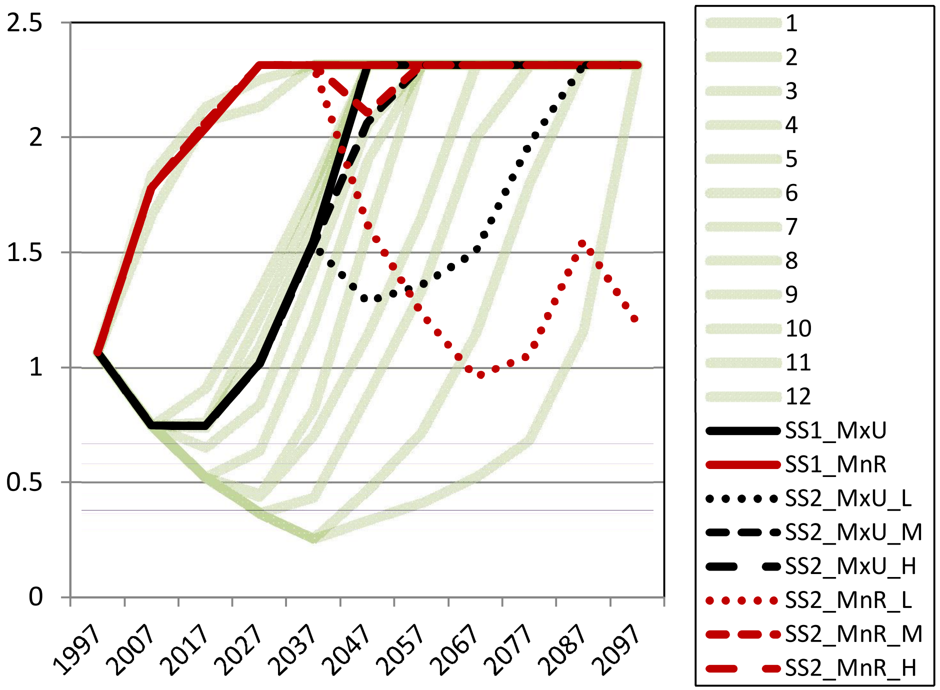


Figure 16 Biomass energy paths of the maximum expected utility (MxU) and minimum regret (MnR) in the single stage decision (SS1)and the two stage decision (SS2)

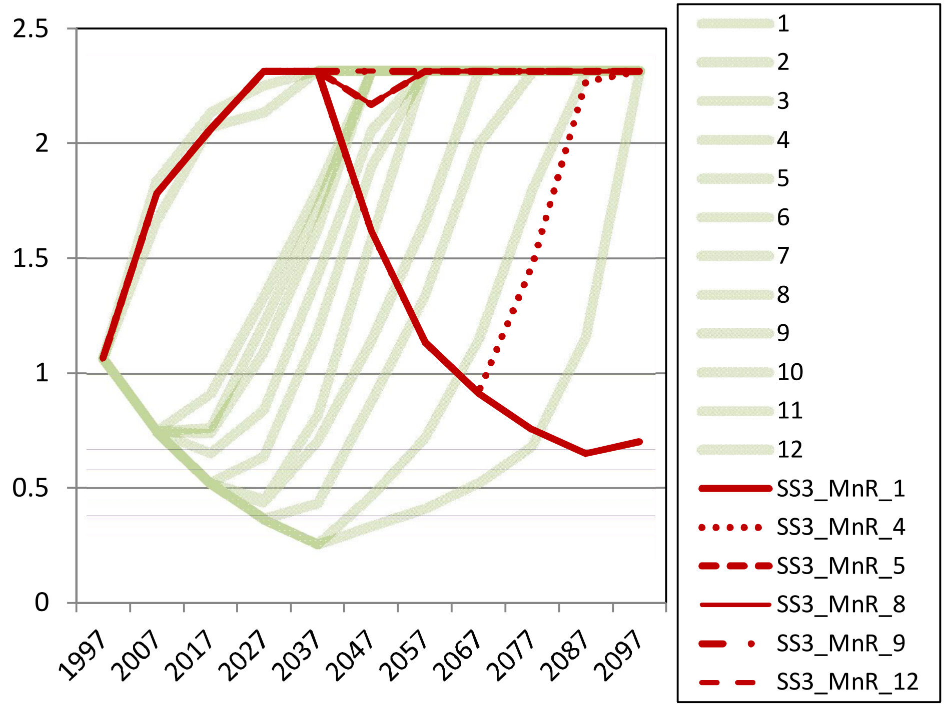


Figure 17 Biomass energy of the maximum expected utility (MxU) and minimum regret (MnR) in the three stage ecision (SS3)

Biomass implementation in MnR are apparently larger than MxU cases.

5. Simulation Results

5-2 Decision making under uncertainty: -5

MnR vs.MxU and Single stage vs. Multi stage

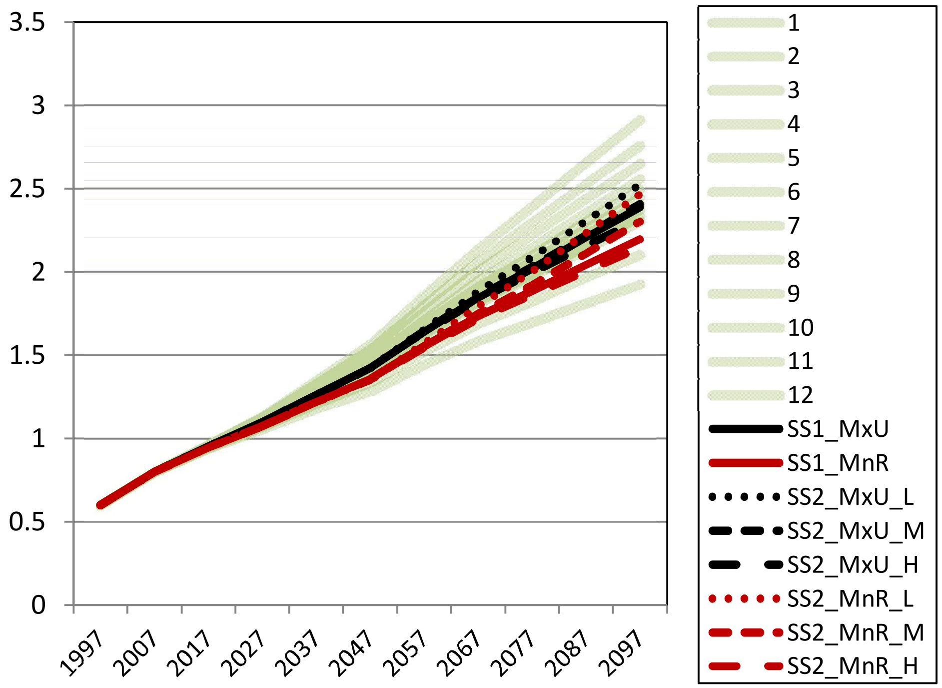


Figure 18 Atmospheric temperature paths of the maximum expected utility (MxU) and minimum regret (MnR) in the single stage decision (SS1)and the two stage decision (SS2)

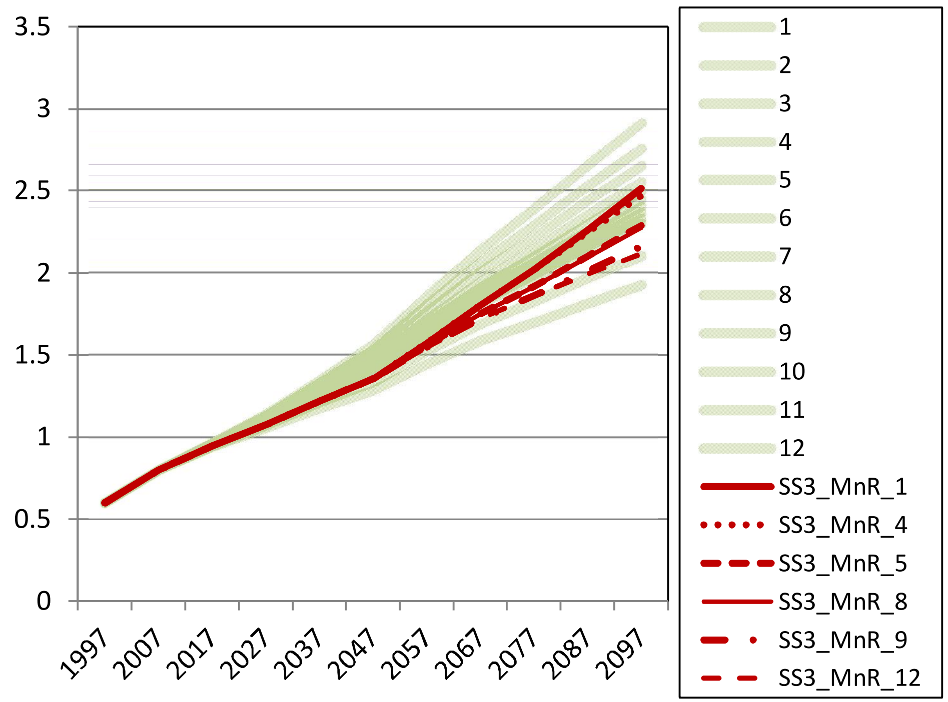


Figure 19 Atmospheric temperature of the maximum expected utility (MxU) and minimum regret (MnR) in the three stage ecision (SS3)

Atmospheric temperature in MnR are apparently lower than MxU cases.

5. Simulation Results

5-3 Decision making under uncertainty: MnR vs.MxU in single stage case

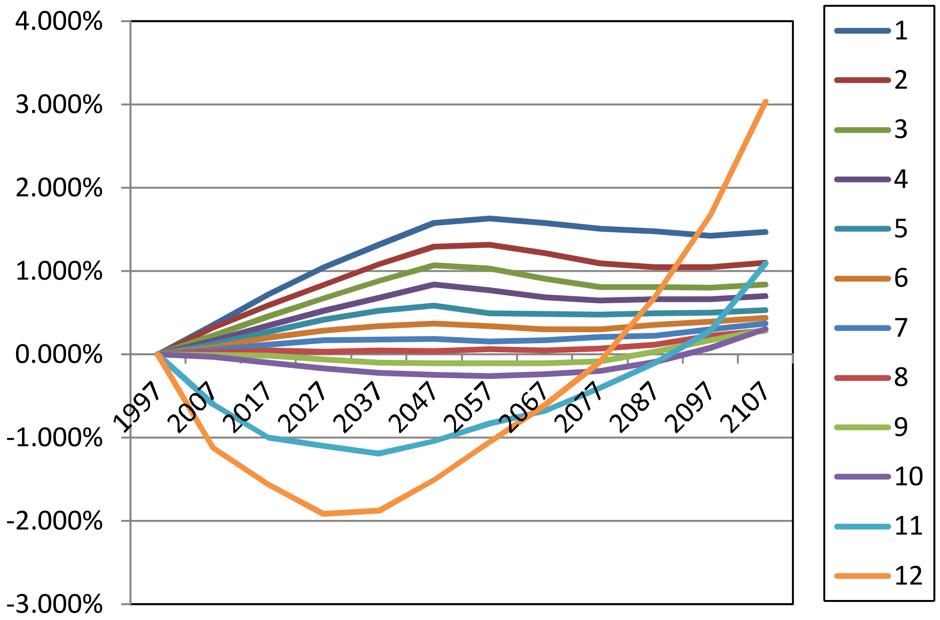


Figure 20 Loss of GDP from the perfect information case in the maximum utility (MxU) of the single stage decision

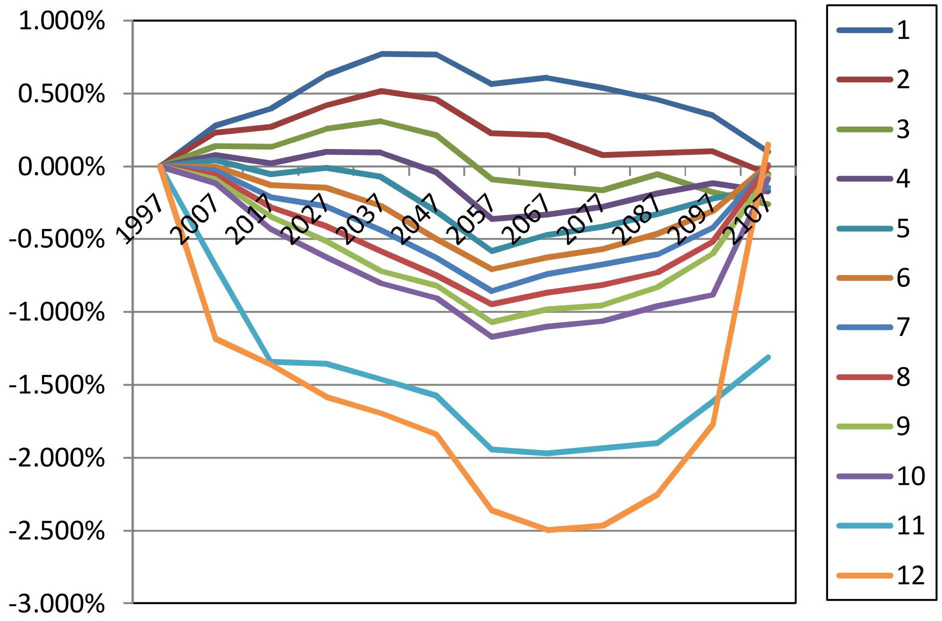


Figure 21 Loss of GDP from the perfect information case in the minimum regret (MnR) of the single stage decision

GDP in MnR tends to increase under the carbon control case. The difference of the property of MxU and MnR appears in consumption figure.

5. Simulation Results

5-3 Decision making under uncertainty: MnR vs.MxU in single stage case

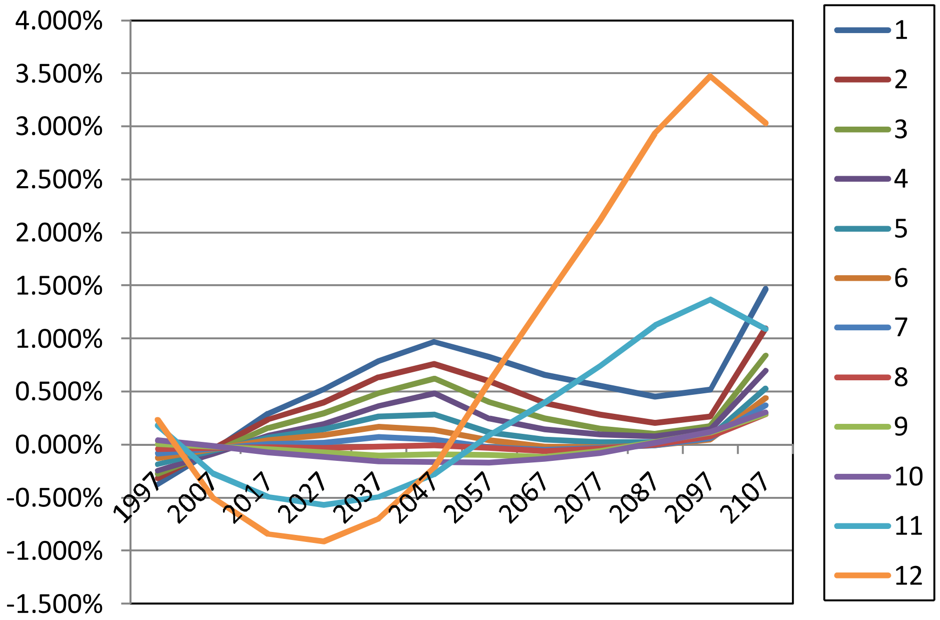


Figure 22 Loss of consumption from the perfect information case in the maximum utility (MxU) of the single stage decision

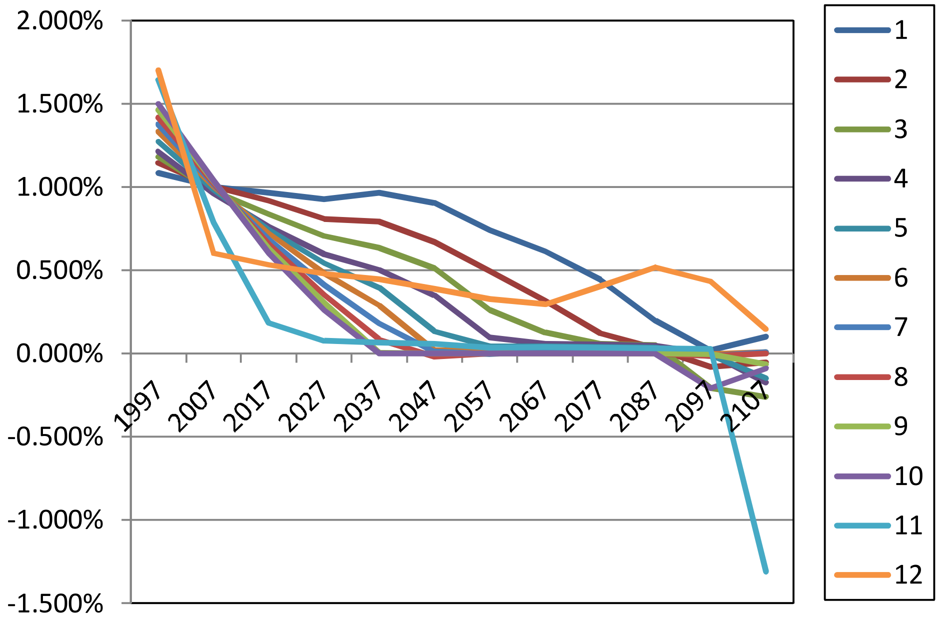


Figure 23 Loss of consumption from the perfect information case in the minimum regret (MnR) of the single stage decision

Loss of consumption in MnR is higher than that in MxU in the early stage. This comparison suggests that the investment and the capital stock in MnR strategy are larger than those in MxU strategy.

6. Conclusion

- A new method to deal with the future uncertainties focusing on the “regret” values.
- When we consider the “long-tail” distribution, decision making based on “expected utility” would underestimate the extreme case, while exaggerated “risk aversion” strategy will derive policy depending on the extreme assumptions regardless of the plausibility.
- The minimum regret policy tends to prefer lower carbon emission paths.
- The approach described in this study will be useful in the irreversible, unrepeatable and asymmetric uncertainty cases.