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Green bonds, transition to a low-carbon economy, and intergenerational fairness: Evidence from an extended DICE Model

Sergey Orlov[12], Julia Puaschunder[31], Elena Rovenskaya[12], Willi Semmler[341]

[1]International Institute for Applied System Analysis (Austria)
[2]Lomonosov Moscow State University (Russia)
[3]New School for Social Research (United States)
[4]University of Bielefeld (Germany)

Motivation

Anthropogenic CO_2 emissions → Global warming

Global warming effects

- Policies to reduce emissions:
  1. Carbon pricing (ETS, carbon tax)
  2. Regulation
  3. Low carbon technology
  4. Large scale climate investments

- Disadvantages of 1. :
  1. Empirical evidence?
  2. Too slow?
  3. Politically difficult?
  4. Intergeneration fairness?

⇒ We propose mixed policies: tax and bonds

Overlapping generations framework (Sachs, 2015)[1]

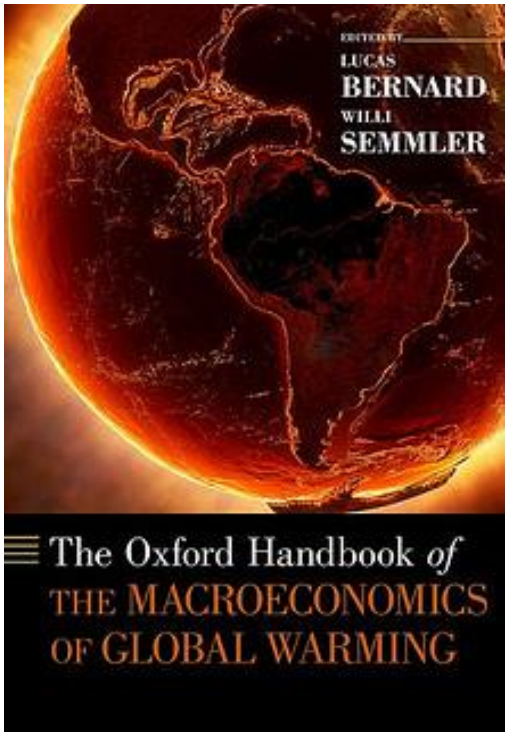
=> **Sachs contrasts**:

- Business-as-usual
- Mitigation effort by current generation, reimbursement through bond issuing
- Bond repayment through next generation

⇒ **Claim**: Intergenerational fiscal policy (bonds and taxes) is welfare improving for both generations

Caveats:

1. Phases are exogenous
2. Emission is exogenous
3. Taxes are exogenous



[1]Jeffrey D. Sachs Climate Change and Intergenerational Well-being // The Oxford Handbook of the Macroeconomics of Global Warming, 2015, pp. 248-260

Continuous time framework (Flaherty et. al, 2016)[2]

- Three stages (phases):
  1. Business-as-usual scenario
  2. Green bonds issued compensating for climate change mitigation
  3. Bond debt repayment through taxation at later time period
- Each stage is solved separately with NMPC[3] until the solution is close to equilibrium

Caveats:

1. Separate phases
2. No dynamic decisions on tax rate
3. Little calibration of the model

[2]M. Flaherty, A. Gevorkyan, S. Radpour & W. Semmler Financing climate policies through climate bonds – A three stage model and empirics // Research in International Business and Finance, 2016

[3]L. Gruene, W. Semmler, M. Stieler Using nonlinear model predictive control for dynamic decision problems in economics // Journal of Economic Dynamics and Control, 60, 2015, pp. 112–133

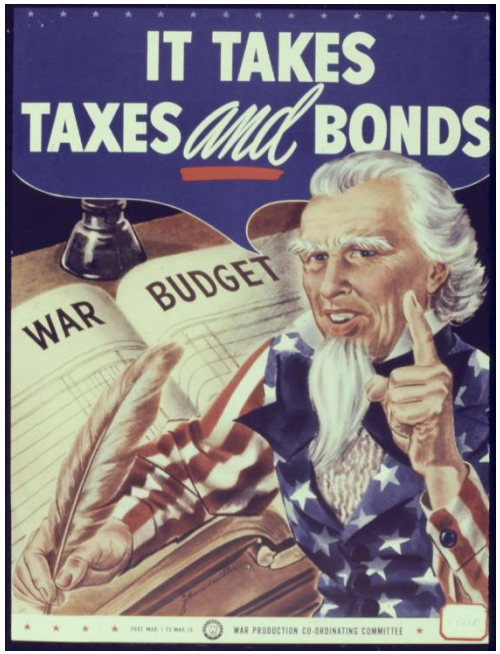
Use of DICE-2013R model with a mix of tax and bond financing

Why did we choose it?

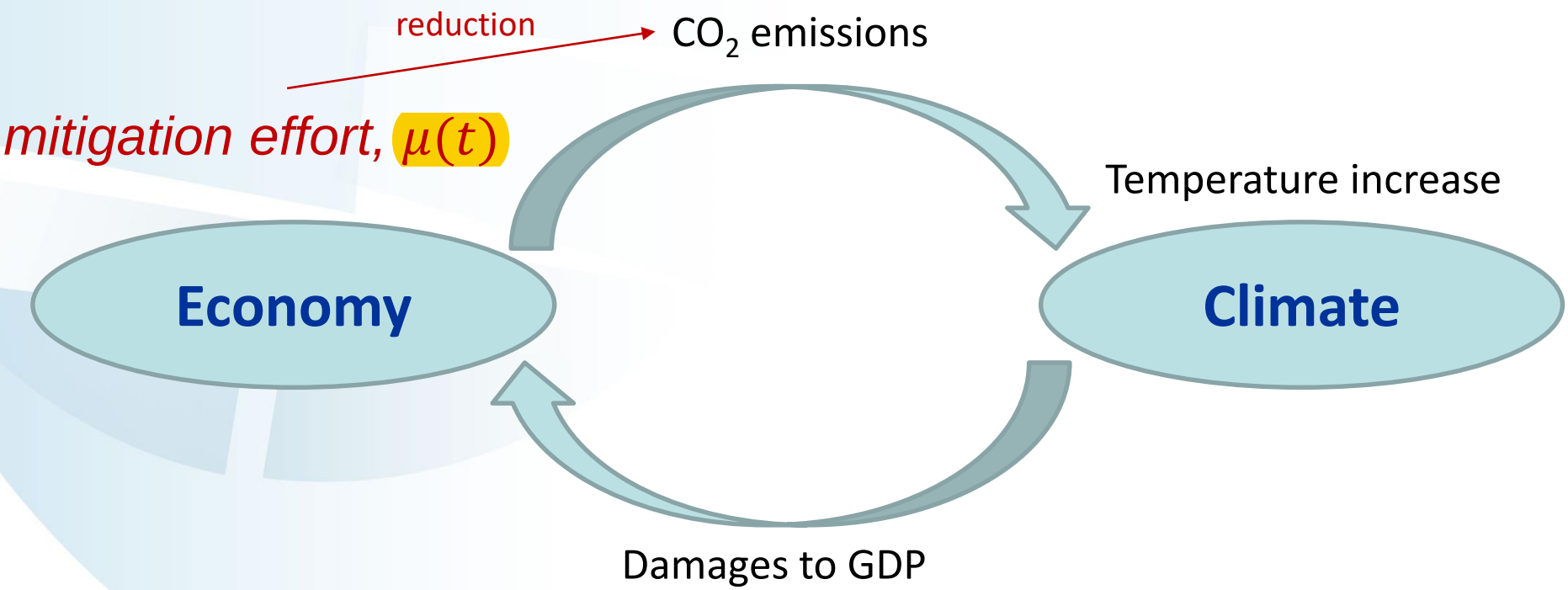
- Core economic and climate variables
- Calibrated model
- Well-known tools to simulate (GAMS/CONOPT)

Objectives of using bonds:

- Politically feasible
- Speeding up the transition
- Intergenerational fairness
- Welfare improvement



DICE-2013R model



DICE-2013R short description

Welfare $W = \sum_{t=0}^{T}(1+\rho)^{-s}U\big(c(t), L(t)\big)$ → max

subject to

Economy

$$Q(t) = \big[1 - \Lambda\big(\mu(t)\big)\big]\Omega(t)Y(t) = C(t) + I(t)$$
$$K(t+1) = I(t) + (1-\delta_K)K(t)$$
$$E_{Ind}(t) = \sigma(t)[1-\mu(t)]Y(t)$$
$$E(t) = E_{Ind}(t) + E_{Land}(t)$$
$$\Omega(t) = \frac{1}{1+aT_{AT}^2(t)}$$

Climate

$$\begin{bmatrix} M_{AT}(t+1) \\ M_{UP}(t+1) \\ M_{LO}(t+1) \end{bmatrix} = \begin{bmatrix} \xi_1 \\ 0 \\ 0 \end{bmatrix} E(t) + \begin{bmatrix} \phi_{11} & \phi_{12} & 0 \\ \phi_{21} & \phi_{22} & \phi_{23} \\ 0 & \phi_{32} & \phi_{33} \end{bmatrix} \begin{bmatrix} M_{AT}(t) \\ M_{UP}(t) \\ M_{LO}(t) \end{bmatrix}$$

$$F(t) = \eta \log_2[M_{AT}(t)/M_{AT}(1750)] + F_{EX}(t)$$
$$\begin{bmatrix} T_{AT}(t+1) \\ T_{LO}(t+1) \end{bmatrix} = \begin{bmatrix} \xi_2 \\ 0 \end{bmatrix} F(t+1) + \begin{bmatrix} \zeta_{11} & \zeta_{12} \\ \zeta_{21} & \zeta_{22} \end{bmatrix} \begin{bmatrix} T_{AT}(t) \\ T_{LO}(t) \end{bmatrix}$$

6 dynamic equations

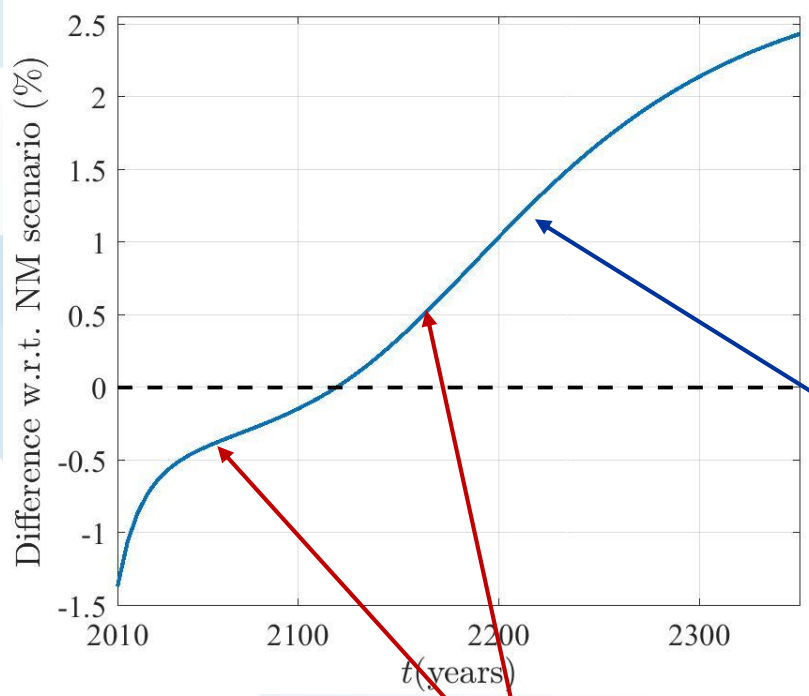
Decision variables: $C(t), \mu(t)$

M – stock of carbon

Two scenarios

DICE scenarios ($C(t), \mu(t)$):

- No mitigation (NM)
- Optimal mitigation (OM)



Sequential social welfare function:

$$W(t) = \sum_{s=0}^{t} (1+\rho)^{-s} U\big(c(s), L(s)\big)$$

- ρ – discount rate
- $c(t)$ – consumption per capita
- $L(t)$ – labor
- $U\big(c(t), L(t)\big)$ – utility function

Plot of percentage change $[W^{OM}(t) - W^{NM}(t)]/W^{NM}(t)$

Intergenerational problem

Bonds in the DICE model

- **Dynamics of bonds**

$$Bonds_{t+1} = (1 + Rate) \cdot Bonds_t - (Taxation_t - Abatement_t)$$

new decision variable

- **Bonds have to be repaid**

$$Bonds_T = 0$$

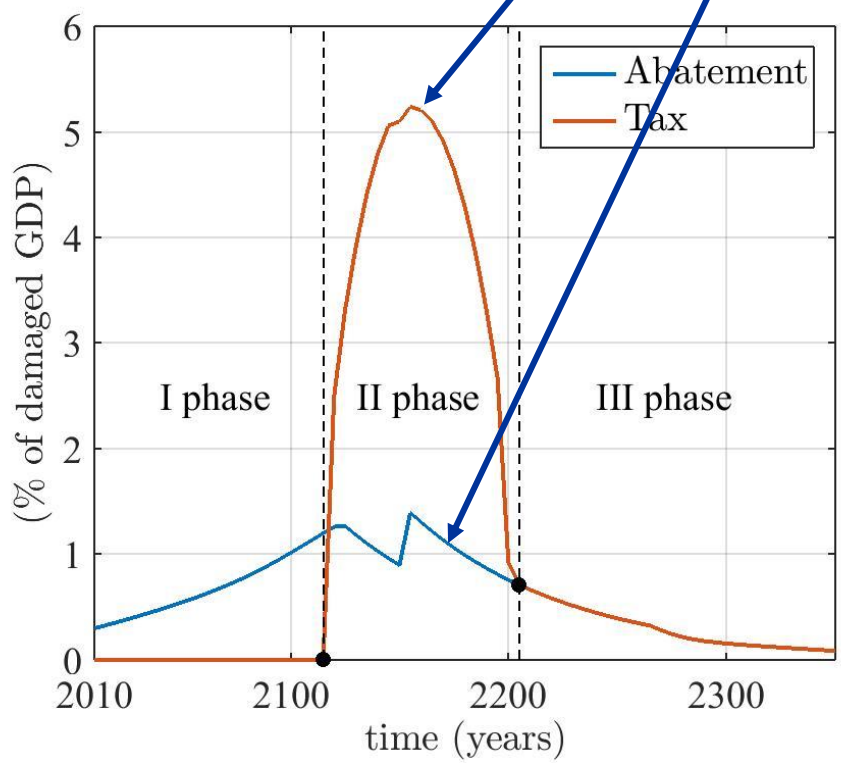
- **Initial governmental debt is zero**

$$Bonds_0 = 0$$

Optimal mitigation with bonds (OMB)

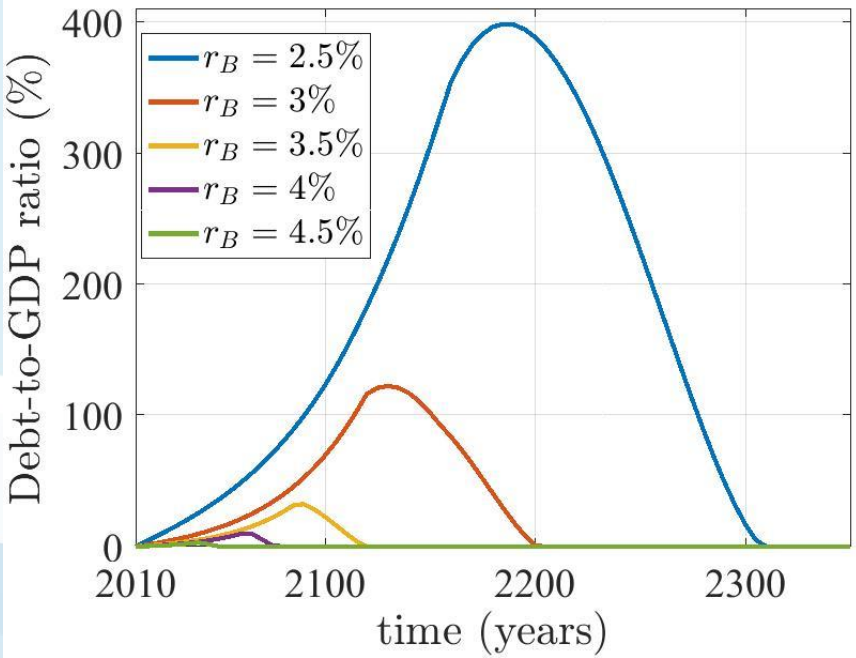
Decision variables: $C(t), \mu(t), \tau(t)$

$$B(t+1) = (1+r_B)B(t) - \left[\tau(t) - \Lambda\big(\mu(t)\big)\right]\Omega(t)Y(t)$$

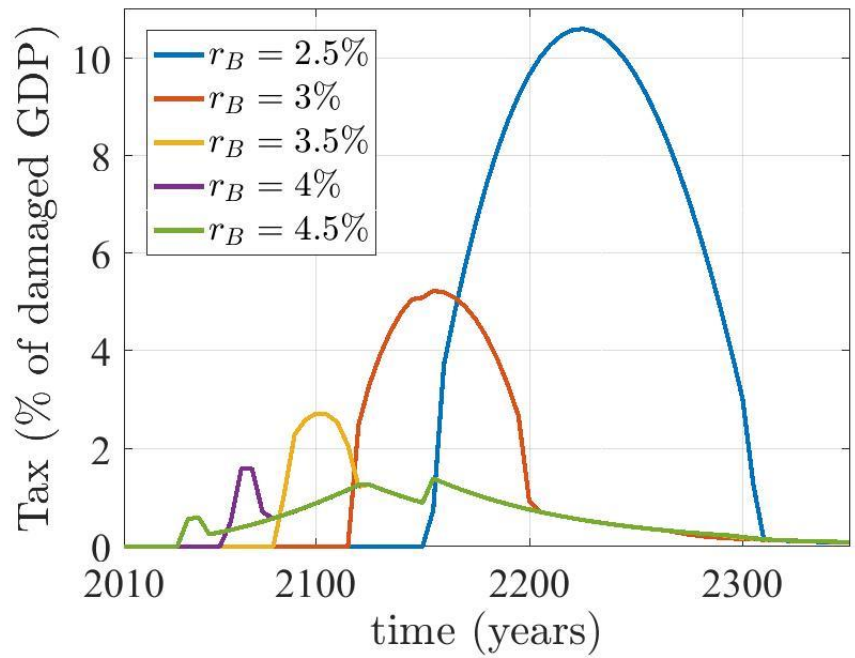


Sequence of three phases

Optimal mitigation with bonds (OMB)



Sensitivity of interest rate to bonds



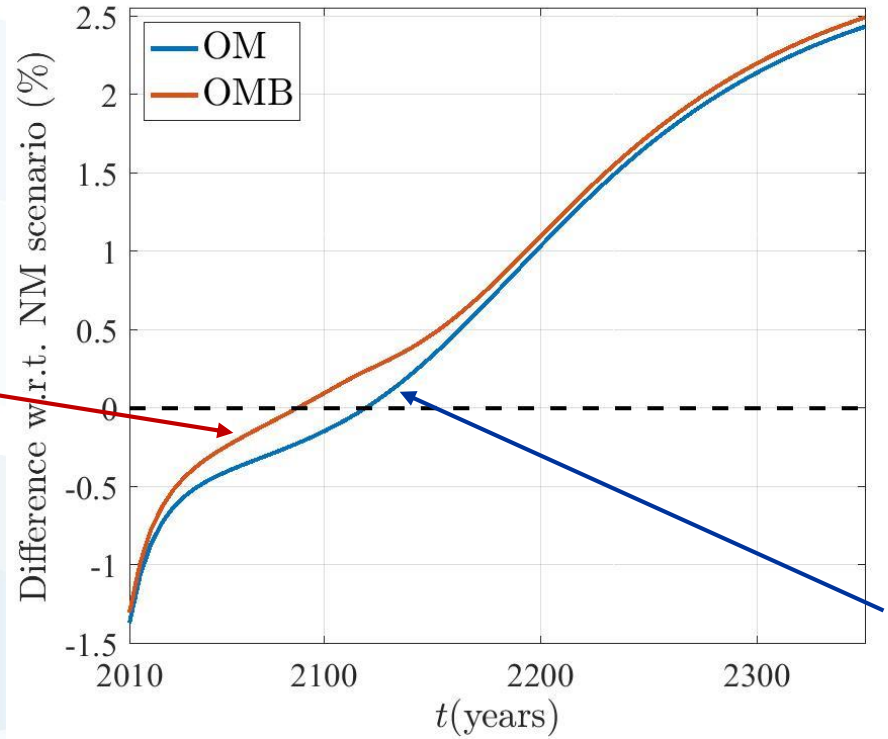
Sensitivity of interest rate to tax

- *The lower the interest rate (more bonds issued) the faster the emissions decrease*

- *The lower the interest rate (more bonds issued) the later bonds are repaid*

Optimal mitigation with bonds (OMB)

$$\frac{W^{OMB}(t) - W^{NM}(t)}{W^{NM}(t)}$$



$$\frac{W^{OM}(t) - W^{NM}(t)}{W^{NM}(t)}$$

- Pareto improvement over OM scenario
- Still no Pareto improvement over NM scenario

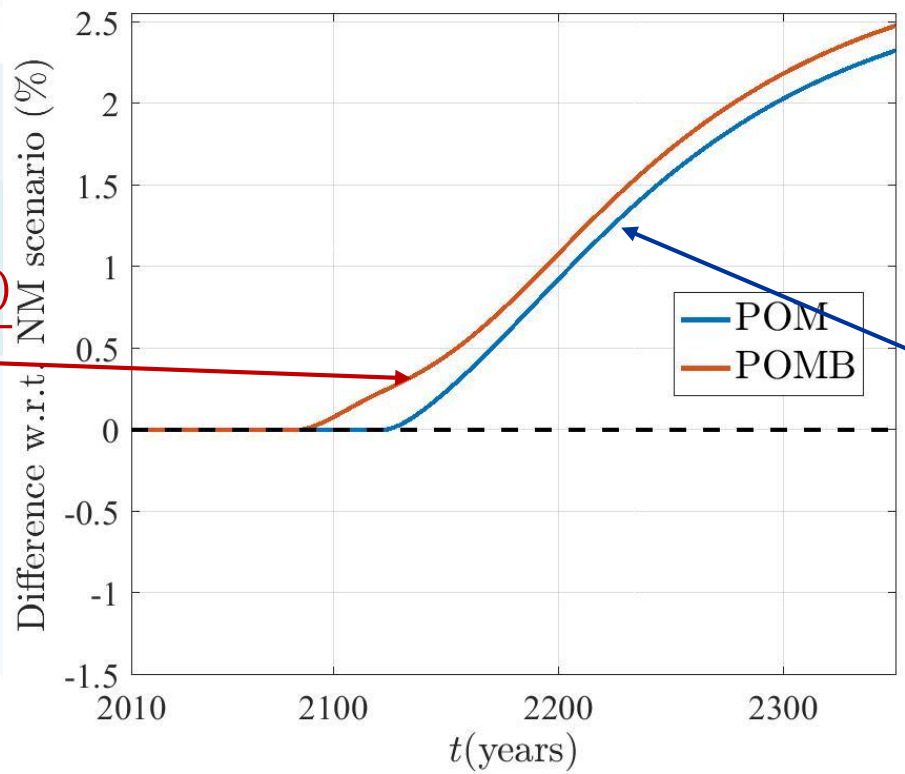
Pareto optimal scenarios

Constraints on consumption: $C(t) \geq C^{NM}(t), \ 0 \leq t \leq T$

Two more scenarios:

- Pareto optimal mitigation (POM) = OM + constraints on consumption
- Pareto optimal mitigation with bonds (POMB) = OMB + constraints on consumption

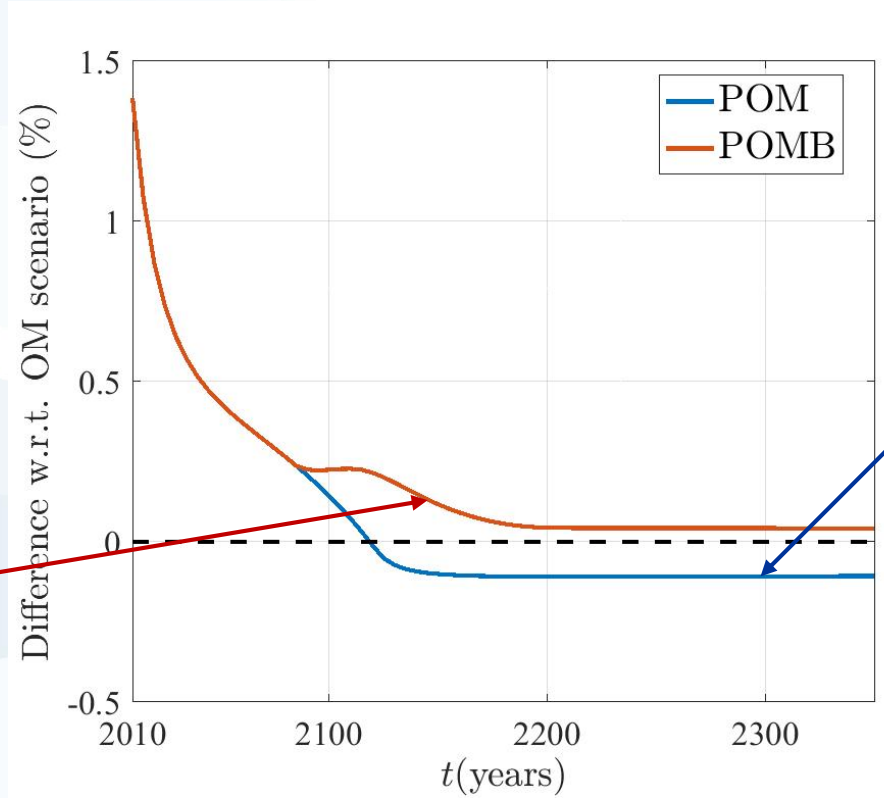
$$\frac{W^{POMB}(t) - W^{NM}(t)}{W^{NM}(t)}$$



$$\frac{W^{POM}(t) - W^{NM}(t)}{W^{NM}(t)}$$

Pareto optimal scenarios

Constraints on consumption: $C(t) \geq C^{NM}(t),\ 0 \leq t \leq T$



$$\frac{W^{POM}(t) - W^{OM}(t)}{W^{OM}(t)}$$

$$\frac{W^{POMB}(t) - W^{OM}(t)}{W^{OM}(t)}$$

- Pareto improvement of POMB over OM scenario and POM

Summary

Does bond financing of climate policy and repayment later through taxation help?

- Politically more feasible than carbon tax alone
- Speeding up the transition
- Intergenerational fairness
- Welfare improvement
- Needs complementary policies (regulation, low carbon technology, infrastructure…, see our IMF work)

Thank you for your attention!

Appendix: Portfolio Approach

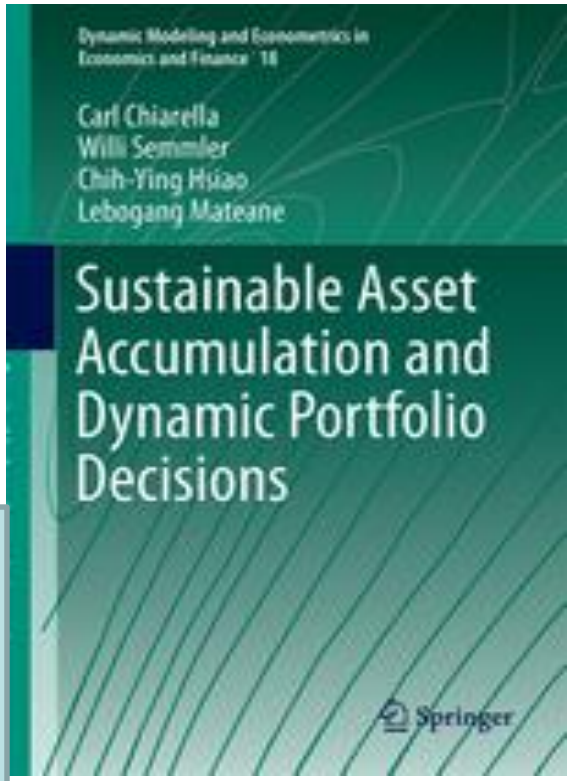
Instead of a 2-asset model (capital stock and bonds) we can have multiple assets

$$\max_{\{C^*,\alpha\}} \int_0^{\infty} e^{-\delta} U(C_t)dt$$

$$\text{s.t. } \dot{W}(t) = \alpha_t R_{e,t} W_t + (1-\alpha_t) R_{f,t} W_t - C_t$$

+ Wages- tau

$$\dot{x}(t) = 1$$



W_dot=K_dot + B_dot, or K_dot=W_dot-B_dot

$$Q(t) = [1 - \Lambda(\mu(t))]\Omega(t)Y(t) = C(t) + I(t)$$

B_dot=G-tau + $(1-\alpha_t) R_{f,t} W_t$