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

Sergey Orlov\textsuperscript{12}, Julia Puaschunder\textsuperscript{31}, Elena Rovenskaya\textsuperscript{12}, Willi Semmler\textsuperscript{341}

\textsuperscript{1}International Institute for Applied System Analysis (Austria)
\textsuperscript{2}Lomonosov Moscow State University (Russia)
\textsuperscript{3}New School for Social Research (United States)
\textsuperscript{4}University of Bielefeld (Germany)
Motivation

• 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

Global warming effects

© http://climate.nasa.gov/effects/
© http://www.easterbrook.ca/pmu199/?p=860
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

¹Jeffrey 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 NMPC³ until the solution is close to equilibrium

Caveats:

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


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

- mitigation effort, $\mu(t)$
- reduction
- CO$_2$ emissions
- Temperature increase
- Damages to GDP
- Economy
- Climate
DICE-2013R short description

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

subject to

Economy

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

Climate

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

\[
F(t) = \eta \log_2[M_{AT}(t)/M_{AT}(1750)] + F_{EX}(t)
\]
\[
\begin{bmatrix}
T_{AT}(t + 1) \\
T_{LO}(t + 1)
\end{bmatrix} = 
\begin{bmatrix}
\xi_2 & 0 \\
0 & \phi_{11} & \phi_{12} & 0 \\
0 & \phi_{21} & \phi_{22} & \phi_{23}
\end{bmatrix}
\begin{bmatrix}
T_{AT}(t) \\
T_{LO}(t)
\end{bmatrix}
\]

Decision variables: $C(t), \mu(t)$  \[ M \text{ – stock of carbon} \]
Two scenarios

DICE scenarios \((C(t), \mu(t))\):
- No mitigation (NM)
- Optimal mitigation (OM)

Sequential social welfare function:
\[ W(t) = \sum_{s=0}^{t} (1 + \rho)^{-s} U(c(s), L(s)) \]
- \(\rho\) – discount rate
- \(c(t)\) – consumption per capita
- \(L(t)\) – labor
- \(U(c(t), L(t))\) – utility function

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

Intergenerational problem
Bonds in the DICE model

• Dynamics of bonds

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

• Bonds have to be repaid

\[ Bonds_T = 0 \]

• Initial governmental debt is zero

\[ Bonds_0 = 0 \]
Optimal mitigation with bonds (OMB)

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

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

Sequence of three phases
Optimal mitigation with bonds (OMB)

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

- **Sensitivity of interest rate to tax**
  - The lower the interest rate (more bonds issued) the later bonds are repaid
Optimal mitigation with bonds (OMB)

- 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
Pareto optimal scenarios

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

- 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

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

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

\[ \dot{x}(t) = 1 \]

\[ W_{dot} = K_{dot} + B_{dot}, \text{ or } K_{dot} = W_{dot} - B_{dot} \]

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

\[ B_{dot} = G - \tau + (1 - \alpha_t) R_{f,t} W_t \]