Pricing in Transition and Physical Risks: Carbon Premiums and Stranded Assets

Christoph Hambel[1] Frederick van der Ploeg[2]

[1]Tilburg University
[2]University of Oxford

EEA 2024
29.08.2024, Rotterdam

Research Question

- Sudden shocks to the political landscape or technological breakthroughs are disruptive changes and examples for transition risk.
- Other examples for disruptive changes are climate tipping points that suddenly affect the Earth's climate system.

Research Questions

1. How do sudden disruptive changes affect the social cost of carbon and the transition to a low-carbon economy?
2. How does the risk of asset stranding interact with this transition?
3. How do financial markets price in those risks?

- To answer those questions, we develop, calibrate, and solve a two-sector DSGE model with a three-dimensional Markov chain that nests the model of Hambel et al. (2024) as a special case.

The Model in a Nutshell

- DSGE model with two sectors (green and brown) and two energy sources (renewable energy and fossil fuel).
  - Cobb-Douglas production with capital, energy composite $E_n = \left(\kappa_{1,n} G_n^{\rho_n} + \kappa_{2,n} F_n^{\rho_n}\right)^{\frac{1}{\rho_n}}$, and TFP damages $\Lambda_n(T, \mathbf{X})$

$$Y_n = A_n K_n^{1-\eta_n} E_n^{\eta_n} \Lambda_n(T, \mathbf{X}), \qquad n = 1, 2.$$

  - endogenous investment, capital reallocation from brown to green.
  - capital is affected by climate-related and exogenous disasters.
- Standard climate model with tipping points.
  - industrial emissions $\sim$ fossil fuel use $E^{ind} = \nu(F_1 + F_2)$.
  - negative emission technology may eventually be available at low marginal costs, $E^{net} = \nu(F_1 + F_2) - D$.
  - temperatures $\sim$ cumulative emissions, but noisy.

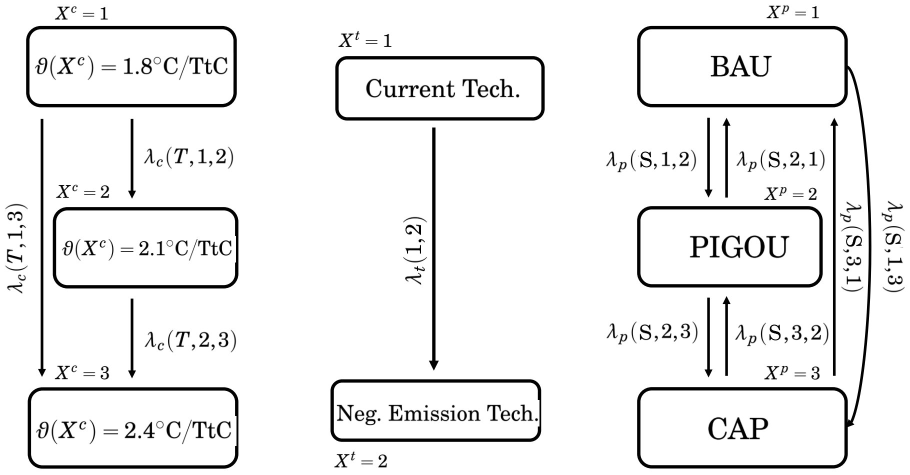
$$\mathrm{d}T = \vartheta(\mathbf{X})[\nu(F_1 + F_2) - D]\,\mathrm{d}t + \sigma_T \mathrm{d}W_3$$

  - climate tipping points affect the TCRE and damages.

Markov Chain for Disruptive Changes

- Three-dimensional Markov chain $\mathbf{X} = (X^c, X^t, X^p)$.
- Climate-related Markov chain X^c with three states:
  - pre-tipping state, intermediate state, post-tipping state.
  - climate tipping points affect the TCRE and damages.
  - transition intensity depends on temperature.
- Technological Markov chain X^t with two states:
  - post-tipping state: Negative emission technology for carbon removal at moderate to low marginal costs (depending on how far the transition is).
- Political Markov chain X^p with three states modeling political regime shifts:
  - BAU "Trump": Social planner ignores damages from climate change.
  - PIGOU: Social planner implements a tax that internalizes the negative externalities.
  - CAP: Social planner forbids CO_2 emissions if temperatures exceed two degrees.

Markov Chain for Disruptive Changes



Consumption and EZ-Preferences

- Consumption goods produced by sector n are the sector's residual cash flow net of investments, energy costs, and costs of negative emissions

$$C_n = Y_n - I_n - c_n(\mathbf{S}, \mathbf{X}, E_n) - \zeta_n b_d(\mathbf{S}, \mathbf{X}, D).$$

  $c_n(\mathbf{S}, \mathbf{X}, E_n)$: aggregate costs of the energy composite E_n.
  $\zeta_n b_d(\mathbf{S}, \mathbf{X}, D)$: costs of negative emissions.

- Aggregate consumption: $C = C_1 + C_2$, Dividends: $\mathcal{D}_n = C_n^{\varphi}$
- We assume that our economy is populated by a representative agent with recursive preferences,

$$J(t, \mathbf{S}, \mathbf{X}) = \sup_{D, F_n, G_n, I_n, R} \mathbb{E}_t \Big[\int_t^\infty f(C_s, J(s, \mathbf{S}_s, \mathbf{X}_s)) \mathrm{d}s \Big],$$

  where f is the EZ-aggregator. We denote the continuous state variables in the econmoy by $\mathbf{S} = (K_1, K_2, T)$.

Solution Approach

- The model contains the two-sector model of Hambel et al. (2024) as a special case.
- Rewrite the indirect utility function

$$J(t, K_1, K_2, T, \mathbf{X}) = \frac{1}{1-\gamma}(K_1 + K_2)^{1-\gamma} V(t, S, T, \mathbf{X})$$

  where $S = \frac{K_2}{K_1+K_2}$.
- Solve the corresponding Hamilton-Jacobi-Bellman equation and determine carbon prices.
- Derive the dynamics of the pricing kernel and determine
  - risk-free rate,
  - risk premia,
  - dividend yields.
- Simulate the model forward.

Semi-analytical Results I: SCC and NET

- SCC = Present value of the damages from releasing one ton of carbon into the atmosphere:

$$\tau = \frac{\vartheta(\mathbf{X})c^{1/\psi}}{\delta(\gamma - 1)} \frac{V_T}{V^{1-1/\theta}} K > 0.$$

  It is the optimal Pigouvian tax that internalizes the negative externalities from global warming, and is implemented in PIGOU and CAP.

- After a technological breakthrough, the social planner keeps extracting carbon from the atmosphere until the marginal costs exceed the marginal benefits (i.e., the SCC):

$$\frac{\partial b_d(\mathbf{S}, \mathbf{X}, D)}{\partial D} = \tau$$

Semi-analytical Results II: Risk-free Rate

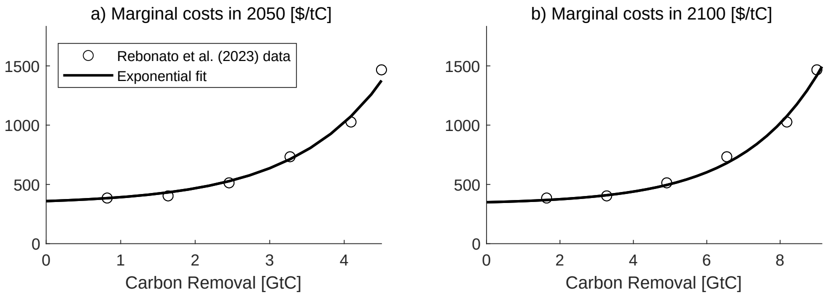
$$
\begin{aligned}
r_t^f = \; & \underbrace{\delta}_{\textit{Discounting}} + \underbrace{\frac{1}{\psi}\mu_C}_{\textit{Consumption Smoothing}} \underbrace{- \frac{1}{2}\gamma\Big(1 + \frac{1}{\psi}\Big)\|\sigma_C\|^2}_{\textit{Standard Diffusion Risk}} \\
& \underbrace{- \sum_{i=c,e} \lambda_i(T)\mathbb{E}\Big[Z_i^{-\gamma} - 1 + \frac{\theta - 1}{\theta}\big(1 - Z_i^{1-\gamma}\big)\Big]}_{\textit{Disaster Risk}} \\
& \underbrace{+ \frac{\gamma\psi - 1}{2\psi^2}\Big(\|\sigma_C - \sigma_k\|^2 + \psi\big(\|\sigma_C\|^2 - \|\sigma_k\|^2\big)\Big) + \frac{\theta - 1}{\theta}\frac{1}{\psi}\sigma_g^\top(\sigma_C - \sigma_k)}_{\textit{Temperature Interaction Risk}} \\
& \underbrace{- \sum_{x \neq \mathbf{X}} \lambda_x(\mathbf{S}, \mathbf{X}, x)\Big[(1 - j_v^x)^{1-1/\theta}(1 - j_c^x)^{-1/\psi} - 1 + \frac{\theta - 1}{\theta} j_v^x\Big]}_{\textit{NEW: Climate Tipping and Transition Risk}}
\end{aligned}
$$

Benchmark Calibration I

1. Green sector only takes renewable energy. Brown sector takes both energy forms as substitutes. Costs of renewable energy fall in accordance with Swanson's law. $\rightarrow$ No asset stranding
2. We calibrate the economic part of the model such that it matches the historical average (e.g., Hambel et al., 2023, 2024)
    - consumption growth rate of $\approx 2\%$,
    - investment-output ratio of $\approx 25\%$,
    - real interest rate of $\approx 0.8\%$,
    - equity premium of $\approx 6.6\%$,
    - Tobin's Q of ≈ 1.5,
    - consumption volatility of $\approx 2\%$.
3. We calibrate the climate part to match a relaxed RCP8.5 scenario and Allen et al. (2009), tipping points and TFP damages in line with Cai and Lontzek (2019), and climate disasters in line with Karydas and Xepapadeas (2022).

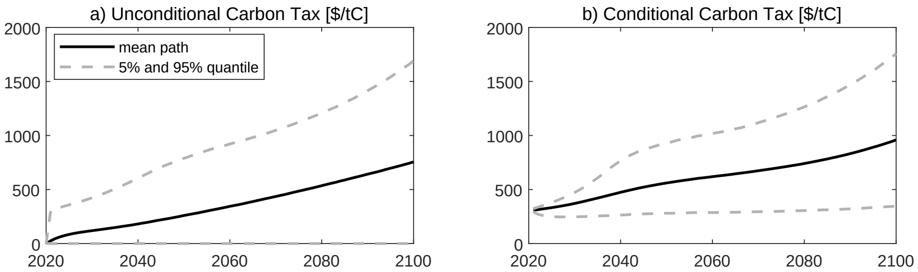
Benchmark Calibration II

4. We calibrate the cost functions for the net emission technology and the breakthrough probability to be in line with Rebonato et al. (2023) and Fuss et al. (2018).



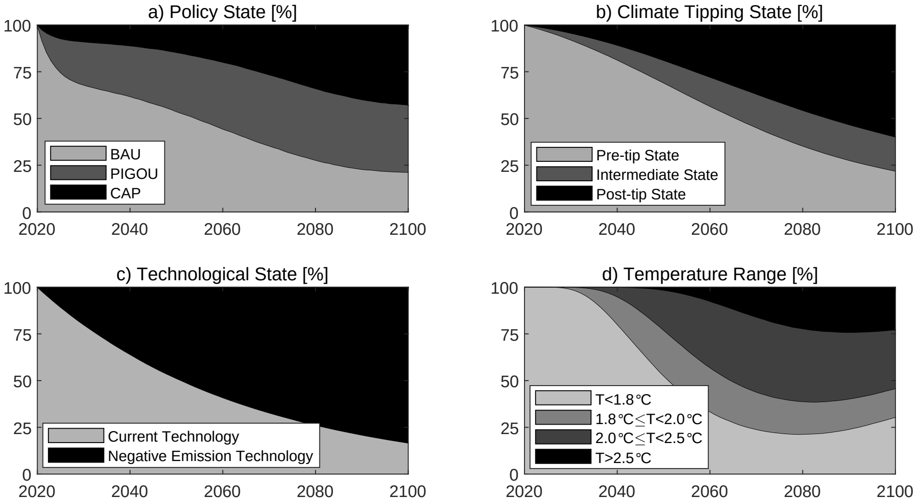
5. The political Markov chain is calibrated to roughly match the likelihood and resulting temperature increase of the various transition scenarios in Moore et al. (2022).

Simulation Results for the Benchmark Calibration I

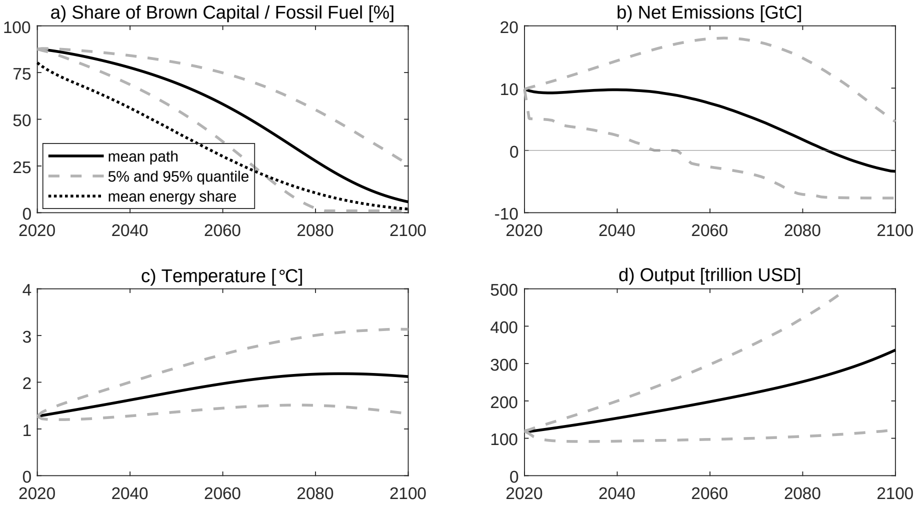


- Carbon taxes are initially zero as the world starts in BAU.
- When society starts pricing, taxes are sizable but depend to a large extend on the current state of the Markov chain.
- Average taxes in 2021 are 308 USD/tC or 84 USD/tCO_2.

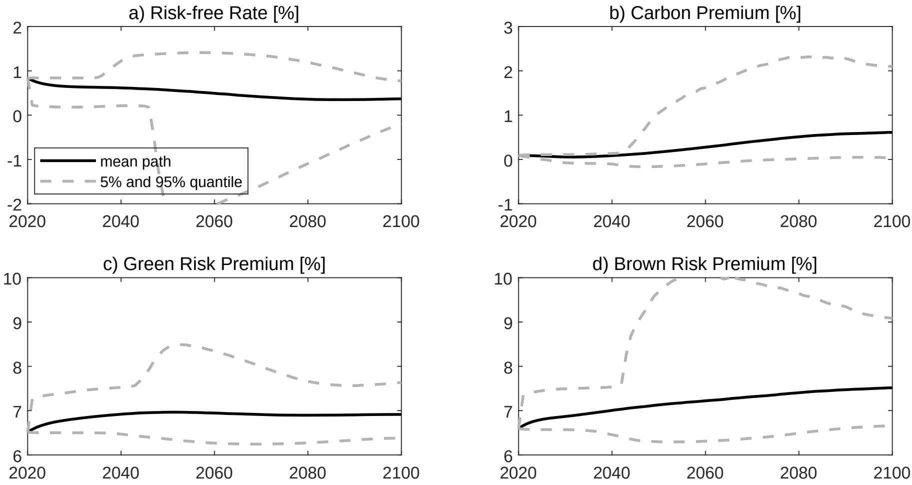
Simulation Results for the Benchmark Calibration II



Simulation Results for the Benchmark Calibration III



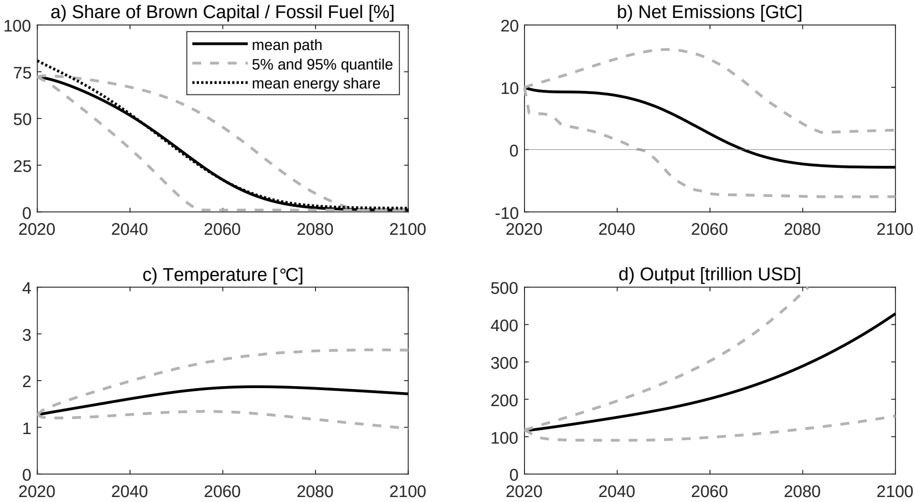
Simulation Results for the Benchmark Calibration IV



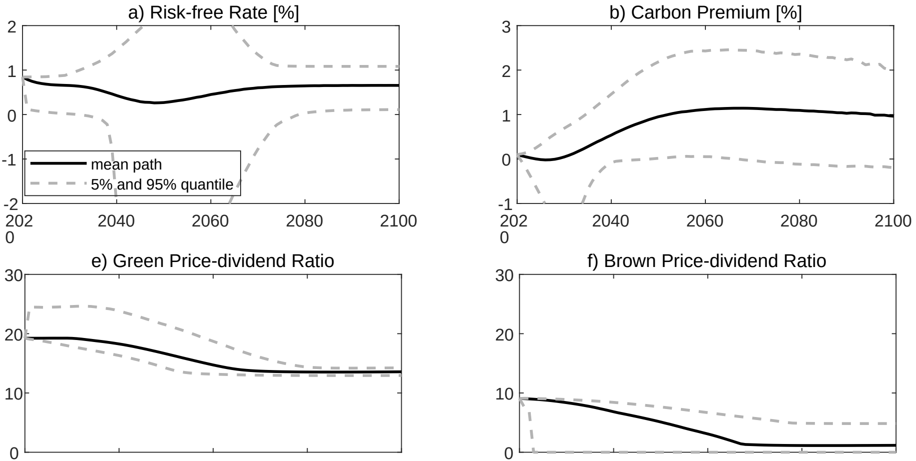
Simulation Results for the Stranded Asset Case I

- As a variant, we calibrate the model such that it can generate asset stranding.
  - The brown sector takes fossil fuel only.
  - The green sector accepts both energy forms as substitutes with a much higher weight on renewable energies.
  - We provide several alternative specifications that lead to qualitatively similar results.
- The brown sector can now be interpreted as the fossil fuel industry.
- If temperature exceeds 2°C and there is a policy transition to CAP, the brown sector must not be operated anymore. $\rightarrow$ Asset stranding
- The costs of stranding are sizable and society aims to counter this risk by implementing more stringent carbon taxes (366 USD/tC) and an accelerated transition towards net zero.
- Financial markets price in the risk of stranding.
  - More precautionary savings $\rightarrow$ lower interest rates.
  - Higher risk premia for both risky assets.
  - Price of the brown asset is sizable lower than in the benchmark case.

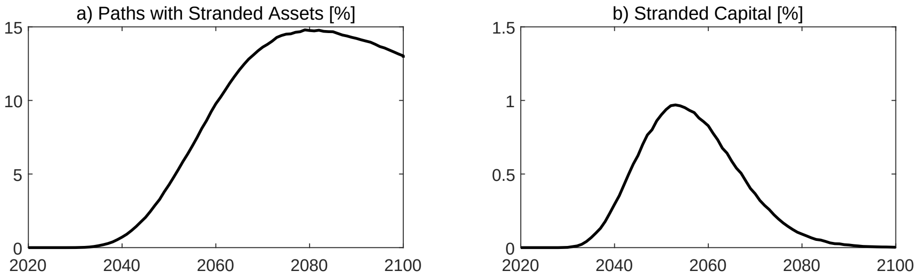
Simulation Results for the Stranded Asset Case II



Simulation Results for the Stranded Asset Case III



Simulation Results for the Stranded Asset Case IV



- Number of paths with stranded assets peaks in 2080 at 15% of the paths.
- Stranding can be reverted if either the policy state transitions back from the CAP state or if temperatures fall below two degrees.
- Negative emission technology reduces the likelihood of stranding and increases the likelihood that the brown technology may eventually be operated again.

Conclusion

- Our results indicate that the existence of the carbon premium (Bolton and Kaspercyk 2021, 2023; Hsu et al. 2023) is driven by political transition risk.
  - It is initially small (Aswani et al. 2024; Hambel and van der Sanden 2024; Zhang 2024).
  - When transition risks become more pronounced, it becomes sizable.
- Negative emission technologies are essential to keep temperatures below two degrees.
- We provide a detailed numerical analysis on how political shocks affect asset prices and find (among other things):
  - If climate policy has already tightened, the risk of a transition to CAP has sizable effects on risk premia and the risk-free rate.
  - If temperatures are already close to two degrees, the magnitude of the risk premia and precautionary savings can be about as high as for Barro-type disaster risk.
  - These effects vanish when the transition is complete.