Climate Policy, Financial Frictions, and Transition Risk

S. Carattini, G. Heutel, G. Melkadze

March 2022
Motivation

- Climate change is a growing threat to the Earth and our well-being
Motivation

- Climate change is a growing threat to the Earth and our well-being
Les émissions de CO2 du secteur énergétique ont remonté fortement en 2021, selon l’AIE

L’énergie, premier secteur producteur de gaz à effet de serre, a vu ses émissions progresser de 6 % en 2021, pour atteindre 36,3 gigatonnes, leur « plus haut niveau », précise l’Agence internationale de l’énergie.

Le Monde avec AFP.

Publié le 08 mars 2022 à 18h52 - Lecture 1 min.

Les émissions de CO2 du secteur de l’énergie ont de nouveau augmenté, l’an dernier, en raison du rebond économique mondial et d’un recours accru au charbon, a annoncé, mardi 8 mars, l’Agence internationale de l’énergie (AIE).
Motivation

- Ambitious climate action needed to achieve the goal of the Paris Agreement

- Gradual carbon tax increase suggested by Integrated Assessment Models (e.g. DICE) likely insufficient to achieve 2°C goal
The financial sector matters a great deal for real economic activity

- Credit market frictions (e.g., moral hazard, costly defaults)
- Climate-policy-induced “transition risk” (Carney ‘15, ECB ‘19, IMF ‘19)
  - Financial intermediaries exposed to climate-policy-relevant sectors
  - Risk of asset stranding in carbon-intensive sectors
  - Environmental factors in macroprudential regulation
  - Risk of a recession from aggressive climate policy
Growing call for central bankers to consider climate in policy design

“At a time when the Intergovernmental Panel on Climate Change is warning of the potential catastrophic and irreversible damage inflicted by a changing climate, we need a leader at the helm [of the Fed] that will take bold and decisive action to eliminate climate risk.”

Biden administration Executive Order on climate-related financial risk (May 2021)

Federal Reserve Financial Stability Climate Committee (announced March 2021)

ECB Climate stress tests
Motivation

Imposing a carbon tax.

Requiring commercial banks to charge higher interest rates on loans to some fossil fuel or otherwise carbon-intensive activities.

(courtesy of Matt Darling via Twitter @besttrousers)
Beyond the transition, financial frictions can affect the efficient design of climate policy

- Two inefficiencies (climate and financial) $\Rightarrow$ two instruments needed
- Or, second best

- Long run (steady state) and business cycles
Research questions

1. Could a sudden and ambitious climate policy create transition risk?
   - Can macroprudential policies alleviate this risk?

2. How do financial frictions affect the efficient design of climate policy in the long-run and over business cycles?
   - Can financial regulation address the climate externality?
What Do We Do?

- DSGE model
- Two sources of market failure
  - Pollution externality
    - Brown and green producers
  - Financial friction between banks and households
    (Gertler & Kiyotaki 2010)
    - Credit to the economy limited by banks’ net worth
What Do We Do?

- DSGE model
- Two sources of market failure
  - Pollution externality
    - Brown and green producers
  - Financial friction between banks and households (Gertler & Kiyotaki 2010)
    - Credit to the economy limited by banks’ net worth
- Two policy instruments
  - Climate: emissions tax
  - Macroprudential: taxes/subsidies on banks’ assets
    - Could be uniform or differentiated (different for green vs. brown)
- TFP shocks (RBC)
Two sets of simulations

1. Transition: unexpected implementation of high carbon tax
   - Does the tax cause macroeconomic instability (recession) with financial frictions?
   - Can macroprudential policies alleviate the risk?

2. Long run and business cycles: steady state and TFP fluctuations
   - Efficient design of climate and/or macroprudential policy (Ramsey problem)
   - First- and second-best policies
What Do We Find?

1. Transition
   - Financial frictions plus climate policy can lead to recession
   - Macroprudential policy can alleviate the risk

2. Long run and business cycles
   - Financial frictions affect steady state and cyclical properties of efficient carbon tax
   - Macroprudential policies alone (even differentiated) not very effective at addressing climate externality
Related literature


- DSGE models with financial sector: Gertler & Karadi (2010), Gertler & Kiyotaki (2011), Gertler et al. (2012), Aoki et al. (2018), among others

Related literature

- Other E-DSGE models with financial frictions:
  Diluiso et al. (2021), Benmir & Roman (2020), Ferrari and Nispi Landi (2020)
- Our paper:
  - Looks at transition AND long-run/business cycles
  - Ramsey-efficient policy design (externality from pollution, endogenous emissions tax)
  - But, no monetary policy/price stickiness
Model: Overview

- Households, banks, government, and non-financial firms ('green', 'brown', final, capital)
- 2 sources of inefficiencies: pollution externality from brown firms; financial friction from banks
- 2 policies: climate policy (emissions tax), macroprudential policy (tax/subsidy to banks assets)
Model: Households

- A continuum of identical households of measure unity
- Fraction $1 - \iota$ of members are workers, and fraction $\iota$ are bankers
- Workers supply labor; return the wages to the HH
- Bankers manage financial intermediaries (banks); transfer dividends to the HH
A representative household chooses $C_t$, $L^b_t$, $L^g_t$, $D_t$ to maximize

$$E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \frac{1}{1-\eta} \left( C_t - \omega \frac{\left( \left( \left( L^b_t \right)^{1+\rho_L} + \left( L^g_t \right)^{1+\rho_L} \right)^{\frac{1}{1+\rho_L}} \right)^{1-\eta}}{1+\xi} \right) \right\} ,$$

subject to

$$C_t + D_t = w^b_t L^b_t + w^g_t L^g_t + R_{t-1} D_{t-1} + \Xi_t + \Pi_t + T_t.$$
Model: Financial friction overview

- Agency problem between a bank and its depositors (Gertler & Kiyotaki 2010)
- The banker can divert a fraction $\kappa$ of assets for personal benefit
- The depositors will lend as long as a banker does not have incentives to misbehave
- The amount of capital limited by banks’ net worth
Model: Banks

- Bank $j$ combines its own net worth $N_{j,t}$ and deposits $D_{j,t}$ to buy financial claims on firms $(S_{gj,t}, S_{bj,t})$

- Bank's balance sheet:

$$
(1 + \tau_t^b)Q_t^b S_{j,t}^b + (1 + \tau_t^g)Q_t^g S_{j,t}^g + \Psi_{j,t} = D_{j,t} + N_{j,t}.
$$

- $\Psi_{j,t} \cdot \cdot$ - small quadratic asset management costs (helps pin down steady state portfolio).
Model: Agency problem in banks

- An agency problem between a bank and its depositors (Gertler and Karadi 2011, Gertler and Kiyotaki 2010)
- The bank can divert the fraction $\kappa$ of total assets for its personal benefit
- Depositors can force the bank into bankruptcy and recover $(1 - \kappa)$ fraction of assets
- The depositors will lend as long as a banker does not have incentives to run away:

$$V_{j,t} \geq \kappa \left( Q_{t}^{b} S_{j,t}^{b} + Q_{t}^{g} S_{j,t}^{g} \right).$$
Model: Banks

- Denote by $R_{k,t+1}^b$ and $R_{k,t+1}^g$ the returns on brown and green assets.
- The evolution of net worth:

$$N_{j,t+1} = R_{k,t+1}^b Q_t^b S_{j,t}^b + R_{k,t+1}^g Q_t^g S_{j,t}^g - R_tD_{j,t}$$

- Exogenous bank exit i.i.d. probability $1 - \gamma$
- Upon exit a banker transfers its retained earnings to the household.
- Continuation (or franchise) value at the end of period $t$,

$$V_{j,t} = \mathbb{E}_t \left\{ \sum_{\tilde{\tau} = t+1}^{\infty} (1 - \gamma) \gamma^{\tilde{\tau} - t - 1} M_{t,\tilde{\tau}} N_{j,\tilde{\tau}} \right\}$$
Model: Bank optimization problem

- The bank solves

\[ V_{j,t} = \max_{S_{j,t}^b, S_{j,t}^g} \mathbb{E}_t \left\{ \left[ (1 - \gamma) M_{t+1} N_{j,t+1} + \gamma M_{t+1} V_{j,t+1} \right] \right\}, \]

subject to the balance sheet constraint, IC, the evolution of net worth

- Value function linear in bank’s net worth ⇒ easy aggregation of the banking sector
Model: Banks’ net worth and aggregate capital

- When banks are financially constrained:

\[ Q_t^b K_t^b + Q_t^g K_t^g = \frac{\varphi_t}{\kappa} N_t, \]

where \( \varphi_t \) is marginal shadow value of net worth

- This is the key equation capturing the financial friction
- Capital in the economy is constrained by banks’ net worth
- Shocks to the economy get amplified through fluctuations in banks’ equity capital
- Bankers do not internalize this effect and thus the equilibrium is inefficient
  - analogous to a second externality
Model: Pollution externality

- Production technology, \( i = \{b, g\} \)

\[
Y^i_t = [1 - d(X_t)] A_t (K^i_{t-1})^{\alpha^i} (L^i_t)^{1-\alpha^i}, \quad 0 < \alpha^i < 1
\]

- Damage function \( d(X_t) \) increasing in pollution stock \( X_t \)

- Firms do not internalize pollution externality
Model: Brown sector

- Emissions are a by-product of ‘brown’ production
  \[ e_t = (1 - \mu_t) \left( Y_t^b \right)^\epsilon \]

- Pollution stock evolves according to
  \[ X_t = \delta X_{t-1} + e_t + e^{row} \]

- Cost of emissions abatement \( \mu_t \)
  \[ Z_t = \theta_1 \mu_t^{\theta_2} Y_t^b \]
Model: Calibration

- Standard RBC parameters
- Financial frictions parameters (target bank leverage ratio, credit spreads)
- Environmental parameters (damage function, abatement cost function, etc.)
  - Calibrated based on DICE model

Parameter values
Results

- Two sets of simulations/results
  1. Transition risk – Exogenous climate policy shock
  2. Ramsey-efficient first- and second-best policies:
     - Deterministic steady-state
     - Business cycles (TFP shocks)
Results: Transition Risk Simulations

- Unexpected introduction of a $31 per ton tax on CO2
  - Our (Ramsey) efficient tax
  - Roughly equal to DICE, IMF recommendations, SCC
- Start in baseline (no tax) steady state, hit with tax in period 5
- Compare model with and without financial frictions
Results: Transition risk

(a) Emissions

(b) Aggregate investment

(c) Aggregate output

(d) Banks' net worth

(e) Green capital

(f) Brown capital

Financial Frictions vs. No Financial Frictions

S. Carattini, G. Heutel, G. Melkadze

Georgia State University
Results: Transition risk (2)

- Instead of switch from brown to green, financial frictions lock up both types of capital
- Carbon tax can cause a recession, and the recession is worse with financial frictions
Results: Transition risk (2)

- Instead of switch from brown to green, financial frictions lock up both types of capital
- Carbon tax can cause a recession, and the recession is worse with financial frictions

Can macroprudential policy alleviate these risks?
- Reduce banks’ exposure to brown assets
- A tax on ‘brown’ & subsidy to ‘green’ assets
- Lowers banks’ ss exposure to brown from 40% (baseline) to 33%

Compare transition dynamics with and without macroprudential policies
Results: Transition risk and macroprudential policy

- **Emissions**
- **Aggregate investment**
- **Aggregate output**
- **Banks' net worth**
- **Green capital**
- **Brown capital**
Results: Transition risk and macroprudential policy

- Macroprudential policies reduce the extent of the transition risk
- Alternate assumptions on timing, magnitude can affect quantitative results
Results: Efficient policies

- No longer transition, now steady state and fluctuations around it
- The Ramsey problem:

$$\max_{\{\text{allocations}\}, \{\text{instruments}\}} \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t U(C_t, L_t^b, L_t^g),$$

subject to competitive equilibrium conditions.

- Instruments (not all are available in each simulation):
  - Emissions tax - $\tau^e_t$
  - Taxes or subsidies on banks’ assets - $\tau^b_t, \tau^g_t$
    - Could be uniform or differentiated

- First, look at steady state
Results: Efficient policies (2) Steady state

Table 2: Steady state

<table>
<thead>
<tr>
<th></th>
<th>No financial frictions</th>
<th>Financial frictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No policy</td>
<td>Emissions tax only</td>
</tr>
<tr>
<td>Emissions tax ($\text{$ per ton}$)</td>
<td>0</td>
<td>30.5</td>
</tr>
<tr>
<td>Tax on brown assets (%)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Tax on green assets (%)</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Emissions</td>
<td>0.676</td>
<td>0.432</td>
</tr>
<tr>
<td>Aggregate output</td>
<td>1.506</td>
<td>1.519</td>
</tr>
<tr>
<td>Welfare loss (% CV)</td>
<td>0.84</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: This table shows the steady state values of selected variables in the economy with and without financial frictions under different policy scenarios. The units of the emissions tax are dollars per ton of CO$_2$, based on the calibration described in the text. Tax rates on banks’ assets are in percentages. Welfare loss is in terms of compensating consumption variation relative to the first-best allocations. All other variables are in arbitrary model units.
Results: Efficient policies (2) Steady state

- Without financial frictions, emissions tax alone yields first best
- With financial frictions, need emissions tax and macroprudential tax for first best
- Second-best policies
  - Emissions tax alone
    - Emissions close to first-best level
    - Output still too low
  - Macroprudential policies alone
    - Output closer to first-best level
    - Emissions even higher than no-policy
    - Even with differentiated macroprudential policies

- Sensitivity Analysis
Results: Efficient policies (3) cyclical properties

- Now, look at dynamic/cyclical properties
- Impulse response functions after one-time negative TFP innovation
- First, consider just emissions tax (no macroprudential policies), with and without financial frictions
- Second, consider different policy combinations, under financial frictions
Results: Efficient policies (3) Emissions tax alone

(a) TFP

(b) Emissions tax

(c) Emissions

(d) Aggregate investment

(e) Aggregate output

(f) Banks' net worth

Financial Frictions
No Financial Frictions
Results: Efficient policies (3) Emissions tax alone

- Emissions tax much more cyclical with financial frictions
- The regulator cuts the emissions tax more aggressively to mitigate the fall in banks’ net worth and credit supply
- Procyclicality of emissions is thus dampened; emissions actually increases initially after shock
Results: Efficient policies (3) Emissions tax alone

- Emissions tax much more cyclical with financial frictions
- The regulator cuts the emissions tax more aggressively to mitigate the fall in banks’ net worth and credit supply
- Procyclicality of emissions is thus dampened; emissions actually increases initially after shock

Next, consider macroprudential policies too (uniform or differentiated)
- Only uniform macroprudential policy (second best)
- Only differentiated macroprudential policy (second best)
- Uniform macroprudential policy and emissions tax (first best)
Results: Efficient policies (4) Emissions tax and macroprudential policies

- **TFP**
- **Emissions tax**
- **Emissions**
- **Aggregate investment**
- **Aggregate output**
- **Banks’ net worth**
- **Tax on brown assets**
- **Tax on green assets**

\[ \tau_b(t) = \tau_g(t) \]
\[ \tau_b(t) = \tau_g(t) \]
\[ \tau_e(t) \& \tau_b(t) = \tau_g(t) \]
Results: Efficient policies (4) Emissions tax and macroprudential policies

- Most outcomes similar (cyclical response) under first best or second best
- Exception: emissions much more procyclical under second best, without emissions tax
- No different between uniform and differentiated second-best macroprudential policies
  - Macroprudential policy not effective at responding to climate externality over the business cycle

Alternate emissions calibration
Can abrupt climate policy trigger financial instability risk?

- Unfortunately, yes. But, macroprudential policies, by improving the financial sector’s resilience, can mitigate this risk.

Efficient design of climate and macroprudential policy in the long run and over business cycles

- Macroprudential policies alone do poorly at addressing the climate externality.
- Carbon policy (emissions taxes) needed too.
Thank you!

Merci!
Banks’ portfolio choice

- Portfolio composition (the share of green assets, $s_t^g$):
  \[
  s_t^g = \mathbb{E}_t \left\{ \Omega_{t+1} \left[ \left( R_{k,t+1}^g - R_{k,t+1}^b \right) - (\tau_{t}^g - \tau_{t}^b) R_t \right] \right\} \psi \mathbb{E}_t [\Omega_{t+1} R_t] + \bar{s}^g
  \]

- Aggregate banking sector net worth:
  \[
  N_t = \gamma \left[ \sum_{i=\{g,b\}} R_{k,t}^i Q_{t-1}^i K_{t-1}^i - R_{t-1} D_{t-1} \right] + \zeta \sum_{i=\{g,b\}} Q_{t-1}^i K_{t-1}^i.
  \]
Brown sector

- Demand for labor:

\[ w^b_t = \left(1 - \alpha^b\right) \frac{Y^b_t}{L^b_t} \left[ p^b_t - \theta_1 \mu^b_t - \tau^e_t (1 - \mu_t) \epsilon \left(Y^b_t\right)^{\epsilon - 1} \right] \]

- Emissions abatement:

\[ \tau^e_t = \left(Y^b_t\right)^{1-\epsilon} \theta_1 \theta_2 \mu^b_t^{\theta_2-1} \]

- State-contingent gross return on brown capital:

\[ R^b_{k,t} = \frac{\alpha^b \frac{Y^b_t}{K^b_{t-1}} \left[ p^b_t - \theta_1 \mu^b_t - \tau^e_t (1 - \mu_t) \epsilon \left(Y^b_t\right)^{\epsilon - 1} \right] + (1 - \delta^b) Q^b_t}{Q^b_{t-1}} \]
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\beta$</td>
<td>0.995</td>
<td>Discount factor</td>
</tr>
<tr>
<td>$\eta$</td>
<td>2</td>
<td>Risk aversion</td>
</tr>
<tr>
<td>$\xi$</td>
<td>1</td>
<td>Frisch elasticity of labor hours</td>
</tr>
<tr>
<td>$\varpi$</td>
<td>8.3849</td>
<td>Labor disutility</td>
</tr>
<tr>
<td>$\rho_L$</td>
<td>1</td>
<td>Intrasectoral CES of labor hours</td>
</tr>
<tr>
<td>$\alpha^g$</td>
<td>0.33</td>
<td>Capital share in ‘green’ prod.</td>
</tr>
<tr>
<td>$\alpha^b$</td>
<td>0.35</td>
<td>Capital share in ‘brown’ prod.</td>
</tr>
<tr>
<td>$\delta^b, \delta^g$</td>
<td>0.025</td>
<td>Capital depreciation rate</td>
</tr>
<tr>
<td>$\phi^b, \phi^g$</td>
<td>10</td>
<td>Investment adjustment cost</td>
</tr>
<tr>
<td>$\rho_A$</td>
<td>0.95</td>
<td>Persistence of aggregate TFP shocks</td>
</tr>
<tr>
<td>$\sigma_A$</td>
<td>0.007</td>
<td>Std. dev. of innovations to TFP</td>
</tr>
</tbody>
</table>
Table. Calibration

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\theta_1$</td>
<td>0.0335</td>
<td>Abatement cost function parameters</td>
</tr>
<tr>
<td>$\theta_2$</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>$d_0$</td>
<td>$-0.0076$</td>
<td>Damage function parameters</td>
</tr>
<tr>
<td>$d_1$</td>
<td>$1.52 \times 10^{-5}$</td>
<td></td>
</tr>
<tr>
<td>$d_2$</td>
<td>$3.71 \times 10^{-8}$</td>
<td></td>
</tr>
<tr>
<td>$\delta X$</td>
<td>0.9965</td>
<td>Pollution decay</td>
</tr>
<tr>
<td>$\epsilon$</td>
<td>1</td>
<td>Emissions elasticity parameter</td>
</tr>
<tr>
<td>$e^{row}$</td>
<td>3.1499</td>
<td>Emissions in the ROW</td>
</tr>
<tr>
<td>$\rho_Y$</td>
<td>2</td>
<td>CES between ‘green’ and ‘brown’ outputs</td>
</tr>
<tr>
<td>$\pi_b$</td>
<td>0.3326</td>
<td>Share of ‘brown’ output</td>
</tr>
<tr>
<td>$\kappa$</td>
<td>0.3409</td>
<td>Fraction of divertable assets</td>
</tr>
<tr>
<td>$\gamma$</td>
<td>0.972</td>
<td>Bankers’ survival rate</td>
</tr>
<tr>
<td>$\zeta$</td>
<td>0.003</td>
<td>Proportional transfer to new bankers</td>
</tr>
<tr>
<td>$\psi$</td>
<td>$10^{-4}$</td>
<td>Banks’ portfolio management cost</td>
</tr>
<tr>
<td>$s^g$</td>
<td>0.60</td>
<td>Portfolio share of green assets</td>
</tr>
</tbody>
</table>
Appendix: Transition – Additional variables

(a) Emissions tax
(b) Aggregate labor
(c) Green production
(d) Brown production
(e) Price of brown assets
(f) Price of green assets

S. Carattini, G. Heutel, G. Melkadze
Appendix: Transition w/ macroprudential policies—
Additional variables

(a) Emissions tax

(b) Aggregate labor

(c) Green production

(d) Brown production

(e) Price of brown assets

(f) Price of green assets

S. Carattini, G. Heutel, G. Melkadze
Appendix: Transition dynamics: Abrupt versus gradual “ramp-up” approach

(a) Emissions
(b) Aggregate investment
(c) Aggregate output
(d) Banks' net worth
(e) Green capital
(f) Brown capital

Periods
% dev. from ss

(a) Emissions
(b) Aggregate investment
(c) Aggregate output
(d) Banks' net worth
(e) Green capital
(f) Brown capital

Periods
% dev. from ss

Abrupt
Gradual
Appendix: Transition dynamics: Immediate versus pre-announced implementation

(a) Emissions
(b) Aggregate investment
(c) Aggregate output
(d) Banks' net worth
(e) Green capital
(f) Brown capital

- Immediate
- Pre-announced
Appendix: Transition dynamics: Simultaneous macroprudential policies

(a) Emissions
(b) Aggregate investment
(c) Aggregate output
(d) Banks' net worth
(e) Green capital
(f) Brown capital

S. Carattini, G. Heutel, G. Melkadze
Appendix: Transition dynamics: Sequential implementation of policies

(a) Emissions
(b) Aggregate investment
(c) Aggregate output
(d) Banks' net worth
(e) Green capital
(f) Brown capital
Table A1. Deterministic steady state: additional variables

<table>
<thead>
<tr>
<th></th>
<th>No financial frictions</th>
<th>Financial frictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No policy  ( \tau^e )</td>
<td>( \tau^b = \tau^g )</td>
</tr>
<tr>
<td>Consumption</td>
<td>1.082 1.093</td>
<td>1.038 1.046 1.075</td>
</tr>
<tr>
<td>Green output</td>
<td>0.850 0.862</td>
<td>0.795 0.804 0.840</td>
</tr>
<tr>
<td>Brown output</td>
<td>0.676 0.675</td>
<td>0.630 0.629 0.668</td>
</tr>
<tr>
<td>Green investment</td>
<td>0.254 0.257</td>
<td>0.221 0.223 0.248</td>
</tr>
<tr>
<td>Brown investment</td>
<td>0.170 0.168</td>
<td>0.147 0.146 0.166</td>
</tr>
<tr>
<td>Labor in green prod.</td>
<td>0.272 0.273</td>
<td>0.263 0.264 0.270</td>
</tr>
<tr>
<td>Labor in brown prod.</td>
<td>0.212 0.211</td>
<td>0.205 0.204 0.211</td>
</tr>
<tr>
<td>Climate damages</td>
<td>0.053 0.047</td>
<td>0.052 0.047 0.053</td>
</tr>
</tbody>
</table>

S. Carattini, G. Heutel, G. Melkadze
Georgia State University
Note: This figure plots the second-best steady-state value of the emissions tax when varying either the banks’ transfer parameter ($\zeta$) or the agency problem parameter ($\kappa$) from their base-case values of 0.003 and 0.3409, respectively.
Calibrate emissions damage function from DICE

- Base-case calibration results in steady-state pollution stock damages of about 5% of gross output, very high carbon stock
  - Why? Using DICE, a Solow-type macro growth model, to calibrate an E-DSGE model, solved around a steady state

- Alternative calibration (still using DICE), lower discount rate, long-run temperature damages

- Yields carbon price about the same, but with lower damages and lower pollution stock
### Table 2: Steady state

<table>
<thead>
<tr>
<th></th>
<th>No financial frictions</th>
<th>Financial frictions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No policy</td>
<td>Emissions tax only</td>
</tr>
<tr>
<td>Emissions tax ($$ per ton)</td>
<td>0</td>
<td>34.5</td>
</tr>
<tr>
<td>Tax on brown assets (%)</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Tax on green assets (%)</td>
<td>-</td>
<td>0</td>
</tr>
<tr>
<td>Emissions (43)</td>
<td>0.729</td>
<td>0.443</td>
</tr>
<tr>
<td>Aggregate output (5)</td>
<td>1.622</td>
<td>1.629</td>
</tr>
<tr>
<td>Banks’ net worth (5b)</td>
<td>-</td>
<td>3.393</td>
</tr>
<tr>
<td>Welfare loss (% CV)</td>
<td>0.65</td>
<td>0</td>
</tr>
</tbody>
</table>

Note: This table shows the steady state values of selected variables in the economies with and without financial frictions under different policy scenarios. The units of the emissions tax are dollars per ton of CO₂, based on the calibration described in the text. Tax rates on banks’ assets are in percentages. Welfare loss is in terms of compensating consumption variation relative to the first-best allocations. All other variables are in arbitrary model units.
Alternate Emissions Damage Calibration

(a) Emissions
(b) Aggregate investment
(c) Aggregate output

(d) Banks’ net worth
(e) Green capital
(f) Brown capital

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods

% dev. from ss

Periods