COPING WITH COLLAPSE UNDER UNCERTAINTIES

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Central Banking and Green Finance
Outlines

1 Introduction
2 Related Literature
3 Modeling set-up
4 Target achievements
5 Modeling uncertainty
6 Climate prospective
7 Concluding remarks
Introduction – Research program

The modelling tree

- Inequality
- Financial Markets
- Inventories
- Climate feedback loop
- Goodwin (1967)
- Keen (1995)
- Prices
- Open economy
- Multisectoral
- Government
- Banks
- Resources
Introduction – Research program

7. Brazil: On financing the energy shift.
8. Other prospects: Colombia, Ivory Coast, Vietnam, Tunisia...
Introduction

Climate change is a milestone for the 21st century
Introduction

The trouble with macroeconomics

- Banchard (PIIE, 2016):
  *I see the current DSGE models as seriously flawed...*

- Romer (2016):
  *For more than three decades, macroeconomics has gone backwards...*

- Kocherlakota (2016):
  *...we simply do not have a settled successful theory of the macroeconomy. The choices made 25-40 years ago - made then for a number of excellent reasons - should not be treated as written in stone or even in pen.*
Introduction

The role of private debt

Figure: Change in private debt and employment rate in the United States – Period 1990-2010
Introduction

Research questions

- Combine two sources of global instabilities, climate and finance, in a minimal dynamic framework to perform a prospective analysis.

  *Can climate change drive the global economy in a deep recessionary state?*

- Provide guidance for the implementation of public policy objectives in order to ensure economic stability and perform the energy shift.

  *Is a price signal sufficient?*

- Cope with climate as well as economic uncertainties in order to have a deeper understanding of our chances to meet to Paris Agreement’s objectives.

  *What are our chances to stay below +2°C?*
Introduction

Main findings

- In a business as usual scenario, climate change drives the global economy toward a situation of “economic collapse.”

- A price signal (carbon tax) provides indeed the right incentives to perform the energy shift and avoid most of climate damages.

- However, financial risks are not entirely precluded: in line with the Stern-Stiglitz report (2017), a green public intervention is required to tackle both instabilities.

- Our chances to achieve the Paris Agreement target stay, at most, below 25%.
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Related Literature

The Integrated Assessment Modeling (IAM) approach


- The Ramsey-Kass-Coopmans’ approach as a core macroeconomic model
- A climate feedback loop with a damage function
- A carbon price instrument to shape the energy shift

Various extensions of the climate-economic interactions

- Endogenous technological progress (Moyer, 2014)
- Allocation of climate damages (Dietz and Stern, 2015)
- Finance and green policies (Dafermos, 2016)

This paper: assesses financial instability (Keen, 1995 and Grasselli et al., 2012)
Related Literature

The approaches of Goodwin (1967) and Keen (1995)

- **Endogenous business cycles** as in Goodwin (1967)

- **Dynamic interaction of deep macroeconomic behaviors**
  - Lotka-Volterra relationship linking the employment rate to the wage share
  - Short-term Phillips curve (Mankiw, 2010 or Krugman, 2014)
  - Investment as a function of profit share
  - Dynamics of corporates’ private debt

- **Multiplicity of long-term equilibria**
  - A Solovian steady-state
  - A bad attractor leading to a breakdown in the long-run
  - Asymptotic local stability becomes key
Related Literature

Another view on public policy

\[ \lambda: \text{employment rate} \; ; \; \omega: \text{wage bill/GDP} \; ; \; d: \text{debt/GDP} \]

Source: Grasselli and Costa-Lima (2012)
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Modeling set-up

Key modeling highlights

Bridging climate and a global monetary economy

1. The macroeconomic core
   - Non-neutrality of money
   - Severe breakdowns do not appear as “black swan events”
   - Emissions, carbon price and abatement technology (Nordhaus, 2016)
   - Price dynamics under imperfect competition (Grasselli et al., 2014)
   - Sigmoïd pattern of the global workforce (UN population scenarios, 2015)
   - Dividends payments

2. The DICE climate feedback loop of Nordhaus (2016) refined with
   - More convex damage functions (Weitzman, 2011)
   - Allocation of environmental damages between output and capital (Dietz et al., 2015)
### Modeling set-up

**Stock-flow consistency**

<table>
<thead>
<tr>
<th>Balance Sheet</th>
<th>Households</th>
<th>Productive Sector</th>
<th>Banks</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capital stock</td>
<td>$M^h$</td>
<td>$pK$</td>
<td></td>
<td>$pK$</td>
</tr>
<tr>
<td>Deposits</td>
<td>$M^c$</td>
<td>$-M$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Loans</td>
<td>$-L_C$</td>
<td>$L_C$</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Equities</td>
<td>$E$</td>
<td>$-E_f$</td>
<td>$-E_b$</td>
<td></td>
</tr>
<tr>
<td>Sum (net worth)</td>
<td>$X^h$</td>
<td>$X^f = 0$</td>
<td>$X^b = 0$</td>
<td>$X$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transactions</th>
<th>current</th>
<th>capital</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption</td>
<td>$-pC$</td>
<td>$pC$</td>
</tr>
<tr>
<td>Investment</td>
<td>$pl$</td>
<td>$-pl$</td>
</tr>
<tr>
<td>Acc. memo [GDP]</td>
<td>$[pY]$</td>
<td></td>
</tr>
<tr>
<td>Wages</td>
<td>$W$</td>
<td>$-W$</td>
</tr>
<tr>
<td>Capital depr.</td>
<td>$-(\delta + D^K)pK$</td>
<td>$(\delta + D^K)pK$</td>
</tr>
<tr>
<td>Carbon taxes</td>
<td>$pT_f$</td>
<td>$-pT_f$</td>
</tr>
<tr>
<td>Int. on loans</td>
<td>$-r_c L_C$</td>
<td></td>
</tr>
<tr>
<td>Bank’s dividends</td>
<td>$\Pi_b$</td>
<td>$-\Pi_b$</td>
</tr>
<tr>
<td>Productive sector’s dividends</td>
<td>$\Pi_d$</td>
<td>$-\Pi_d$</td>
</tr>
<tr>
<td>Int. on deposits</td>
<td>$r_M M^h$</td>
<td>$r_M M^c$</td>
</tr>
<tr>
<td>Column sum (balance)</td>
<td>$S^h$</td>
<td>$S^c$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Flow of Funds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Change in capital stock</td>
</tr>
<tr>
<td>Change in deposits</td>
</tr>
<tr>
<td>Change in loans</td>
</tr>
<tr>
<td>Column sum (savings)</td>
</tr>
</tbody>
</table>

| Change in equities | $E_f$ | $-(S^c + \dot{p}K)$ |
| Change in bank equity | $\dot{E}_b$ | $-S^b$ |
| Change in net worth | $S^h + \dot{E}$ | $0$ | $\dot{p}K + \dot{p}K$ |

**Table:** Balance sheet, transactions, and flow of funds in the economy.
Modeling set-up – The macroeconomic core

Dynamics and behavioural relations

- Short term Phillips curve: \( \frac{\dot{w}}{w} = \phi(\lambda) \)

- Dynamic of prices (Grasselli et al., 2014): \( \frac{\dot{p}}{p} = \eta(m\omega - 1) \)

- Investment behavior: \( I = \kappa(\pi) \)

- Dynamics of private debt: \( \dot{D} = I - \Pi - \Pi_d \)

- Taylor rule: \( r = \max \{0, r^* + i + \phi(i - i^*)\} \)

- Dynamics of capital: \( \dot{K} = I - (\delta + D^K)K \)
Modeling set-up – The macroeconomic core

Introducing climate change and public policies

- Joint production process incorporating climate damages
  \[
  Y^0 = \min\{K/\nu; aL\}
  \]
  \[
  Y = (1 - D^Y)(1 - A(p_{BS})) Y^0
  \]
  \[
  E_{ind} = \sigma(1 - n(A)) Y^0
  \]

- Public policies and aggregate profit
  \[
  \Pi = pY - wL - rD - pT(p_C, E_{ind}) - (\delta + D^K)pK,
  \]

- Endogenous choice of the emission reduction rate in the productive sector
  \[
  n = \min\left\{\left(\frac{p_C}{p_{BS}}\right)^{\frac{1}{\theta-1}}; 1\right\}
  \]
Modeling set-up – The climate module

Physical processes overview

Figure: Climate-economy interaction diagram
Modeling set-up – The climate module

$CO_2$ accumulation

![Diagram of a three-layer model of $CO_2$ accumulation](image)

**Figure**: $CO_2$ accumulation in a three-layer model
Modeling set-up – The climate module

*Climate damage as a percentage of real GDP*

![Graph showing the shape of various damage functions](image)

**Figure:** Shape of various damage functions
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Target achievements –

Which temperature targets can be reached?

- Nordhaus (2016) following a recalibration of the climate module of DICE:\(^1\)

  The study confirms past estimates of likely rapid climate change over the next century if there are not major climate-change policies. It suggests that it will be extremely difficult to achieve the 2\(^\circ\) C target of international agreements even if ambitious policies are introduced in the near term. The required carbon price needed to achieve current targets has risen over time as policies have been delayed.

- Illustration:

  **Figure:** Temperature increase in 2100 as a function of the climate sensitivity whenever zero net emission is reached in 2016 (blue line) or 2018 (red line).

\(^1\)http://cowles.yale.edu/sites/default/files/files/files/pub/d20/d2057.pdf
Target achievements –

*Which shape for the carbon price (1/2)?*

- A generalized logistic path:

\[
\frac{\dot{p}_C}{p_C} = \beta_{pC} \left( 1 - \gamma_{pC} \frac{p_C}{p_{BS}} \right),
\]

with, \( \beta_{pC} > 0 \), and \( 1 \geq \gamma_{pC} \geq -1 \).

- Set of carbon price paths considered

![Graph showing the carbon price for the boundaries conditions and included exponential cases.](image)

**Figure:** The carbon price for the boundaries conditions and included exponential cases.
Target achievements –

Which shape for the carbon price (2/2)?

Figure: Heatmap in 2100 depending on the carbon price path in the Type 3 scenario (exponential case in the white line).
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Modeling uncertainty

Uncertainty parameters

Uncertainty is divided into two classes:

1. On the macroeconomic parameters
   - $\alpha$, that drives the labor productivity growth, and consequently, the long-term growth.

2. On the climate module parameters
   - $S$, the climate sensitivity parameter.
   - $C^{up}$, the biosphere and upper ocean’s ultimate load capacity of absorption CO$_2$.
   - In all our simulations, we test various damage functions between Nordhaus’s and the Dietz and Stern’s.
Modeling uncertainty

*Shapes of the probability density functions*

![Graphs showing different probability density functions for parameters α, S, and C^up.](image)

**Normal density**
- \( \mu = 0.0206 \)
- \( \sigma = 0.0112 \)

**Log-Normal density**
- \( \mu = 1.107 \)
- \( \sigma = 0.264 \)

**Log-Normal density**
- \( \mu = 5.8855763 \)
- \( \sigma = 0.2512867 \)

**Figure:** Probability density function of the parameters
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Climate prospective – Scope of analysis

*Design of the prospective scenarios*

- Calibration over a reconstructed world economy (approx. 85% of the “real” world) with a panel of 36 countries over the period 2000 – 2015 (dataset from World Bank, Penn University, the Bureau of Economic Analysis and the United Nations).

- Prospective analysis through 4 classes of scenarios:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>No climate</th>
<th>Baseline</th>
<th>Low policy</th>
<th>High policy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carbon tax (Weak $p_C$)</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Carbon tax (High $p_C$)</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Abat. subsidy (25%)</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
</tr>
<tr>
<td>Damage Type</td>
<td>-</td>
<td>Stern</td>
<td>Stern</td>
<td>Stern</td>
</tr>
</tbody>
</table>

*Table: Scenarios considered for the prospective analysis*

- Where the public policies are

1. Weak $p_C$ represents non-constraining carbon price starting at approx. 2 in 2016 and growing at a 2% rate per year
2. High $p_C$ represents a carbon price at 80 in 2020 and 100 in 2030
3. A $x\%$ of abatement subsidy in equivalent to reducing abatements costs by $x\%$

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*2 The scenarios listed in the presentation are drawn from a broader range assessed in this study.*
Climate prospective – Scenario analysis

The no-warming scenario

Figure: [0.25; 0.75] probability interval of the No climate scenario with a damage-to-capital ratio of 0% in black shades (medians in solid lines)
Climate prospective – Scenario analysis

Policy scenarios – Trajectories and narratives

Figure: [0.25; 0.75] probability interval of the **Baseline**, **Low policy** and **High policy** scenarios with a damage-to-capital ratio of 0% in red, purple and blue shades (medians in solid lines)
Climate prospective – Scenario analysis

Policy scenarios – Staying under the temperature and debt thresholds

Figure: Probability density function of the temperature anomaly ratio in 2050 (dark blue) and 2100 (light blue).
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Concluding remarks

Main results

- Development of a stock-flow consistent monetary integrated assessment model calibrated at the world level

- Inaction would most likely lead to a global collapse of the economic system

- A limited action (carbon price only) allows to avoid most climate damages but remains insufficient to preclude financial instability

- A wider public involvement (carbon price and subsidies) is more likely to meet both objectives, in line with the recommendations of the Stern-Stiglitz report (2017)
Concluding remarks

Areas for further research

- Refine the economic modeling (role of technical progress, explicit demand side)
- Distinguish between the various vintages of capital
- Build the spacial dimension of the energy shift
- Design additional green tools to tackle both instabilities
Thanks for your attention.