Dynamiques Macroéconomiques et Environnement: Couplage et Modélisation des Risques et Dommages Economiques et Financiers

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Abstract

L'objectif de cet atelier est de présenter quatre papiers de recherche mobilisant des outils de modélisation semblables pour rendre compte de l'interaction entre macroéconomie et réchauffement climatique en vue d'offrir une alternative aux modèles IAM néo-classiques généralement de type Ramsey-Cass-Koopmans.

Papier 1 : présentation de Bovari et al. (2018) et Bovari et al. (2020), comme soubassement théorique aux trois autres papiers : couplage d'une boucle de rétroaction climatique avec une dynamique macro-économique simple, stock-flux cohérente, ayant donné le modèle GEMMES de l'AFD.

Papier 2 : présentation du premier couplage d'une dynamique macroéconomique avec le modèle climatique iLOVECLIM.

Papier 3 : Présentation d'un second couplage, régionalisé, d'une dynamique macroéconomique avec iLOVECLIM.

Papier 4 : Présentation d'une fonction de dommage climatique régionalisée fondée sur l'impact du réchauffement sur la biomasse et plusieurs scenarii prospectifs concernant l'appropriation humaine de la production primaire de biomasse.

Keywords: environmental impact, transition risk, debt burden, climate policy, integrated assessment, macroeconomic dynamics, stock-flow consistency, out-of-equilibrium modelling, regionalisation, climate justice, environmental impact, extreme risk, private-debt instability

Proposition d'atelier thématique ouvert — Résumé étendu

Paper 1

A synthesis of Bovari et al. (2018) and Bovari et al. (2020), which present the first coupling of a climate back-loop (first introduced by Nordhaus) with an out-of-equilibrium stock-flow consistent dynamics. The latter consists roughly in a Lotka-Volterra dynamics between wages and employment built on a short-run Phillips curve (à la Goodwin (1967)) and further extended so as to accommodate private debts (of both firms and households). The dynamics boils down to an autonomous non-linear dynamical system of small dimension (from 3 to 8, depending upon the ingredients of the economy under scrutiny).

A more ambitious approach consists in coupling a full-fledged climate model to the economy, that can generate spatial dynamics. Papers 2 and 3 couple iLOVECLIM —a medium-size climate

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model, (Goosse et al. 2010, Bouttes et al. 2015)— with a macroeconomic SFC predator-prey model and studies various scenarios where GHG emissions are endogenized. In this specific macroeconomic model, two components have been added. The first (i) is endogenous growth *à la Kaldor-Verdoorn*,:

$$\frac{\dot{a}}{a} = \alpha + \gamma_g g \tag{1}$$

These dynamics also introduce path-dependence from growth to technical progress (and *vice versa*). One consequence is that, in general, the interior steady state need no longer be asymptotically stable.

The second element (ii) consists in improving the unrealistic feature of corporate debt being able to explode to infinity around a debt-deflationary steady state. One way to do so consists in adding a collateral requirement and the possibility of default in the indebtedness process of firms in the spirit of Geanakoplos and Zame 2014 and Fostel and Geanakoplos 2014. As much lending in modern economies, indeed, corporate debt is secured by some collateral, which, here, is the current stock of capital valued at its current market price. Default is accompanied by a transfer of ownership over the collateral from borrowers to lenders. As a consequence, the debt-to-output ratio, d, can no longer exceed the capital-to-output ratio, ν. Moreover, the authors assume that, as d gets close to its upper bound, ν, firms refrain from investing —a way to answer the legitimate criticism expressed in Pottier and Nguyen-Huu 2017 about the unrealistic feature of the Keen model, where corporates keep investing in the neighborhood of the "bad" equilibrium while their profit rate vanishes.

The coupling of this SFC predator-prey macrodynamics with iLoveclim is dubbed an IDEE (Integrated Dynamic Environment-Economy) model. Its conclusions are striking:

> (i) Due to global warming, and even with the "optimistic" Nordhaus's damage function, there is a risk for firms to reach an irreversible financial tipping point in business-as-usual scenarios above which the world private sector would be trapped into a cascade of defaults. This would lead to a "financial Minsky moment" (Carney) which, with the Dietz-Stern damage function, would be reached as early as in the last quarter of the 21st century. One consequence is that, in the very long run, the choice of the damage function becomes irrelevant: action is needed however "optimistic" our views might be about the impact of climate change.
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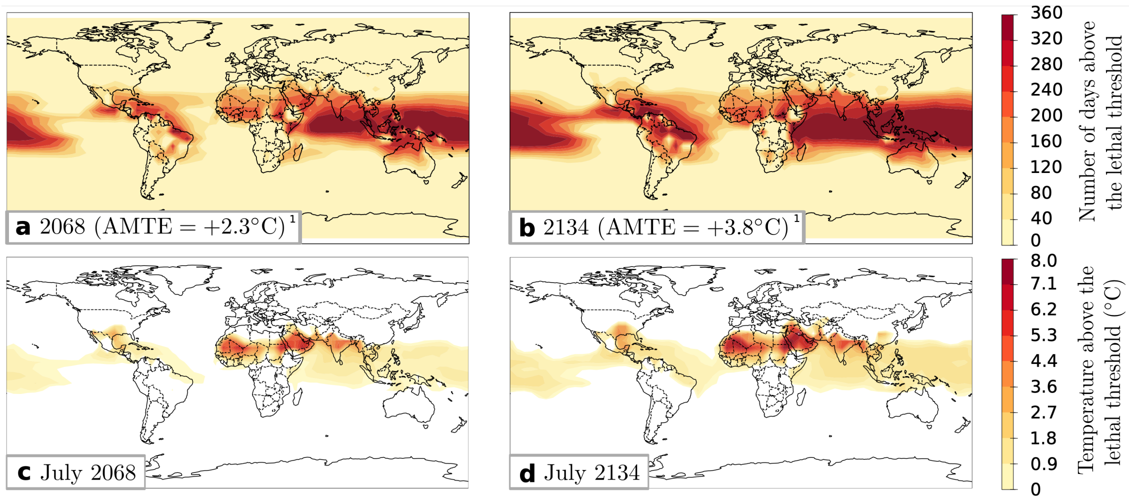
> (ii) The temperature associated with this financial tipping point ranges from +2.3°C to +3.8°C, depending upon the damage function. This provides a new —financial— justification for the Paris Agreement target of +2°C.
>
> (iii) A carbon tax policy cannot be dispensed with if a catastrophic endgame is to be avoided. Moreover, it must be quickly implemented and ambitious: about 2015US$ 400/t by 2050.
>
> (iv) Moreover, it must be accompanied by an equally ambitious public expenditure policy in order to enable the private sector to afford both the cost of mitigation and that of adaptation: public spending of at least 50% of the abatement costs are needed to avoid the financial tipping point.This expense, however, never exceeds 10% of the current GDP. It enables to reach net-zero emissions before 2075, even with the Dietz-Stern damage function, and to stay broadly around a +2°C temperature deviation by 2100. The estimated global cost of the low-carbon transition —approximately 90 US$ trillions up to 2035— is in good agreement with The Global Commission on the Economy and Climate 2018.

FIGURE 1 **Deadly heatwaves and damage functions. a,b Maps representing the number of days spent above the lethal thresholds in the years 2068 and 2134, Martin et al. (2023). c,d Maps representing the average relative temperature above the lethal threshold for July of the same years.**



Absent such a voluntarist action from both the public and the private sectors, Fig. 1 describes the state of the planet in the last third of the 21st century and the first third of the next one, suggesting that most of the Tropical belt would become uninhabitable. **?** showed, indeed, that high temperature and humidity combinations —called "deadly heatwaves"— might generate situations that exceed human thermoregulatory capacity: sweating becomes ineffective at high relative humidity, potentially leading to death. Empirical data suggests the existence of a *lethal temperature threshold* (**?**), which depends on relative humidity. What Fig. 1 shows is that a business-as-usual scenario would make a large part of the tropics uninhabitable before the last quarter of this century, even though the average global temperature increase would be around +2.3°C and would reach +3.8°C "only" around 2134.

Climate science, today is essentially driven by thermodynamics and fluid mechanics. The first two laws of thermodynamics play a decisive role in it. One way to go further in combining macroeconomics with environmental sciences is to rewrite macro-dynamics as a thermodynamic flow. This is far from being an easy task as most conventional economic models violate both laws of thermodynamics.

Papier 2

"Climate-Induced Economic Damages Can Lead to Private-Debt Tipping Points"

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Designing climate change policies requires considering the feedback loops between mitigation and adaptation, since more mitigation efforts today will trigger lower adaptation costs. In this framework, carbon taxes are often seen as promising tools but at the risk of financially overburdening the private sector, depriving it of important economic resources. However, analyzing the financial feasibility of mitigation-adaptation policies using conventional Integrated Assessment Models (IAM) is limited, as they do not simultaneously endogenize economic growth, emissions, and damages.

Here, we present (Integrated Dynamic Environment-Economic), a new IAM based on the coupling of an Earth Model of Intermediate Complexity and a non-linear macroeconomic model in continuous time. Then, we analyze the simultaneous effects of carbon taxes and public spending, both on climate and on the world economy. We show that, above a warming about +2.3°C, damages drastically foster the need for additional investments in productive capital—an adaptation necessity—that potentially leads private firms to a debt overhang and a worldwide cascade of defaults.

This suggests that the Paris Agreement target should not only be motivated by the climatic non-linearities and tipping points arising beyond the +2°C threshold, but also by the emergence of tipping points. We also show that, provided public subsidies are high enough, a tax of USD 300 per tCO_2 by 2030 enables reaching net-zero emissions in 2050, preventing firms from suffering global bankruptcy.

We anticipate IDEE to be a starting point for a new class of IAMs that better represent the reciprocal feedback loops between the environment and the economy.

Papier 3
"Regional Cascading Private-Debt Tipping Points Induced by Climate Change"

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In Paper 2, a previous article devoted to the introduction of the aggregated model IDEE, we demonstrated that the climate change could push the global economy to a private-debt tipping point. In this paper, we refine this result by showing that the world's economic regions are not equal in terms of both the climate risks they face and the more or less imminent moments when they will reach their tipping point. We demonstrate that the regions that have contributed the most to the global temperature rise through their greenhouse gas emissions are also those at the lowest risk in terms of climate impacts and economic stability. They are relatively distant from their private-debt tipping point compared to the rest of the world.

To achieve this, we use a regionalized version of the model IDEE, a model resulting from the coupling of an Earth systems Model of Intermediate Complexity (EMIC) climate model and a Stock-Flow Consistent (SFC) economic model. Economic damages are thus regionalized, specific to each of the 11 regions. This paper encourages these regions to take responsibility in order to support economically more fragile regions, thus preventing a widespread bankruptcy of our globalized economy.

Paper 4
"A Regionalized Climate Damage "function" based on Biomass"

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This paper presents a first attempt to build a sensible regionalized climate "damage function" based on the impact of global warming on biomass and on a number of prospective scenarios regarding Human Appropriation of Natural Primary Production (cf. Imhoff et al. (2004)). Building on the good knowledge today available about the damages inflicted worldwide to biodiversity on climate change and on the strong empirical correlation between biomass, GDP and international trades, we construct a damage "function" for 11 regions and 4 prospective scenarios which is at par with the estimations of Swiss Re.

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