Mathematical Climate Finance

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Timetable: 16 hrs. First lecture on February 25, 2025, 15:00 (dates already fixed, see Calendar of Activities on https://dottorato.math.unipd.it/calendar/), Torre Archimede, Room 2BC30.

Course requirements: Probability and stochastic process theory in continuous time, and MSc-level financial mathematics knowledge/skills.

Examination and grading: None

Aim: This is an introduction to mathematical climate finance by in-depth treatment of some of the recent advances in this burgeoning field of research in financial mathematics. The focus will be on climate transition risk that, together with physical risk, is a major source of climate change risk impacting economies and financial markets. The mathematics, especially the formulation and modelling aspects, on which climate finance is based, is at the core of this course. The aim is thus the study and development of climate finance anchored in financial mathematics. Mathematical climate finance is an active area of research, and this course aims at keeping up-to-date with new insights and ongoing research progress in academia and the industry. A taste of the topic treated in this course can be sampled from the cover story in the *Fields Notes*, Vol. 12:4, Spring/Summer 2024.

Course contents:

1. *The carbon equivalence principle and the design of a probability space for climate policy-making*

   The carbon equivalence principle (CEP) is introduced that requires carbon-equivalent flows enabled, or caused, by a financial product to have equal status with cash flows. This reveals that existing financial products already have environmental impact and so are ESG-linked, without the need for any add-on terms. We show how treating enabled, or caused, carbon-equivalent flows enables position-keeping, and management to carbon net-zero. We apply the CEP to minimize the cost to achieving carbon net zero on financing portfolios that are of interest to Net Zero Banking Association members. We present a mathematical programming implementation for loan financing and associated data generation.

2. *Project finance under climate transition risk*

   The Carbon Equivalence Principle (CEP) states: all financial products shall contain a termsheet of the equivalent carbon flows from greenhouse gases that the financial products cause or enable, as well as their existing termsheet in terms of currency or other flows. This reveals that all existing financial products may already be environment-related. We apply the CEP to project finance, taking the example of power generation. The financial requirements to offset the costs of the future carbon flows radically change project costs,

and risk that the assets become stranded, thus further increasing costs. For financial viability we introduce project re-designs that are financially net-zero, where a carbon net-zero constraint can also be included. The numerical project finance examples give a blueprint for wider application and insights into project finance impacted by carbon price risk.

3. *Internalisation of Scope 3 emissions in the trading book*

   Methods are presented for steering derivative portfolios based on the mitigation cost (benefit) of CO2-equivalent emissions (sequestration) these derivatives enable with counterparties. Thus, we price the cost-benefit of transitioning carbon externalities into changes affecting deals won and lost to steer the portfolios to net-zero based on a CO2-equivalent valuation adjustment (CO2eVA). This CO2eVA can be used in return-on-capital calculations, or as a shadow cost-benefit. We provide numerical examples considering interest rate swaps with a stylized regional airline, and a stylized shipping company that demonstrate highly significant effects in both cases.

4. *Climate-contingent convertible bonds*

   Adjustments to governmental climate transition policies and uncertainties linked to the ability for industry sectors and consumers to manufacture and purchase low carbon technologies, respectively, have led to an increasing need to embed a richer framework for uncertainty in climate transition outcomes. Such uncertainties create a number of financial risks for firms, their investors, the banking sector, and potentially sovereign risks. The need thus arises for the development of a bespoke pricing setup and financial instruments, which offer a mechanism to share climate transition risk. As an example, the so-called climate-contingent convertible (CLoCo) bond is proposed. This instrument enables firms to reduce the risk of default due to adverse climate transition policies over the product's lifetime. The proposed financial innovation implies reduced risk of default for firms, thereby increasing the expected firm value, but it also reduces the dependency of firm failures on the banking sector and potential bail-out costs incurred by sovereign nations.

5. *Stochastic integrated assessment models*

   Integrated assessment models (IAM) and climate-economic systems are developed in a deterministic setting. The most known example is the DICE model, by which optimal consumption and greenhouse emissions/reduction rates are calculated. We shall consider stochastic extensions to IAMs, and derive the optimal control levels. Applications to asset pricing are envisaged. Moreover, an alternative method to inject randomness into DICE shall be treated, too.

Bibliography (selected):

1. D. Brigo & F. Mercurio (2006) Interest Rate Models – Theory and Practice. Springer Berlin, Heidelberg
2. C. Cormack & A. Macrina (2024) Climate Transition Mitigation: Introducing the CLoCo Bond. SSRN:4851975.
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4. C. Kenyon, M. Berrahoui & A. Macrina (2024) The Carbon Equivalence Principle: Minimising the Cost to Carbon Net Zero. Risk, Cutting Edge: Climate Finance, Risk.net Feb. 2024. Full version at SSRN:3979608.
5. C. Kenyon, A. Macrina & M. Berrahoui (2023) The Carbon Equivalence Principle: Methods for Project Finance. Risk, Cutting Edge: Climate Finance, Risk.net May 2023. Full version at SSRN:4035833.
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7. F. Krach, A. Macrina, A. Kanter, E. Hampwaye, S. Hlalukana & N. T. Rateele (2024) The Financial Impact of Carbon Emissions on Power Utilities Under Climate Scenarios. International Journal of Theoretical and Applied Finance, 2450013 (open access). DOI: 10.1142/S0219024924500134
8. A. Macrina (2024) Mathematical climate finance: an investment in our future. Fields Notes, Vol. 12:4, Spring/Summer 2024.
9. G. Kassis & A. Macrina (2024) Arcade processes for informed martingale interpolation. ArXiv:2301.05936
10. S. E. Shreve (2004) Stochastic Calculus for Finance II: Continuous-Time Models. Springer Science & Business Media, LLC.