Macroeconomic modelling of climate and transitions

Climate macro & finance course 2022/23 - Lecture 8

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Outline of today's lecture

- Neoclassical macro on climate/transition
  - Dynamic Stochastic General Equilibrium (DSGE) models
  - Capital Asset Pricing Models (CAPM)
- Non-neoclassical macro on climate/transition
  - Stock-Flow Consistent (SFC) models
  - Agent-Based Models (ABM)
- Hybrid models
  - Go beyond model limitations by coupling them

Neoclassical macro approaches

Real Business Cycle (RBC) models

- Starting point: Lucas critique (1976)
    - Microfoundations against Keynesian macro-econometric models
- Real Business Cycle (RBC) models
    - Representative agents; perfect competition; rational expectations; market clearing; labour supply choice
    - Fluctuations explained by exogenous ‘real’ shocks to TFP
    - Relevant papers: Long & Plosser (1983); Kydland & Prescott (1982)

RBC applications to climate economics

- Initial papers introducing pollution in standard RBC setting:
    - See review in Fischer and Heutel (2013) on ARRE
- Fischer and Springborn (2011) on JEEM
    - Emissions in production function
    - Compare macro effects of three policies: carbon tax; cap-and-trade system; intensity targets
    - Different welfare/volatility outcomes; argue in favour of intensity targets
- Heutel (2012) on RED
    - Emissions and climate à la DICE
    - Optimal environmental policy (either tax or cap) is procyclical
- A more recent paper:
    - Dissou and Karnizova (2016) on JEEM

'New-Keynesian' DSGE models

- Share the RBC root but include frictions:
  - Habit persistence
  - Nominal rigidities (e.g. pricing à la Calvo, 1983 on JME)
  - Capital/investment adjustment costs (e.g. Christiano et al., 2005 on JPE)
- Financial variables are important too
  - Financial frictions: Kiyotaki and Moore (1997) on JPE, Bernanke et al. (1999)
  - Monetary policy shocks as cycle drivers: Taylor (1993); Clarida et al. (1999) on JEL

NK DSGE applications to climate economics

- Annicchiarico and Di Dio (2015) on JEEM
  - Calvo pricing, capital adjustment costs, monetary policy
  - Emissions/climate following Heutel (2012)
  - Policy options: tax, cap, intensity targets (as in F&S 2011)
  - Three shocks: TFP, government expenditure, monetary policy
  - Cap tames macro volatility, intensity targets fuels it
  - Policy welfare ranking depends on price stickiness
- Annicchiarico and Di Dio (2017) on ERE
  - Similar NK setting, but focus on policy interactions
  - Planner choosing both environmental (tax or cap) and monetary policy, or just one of them
  - Optimally missions are usually, but not always, procyclical, depending on monetary policy reactivity
  - Environmental policy might affect optimal monetary policy

Since then, expanding field

- Comerford and Spiganti: 'The carbon bubble : climate policy in a fire-sale model of deleveraging'
- Diluiso et al.: 'Climate Actions and Stranded Assets: The Role of Financial Regulation and Monetary Policy'
- Benmir and Roman: 'Policy interaction and the transition to clean technology'
- Carattini et al. 'Climate Policy, Financial Frictions, and Transition Risk'

Capital asset pricing models (CAPM)

- Simple formula is

$$E(r_i) = r_f + \beta_i(r_m - r_f)$$

  - r_i: return of an asset
  - $r_m - r_f$: market premium
  - $\beta_i = \frac{cov(r_i, r_m)}{var(r_m)}$
- Recursive utility (See Epstein and Zin 1989)
  - Distinguish risk aversion from intertemporal substitution (bundled in power utility)
  - E.g.

$$V_t = \left((1-\beta)c_t^{1-\rho} + \beta \left(E_t V_{t+1}^{1-\alpha}\right)^{\frac{1-\rho}{1-\alpha}}\right)^{\frac{1}{1-\rho}}$$

- Multiple stochastic processes (Brownian motions + jumps)
  - Including capital (physical/financial conflation)

Asset pricing models

- This leads us to the more financial literature linked to asset pricing
  - Hambel et al; Karydas & Xepapadeas
- Introduction of stochastic processes
  - Wiener processes (Brownian motions) on the dynamics of capital and/or climate
  - Jump variables (representing tipping points)
- Epstein-Zinn preferences
- Stranding costs (HKP)
  - Quadratic reconversion costs: firms can reconvert dirty capital into green capital, but only at a cost. They spend R into reconversion, but some of the value $(\frac{1}{2}\kappa\frac{R^2}{K})$ is lost, where κ is the reconversion cost parameter

Asset pricing insight for climate econ

- Bansal et al. (2017): Climate change and growth risk
- Dietz et al. (2018): The ‘climate beta’
- Daniel et al. (2019) on PNAS
- Karydas and Xepapadeas (2019): CAPM with Rare Disasters and Stochastic Probabilities
- Hambel et al. (2020): Asset Pricing and decarbonization: Diversification versus climate action

Issues with neoclassical climate economic models

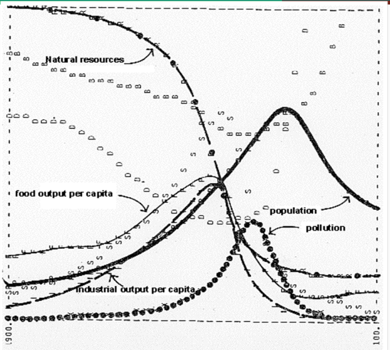
- DSGE heavily under attack after the GFC
  - Romer (2016): Fluctuations driven by 'imaginary causal forces'
  - Krugman (2016): 'Were there any interesting predictions from DSGE models that were validated by events?'
  - Stiglitz (2011): 'core DSGE models is not good theory'
- Equilibrium
  - Economies on a BGP until some random shock hits them
- Intertemporal optimisation
  - Behavioural economics/finance (heuristics, norms, networks)
- Hard to introduce heterogeneity
  - e.g. HANK model, see Kaplan et al. 2018 on AER
- Banks as pure intermediaries
- Supply-side approach
  - Little role for aggregate demand dynamics
  - Hard to have underutilisation of capital stocks

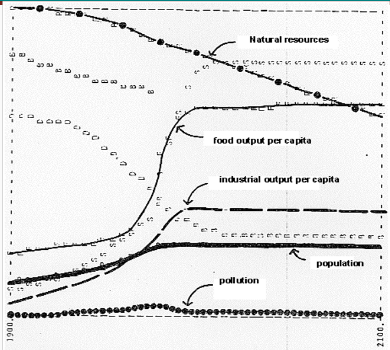
Non-equilibrium modelling

System dynamics

- System dynamics
  - Aim: capture real-world complexity (feedback loops, amplification, emergent behaviours)
  - Focus on stocks and flows (ecological modelling)
  - Macroeconometric approach: behavioural functions driven by estimation/calibration
  - Adaptive expectations (linear extrapolation to next period)
- The Limits to Growth (1972)
  - Forrester and MIT team; Meadows and Club of Rome
  - A continuation of business-as-usual would result into economic collapse driven by exhaustion of resources or pollution damages
  - Suggestion for radical policies
  - Economists were not happy (see Nordhaus, 1973)

The Limits to Growth (1972)





"Population and capital are the only quantities that need be constant in the equilibrium state. Any human activity that does not (..) produce severe environmental degradation might continue to grow indefinitely. In particular, those pursuits that many people would list as the most desirable and satisfying activities of man - education, art, music, religion, basic scientific research, athletics, and social interactions - could flourish."

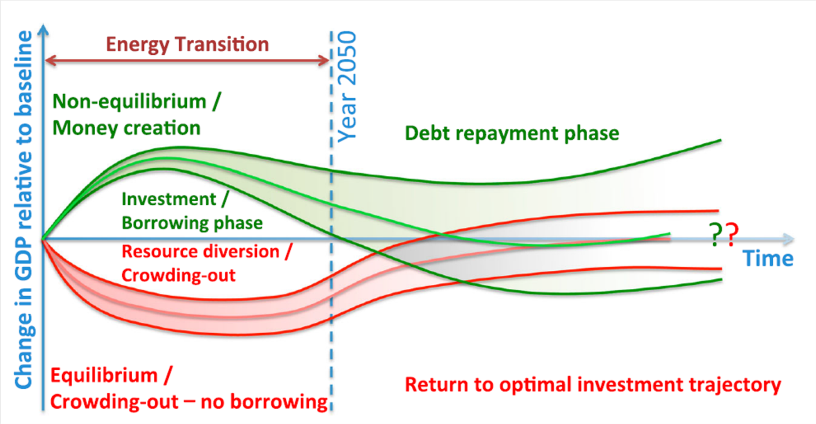
Stock-flow consistent (SFC) models

- Modelling approach based on a set of interacting balance sheets
  - Institutional sectors: households, firms, banks, government,..
  - Balance sheets made of assets and liabilities (deposits, loans, financial assets)
  - Productive capital only 'net' assets
- Sectoral behavioural functions
  - Usually based on post-keynesian theory
  - Radical uncertainty; no optimisation; adaptive expectations
- Rarely analytical solutions:
  - Numerical simulations of future scenarios (e.g. policy implementation)
- Key references
  - Godley, W., & Lavoie, M. (2007). Monetary Economics.
  - SFC tutorials by Dafermos

Post-keynesian economics

- SD or SFC per se are methodological approaches, not linked to any specific economic theory
  - However, SFC deeply rooted into post-Keynesian thinking
- Post-Keynesian modelling
  - Economies are demand-led: economic activity is driven by expenditure decisions
  - Aggregate behaviour is not an aggregation of individual behaviours (e.g. paradox of thrift)
  - Decisions taken in a context of fundamental uncertainty $\rightarrow$ heuristics, rules of thumb, social conventions, herd behaviour, path dependency, sentiments.. $\rightarrow$ Adaptive expectations
  - Prices are fixed by unit costs plus a mark-up (not by MPK)
  - Wages set by negotiations (not by MPL)
  - Banks do not have to wait for deposits before lending (endogenous money)

Equilibrium vs non-equilibrium models



Source: Mercure et al. (2019)

Behavioural functions

- Consumption
  - Function of disposable income and financial wealth

$$c_t = \alpha_1 Y^d_{t-1} + \alpha_2 v_{t-1}$$

  - Parameters change across household types (e.g. workers vs entrepreneurs)
- Desired physical investments
  - Can be function of capacity utilisation, interest rates, market valuation..

$$g_x = \eta_0 + \eta_1 u^e_x - \eta_2 rr_{l,x} \lambda_{x,-1} + \eta_3 q_{x,-1}$$

- Desired financial investments
  - Portfolio allocation matrix, e.g:

$$\begin{pmatrix} M_f \\ p_{c,e} e_c \\ p_{h,e} e_h \end{pmatrix} = \begin{pmatrix} \lambda_{10} & \lambda_{11} & \lambda_{12} & \lambda_{13} \\ \lambda_{20} & \lambda_{21} & \lambda_{22} & \lambda_{23} \\ \lambda_{30} & \lambda_{31} & \lambda_{32} & \lambda_{33} \end{pmatrix} \begin{pmatrix} 1 \\ \mathrm{R}_m \\ \mathrm{R}_c \\ \mathrm{R}_h \end{pmatrix} V.$$

SFC modelling applied to environmental economics

- Usually referred to as 'ecological macroeconomics'
  - See 2016 special issue on EcolEc
- Some papers using SFC modelling to study macro-environment links:
  - Dafermos et al. (2017) on EcolEc
  - Bovari et al. (2018) on EcolEc
  - D'Alessandro et al. (2020) on NatureSust
  - Jackson and Victor (2020) on EcolEc
  - Botte et al. (2021) on modelling transition risks

Agent-based models (ABMs)

- Atomistic representative agents poor representation of reality
  - Individuals are heterogeneous in their preferences, endowments, social networks, decision criteria, planning horizons..
- ABMs
  - Multiple populations of heterogenous agents
  - Interactions among agents (networks) create emerging macro behaviours
  - Heuristic behavioural rules (+ switching)
  - Innovation/imitation dynamics (Link to Schumpeterian literature)
  - Out-of-equilibrium dynamics
- Adaptive expectations
  - Methodological stance: bounded rationality
  - Computational limits

ABMs can be used to study climate-related issues

- They can be used to study diffusion of low-carbon technologies and environment-friendly behaviour
  - See recent review by Castro et al. (2020)
- A limited number of ABMs incorporate both environmental and financial dimensions
  - Safarzynska and van den Bergh, 2017) on transition-driven financial instability
  - Raberto et al. (2018) using EURACE model
  - D'Orazio and Valente (2019) on finance and environmental innovation diffusion
  - Lamperti et al. (2019) on public costs of climate-triggered banking bailouts
  - Botte et al. (2021) on modelling transition risks

Lamperti et al (2019)

- Dystopian Schumpeter meeting Keynes (DSK) model
- Climate change creates damages to:
  - Capital stocks
  - Labour productivity
- Firms' loss of profitability
  - Higher ratio of non-performing loans
- Banks' reduction of equity
  - When equity becomes negative, they are bailed out from the government

Lamperti et al. (2019) on NCC

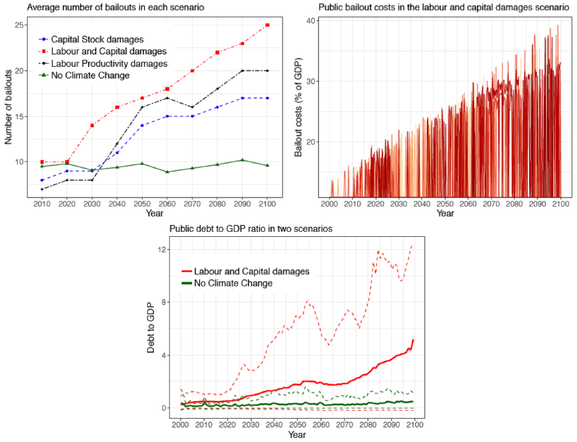


Figure 2: Ten years average number of bailouts (out of 500 simulations) in the three scenarios and in the baseline (top-left); bailout costs as share of GDP in the Labour and Capital Damages scenario, each line represents a model run (top-right); public debt behaviour in the Labour and Capital Damages scenario and in the No Climate Change scenario, solid lines are yearly averages (out of 500 simulations) and dashed lines are 90% confidence intervals.

Source: Lamperti et al. (2019)

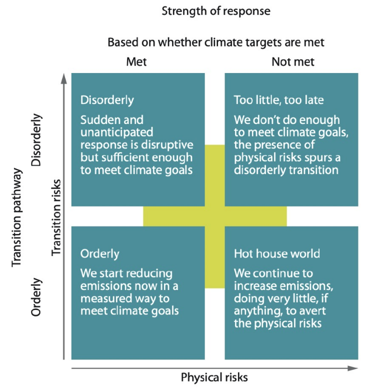
Issues with SFC/ABMs

- Expectations
  - Adaptive expectations are the norm (for both methodological preferences and computational complexity)
  - Limiting approach: no forward-looking behaviour
  - Combine with animal spirits literature? Franke et al. (2017), De Grauwe and Macchiarelli (2015)
- Black box problem ('garbage in – garbage out')
  - Large number of assumptions on behaviour and parameter values (especially ABM)
  - Hard to empirically estimate and validate
  - Hard to interpret results and to extrapolate fundamental dynamics
  - What do we make of these models and their results?
- SFC: the sectoral classification is limiting
  - One can split in sub-sectors, but still no microeconomic behaviour

Coupling models

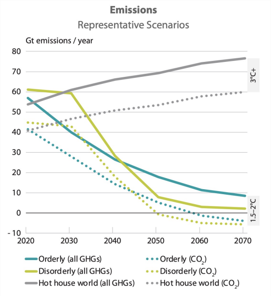
NGFS framework - Three representative scenarios

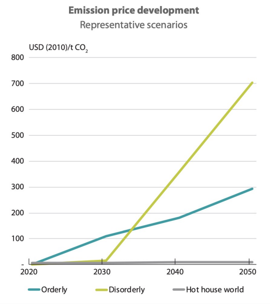
- Orderly transition:
  - Carbon price in 2020 and increasing $10/tCO_2$ per year
  - Full availability of CDR technologies
- Disorderly transition:
  - NDCs until 2030
  - Carbon price in 2030 and increasing $35/tCO_2$ per year
  - Limited availability of CDR technologies
- Hot house world:
  - Only current policies implemented

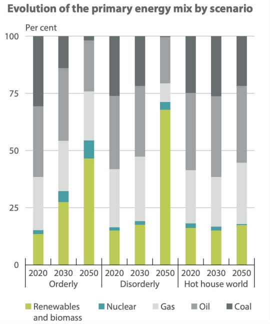


Source: NGFS (2020)

NGFS representative scenarios



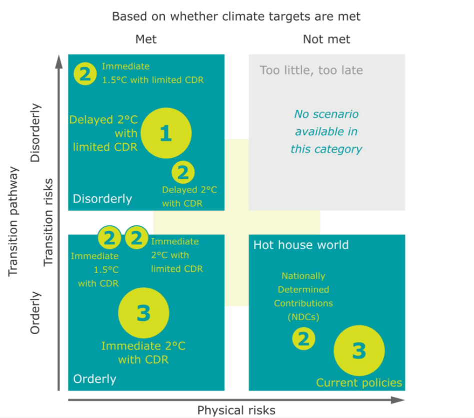




Source: NGFS (2020)

NGFS framework - All scenarios

- Temperature target:
  - 1.5°C vs 2° C
- Policy implementation timing:
  - 2020 ('immediate') vs 2030 ('delayed')
  - Technological landscape: fully available CDR vs limited CDR
- Technological landscape:
  - Fully available CDR vs limited CDR



Source: Large circles for representative scenarios. Numbers in circles represent number of models running scenario. Bertram et al. (2020)

IAMs used in NGFS simulations

- Three IAMs used
- All scenarios modelled under SSP2 assumptions
- Delayed policies assumed not to be expected
    - Similar to Johnson et al. (2015)
- Database explorer

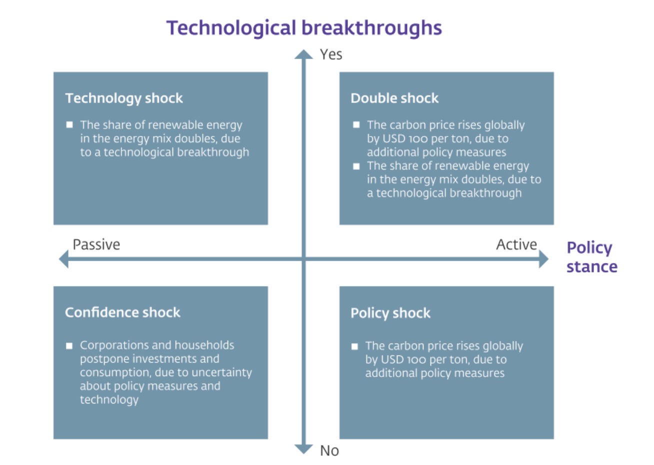
Integrated Assessment Model	GCAM 5.2	MESSAGEix_GLOBIOM 1.0	REMIND1.7-MagPIE3.0
Short name	GCAM	MESSAGEix-GLOBIOM	REMIND-MAgPIE
Solution concept	Partial Equilibrium (price elastic demand)	General Equilibrium (closed economy)	REMIND: General Equilibrium (closed economy) MAgPIE: Partial Equilibrium model of the agriculture sector
Anticipation	Recursive dynamic (myopic)	Intertemporal (perfect foresight)	REMIND: Inter-temporal (perfect foresight) MAgPIE: recursive dynamic (myopic)
Solution method	Cost minimisation	Welfare maximisation	REMIND: Welfare maximisation MAgPIE: Cost minimisation
Temporal dimension	Base year: 2015 Time steps: 5 years Horizon: 2100	Base year: 1990 Time steps: 10 years Horizon: 2100	Base year: 2005 Time steps: 5 (2005-2060) and 10 years (2060-2100) Horizon: 2100
Spatial dimension	32 world regions	11 world regions	11 world regions
Technological change	Exogenous	Exogenous	Endogenous for Solar, Wind and Batteries
Technology dimension	58 conversion technologies	64 conversion technologies	50 conversion technologies

Hybrid models

- Aim: put all the pieces together in an integrated framework
  - Transition pathways and climate from IAMs
  - Macroeconomic dynamics from (multi-regional) macro models
  - Sectoral dynamics from sectoral models (production networks)
  - Financial dynamics from financial models
- Two main modelling drivers:
  - Central banks (Vermeulen et al., 2018; Allen et al., 2020)
  - Financial institutions (HSBC, 2018, Mercer et al., 2019)

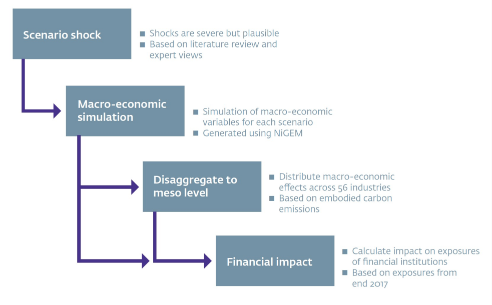
Vermeulen (2018): De Nederlandsche Bank

- Vermeulen et al. (2018): 'An energy transition risk stress test for the financial system of the Netherlands'
- A 2x2 matrix of global shock scenarios to represent tail risks



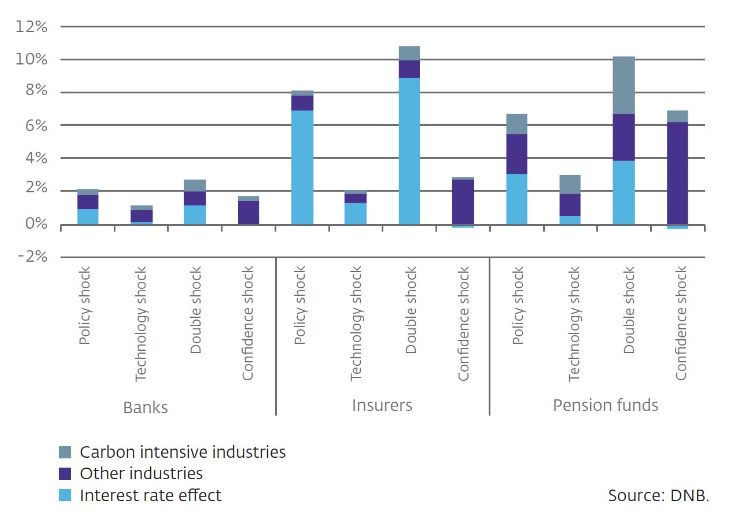
Vermeulen et al. (2018): Modelling approach

- NiGEM macro model with 5-year horizon
- Sectoral results via ‘Transition Vulnerability Factors’
  - TVFs based on sectoral ‘embodied’ CO_2 emissions
- Calculate equity/bond sectoral price changes
- Impacts on holdings of Dutch banks/insurers/pension funds
  - Assets: equity, bonds, loans



Modelling approach. Source: Vermeulen et al. (2018)

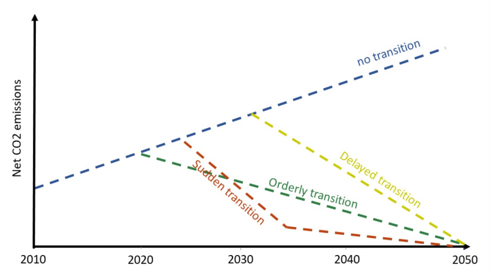
Vermeulen et al. (2018): Results



Impact on assets as a percentage of total stressed assets per sector. Source: Vermeulen et al. (2018)

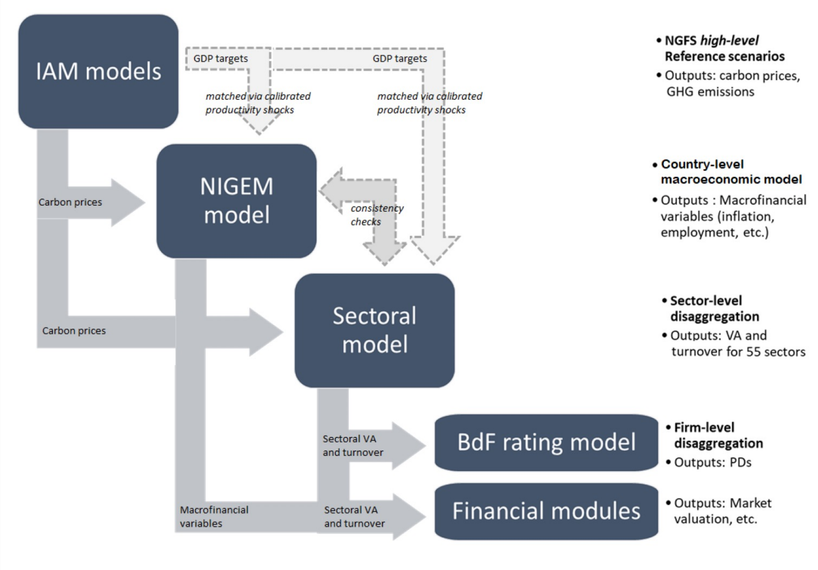
Allen et al. (2020): Banque de France

- They choose the orderly transition as a baseline
    - Different from usual IAM approach (baseline set to BAU)
    - Follows the stress testing logic
- Two disorderly transition narratives:
    - 'Delayed': follows NGFS delayed scenario with carbon price jumping in 2030
    - 'Sudden': carbon price jumps in 2025 but no low-carbon technological progress



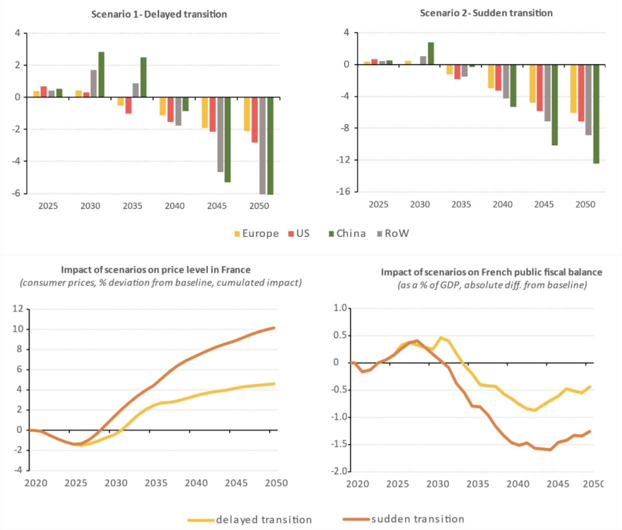
Source: Allen et al. (2020)

Allen et al. (2020): An ensemble of models



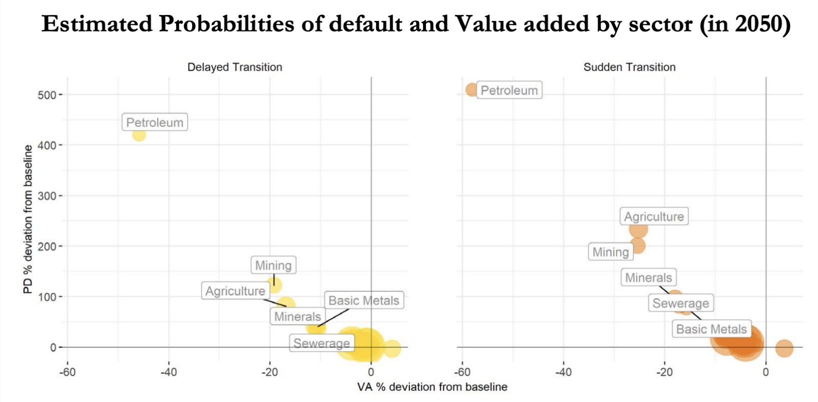
Source: Allen et al. (2020)

Allen et al. (2020): Macro results



Above: GDP levels (% deviation from baseline). Below: impact on prices and fiscal balance. Source: Allen et al. (2020)

Allen et al. (2020): Sectoral results



Estimated probabilities of default and value added by sector (France in 2050). Size of the bubble proportional to size of sample. Source: Allen et al. (2020)

Conclusions

Conclusions

- Modelling macro-financial implications of climate change and low-carbon transitions
  - Multiple methodological approaches, all needed $\rightarrow$ pluralism
- Urgent/promising research avenues
  - A more realistic representation of expectations
  - Inclusion of network effects
  - Inclusion of uncertainties