Climate-related macro-financial modelling (II)

Climate macro & finance course 2022 - Lecture 4

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Last lecture

- We want to explore possible futures
  - $\rightarrow$ We need models
- Strategies for climate/transition macro-financial modelling
  - Include macro-finance into climate economic models
  - Include climate/transition into neoclassical macro models
  - Include climate/transition into non-neoclassical macro models
- Integrated Assessment Models (IAMs)
  - Nordhaus' DICE model
  - Large-scale numerical IAMs

Today's lecture

- We terminate the climate economic modelling part
    - Analytical IAMs
    - Computable General Equilibrium (CGE) models
    - $\rightarrow$ Unanswered questions on macro and finance
- 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
    - $\rightarrow$ Angela's presentation on Dafermos et al. (2021)
    - Agent-Based Models (ABM)
    - $\rightarrow$ Adrianna's presentation on Rengs et al. (2020)
- Hybrid models
    - Go beyond model limitations by coupling them

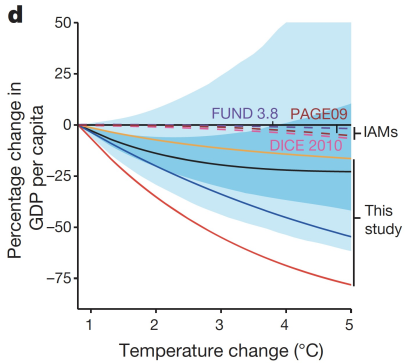
Analytical IAMs

Analytical IAMs

- Small-scale IAMs with simplified relations
- Usually aimed at deriving analytical rules for the SCC (i.e. optimal carbon price)..
  - Golosov et al. (2014) on Econometrica
  - Rezai and Van der Ploeg on JAERE
  - Gerlagh and Liski (2018) on EJ
  - Cai and Lontzek (2018) on JPE
  - van den Bijgaart et al (2016) on JEEM
- .. or cost-efficient paths to a temperature target / carbon budget
  - Lemoine and Rudik (2017) on AER
  - Rozenberg et al. (2020) on JEEM
- Let's look at an example from van der Ploeg (2020)

Damages from temperature

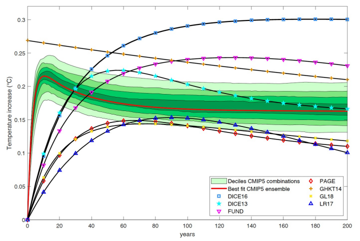
- Assumption:
  - Damages proportional to GDP
- Assumption:
  - Damage/GDP ratio linear function of temperature
  - Justification: Burke et al. (2015) on Nature
- Constant Marginal effect of temperature on damage ratios (MDR): $\frac{\partial \Omega}{\partial T}$

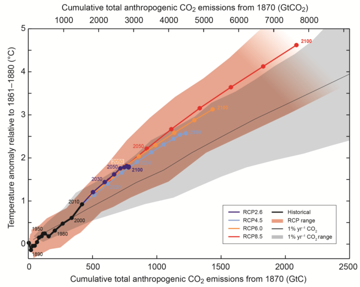


Source: Burke et al. (2015)

Effect of emissions on temperature

- We assume T to be a linear function of cumulative emissions (S)
- That is, $\frac{\partial T}{\partial S}$, the Transient Climate Response to Cumulative Emissions (TCRE), is independent of time and concentration M
- Assume TCRE≈1.8°C per tn tons of carbon (Matthews et al. 2018 give a 0.8-2.4°C range)





Source: Dietz et al. (2021) and IPCC (2013)

A simple formula for the SCC

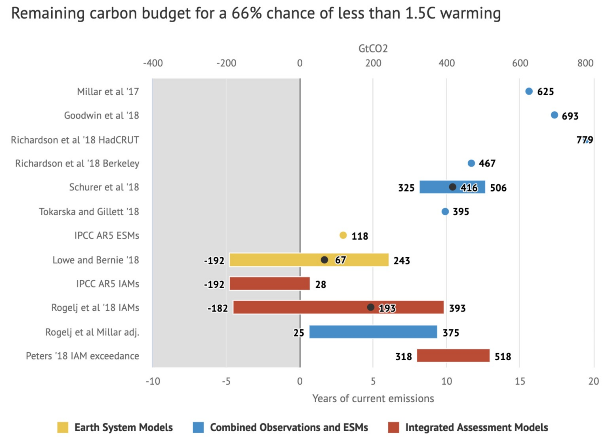
- Further assuming:
  - Exponential discounting with RTI: rate of time impatience (ρ in DICE); and IIA: relative intergenerational inequality aversion (α in DICE)
  - Constant trend growth rate g
- We can write the optimal carbon price as

$$P_t = \frac{MDR * TCRE}{RTI + (IIA - 1)g} Y_t$$

- Depending on assumptions on damages, discount rate, IIA, etc. we can obtain a large range of optimal prices..
- P increases at rate g (adjusted for inflation)

Alternative approach: put a cap on temperature

- Remember: T linear function of S
  - Temperature cap $\rightarrow$ Carbon budget



Source: Carbon Brief (2018)

Objective: find efficient path to get there

- Hotelling structure applicable
  - Remember Hotelling rule: optimal net price ('Hotelling rent') of an exhaustible resources grows at the rate of interest
  - Remaining allowable CO_2 emissions are like an exhaustible resource
- Optimal carbon price is a function of interest rate (or SDR) $P_t = e^{rt} P_0$
- Risk-adjusted interest rate is what we're interested in
  - Gollier et al. (2020): 3.75%
  - If it's too high, it means that, for a specific carbon budget, price today is too low
  - More on uncertainty later on

Growth theory on asset stranding

- Analytical Ramsey growth models can also be used to study optimal capital stranding
  - Stranding as loss of capacity utilisation ('endogenous capacity constraints')
- A selection of papers
  - Amigues et al. (2015) on JEDC (A+)
  - Vogt-Schilb et al. (2018) on JEEM (VS+)
  - Coulomb et al. (2019) on ERE (C+)
  - Baldwin et al. (2020) on JEEM (B+)
  - Rozenberg et al (2020) on JEEM (R+)

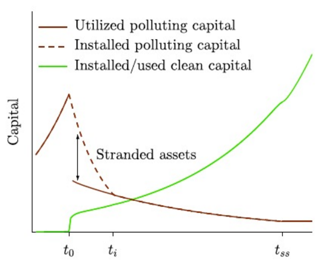
Common features

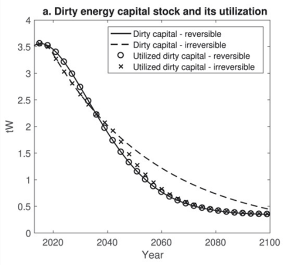
- Intertemporal maximisation of welfare $u(c_t)$
- Two (or more) technologies: clean and dirty capital (k_C, k_D)
  - Investments are irreversible: Jorgenson (1967), Arrow and Kurz (1970)
  - They allow for underutilisation of capital ($q_t \leq k_t$)
- Using k_D produces emissions: $e_t = F_t k_{D,t}$
  - where F is carbon intensity
- In the social planner programme, some constraint is imposed
  - Typically a carbon budget $\bar{m}$ (on resources or cum. emissions)
- No explicit financial considerations

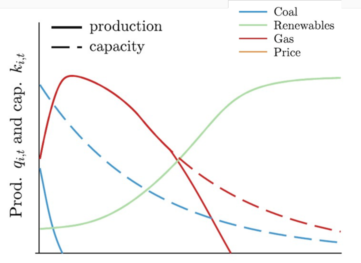
General results

- They then derive optimal paths for investments, utilisation rates, etc.
- $\rightarrow$ Optimal paths under carbon budgets would inevitably involve some stranding of capital stocks
    - A period in which it is optimal to leave some installed capital unutilised
- The exact features of the optimal transition depend on some crucial 'exogenous' values
    - eg. carbon budget, investment cost parameters
    - $\rightarrow$ a variety of possible optimal transition profiles (sequential vs overlapping, timing, stranding profiles)

Typical results concerning underutilisation



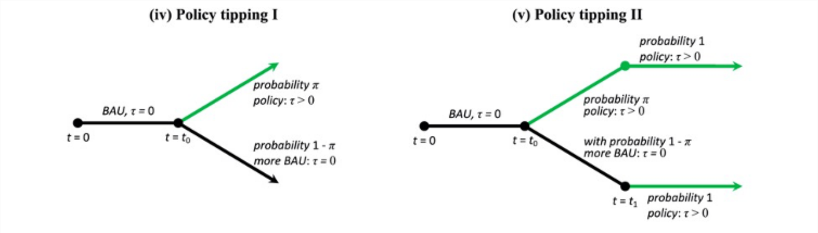




Source: Rozenberg et al. (2020), Baldwin et al. (2020) and Coulomb et al. (2019)

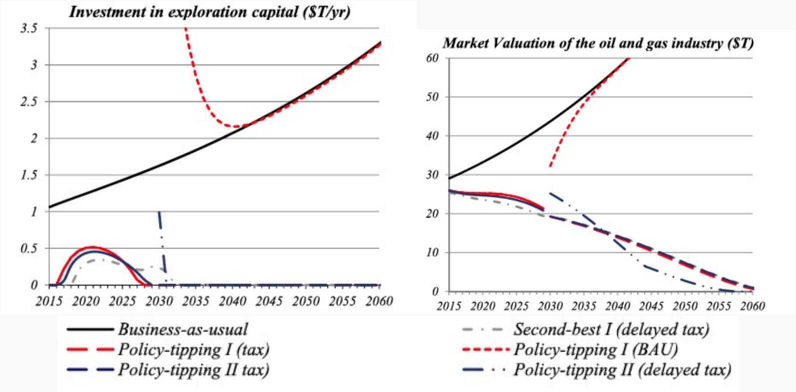
van der Ploeg & Rezai (2020) on JEEM

- Focus on the fossil fuel sector
  - A single type of capital to work with: extraction capital k
  - No underutilisation of capital allowed
- Market valuation of fossil firms given by future profits
  - They decide investments by maximising $V^R \equiv \int_0^\infty e^{-rt}\Pi^R$
- Policy tipping setting:



Source: van der Ploeg & Rezai (2020)

- Uncertainty (and its resolution) affect transition profiles
  - I might go to zero but K continues to operate
  - $\rightarrow V$ moves more smoothly



Source: van der Ploeg & Rezai (2020)

Computable General Equilibrium (CGE) models

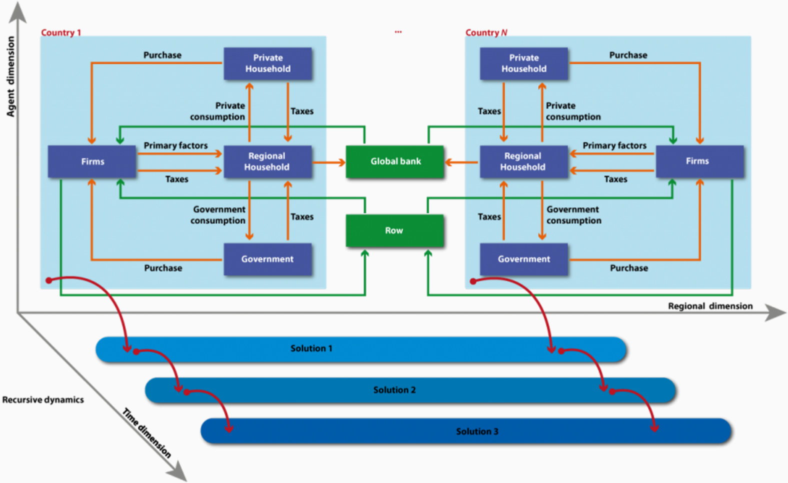
CGE models

- Start from actual data capturing economic inter-dependencies
  - Input-Output (IO) tables
  - Social Accounting Matrices (SAM) also include institutional accounts
  - e.g. GTAP Database
- Define a set of behavioural rules
  - Profit maximisation or cost minimisation by firms
  - Welfare maximisation by households
  - e.g. GTAP model
- Calibrate parameters on available data
  - E.g. Armington elasticity (of substitution between products of different countries)
- Introduce a change
  - E.g. a change in taxes or border tariffs
  - Observe how the system reacts to the change in prices

CGE models in climate economics

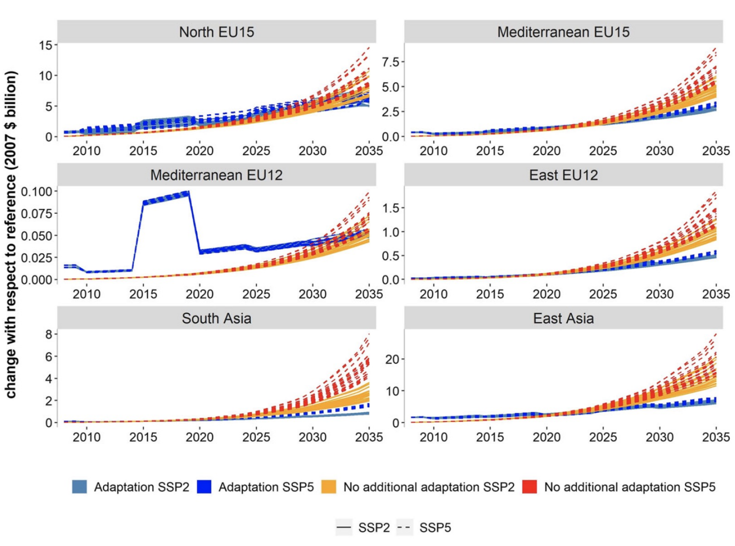
- They can adapted to include energy/environment
  - Impact of mitigation policies (carbon tax) or climate impacts
  - Multi-sectoral dimension is important (structural change)
  - Multi-regional dimension is important (trade impacts)
- Stylized representation of macro-financial dimension
  - All savings aggregated into a global banks that reallocates them according to relative returns
  - Crowding-out assumption (exogenous money)
- Example: ICES model (CMCC Venice)
  - Recursive model generating a sequence of static equilibria under myopic expectations
  - Derived from GTAP-E model
  - Cost-minimizing firms, representative household and government

An example: the ICES model



ICES model structure. Source: ICES website

An application: Public deficit and adaptation to sea level rise



Impacts on public deficit. Source: Parrado et al. (2020)

Unanswered questions on macro and finance

- IAM/CGEs have no or little representation of macro-financial system
    - No banking or financial institutions
    - Production networks: yes in CGE; financial networks: no
    - No monetary/banking/financial policies
    - Physical/financial conflation (investments, capital)
    - Stranding possible only for fossil reserves
- Wider issues with IAMs
    - See Bob Pindyck's opinion
- What alternatives do we have?
    - Let's try to use traditional macro/finance tools
    - Methodological dichotomy: neoclassical vs complexity

Reminder: Two main methodological avenues

	Equilibrium	Non equilibrium
Behaviour drivers	Intertemporal optimisation of a welfare function	Macro-econometric relations
Determination of output	Supply-driven: output (production) is allocated between different uses (consumption and investment) Y=AKL	Demand-driven: output (income) is determined by the expenditure desires (consumption and investment) Y=C+I+G
Expectations	Forward-looking expectations by rational agents	Adaptive expectations by agents in a context of deep uncertainty
Decisions	Rational	Routines in a context of deep uncertainty
Equilibrium	The system moves to an equilibrium state (balanced growth path)	There is not necessarily an equilibrium (cycles, emergent behaviours)
Money	Money as a 'veil' (banks as intermediaries)	Endogenous money (credit creation by commercial banks)
Modelling approaches	IAM, CGE, DSGE, CAPM	SD, SFC, ABM
Communities	Economics, Finance, Environmental/Energy Economics	Social sciences, Ecological/Evolutionary Economics

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

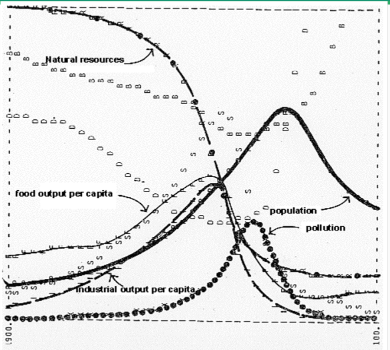
- DSGE heavily under attack after the GFC
  - Romer (2016): Fluctuations driven by 'imaginary causal forces'
  - Krugman (2016): 'Were there any interesting predictions from DSGE models that were validated by events?'
  - Stiglitz (2011): 'core DSGE models is not good theory'
- Equilibrium
  - Economies 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

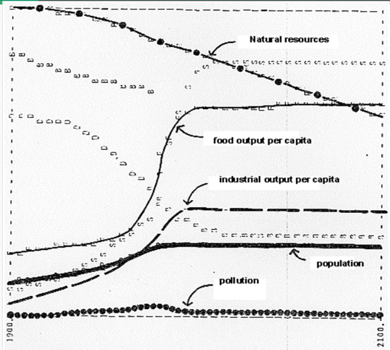
Non-equilibrium modelling

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."

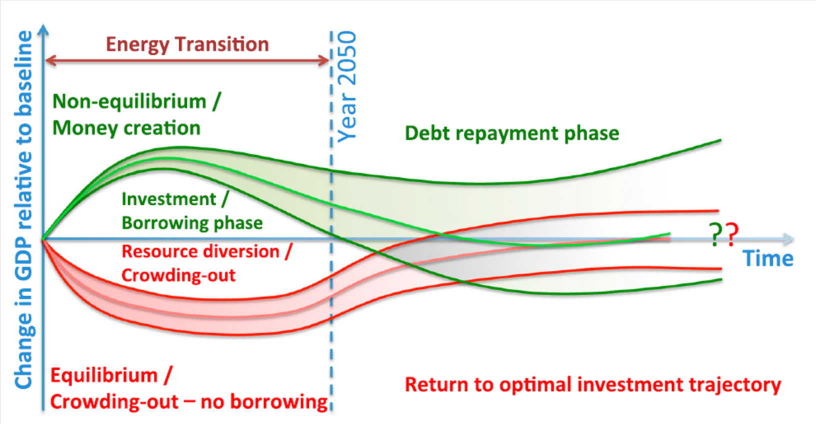
Stock-flow consistent (SFC) models

- 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
    - $\rightarrow$ Move to Angela's presentation
  - 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
- Move to Adrianna's presentation

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

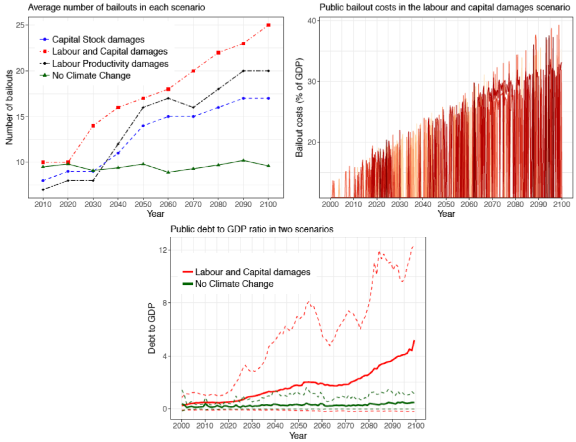


Figure 2: Ten years average number of bailouts (out of 500 simulations) in the three scenarios and in the baseline (top-left); bailout costs as share of GDP in the Labour and Capital Damages scenario, each line represents a model run (top-right); public debt behaviour in the Labour and Capital Damages 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)

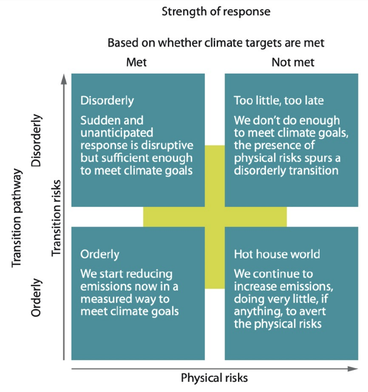
Issues with SFC/ABMs

- 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

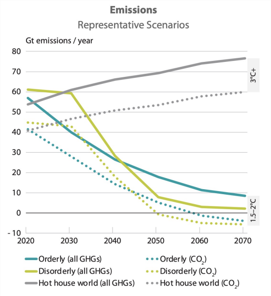
NGFS framework - Three representative scenarios

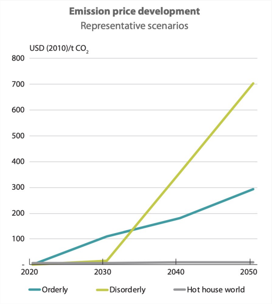
- Orderly transition:
  - Carbon price in 2020 and increasing $\$10/tCO_2$ per year
  - Full availability of CDR technologies
- Disorderly transition:
  - NDCs until 2030
  - Carbon price in 2030 and increasing $\$35/tCO_2$ per year
  - Limited availability of CDR technologies
- Hot house world:
  -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

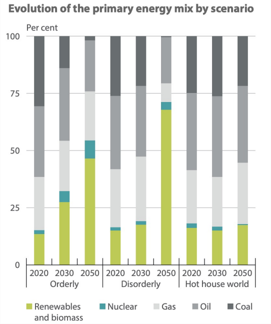


Source: NGFS (2020)

NGFS representative scenarios



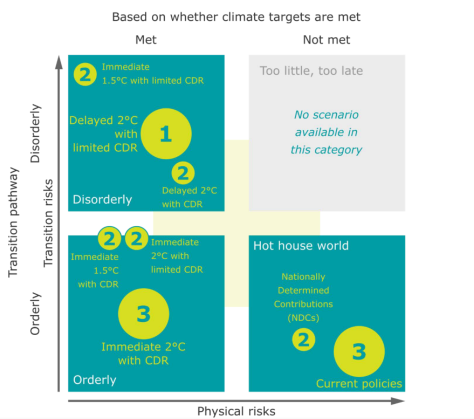




Source: NGFS (2020)

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

NGFS (2020)

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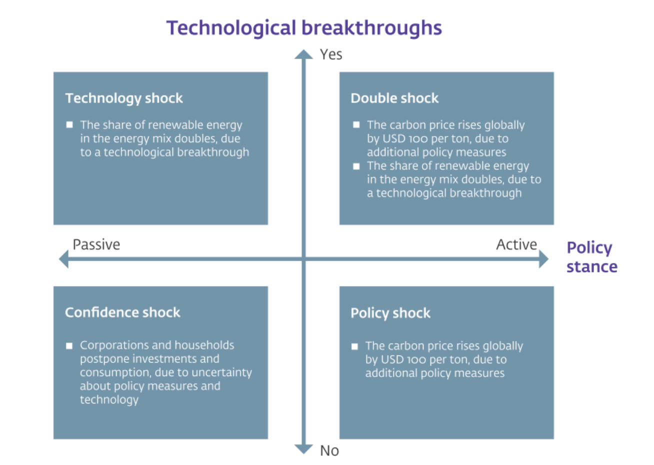
Source: NGFS (2020)

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)

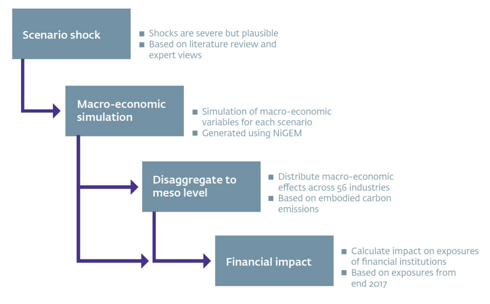
Vermeulen (2018): De Nederlandsche Bank

- 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



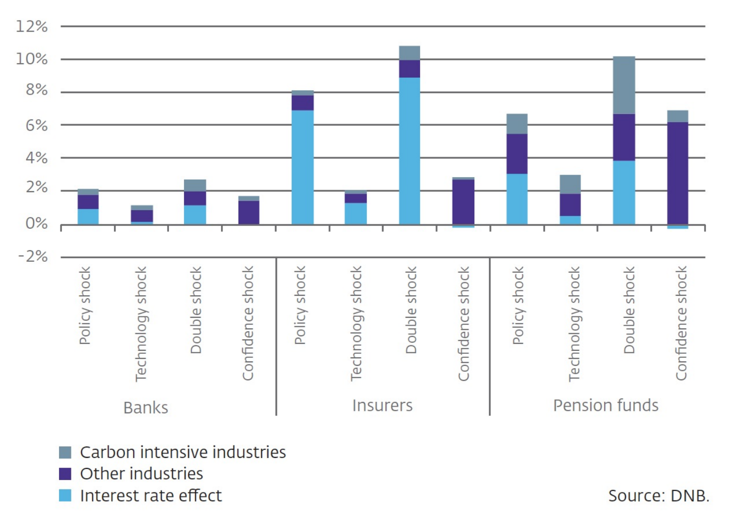
Vermeulen et al. (2018): Modelling approach

- 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)

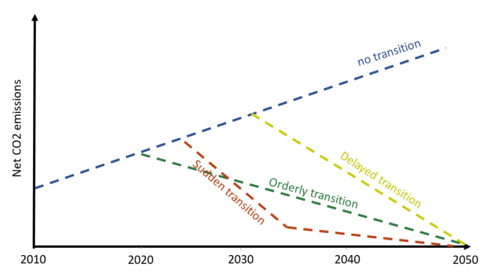
Vermeulen et al. (2018): Results



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

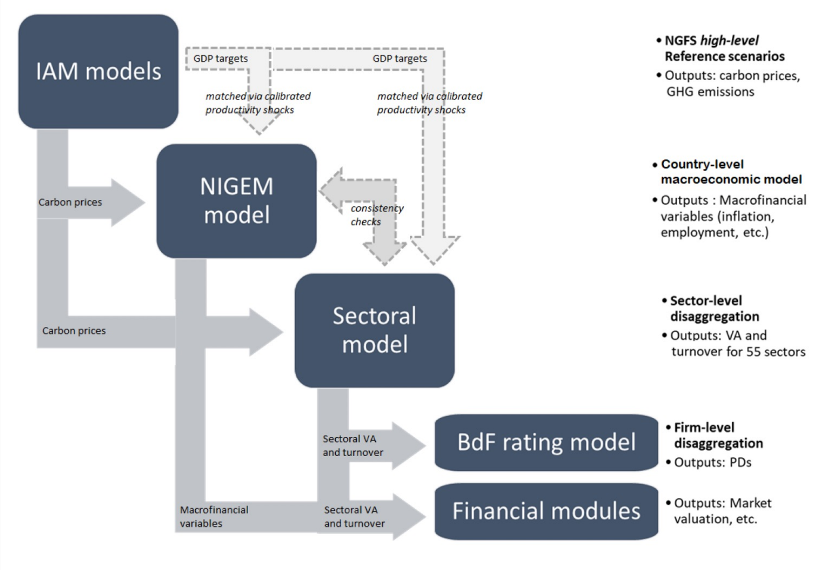
Allen et al. (2020): Banque de France

- 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



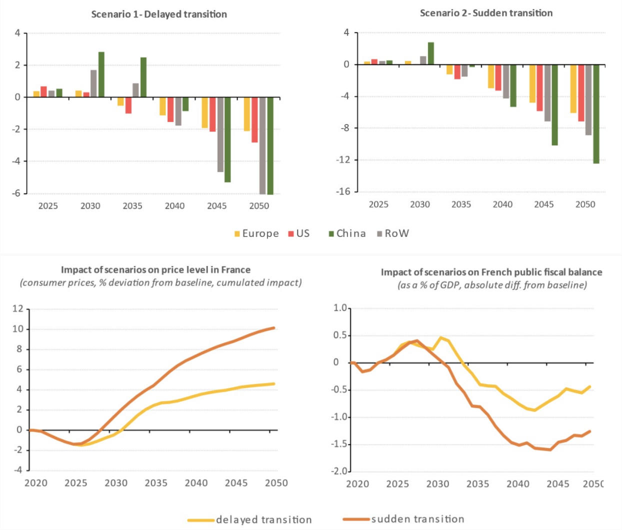
Source: Allen et al. (2020)

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



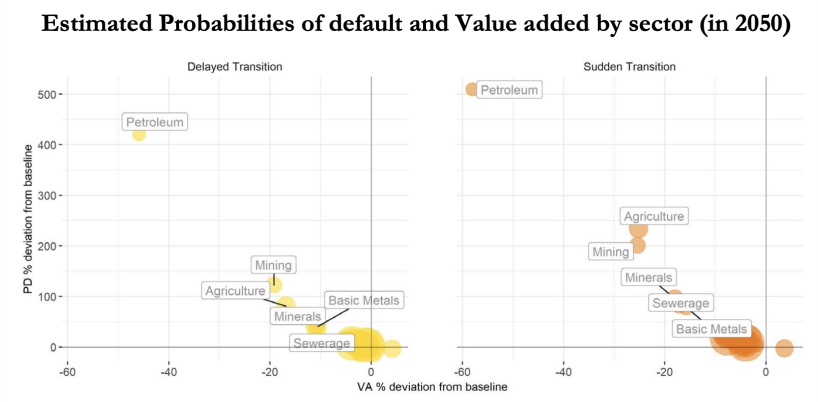
Source: Allen et al. (2020)

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

- We have multiple dimensions to explore to understand how to achieve a smooth and rapid low-carbon transition
- Traditional climate econ (IAM/CGE) offers multiple insights..
  - Carbon prices, energy composition, energy investments, etc.
- .. but lacks several important dimensions
  - Namely, financial dynamics and related institutions/policies
- So, let's look at macroeconomics and finance literature
  - Dichotomy between neoclassical (DSGE, CAPM, IAM+)..
  - .. and complexity-driven approaches (SFC, ABM)
- They are all being used to study macro-financial implications of climate/transition