THE MACRO-FINANCIAL DIMENSIONS OF LOW-CARBON TRANSITIONS

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Summer School 2020

Outline of the lecture

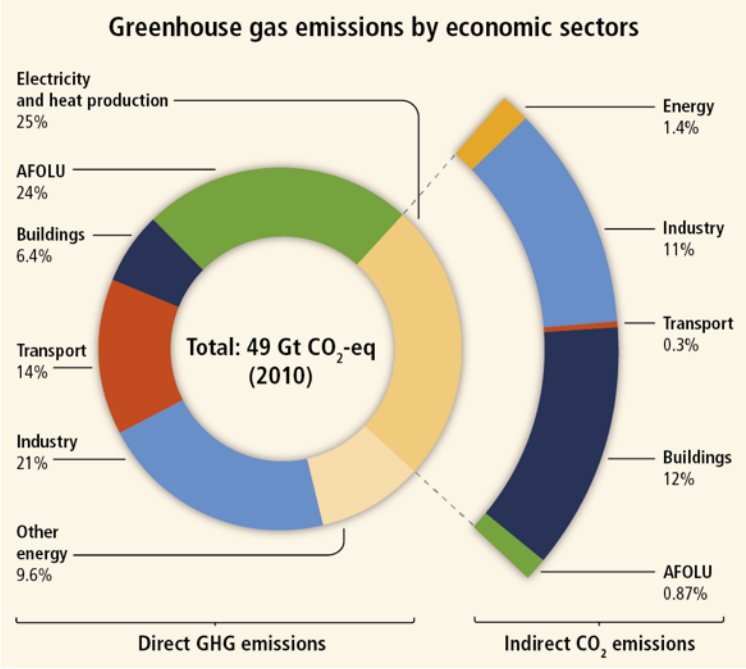
- What are the social objectives?
  - A rapid and smooth low-carbon transition
- What do we need to understand?
  - How to shift investments to low-carbon activities
  - How to minimise the socio-economic costs of the transition
- How can we understand it?
  - Multidisciplinarity needed
    - Conceptual frameworks; Political economy; Network analysis
  - Dynamic macroeconomic modelling
    - Neoclassical approaches (IAM, CGE, DSGE, CAPM)
    - Complexity approach (SD, SFC, ABM)

WHAT ARE THE OBJECTIVES?

A rapid and smooth low-carbon transition

1. A rapid low-carbon transition

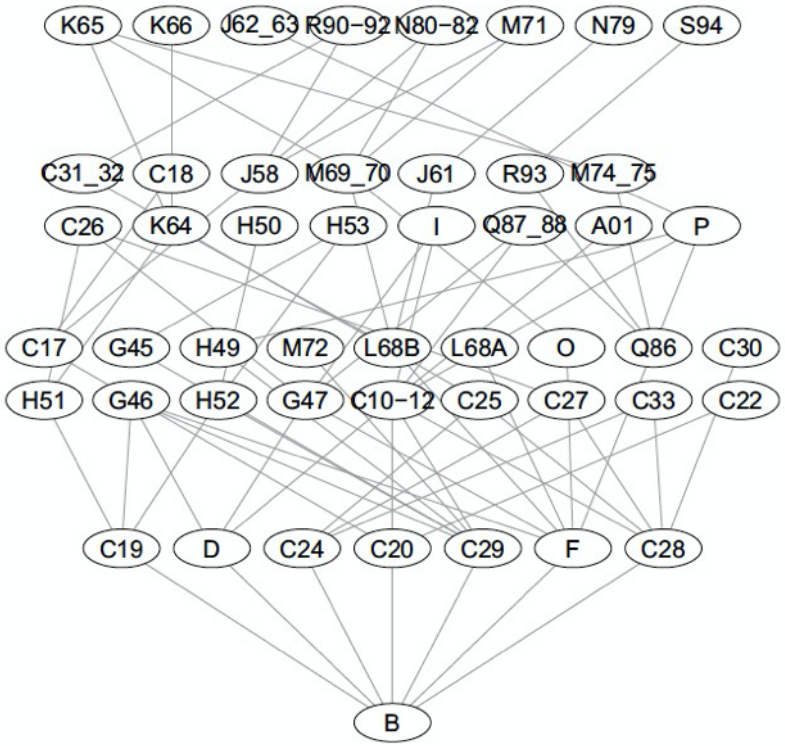
- Threats to climate stability
  - Anthropogenic emissions of 'greenhouse gases' (esp. CO_2)
  - Combustion of fossil fuels
- Policy objective:
  - Keep temperatures below 2°C (1.5°C)
- Low-carbon transition:
  - Technological development
  - Large-scale application of new technologies
- Reallocation of investments needed
  - Physical investments (firms purchasing low-carbon capital stocks)
  - Financial investments (banks and financial firms investing in low-carbon financial assets)



Source: IPCC (2014)

2. A smooth low-carbon transition

- Decarbonisation will involve a deep systemic change
  - Almost all productive activities require fossil fuels as direct/indirect input
  - Technological development:
    - Promising in some sectors (eg. electricity);
    - Lagging behind in others (eg. manufacturing)
- Large disruptions possible?
  - Fossil sectors → fossil-dependent intermediate sectors → downstream services



(a) Germany

Source: Cahen-Fourot et al. (2020) [Link to article]

WHAT DO WE NEED TO UNDERSTAND?

1. Obstacles to a rapid transition
2. Policies for a rapid transition
3. Obstacles to a smooth transition
4. Policies for a smooth transition

Four main sets of research questions

	Rapid transition	Smooth transition
Obstacles	What are the obstacles to expanding physical and financial low-carbon investment?	What are the drivers and transmission channels of potential disruptions along the low-carbon transition?
Solutions	How can societies accellerate the reallocation of investments towards low-carbon activities?	How can societies mitigate transition-related risks?

1. Obstacles to low-carbon investment

- Different stages of technological progress
  - Many low-carbon technologies still bear large risks
- Systemic inertia and lock-ins
  - Technical (supporting infrastructural networks)
  - Cognitive (habits, routines, imitation)
  - Financial (existing stakes in high-carbon companies/assets)
  - Political (troubled implementation process)
- Radical uncertainty
  - Limited information set about the present
  - Uncertainty on the future and short-term planning horizons
- Underlying question:
  - What determines physical and financial investments?
  - Emotions, sentiments, expectations, cognitive biases

2. Policies for low-carbon investments

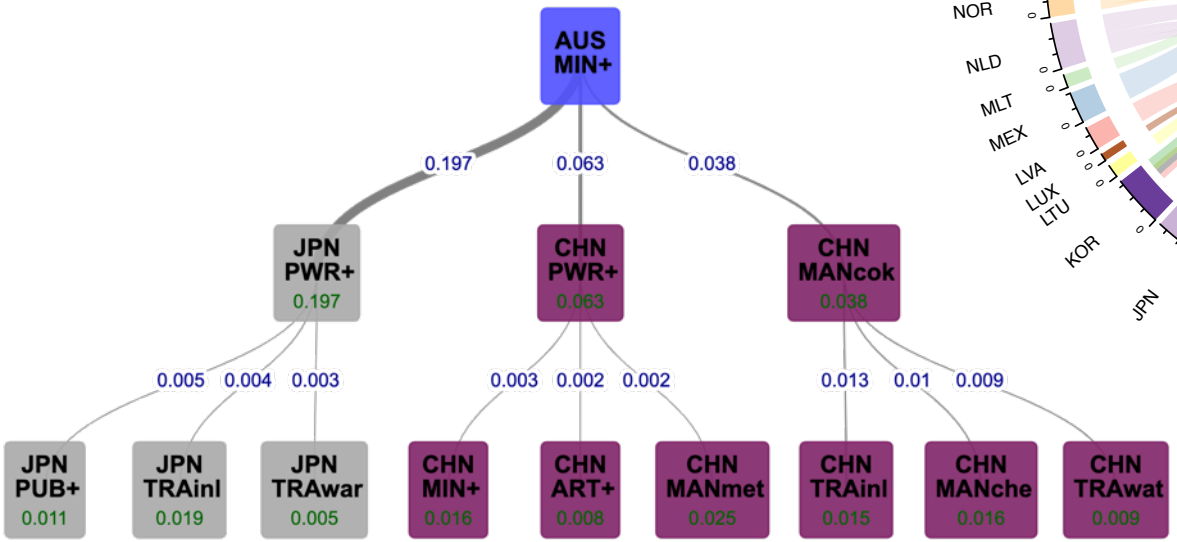
- Carbon pricing
  - Necessary but not sufficient? Additional market failures call for additional policies (Campiglio, 2016 Link to article)
- Additional policies?
  - Disclosure requirements
  - Prudential policies (eg. differentiated reserve/capital requirements)
  - Monetary policies (eg. Green quantitative easing)
  - Public finance interventions (public investment, lending)
- Which institutions?
  - Governments; Development banks; Central banks; Financial supervisors
  - Overall governance framework

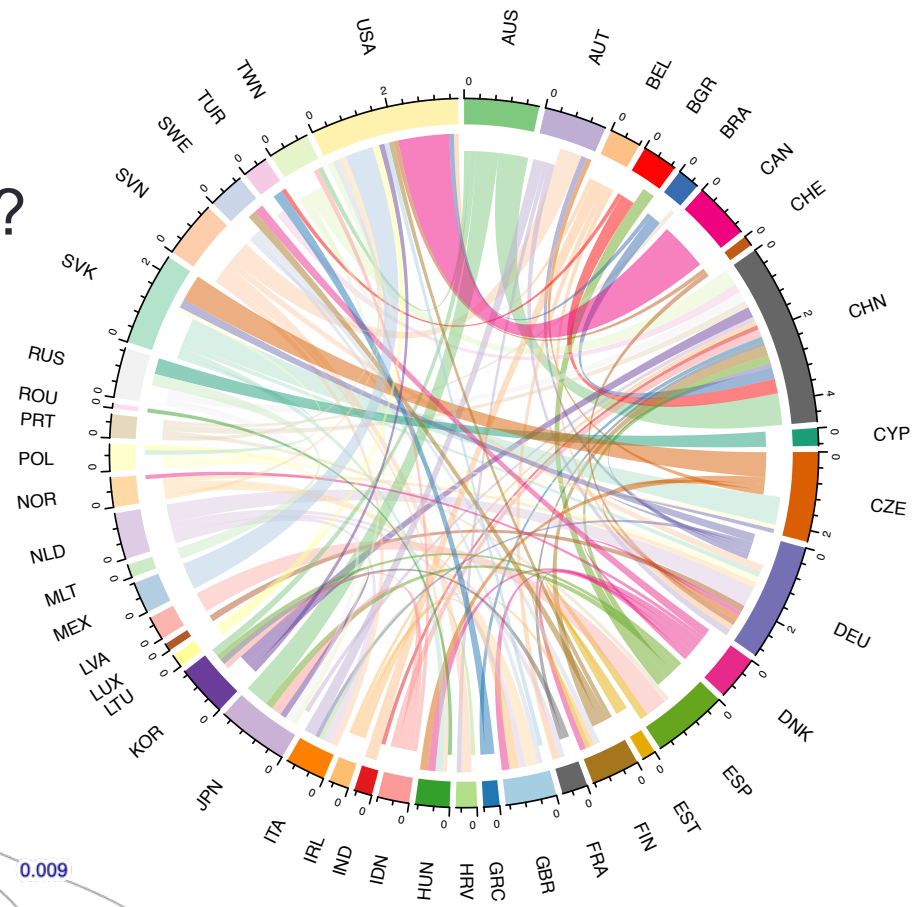
3. Sources of transition disruptions

- What could trigger macroeconomic/financial instability along the transition process?
- Drivers
  - Policies, tech breakthroughs, preferences
  - ‘Late and sudden’ transition; ‘inevitable policy response’
  - + Macro-financial implications of climate change
- Transmission channels:
  - Loss of value of physical and financial assets (stranding)
  - Propagation across production and financial networks
  - Change in financial asset prices (Campiglio et al. 2019 link)
- Aggregate impacts and second-round macro effects
  - A ‘Climate Minsky moment’

Stranding in physical capital assets

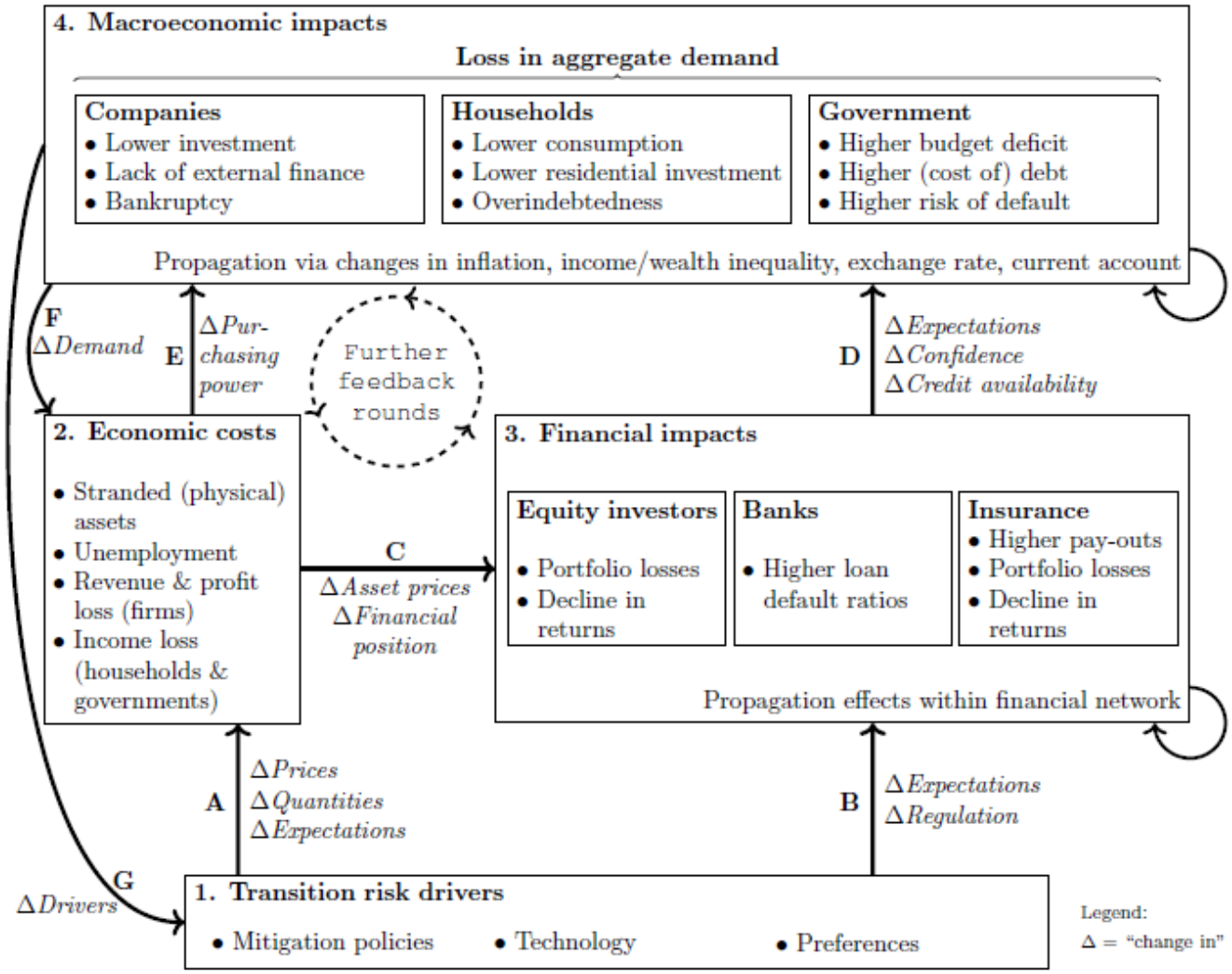
- What would be the effect on capital stock utilisation of decreasing fossil production?





Source: Cahen-Fourot et al. (2019) [Link to working paper]

A framework for transition risks



Source: Semieniuk et al. (2020) [Link to working paper]

4. Policies to mitigate transition risks

- Inclusion of climate/transition in risk assessments
  - Supervisors to suggest/impose stress tests and disclosure to private financial firms
  - Supervisors to run stress tests on banking/financial systems
  - Methodologies still in development
- Additional policies?
  - Calibrate monetary/prudential policies according to risk
  - Move towards promotional dimensions?
- Which institutions?
  - Financial stability concerns: Entry point for central banks
  - Role of central banks in modern societies?
  - Campiglio et al. 2018, link to article
- How do we adapt to transition?
  - Implications for monetary policy (change in relative prices)

HOW DO WE UNDERSTAND ALL OF THIS?

A wish-list of methodological features to study the macro-financial dimensions of the transition

Ideal methodological dimensions (I)

- Representation of multiple technologies
  - At the minimum: High-carbon vs low-carbon
- Representation of physical assets
  - Including capacity utilisation rates (physical stranding)
  - Vintages of stocks; technological development; inertia
- Representation of financial markets
  - Assets: credit, bonds, equities
  - Institutions: firms, banks, asset managers, central banks
  - Realistic representation of credit creation and allocation
- Representation of climate damages?
  - It depends on research focus

Ideal methodological dimensions (II)

- Representation of networks of exchanges and assets
  - Production and financial networks
- Representation of investment behaviour
  - Physical and financial investments
  - Realistic representation of expectations (planning horizons)
  - Representation of ‘sentiments’ (realisation, reversal, herding)
- Representation of structural change
  - Shifts in technological paradygms
  - Sunrise and sunset industries
- Representation of policies
  - Social/fiscal/monetary/financial/…

Four main research strategies

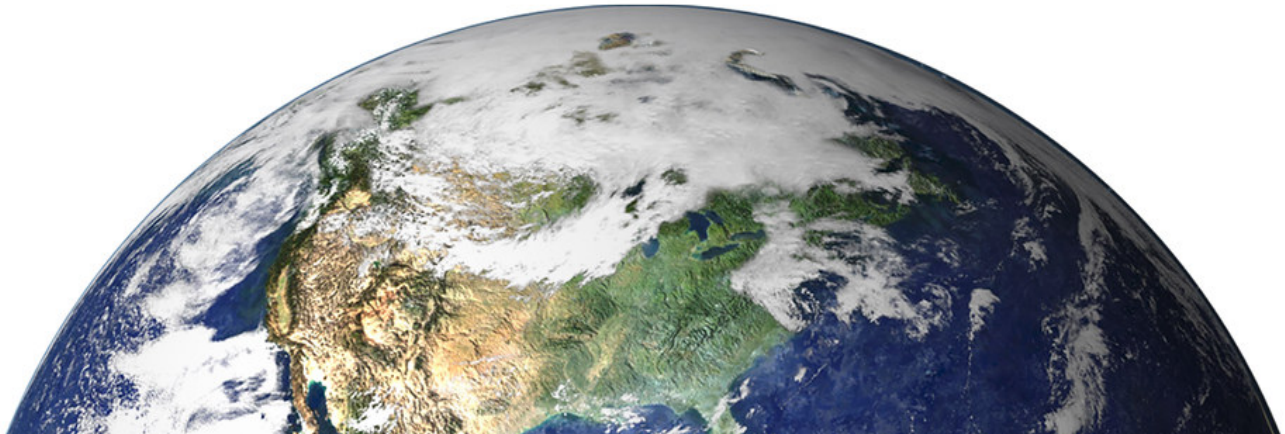
- No single methodology will ever include all the dimensions above
- → Multiple approaches needed in combination
- Four main research strategies
  - Conceptual frameworks
  - Political economy
  - Network analysis
  - Dynamic macroeconomic modelling
- Focus of today‘s lecture:
  - Dynamic macroeconomic modelling

DYNAMIC MODELLING

The macroeconomics and finance of low-carbon transitions

A bit of history

- The scarcity debate (60-70s)
- Wider context:
  - Rapid development creates environmental/health problems (urban pollution: the Great Smog of London of 1952)
  - Development requires energy and materials → geopolitics of fossil fuels (oil crises in 1973 and 1979)
  - Realisation of human planetary dimension (images of Earth from space, Moon landing in 1969)



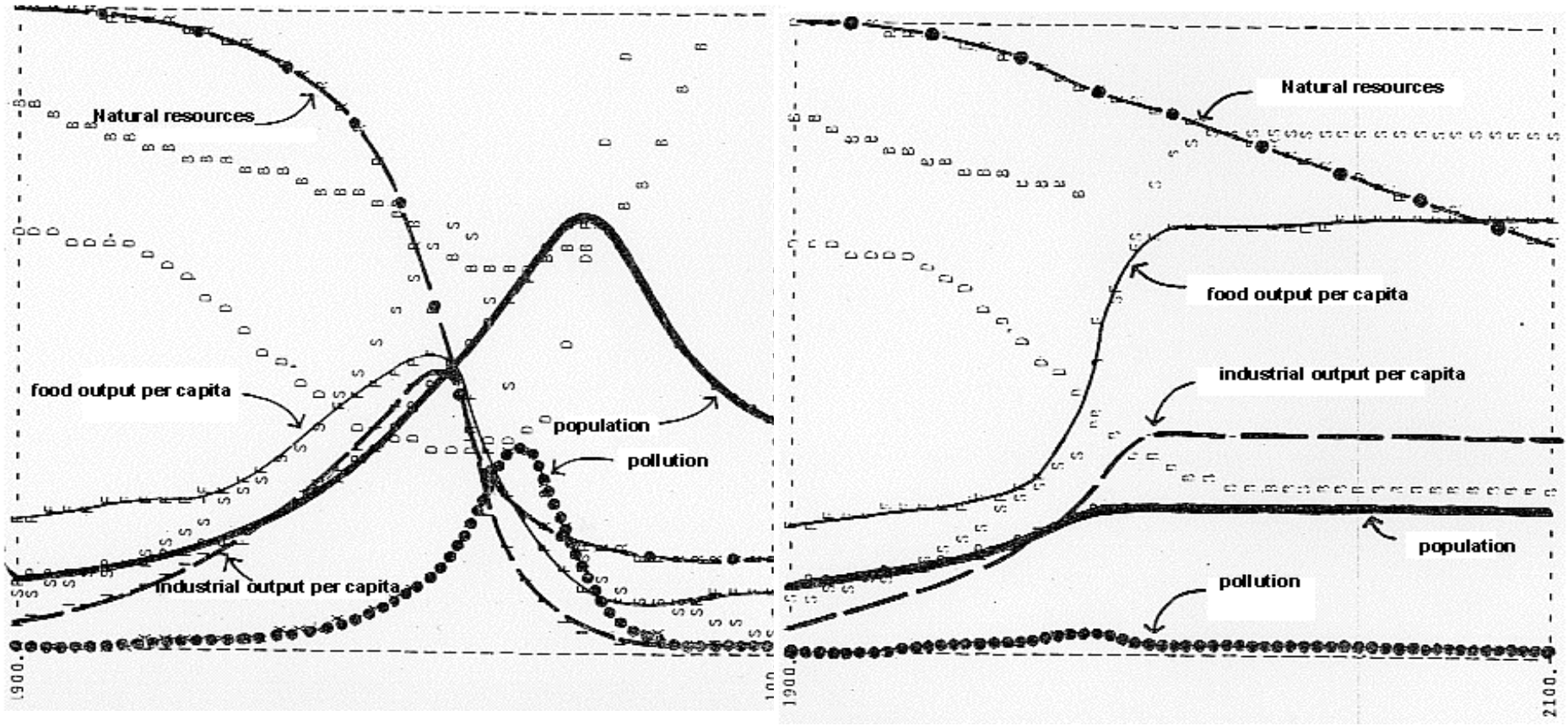
Modelling human-environment relations

- Two main initial approaches
  - System dynamics
  - Neoclassical economics
- Modelling dimension of a larger debate:
  - Weak vs strong sustainability
  - Environmental vs ecological economics
- Neoclassical economists (Hartwick, Solow, Stiglitz, etc.)
  - Substitutability, smoothness, analytical tractability, monetary flows
- Ecological economists (Georgescu-Roegen, Daly)
  - Non-substitutability, complexity, material flows

System dynamics

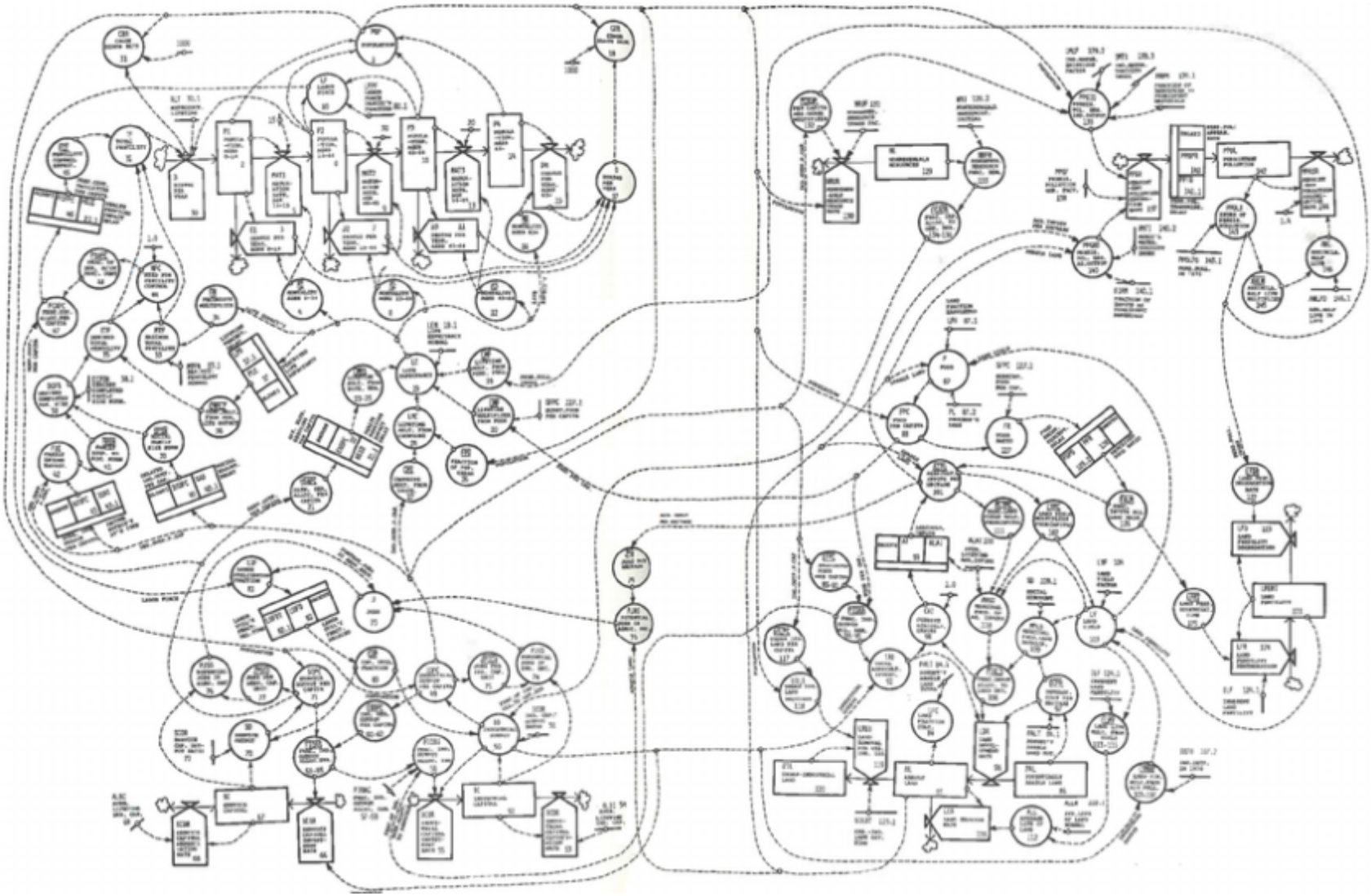
- System dynamics
  - Aim: capture real-world complexity (feedback loops)
  - Focus on stocks and flows (ecological modelling)
  - Macroeconometric approach: behavioural functions driven by estimation/calibration
  - Adaptive expectations (linear extrapolation to next period)
- The Limits to Growth (1972)
  - 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

Two scenarios from the Limits to growth



Source: Meadows et al. (1972)

The World3 model



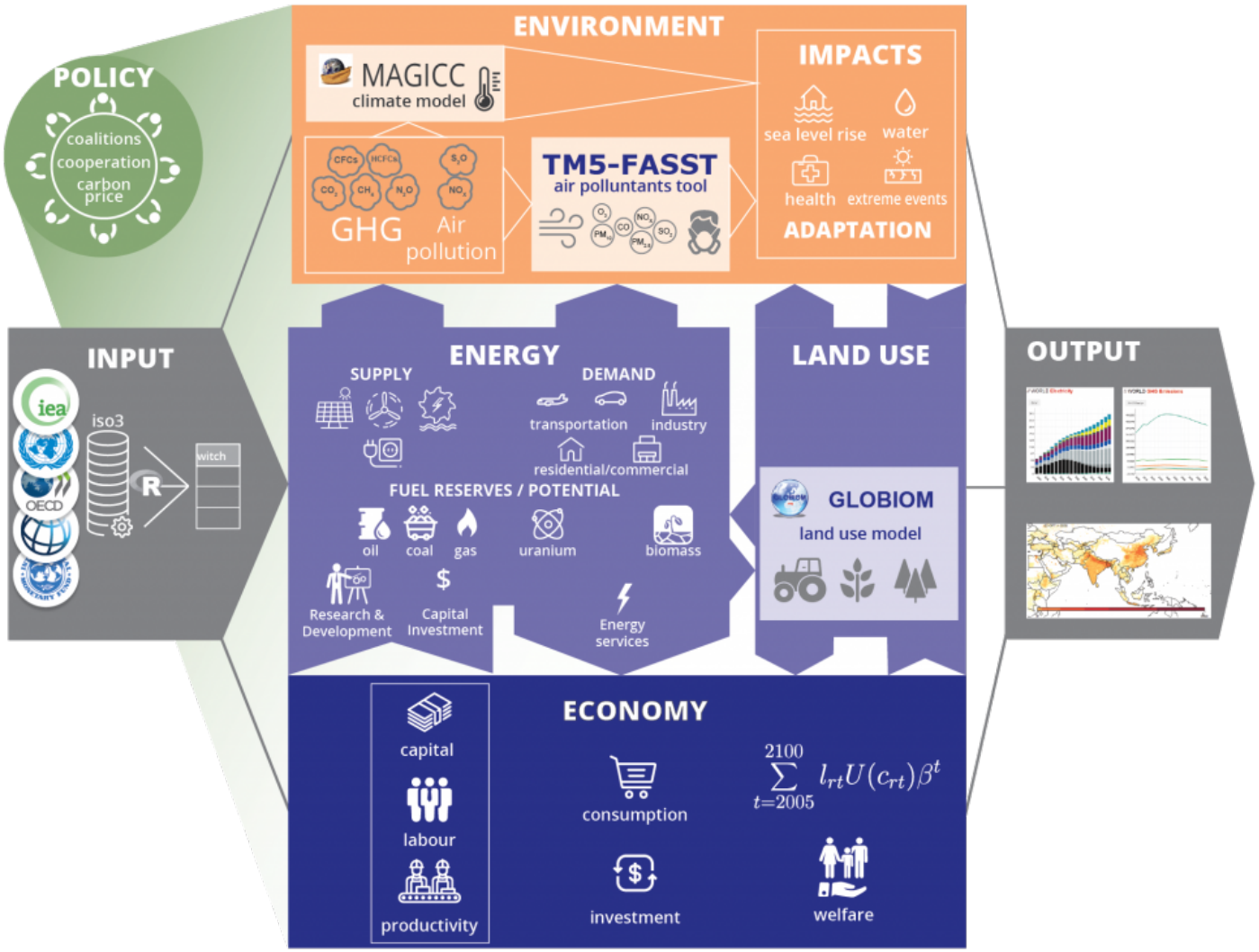
The neoclassical reaction

- Microfoundations needed
  - Lucas critique (1976)
- General equilibrium approach
  - Intertemporal optimisation of welfare/profits
  - Prices as efficient signals of resource scarcity
  - Optimal resource depletion plans
- → Nordhaus' DICE model (1992)
  - The seminal contribution (link to model code)
- → Large-scale numerical IAMs
  - IPCC projections all based on IAMs
  - WITCH, MESSAGE, REMIND, GCAM, IMAGE, IMACLIM…

The typical IAM economic structure

- Detailed technology representation
  - In some cases: endogenous technical change
- Intertemporal optimisation
  - Maximisation of welfare (consumption) or minimisation of costs
  - The discount rate debate (Nordhaus vs Stern)
- Supply side:
  - Production is allocated between consumption and investments (or unproductive mitigation activities)
  - Input factors fully utilised (no stranding)
- Emissions lead to climate damages
  - Debate on climate damage function (Nordhaus, Weitzman)

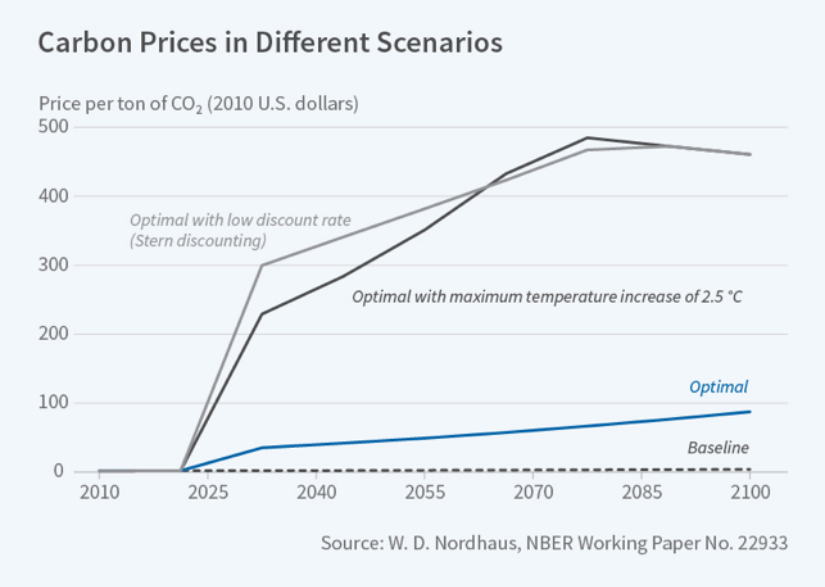
Example: the WITCH model

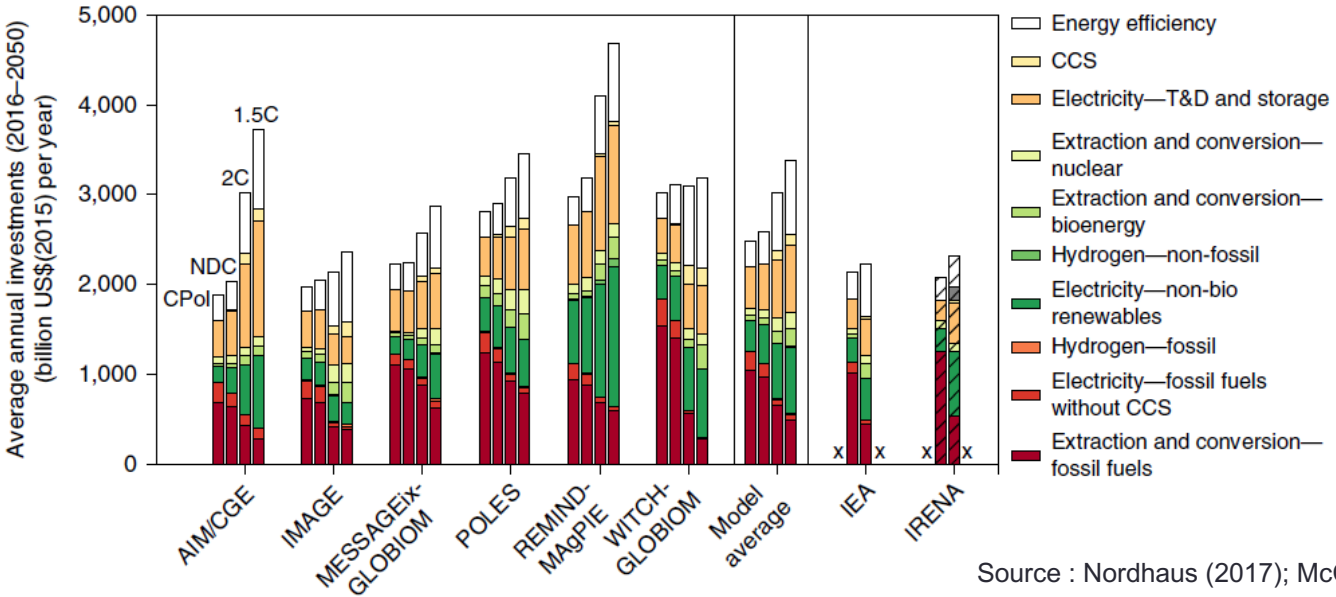


Source: www.witchmodel.org/model/

What they can be used for

- Identify optimal social behaviour
  - Cost-benefit analysis: mitigation costs vs mitigation benefits → Optimal carbon price
- Identify optimal social behaviour *given specific objectives*
  - Eg. objective: 2C temperature in 2100
  - → Optimal investment needs (Tavoni et al 2014 link)
  - → Optimal international transfers (Bowen et al. 2017 link)





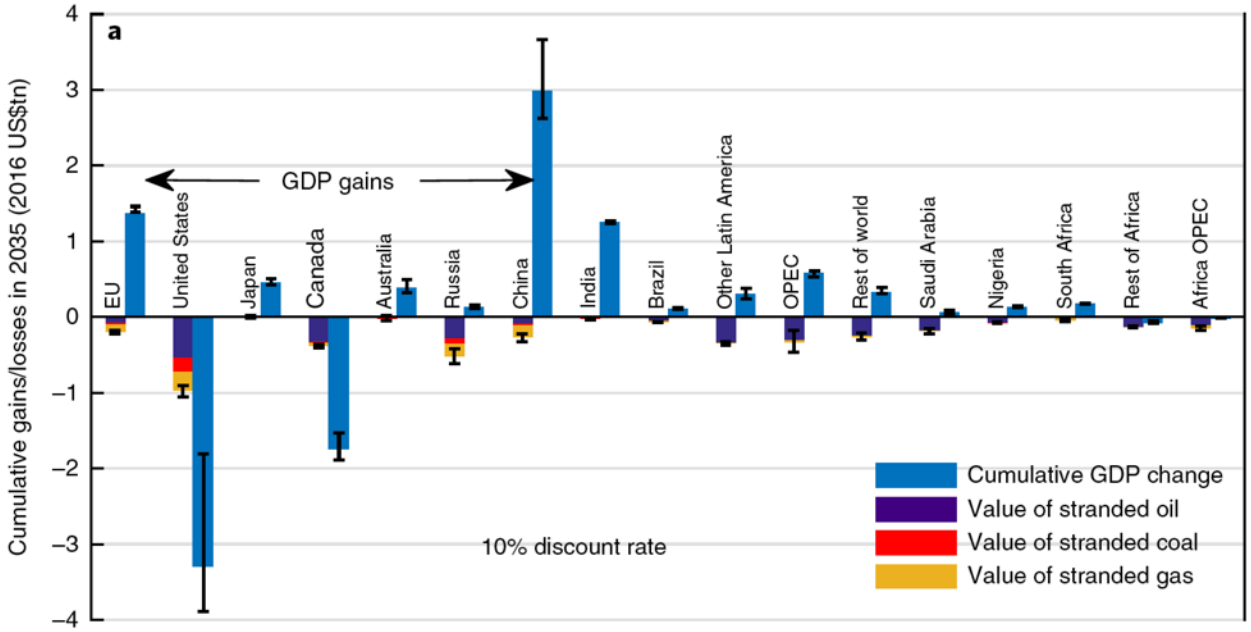
Source : Nordhaus (2017); McCollum et al. (2018)

CGE models

- Computable General Equilibrium (CGE) models
  - Large-scale multi-regional multi-sector models
  - Based on large Input-Output databases (e.g. GTAP)
- General equilibrium
  - Shock → reaction (adjustment) → new equilibrium
  - Optimisation of a welfare functions
  - Full utilization of input factors; price flexibility; market clearing
- What can they be used for?
  - Impact of mitigation policies (carbon tax) or climate physical impacts
  - Multi-sectoral dimension is important (structural change)
  - Multi-regional dimension is important (trade impacts)
- More in Karl's lecture

Macro-econometric modelling

- While minoritarian in economics, large empirical modelling continued
  - E3ME by Cambridge Econometrics
  - T21 model (UNEP 2011: Towards a green economy)
  - System dynamics and growth question (Victor 2007 on Canada)



Source: Mercure et al. (2018)

Weak links with macro/finance

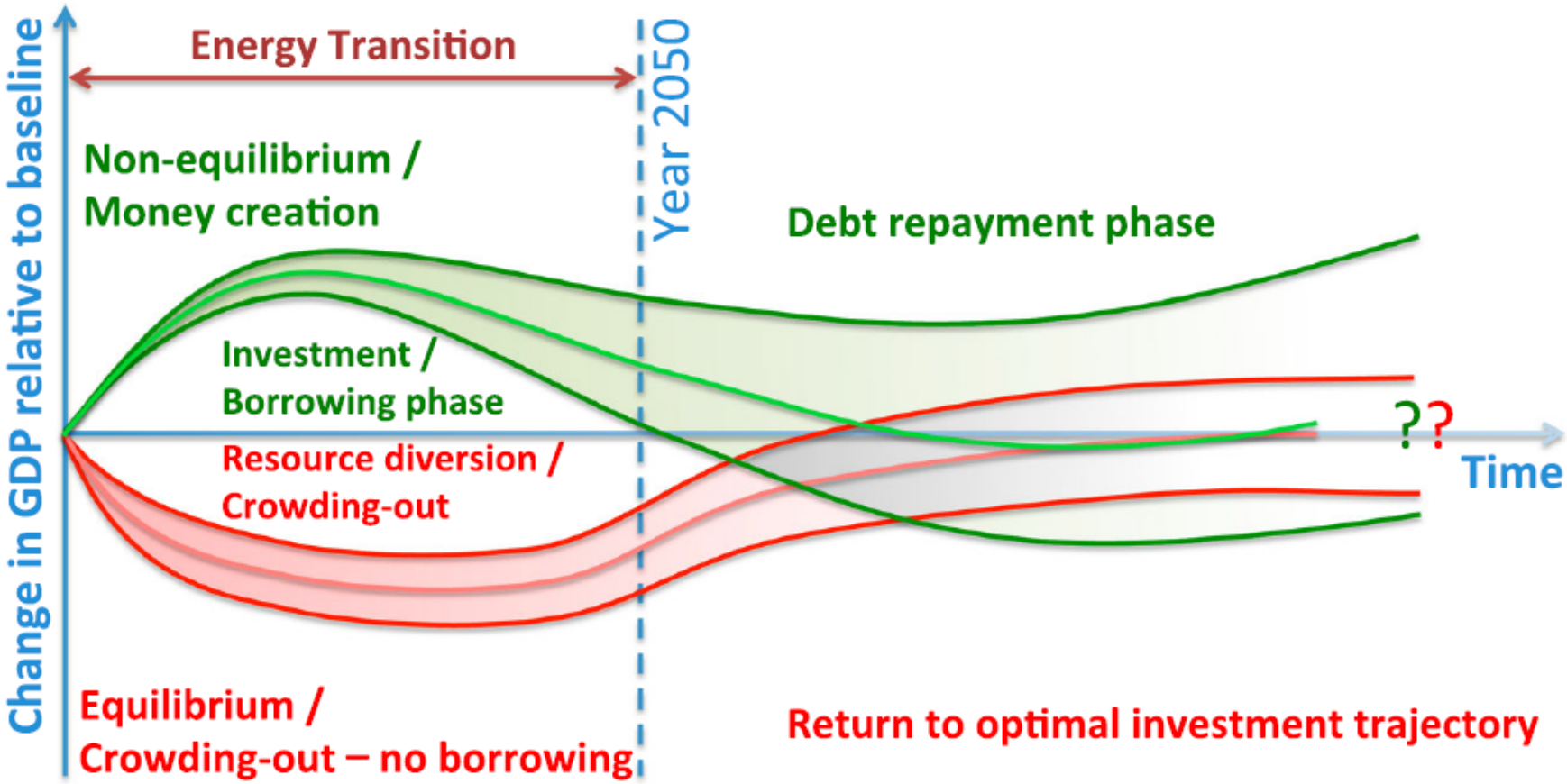
- Weak interest in macro/finance of transitions/climate
  - No financial system
  - No production/financial networks
- Neoclassical macro/finance abstracting from biophysical constraints
  - Dynamic Stochastic General Equilibrium (DSGE) models
  - Capital Asset Pricing Models (CAPM)
- Non-neoclassical approaches also not looking at transitions/climate
  - Post-keynesian, evolutionary, complexity
  - Stock-flow consistent modelling (SFC)
  - Agent-based modelling (ABM)

The big modelling divide

	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

Equilibrium vs non-equilibrium

- Two structurally different modelling approaches:



Source: Mercure et al. (2019) link

MODELLING STRATEGIES

1. Improve existing IAM/CGE models
2. Use neoclassical macro dynamic modelling
3. Use stock-flow consistent models
4. Use agent-based models

Back to the original objective

- Modelling the macro-financial implications of climate change and the low-carbon transition
- Two main strategic directions:
  - The neoclassical approach (equilibrium)
  - The complexity approach (non-equilibrium)
- Neoclassical strategy
  - Improve existing IAM/CGE models
  - Introduce climate/transition into macro dynamic modelling (growth theory, DSGE, CAPM)
- Complexity strategy
  - Climate/transition SFC models
  - Climate/transition ABM models

1. Improve existing IAM/CGE

- Include macro-financial dimensions in IAMs
  - Possible? Century-long view of climate models
  - Dietz et al. (2016):
    - Modified DICE to calculate GDP impacts of mitigation scenarios
    - Assumptions: corporate earnings constant share of GDP
    - Value of financial assets function of discounted cash flows

Table 1 | The present value at risk of global financial assets from climate change between 2015 and 2100—the climate VaR.

Emissions scenario	1st pctl.	5th	Mean	95th	99th
BAU (expected warming of 2.5 °C in 2100)	0.46%	0.54%	1.77%	4.76%	16.86%
Mitigation to limit warming to 2 °C with 2/3 probability	0.35%	0.41%	1.18%	2.92%	9.17%

Source: Dietz et al. (2016) link;

- Include macro-financial dimensions in CGE
  - E.g. Parrado et al. (2020) on Climatic Change
  - The public debt implications of climate impacts (sea level rise and adaptation)

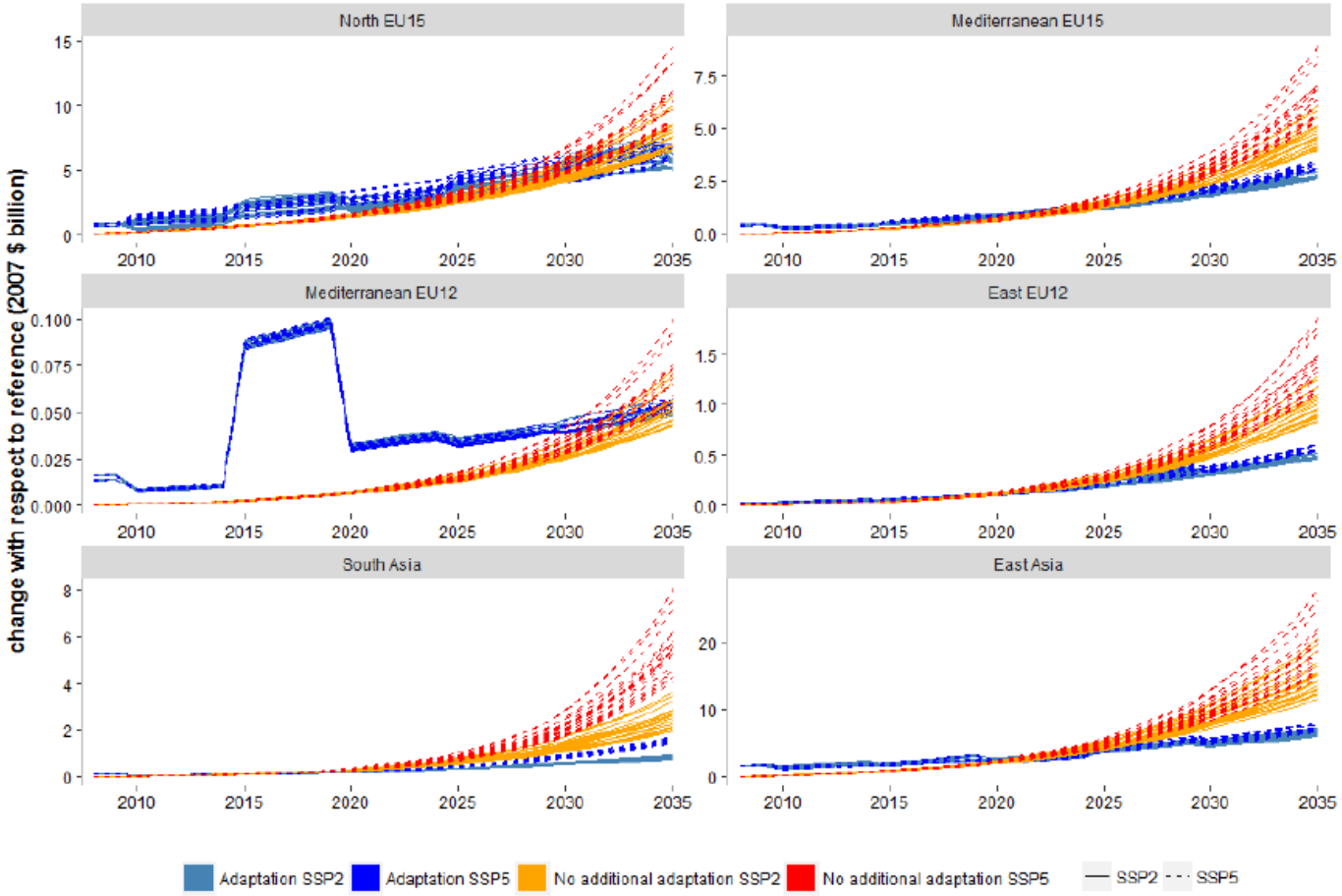


Fig. 3 Impacts on public deficit by SSP and RCP for selected regions (with and without additional adaptation)

Source: Parrado et al. (2020) link

- However, based on crowding out assumptions:
  - Higher deficit means lower savings available for investments
  - In reality, investements not driven by savings

2. Apply macro modelling to transition

- Initial literature on emissions-RBC
  - Fischer and Springborn (2011); Heutel (2012)
  - Mostly focused on optimal tax response
  - No representation of banks, central banks, financial investors
- Introduction of central bank and monetary policy in DSGE
  - Annicchiarico and Di Dio (2015; 2016)
  - Comerford and Spiganti (2020): Kyotaki-Moore model with green/brown investment goods
  - Punzi (2019): Introduction of banks (green/brown loans)
- CAPM+IAMs applied to transition
  - Karydas and Xepapadeas (2018): Pricing Climate Change Risks: CAPM with Rare Disasters and Stochastic Probabilities link
  - Hambel et al.: Asset Diversification versus Climate Action link
- Growth theory
  - Physical stranding (Baldwin et al., Rozenberg et al on JEEM Special Issue on stranded assets link)

Issues with DSGE/CAPM models

- General issues with neoclassical modelling:
  - Reliance on shocks: ‘Imaginary causal forces’ (Romer)
  - Banks as pure intermediary (no money creation)
  - Supply side: No under-utilisation of capital stocks (asset stranding)
  - No representation of networks
  - Little representation of sentiments
  - Not the best tool to analyse structural shifts

Stock-flow consistent modelling

- Focus on balance sheets of institutional sectors
  - households, firms, banks, government, central bank..
  - Stocks: Assets and liabilities (deposits, loans, financial assets)
- SFC per se not linked to any specific economic theory
  - However, SFC deeply rooted into post-Keynesian thinking
  - Economies are demand-led; fundamental uncertainty; adaptive expectations; endogenous money, mark-up on prices
- Behavioural functions (no optimisation)
  - Consumption function of disposable income and wealth
  - Physical investment function of capacity utilisation, interest rate, leverage, Tobin's q, ..
  - Financial investment: Tobin's portfolio choice

3. Use SFC modelling

- Apply balance sheet modelling to the climate change and/or the low-carbon transition
  - Dafermos et al. (2018) link
  - Bovari et al. (2018; 2019) link
    - Keen's underlying economic structure (debt imbalances, cycles)

	Households	Firms	Commercial banks	Government sector	Central banks	Total
Conventional capital		$+K_C$				$+K_C$
Green capital		$+K_G$				$+K_G$
Durable consumption goods	$+DC$					$+DC$
Deposits	$+D$		$-D$			0
Conventional loans		$-L_C$	$+L_C$			0
Green loans		$-L_G$	$+L_G$			0
Conventional bonds	$+p_C b_{CH}$	$-p_C b_C$			$+p_C b_{CCB}$	0
Green bonds	$+p_G b_{GH}$	$-p_G b_G$			$+p_G b_{GCB}$	0
Government securities	$+SEC_H$		$+SEC_B$	$-SEC$	$+SEC_{CB}$	0
High-powered money			$+HPM$		$-HPM$	0
Advances			$-A$		$+A$	0
Total (net worth)	$+V_H$	$+V_F$	$+K_B$	$-SEC$	$+V_{CB}$	$+K_C+K_G+DC$

Source: Dafermos et al. (2018)

Agent-Based Models (ABMs)

- ABMs simulate economic dynamics assuming the existence of a large number of autonomous agents (households, firms, banks, etc.)
  - Complex evolving systems
  - → Interactions among agents create emerging macro behaviours
  - Linked to innovation literature (Schumpeterian)
- Behavioural rules
  - Can vary across agents of the same type
  - Can include limited rationality
  - Competition, entry/exit of firms
- More in Paola's lecture

4. Use ABM modelling

- Look for further complexity: ABMs
  - Models with multiple interacting sectors/agents (→ Paola's lecture)
- Large ABMs applied to environment
  - Lamperti et al (2019): Implications of climate damages on public debt sustainability; (DSK model in Pisa)
  - Raberto et al. (2019): differentiated capital requirements depending on carbon intensity of bank lending (EURACE model)
- Smaller ABMs
  - Safarzynska and van den Bergh (2017): Financial stability implications due to a rapid low-carbon transition
  - D'Orazio and Valente (2019): The role of finance in environmental innovation diffusion: An evolutionary modeling approach

Issues with SFC/ABM models

- Expectations
  - Adaptive expectations are the norm (for both methodological preferences and computational complexity)
  - Limiting approach: no forward-looking behaviour (Campiglio et al. 2017, link to working paper)
  - Combine with animal spirits literature?
- Black box problem ("garbage in – garbage out")
  - Large number of assumptions on behaviour and parameters (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
  - → Agents

CONCLUSIONS

Conclusions

- Societal objective:
  - A rapid and smooth low-carbon transition
- Numerous gaps in our understanding:
  - What is blocking low-carbon investments?
  - How to shift investments to low-carbon activities?
  - What could go wrong along the transition?
  - How to mitigate transition risks?
- Several approaches to answering to these questions:
  - Multidisciplinarity needed
- Dynamic macroeconomic modelling
  - Improve existing IAM/CGE
  - Apply neoclassical macro modelling to transition/modelling
  - Use stock-flow consistent modelling
  - Use agent-based modelling
- Towards cross-fertilisation?

THANK YOU!

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