Macro-financial transition risks in the fight against global warming

Climate macro and finance course 2021 - Lecture 6

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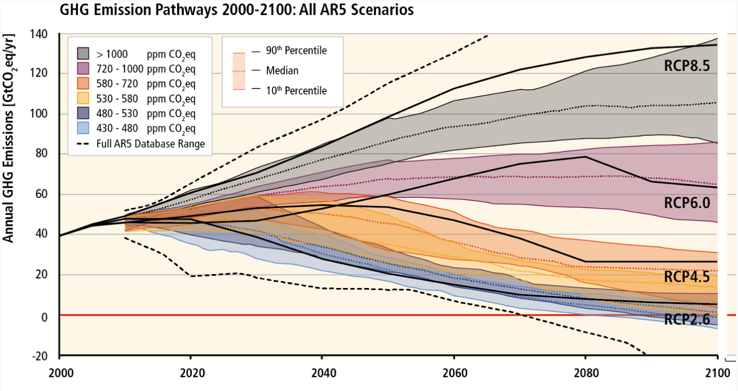
Climate threats suggest decarbonisation

- Anthropogenic emissions contribute to climate change
  - → Climate change impacts society and economic dynamics
- Temperature targets and related emission pathways



Source: IPCC (2014)

What is a low-carbon transition?

- A process of structural change:
  - Current system: fossil fuel + capital assets that runs on fossils $\rightarrow$ production process $\rightarrow$ human prosperity
  - Low-carbon system: new carbon-free technologies $\rightarrow$ further human progress
- Technological shift:
  - Main strategy: Electrify everything possible + Produce carbon-free electricity (wind, solar,..)
  - Improve energy efficiency (e.g. buildings)
  - Install negative emission technologies (e.g. CCS)

Two main things need to happen

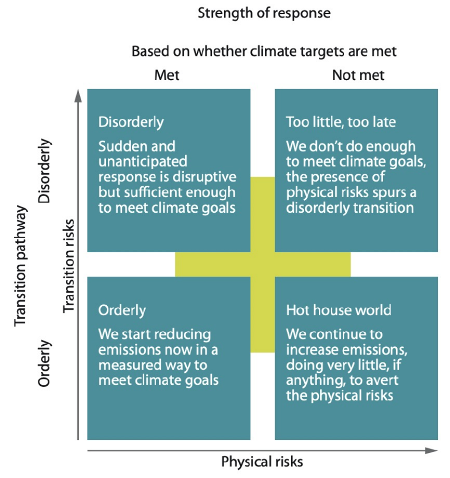
- Expansion of ('sunrise') low-carbon technologies and activities
  - Limited track record and uncertainty on future developments (e.g. storage issue)
  - Still often not competitive with high-carbon incumbents
  - Expansion dependent on credible long-term policies
- Decline of ('sunset') high-carbon technologies and activities
  - The macroeconomic balance sheet still locked in fossil fuels
  - Long-lived fossil and high-carbon capital assets $\rightarrow$ Do they still have value in a low-carbon transition?

High-carbon physical and financial assets

- Emissions embodied in fossils and capital are incompatible with 2°C carbon budget
  - Not all fossil reserves can be burnt
  - Not all capital stocks can be fully utilised
- Companies owning 'stranded' physical assets exposed to:
  - Some owners: dividends and sustained market value (equity)
  - Some creditors: give money back, plus some interest (debt: bonds and bank credit)
- $\rightarrow$ Financial asset stranding
  - If underlying stock fails, expected future income decline..
  - Sudden reversals of expectations $\rightarrow$ Market swings + defaults
  - Financial instability hurts (see GFC)

Transition narratives

- Orderly transition
  - High-carbon assets gradually decline leaving space to low-carbon ones
- Hot house world
  - No transition → climate impacts
- Disorderly transition:
  - High-carbon assets collapse before low-carbon ones are ready

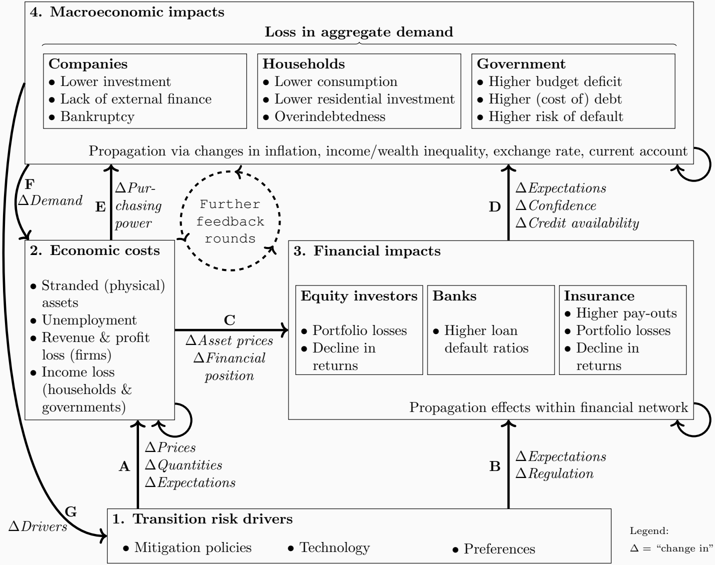


Source: NGFS (2020)

We still know little about disorderly transitions

- What do they look like?
  - How do they originate?
  - What impact transmission channels to aggregate dynamics?
  - How can they be prevented or managed?
- No major historical experiences
  - Past technological transitions driven by 'endogenous' emergence of new better technologies
  - First time transition needs to be guided from above (i.e. robust policies)
- Research addressed the question only recently
  - Climate economics; macro/finance; innovation/transitions: traditionally disconnected

An overview of transition risks



Source: Semieniuk et al. (2021)

Outline of the lecture

- The physical basis:
  - Unburnable carbon and sectoral capital stranding
  - Cascades via production networks
  - $\rightarrow$ Macroeconomic implications
- The financial basis:
  - Financial exposure to sunset industries and network analysis
  - To what extent transition risks are priced in
- What could go wrong? Prospective modelling
  - Scenario making: shocks and carbon prices
  - Neoclassical vs complexity methods

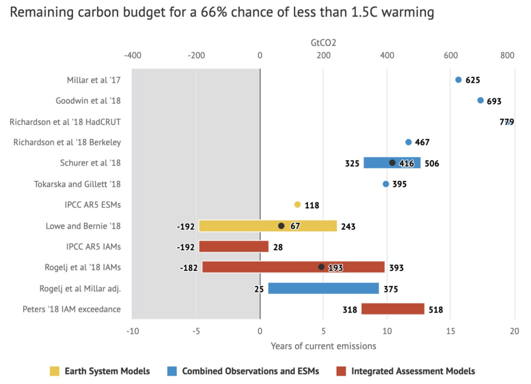
Transition economic impacts: fossil and capital stranding

Outline of the section

- Research aims:
  - Loss of natural and physical assets from balance sheets
  - (Macro)economic implications
- Methodological approaches:
  - Carbon accounting literature: compare carbon budgets with emissions embodied in reserves or capital stocks
  - Numerical IAMs: run numerical models to identify optimal or scenario-driven paths
  - Ramsey growth models: smaller-scale models to obtain stylized analytical results
  - Production network analysis: study how physical stranding propagates
  - Little or no financial dimensions

Temperature targets → Cumulative emission limits

- 'Carbon budget' concept
  - Allen et al. (2009), Meinshausen et al. (2009)
  - Roughly linear relationship (Matthews et al, 2009)
  - Large uncertainties on values (see Rogelj et al, 2019)



Source: Carbon Brief (2018)

McGlade and Ekins (2015) on Nature

- TIAM-UCL regional model:
  - Partial equilibrium model with detailed representation of energy sources and systems
  - Driven by minimisation of energy system NPV costs to 2100
- What is the optimal geographical distribution of unnburnable carbon in a 2°scenario?

Table 1 | Regional distribution of reserves unburnable before 2050 for the 2 °C scenarios with and without CCS

	2 °C with CCS						2 °C without CCS					
	Oil		Gas		Coal		Oil		Gas		Coal	
Country or region	Billions of barrels	%	Trillions of cubic metres	%	Gt	%	Billions of barrels	%	Trillions of cubic metres	%	Gt	%
Africa	23	21%	4.4	33%	28	85%	28	26%	4.4	34%	30	90%
Canada	39	74%	0.3	24%	5.0	75%	40	75%	0.3	24%	5.4	82%
China and India	9	25%	2.9	63%	180	66%	9	25%	2.5	53%	207	77%
FSU	27	18%	31	50%	203	94%	28	19%	36	59%	209	97%
CSA	58	39%	4.8	53%	8	51%	63	42%	5.0	56%	11	73%
Europe	5.0	20%	0.6	11%	65	78%	5.3	21%	0.3	6%	74	89%
Middle East	263	38%	46	61%	3.4	99%	264	38%	47	61%	3.4	99%
OECD Pacific	2.1	37%	2.2	56%	83	93%	2.7	46%	2.0	51%	85	95%
ODA	2.0	9%	2.2	24%	10	34%	2.8	12%	2.1	22%	17	60%
United States of America	2.8	6%	0.3	4%	235	92%	4.6	9%	0.5	6%	245	95%
Global	431	33%	95	49%	819	82%	449	35%	100	52%	887	88%

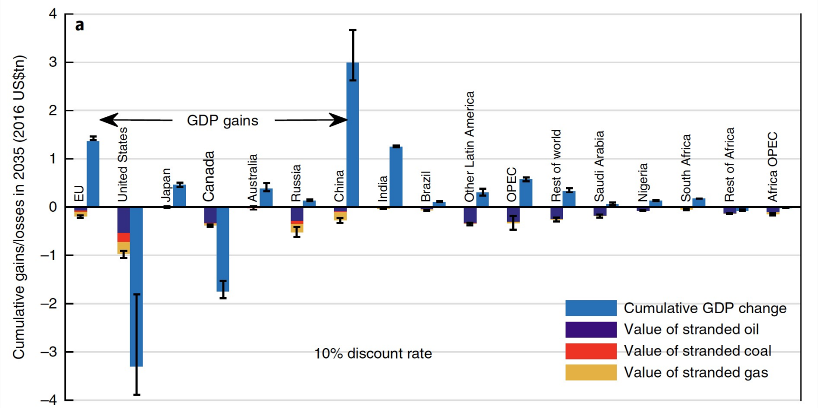
FSU, the former Soviet Union countries; CSA, Central and South America; ODA, Other developing Asian countries; OECD, the Organisation for Economic Co-operation and Development. A barrel of oil is 0.159 m^3; %, Reserves unburnable before 2050 as a percentage of current reserves.

Source: McGlade and Ekins (2015)

Mercure et al. (2018) on Nature CC

- Combination of E3ME (macroeconometrics), FTT (diffusion) and GENIE (Earth systems) models
- Two drivers of stranding: 2°C climate policy or technological diffusion
  - Fossil stranding can happen even without policies
  - Drop in demand for fossil fuels ($\rightarrow$ can trigger a 'sell out')
- Focus on geographical distribution of fossil stranding and macro implications
  - Net importers (e.g China, EU) may benefit from dynamics
  - Producers (Russia, US, Canada) will lose out
  - Global NPV wealth loss of US$1-4 trillion

Fossil stranded assets across regions

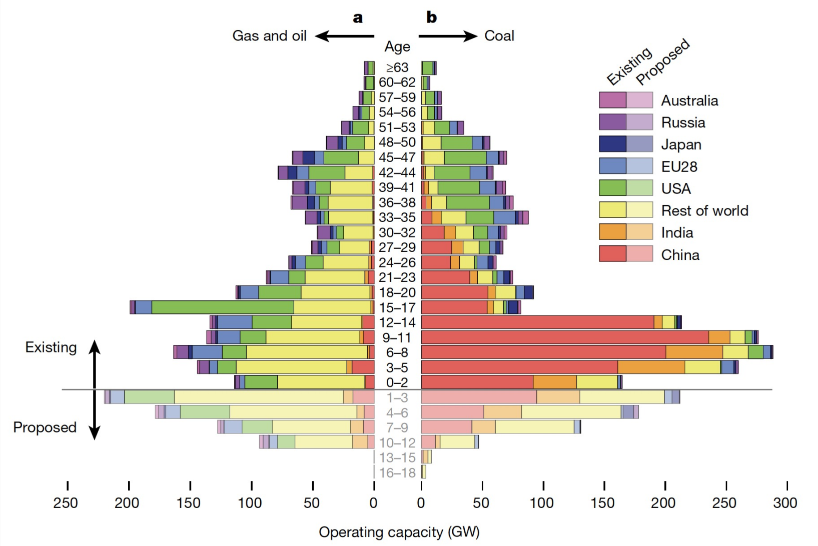


Cumulative GDP changes and discounted fossil fuel value loss to 2035 - 2 C sell-out scenario vs IEA projections. Source: Mercure et al. (2018)

Emissions embodied in capital stocks

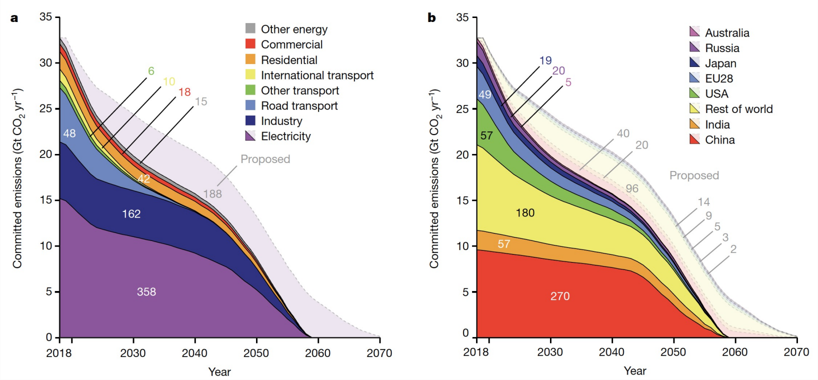
- Capital stocks often work in combination with fossil fuels
  - E.g. electricity plants, blast furnaces, cement kilns, chemical plants, buildings, transport infrastructure..
  - Emissions are already ‘committed’ by their existence, assuming certain lifetimes and utilisation rates
- Committed emissions are already close or above 2°C carbon budgets.
  - Either strand some of them or go beyond 2°C
  - No more high-carbon investments allowed
- Possible forms of stranding:
  - Premature retirement of assets
  - Reduce their capacity utilisation
  - Retrofit them so to make them low-carbon

Long-lived capital stock in electricity generation



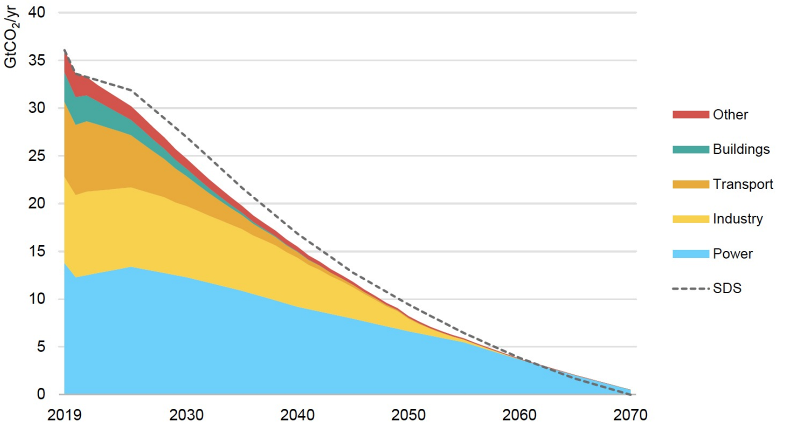
Age structure of global electricity-generating capacity. Source: Tong et al. (2019)

Committed CO_2 emissions



Committed annual CO_2 emissions from existing and proposed energy infrastructure, assuming historical lifetimes and utilization rates. Source: Tong et al. (2019)

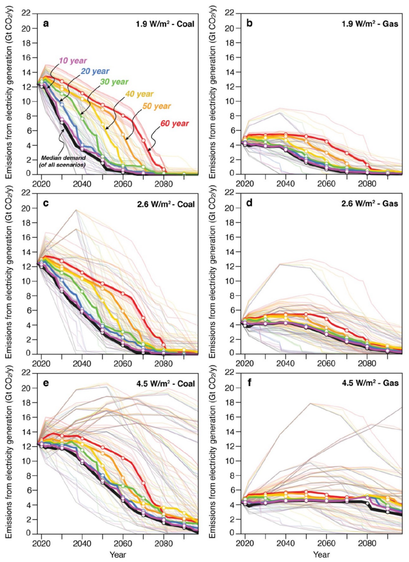
IEA Energy Technology Perspectives 2020

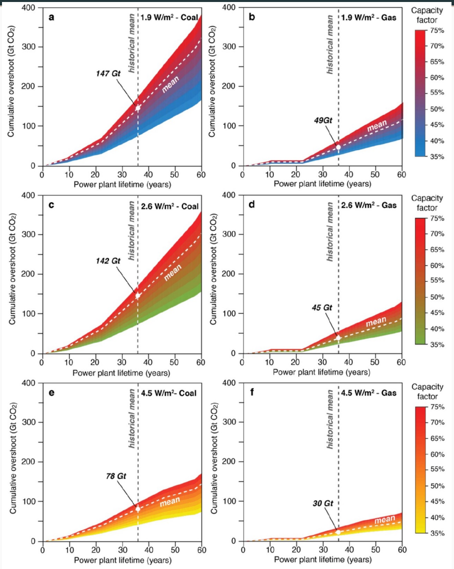


Notes: SDS = Sustainable Development Scenario. The sectors include assets under construction in 2019, the base year of this analysis. Analysis includes industrial process emissions which are accounted on a direct basis. Annual operating hours over the remaining lifetime remain as in 2019.

Global CO2 emissions locked in by existing energy-related assets. Source: IEA (2020)

Fofrich et al. (2020) on ERL using six IAMs



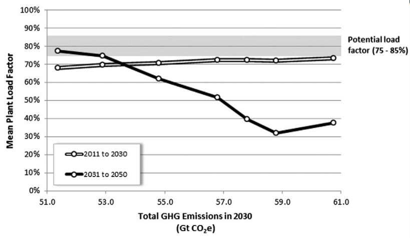


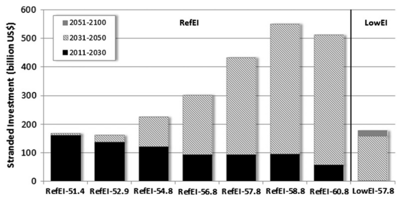
Left: future emission scenarios. Right: excess emissions. Source: Fofrich et al. (2020)

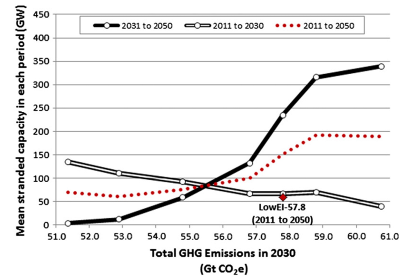
Johnson et al. (2015) on Tech.Forec.Soc.Change

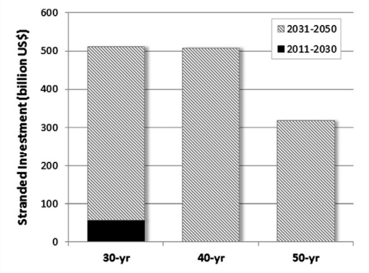
- MESSAGE-MACRO IAM model at IIASA
  - Linear optimization model minimising energy system costs
- They compare:
  - Different near-term (2030) emission targets..
  - .. with common long-term target (2 °C)
- Capital stranding
  - Focus on coal-powered electricity plants without CCS
  - Stranding as unutilised capacity
- Results:
  - Loose near-term targets → Larger coal capacity investment (esp. in China/India) → Stronger stranding after 2030
- Possible policies
  - Extend lifetime of existing assets (default: 30 years)

Johnson et al. (2015) results









Above: mean load factors. Below: mean stranded capacity.

Stranded investments. Below: RefEI60.8 scenario. Source: Johnson et al. (2015)

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+)
- Move to Pietro’s presentation on Rozenberg et al. (2020)

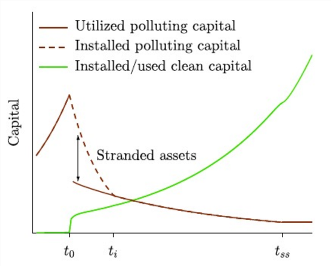
Common features

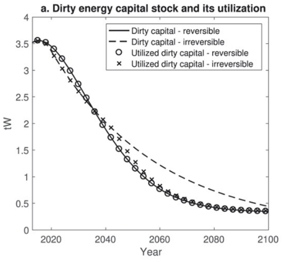
- Intertemporal maximisation of welfare $u(c_t)$
- Two (or more) technologies: clean and dirty capital (k_C, k_D)
  - Investments are irreversible: Jorgenson (1967), Arrow and Kurz (1970)
  - They allow for underutilisation of capital ($q_t \leq k_t$)
- Using k_D produces emissions: $e_t = F_t k_{D,t}$
  - 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

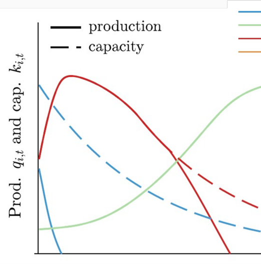
General results

- 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





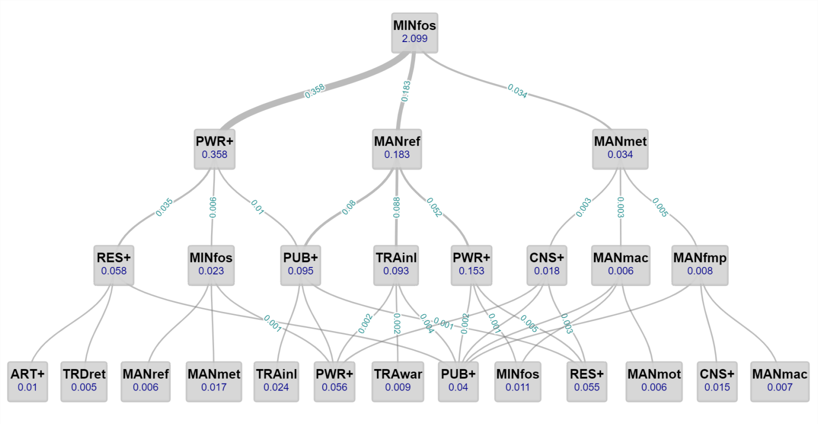


Source: Rozenberg et al. (2020), Baldwin et al. (2020) and Coulomb et al. (2019)

Production networks

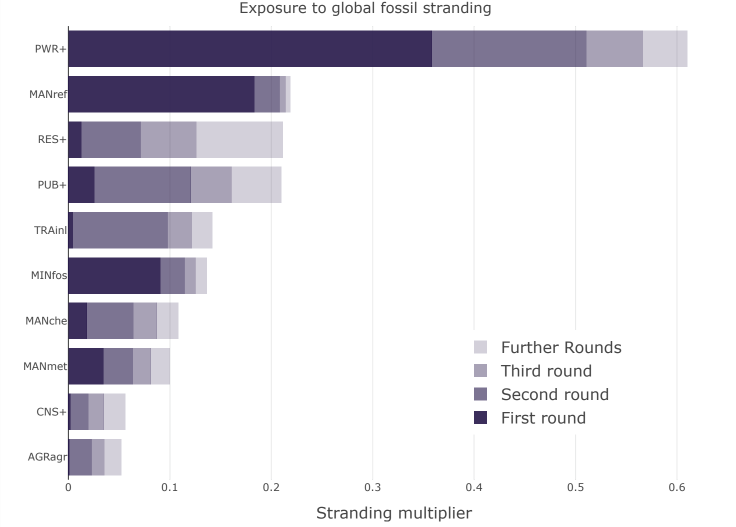
- Network theory
  - See Barabasi's 2016 book 'Network science'
- Production networks analysis
  - See Carvalho and Tahbaz-Salehi (2019) for a primer
  - They can be used to study global value chains, trade, aggregate dynamics, allocation of environmental responsibility.. (e.g Acemoglu et al. 2012 on Ecta)
  - Applied to carbon tax impacts (see for instance Devulder and Lisack (2020); Hebbink et al. (2018)
- Cahen-Fourot et al. (2021): 'Capital stranding cascades'
  - Production networks combined with sectoral capital stock data
  - Supply-side 'marginal stranding multipliers'
  - Stranding as loss of physical capital utilisation

Stranding cascades from marginal shock in global fossil sector



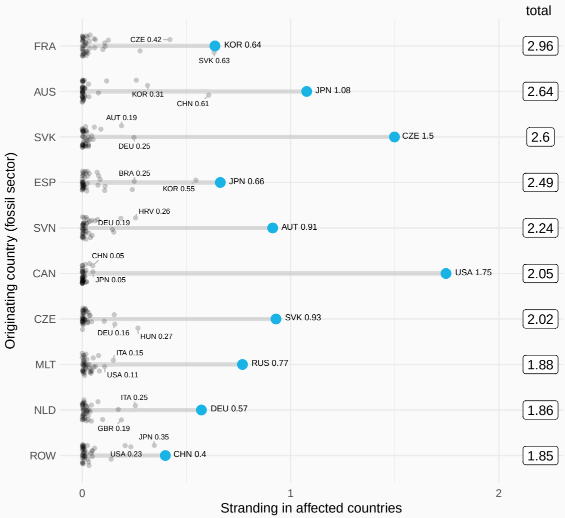
Source: Cahen-Fourot et al. (2021)

Cahen-Fourot et al. (2021): Rounds of stranding



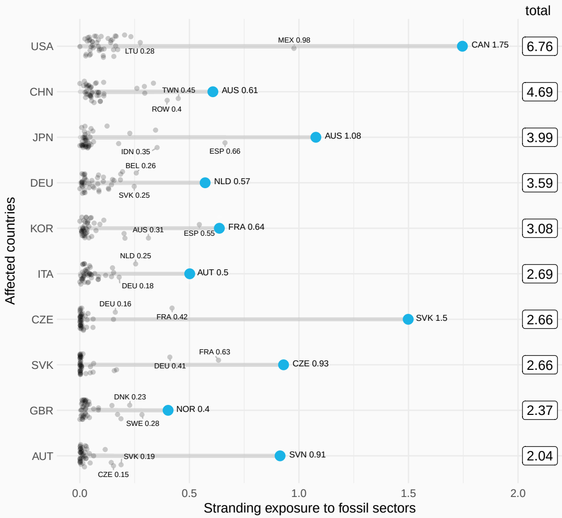
Source: Cahen-Fourot et al. (2021)

Cahen-Fourot et al. (2021): Cross-boundary stranding effects



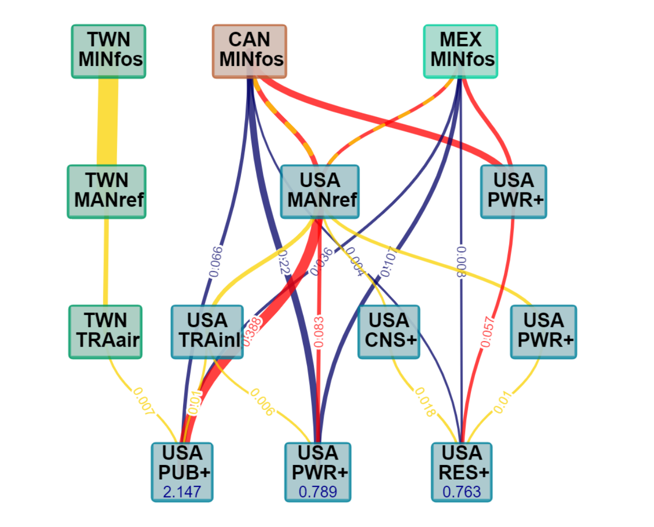
Source: Cahen-Fourot et al. (2021)

Cahen-Fourot et al. (2021): Exposure to cross-boundary stranding



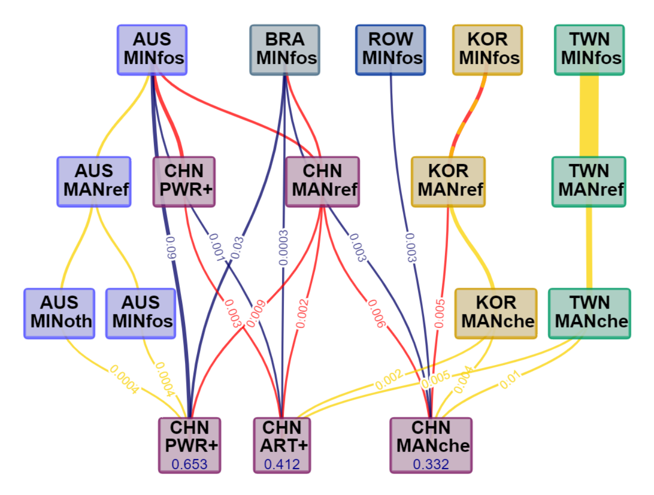
Source: Cahen-Fourot et al. (2021)

Cahen-Fourot et al. (2021): Stranding exposure (USA)



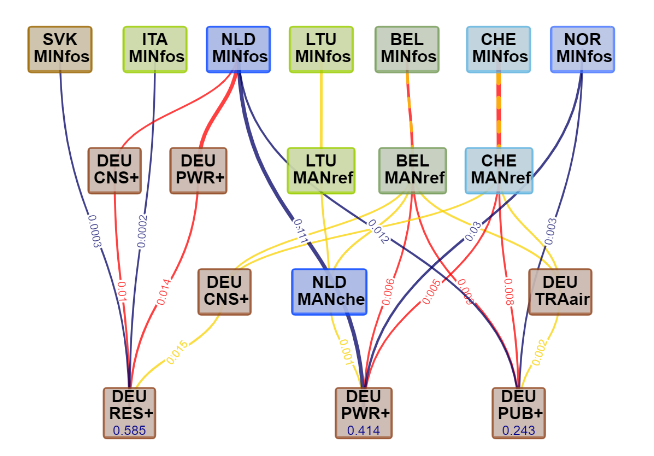
Source: Cahen-Fourot et al. (2021)

Cahen-Fourot et al. (2021): Stranding exposure (China)



Source: Cahen-Fourot et al. (2021)

Cahen-Fourot et al. (2021): Stranding exposure (Germany)



Source: Cahen-Fourot et al. (2021)

Transition financial impacts

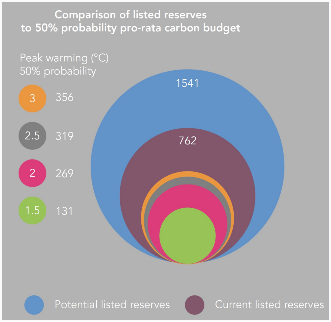
Outline of the section

- Research aims:
    - Financial exposure to high-carbon stranding risk
    - Are transition risks priced in?
- Methodological approaches:
    - Financial data analysis
    - Financial econometrics
    - Financial networks analysis
    - No or little macroeconomic dimensions here

The ‘carbon bubble’

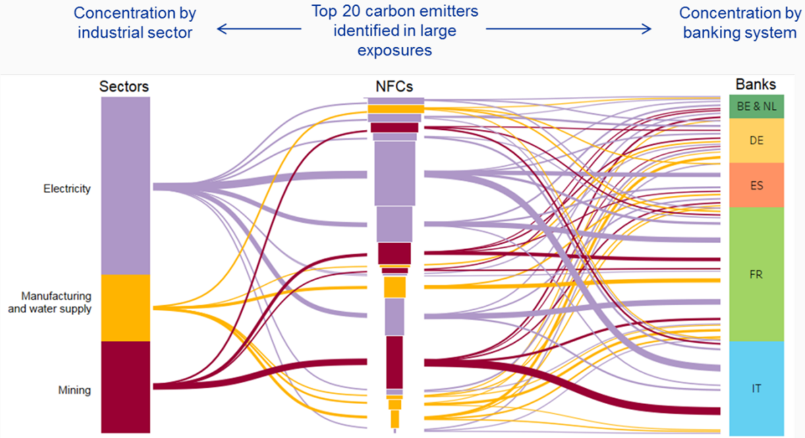
- Unburnable carbon affects market cap of fossil fuel companies
  - Market cap function of future stream of profits from extracting and selling reserves
  - What happens if they remain in the ground?

- ‘Carbon bubble’ concept first proposed by Leaton (2011) and Leaton et al. (2013)
  - Reserves of top 200 companies in coal/oil/gas sectors (around 1/4 of total)
  - Incompatible with 2°C carbon budgets



Source: Leaton (2013)

Studying exposure



Euro area banks' large exposures to reporting firms with the highest carbon emissions. Middle bar: height reports loans; width reports emissions. Source: Giuzio et al (2019)

Are transition risks priced in? Three hypothesis (from Bolton and Kacperczyk, 2020)

- Carbon risk premium
    - Investors realize firms with high CO_2 emissions are exposed to transition risks..
    - .. and demand higher returns to hold their stocks
- Market inefficiency hypothesis
    - Financial markets are subject to inefficiencies and behavioural biases..
    - .. leading transition risks to be underpriced..
    - .. and to abnormal returns for low-carbon stocks (a higher α)
- Divestment hypothesis
    - High-carbon stocks are seen as ‘sin’ stocks and avoided by ‘responsible’ investors..
    - .. leading to higher returns for high-carbon stocks

Bolton and Kacperczyk (2020, 2021)

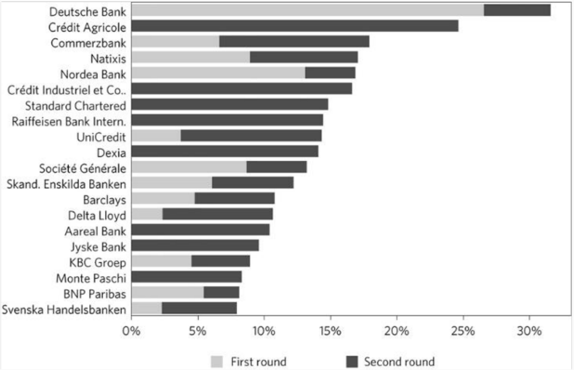
- They find evidence of a positive carbon premium
  - Valid for stock returns in a large number of countries
  - Higher returns associated to:
    - Higher total CO_2 emissions;
    - Growth in emissions;
    - But not emission intensity.
  - Significant divestment happening, but no effect on stock returns
    - Exclusionary screening in selected industries and based on emission intensity
- However, also results in the other direction
  - E.g. In et al. (2019) find a positive carbon alpha

But the debate has not settled yet

- Atanasova and Schwarz (2020)
    - Link between oil firms value and their proved reserves
    - Sample of 600 North American oil firms for 1999-2018
    - Growth of reserves has a negative effect on firm value.
        - Effect stronger for oil producers with higher extraction costs
        - Effect stronger for undeveloped oil reserves located in countries with strict climate policies
- In et al. (2019)
    - They find a positive carbon alpha

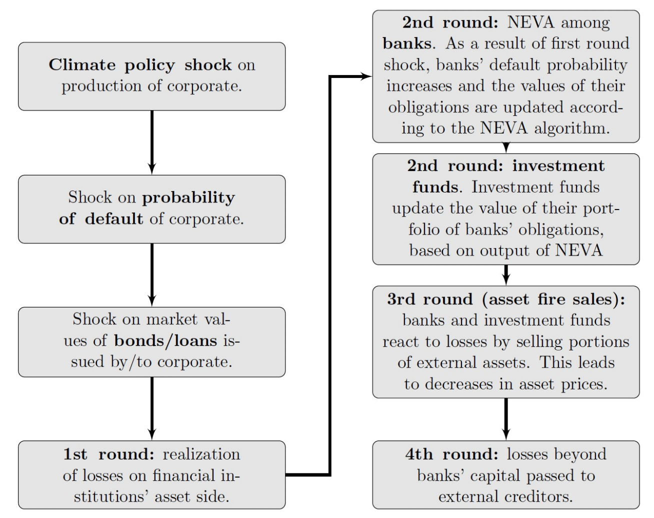
Financial networks and the transition

- Financial networks
    - Connections of cross-exposure among financial institutions
    - Financial contagion risks (Acemoglu et al., 2015)
- Battiston et al. (2017) on Nature CC



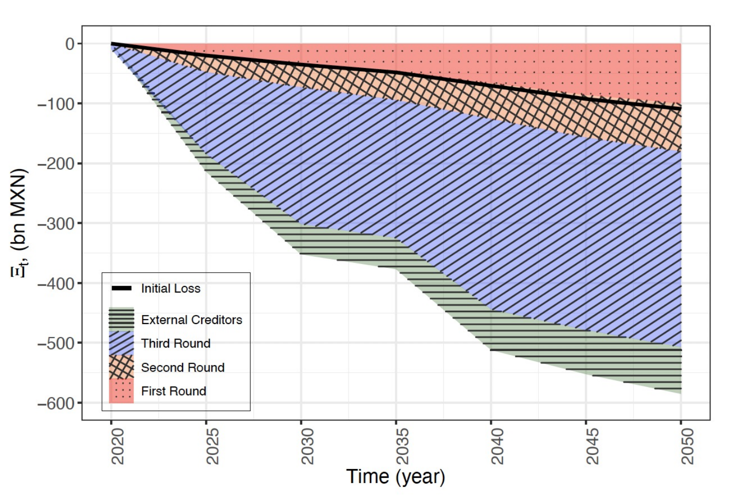
First- and second-round losses in banks equity for most affected EU listed banks. 100% shock in fossil fuel and utility sectors. Source: Battiston et al. (2017)

Roncoroni et al. (2021): Structure



Contagion steps in Roncoroni et al. (2021)

Roncoroni et al. (2021): Results



Losses in the Mexican financial system (mild climate policy shock, weak market conditions). Source: Roncoroni et al. (2021)

Transition macro-financial dynamics

Outline of the section

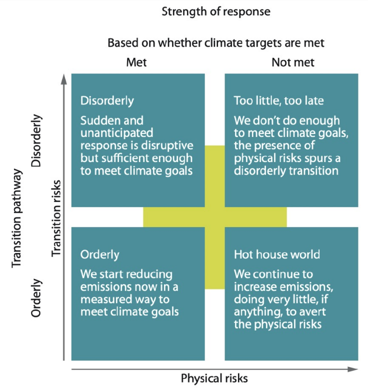
- Research aims
  - Macro-financial transition dynamics
  - Link physical/economic/financial dimensions
- Methodological approaches:
  - Analytical IAMs: introduce uncertainty in determining optimal path
  - DSGE/CAPM models: use neoclassical macro/finance modelling approaches to study transition
  - SFC/ABM models: : use complexity macro/finance modelling approaches to study transition
  - Hybrid models: Combine IAMs, macro and financial modelling

First thing: we need scenarios

- Transition driver is usually a carbon price
  - Immediate vs late policy implementation
  - Gradual tightening vs abrupt jump
  - Perfect foresight vs myopic behaviour
- Narratives mostly based on shocks
  - An unexpected implementation of a stringent carbon price
  - Stress testing framing (severe and plausible scenarios)
  - Optimal reactions vs complexity range
- Less considered issues so far
  - Disruptions originating in sunrise industries (a ‘green bubble’)
  - Technological breakthroughs
  - Sudden change in preferences (role of ‘sentiments’)
  - ‘Endogenous’ disruptions along an orderly transition

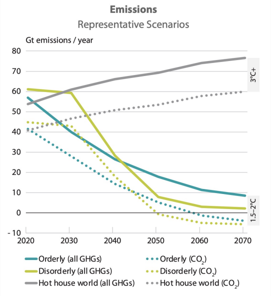
NGFS framework - Three representative scenarios

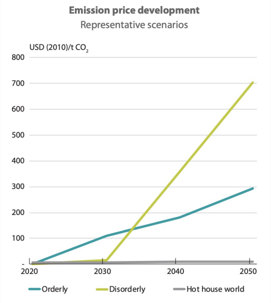
- Orderly transition:
  - Carbon price in 2020 and increasing $10/tCO_2$ per year
  - Full availability of CDR technologies
- Disorderly transition:
  - NDCs until 2030
  - Carbon price in 2030 and increasing $35/tCO_2$ per year
  - Limited availability of CDR technologies
- Hot house world:
  - Only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

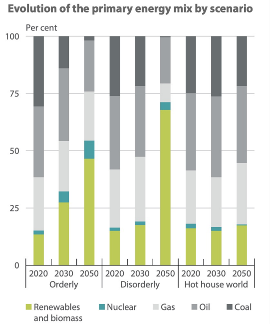


Source: NGFS (2020)

NGFS representative scenarios



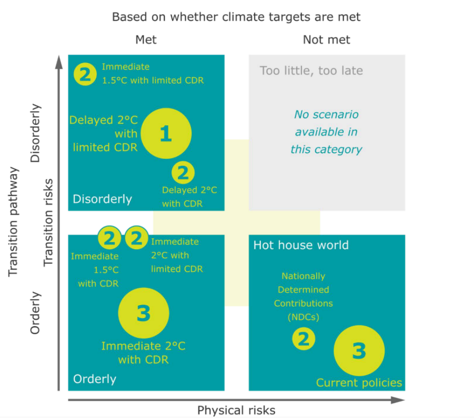




Source: NGFS (2020)

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

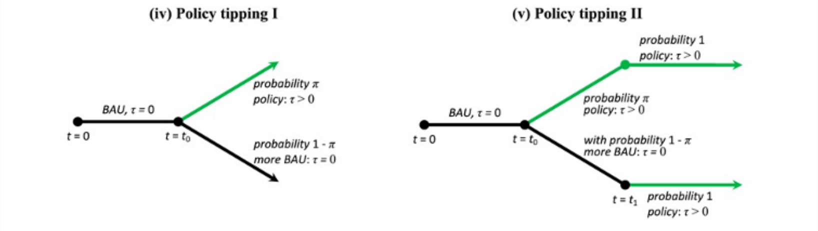
Integrated Assessment Model	GCAM 5.2	MESSAGEix_GLOBIOM 1.0	REMIND1.7-MagPIE3.0
Short name	GCAM	MESSAGEix-GLOBIOM	REMIND-MAgPIE
Solution concept	Partial Equilibrium (price elastic demand)	General Equilibrium (closed economy)	REMIND: General Equilibrium (closed economy) MAgPIE: Partial Equilibrium model 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

Macroeconomic models

- Equilibrium vs non-equilibrium
  - See last lectures
- Equilibrium models:
  - Ramsey growth (e.g. van der Ploeg and Rezai, 2020)
  - DSGE (e.g. Carattini et al., 2021)
  - CAPM (e.g. Hambel et al. 2020)
- Non-equilibrium models:
  - SFC (e.g. Dafermos et al. 2018)
  - ABM (e.g. Botte et al. 2021)
- $\rightarrow$ Move to Filippo's presentation

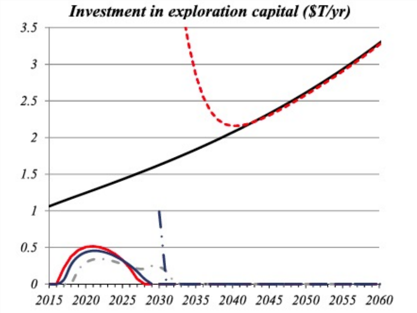
van der Ploeg & Rezai (2020) on JEEM

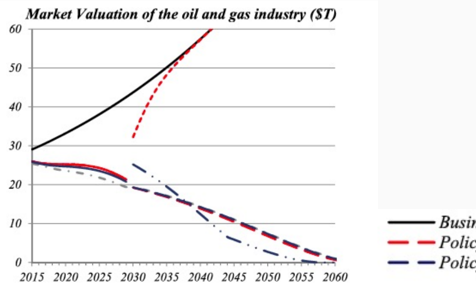
- Focus on the fossil fuel sector
  - A single type of capital to work with: extraction capital k
  - No underutilisation of capital allowed
- Market valuation of fossil firms given by future profits
  - They decide investments by maximising $V^R \equiv \int_0^\infty e^{-rt}\Pi^R$
- Policy tipping setting:



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)

Bretschger and Soretz (2018)

- A further step towards inclusion of uncertainty
- Stochastic process associated to policy implementation
  - τ: tax rate on (polluting) capital
  - Poisson process γ_t leading to increment dq with arrival rate λ: $dT_t = K_t(\tau dt + \gamma_t dq)$
  - γ depends on green service ratio G/K
- Size of the tax increase depends on:
  - The size of the green sector $\frac{G}{K}$ (assumption: policies more easily implemented in systems that are already greening)
  - The level of environmental degradation $\frac{E}{G}$ (more degradation triggers policy demands)
  - $\gamma_t = \bar{\gamma} + \eta \left(\frac{G_t}{K_t}\right)^{\chi} + \epsilon \left(\frac{E_t}{G_t}\right)^{\xi}$
- Fragmented vs activist equilibrium

Asset pricing models

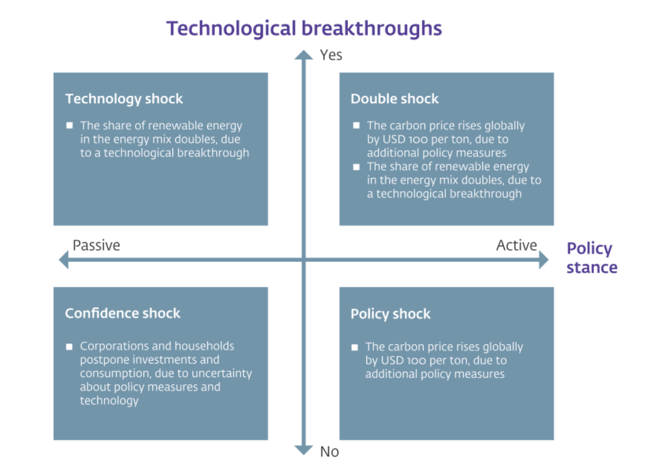
- This leads us to the more financial literature linked to asset pricing
  - Hambel et al; Karydas & Xepapadeas
- Introduction of stochastic processes
  - Wiener processes (Brownian motions) on the dynamics of capital and/or climate
  - Jump variables (representing tipping points)
- Epstein-Zinn preferences
- 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

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)

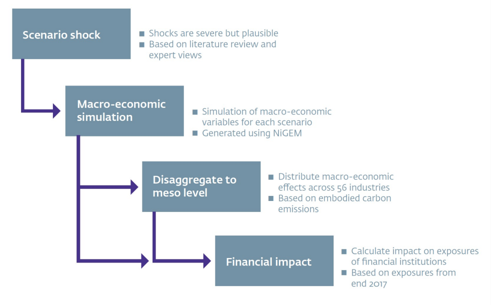
Vermeulen (2018): De Nederlandsche Bank

- 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



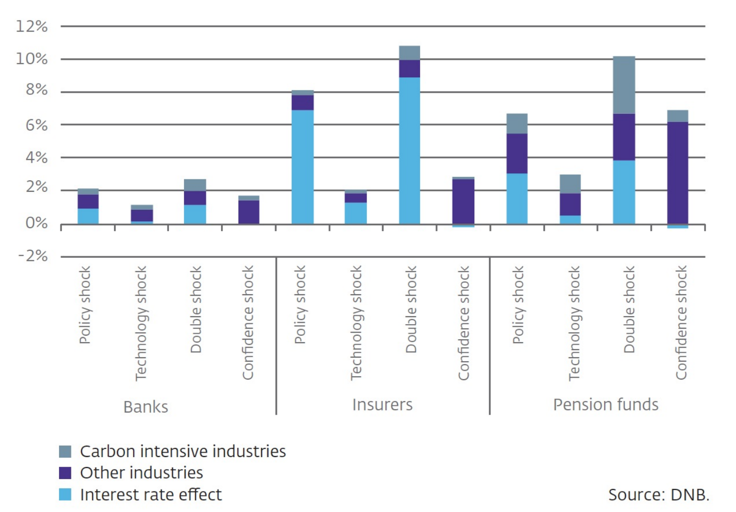
Vermeulen et al. (2018): Modelling approach

- 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



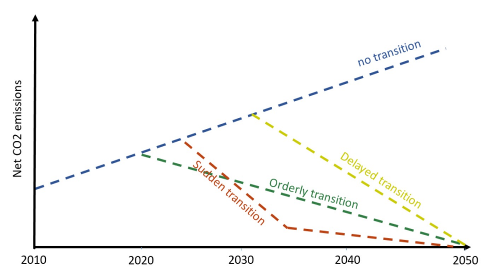
Modelling approach. Source: Vermeulen et al. (2018)

Vermeulen et al. (2018): Results



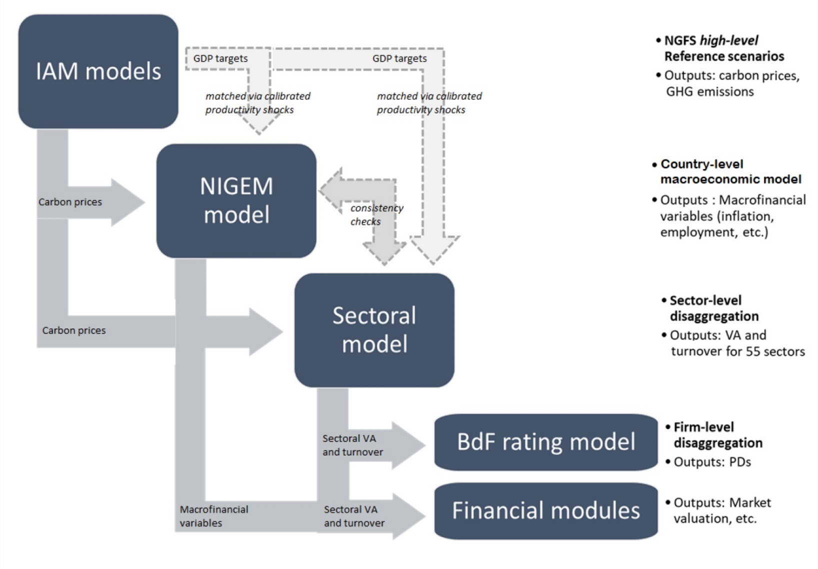
Impact on assets as a percentage of total stressed assets per sector. Source: Vermeulen et al. (2018)

- 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



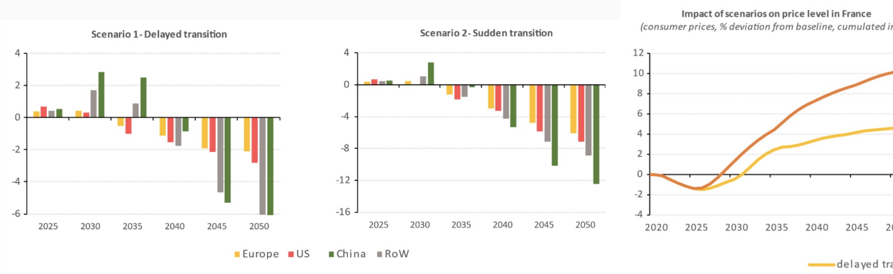
Source: Allen et al. (2020)

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



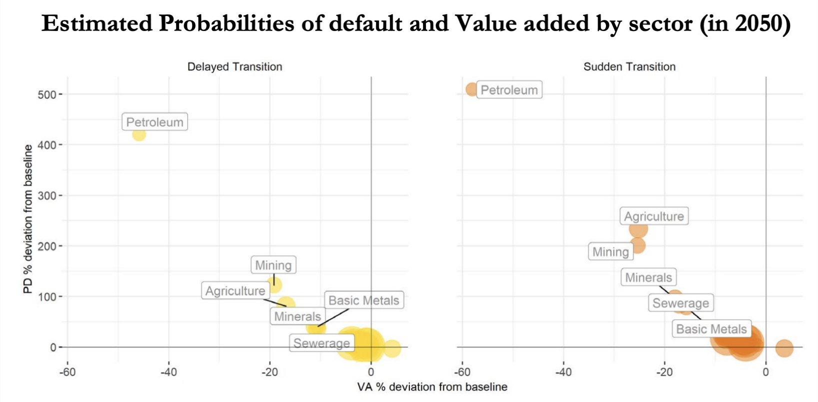
Source: Allen et al. (2020)

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

- The low-carbon transition could be messy
  - Need to no more on what could go wrong
- Several methodologies available
  - Pluralistic approach more likely to offer systemic insights
- Where to next
  - Inclusion of uncertainty
  - Sentiments and animal spirits
  - Real-financial networks

Course assessment

- Second essay due March 4th
    - Please send pdf file to Emanuele.campiglio@unibo.it
- Topic:
    - Option: Choose a methodological approach and discuss pros/cons of their application to climate-related risks
    - Option: Sketch a model
    - Proposals welcome

Course evaluation

- Please complete the course evaluation form at this link