Sensitivity Analysis of Climate-Economy models

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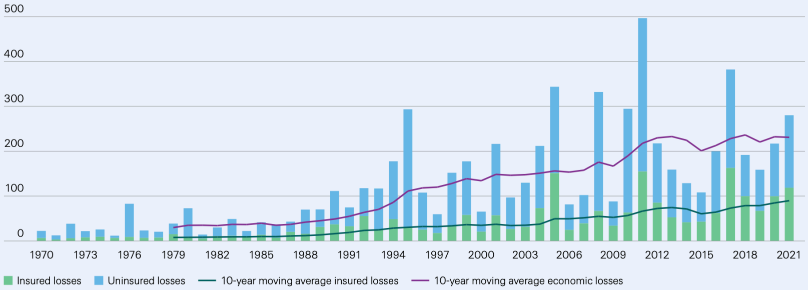
Physical risks

E.g.: losses from extreme events were $ 380 billion in 2017 and are estimated by Allianz (2018) to reach annual average of $1 trillion within 10 years

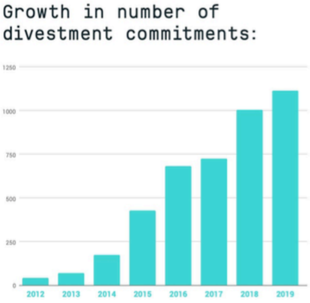
Figure 23
Insured vs uninsured losses, 1970–2021, in USD billion at 2021 prices

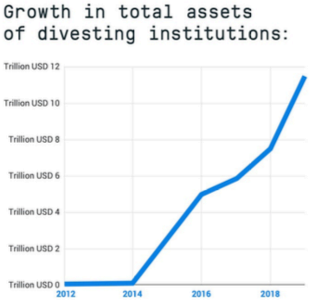


Economic losses = insured + uninsured losses. Source: Swiss Re Institute

Transition risks

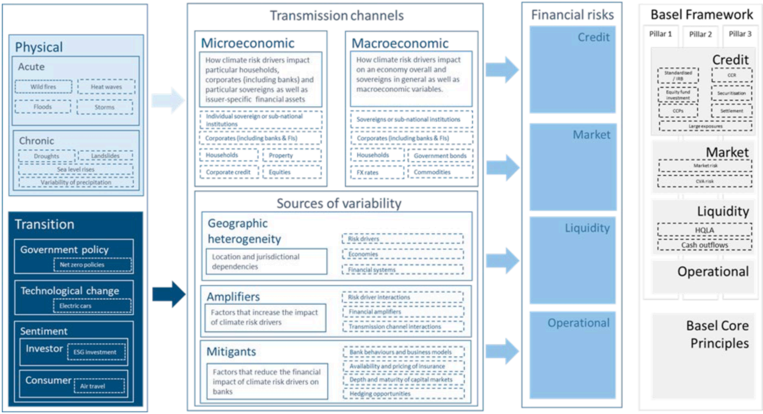
E.g.: stranded assets, portfolio decarbonization, changes in consumer sentiment.





Mapping into Financial Risk Categories (BIS)

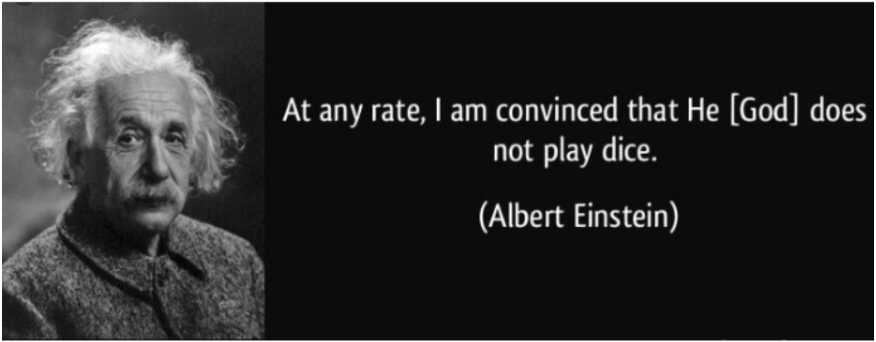
Figure 1: Financial risks from climate risk drivers



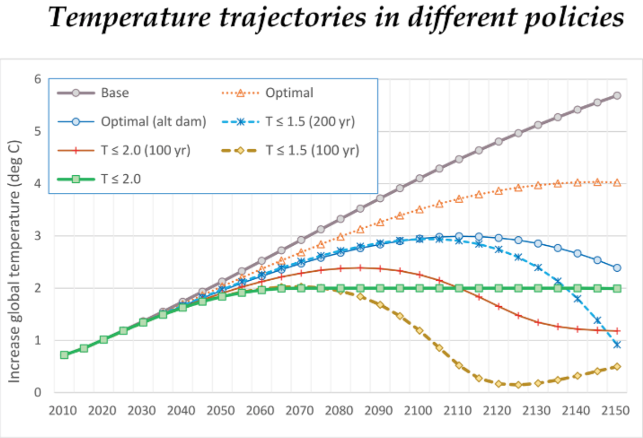
Integrated Assessment Models

- Initially developed to estimate the impact of economic development on the environment.
- Most famous example is The Limits to Growth model published in 1972 by the Club of Rome.
- Current models use of "sophisticated" economics to assess the impact of climate change on the economy.
- Most famous example is the DICE (Dynamic Integrated Climate-Economy) model developed by William Nordhaus in 1992.
- Relies on welfare maximization, general equilibrium, and rational expectations.
- Alternative stock-flow consistent models include COPING (medium scale) and DEFINE (large scale).

Dynamic Integrated Climate-Economy (DICE)



"Optimal" global warming according to Nordhaus



Slide 6 in Nordhaus's lecture, showing the "optimal" temperature path peaking at a 4°C increase by 2150

Hothouse Earth bifurcation (Steffen et al 2018)

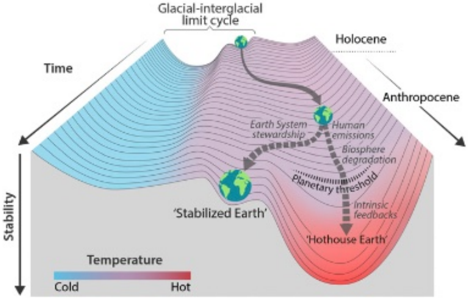
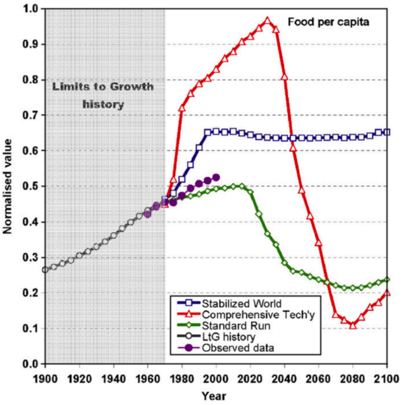
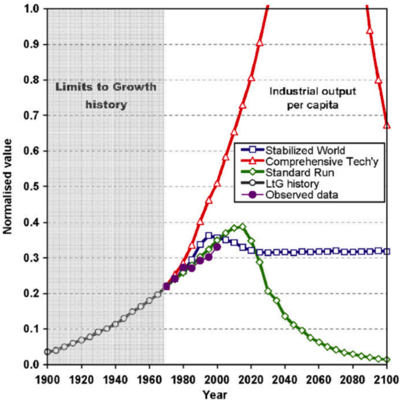


Fig. 2. Stability landscape showing the pathway of the Earth System out of the Holocene and thus, out of the glacial–interglacial limit cycle to its present position in the hotter Anthropocene. The fork in the road in Fig. 1 is shown here as the two divergent pathways of the Earth System in the future (broken arrows). Currently, the Earth System is on a Hothouse Earth pathway driven by human emissions of greenhouse gases and biosphere degradation toward a planetary threshold at ∼2 °C (horizontal broken line at 2 °C in Fig. 1), beyond which the system follows an essentially irreversible pathway driven by intrinsic biogeophysical feedbacks. The other pathway leads to Stabilized Earth, a pathway of Earth System stewardship guided by human-created feedbacks to a quasistable, human-maintained basin of attraction.

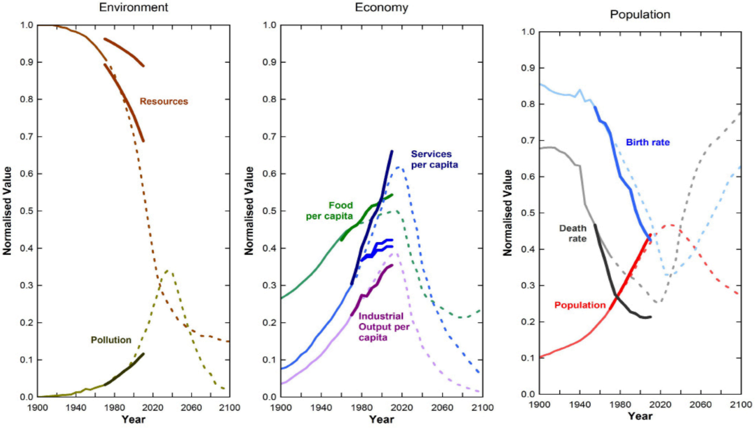
Comparing LtG with Data (Turner 2008)

G.M. Turner / Global Environmental Change 18 (2008) 397–411 405

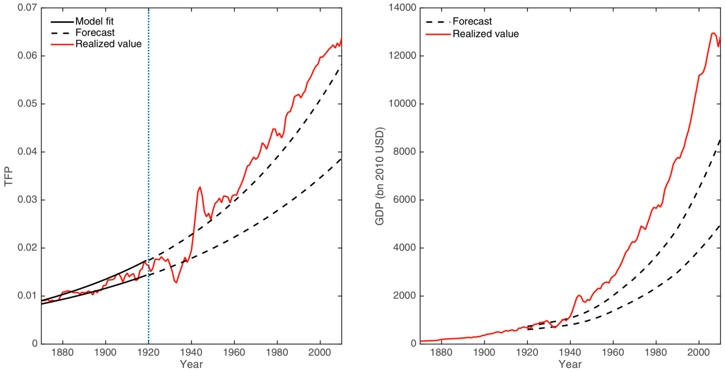




Comparing LtG with Data (Turner 2014)



Comparing DICE with Data (Milner 2016)



Sobol indices

- Let $Y = f(X_1, \ldots, X_n)$
- Define

$$S_i = \frac{V\left[E\left(Y|X_i\right)\right]}{V[Y]}$$

$$S_{ij} = \frac{V\left[E\left(Y|X_i, X_j\right)\right]}{V[Y]} - S_i - S_j$$

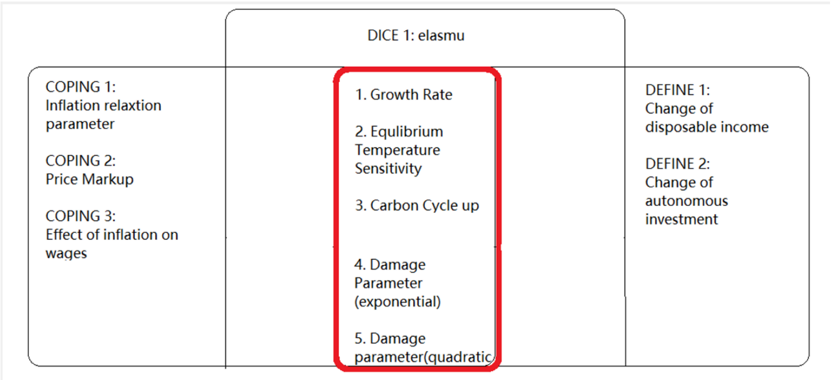
$$\vdots$$

$$S_i^T = 1 - \frac{V\left[E\left(Y|X_{\sim i}\right)\right]}{V[Y]}$$

Sobol index ranking for DICE model

Variable Rank by Total Index	GDP	Emission	Temperature
1	Growth rate	Equilibrium temp impact	Equilibrium temp impact
2	Price mark-up	Growth rate	Growth rate
3	Effect of inflation on wages	Damage function parameter (exponential)	Damage function parameter (exponential)
4	Inflation relaxation parameter	Damage function parameter (quadratic)	Damage function parameter (quadratic)
5	Equilibrium temp impact	Carbon cycle up	Carbon cycle up

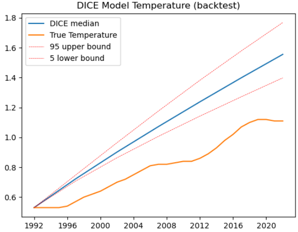
Sobol index ranking - common parameters

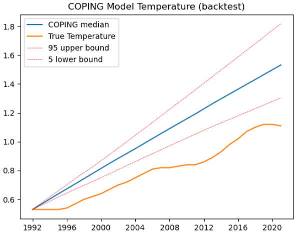


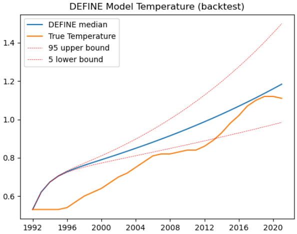
Backtesting Methodology

- Set initial conditions for all models in 1992.
- Re-estimate economic parameters using time series from 1962 to 1992.
- Set physical parameters to current (i.e. 2022) values.
- Select the n (e.g 5) most important parameters for each model according to total Sobol index.
- Simulate each model with parameters sampled from appropriate distributions.

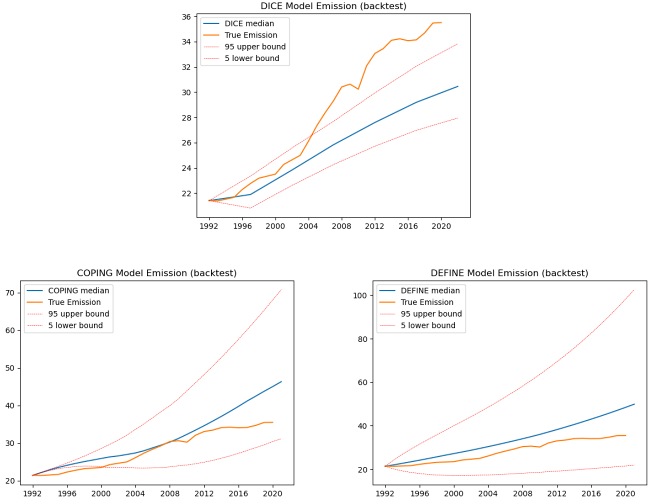
Temperature backtesting



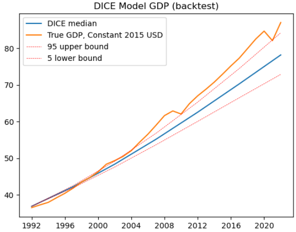


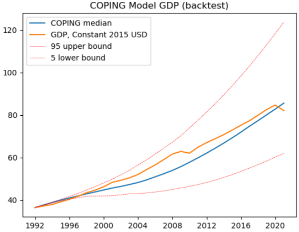


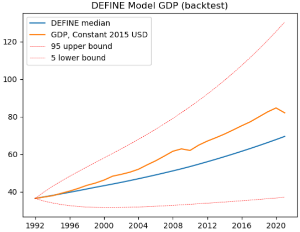
Emissions backtesting



GDP backtesting



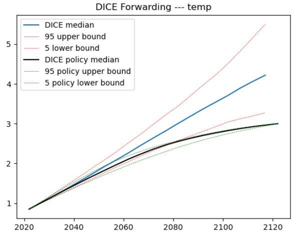


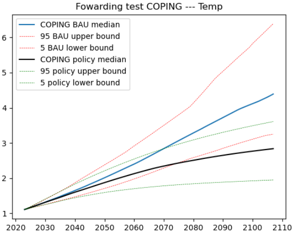


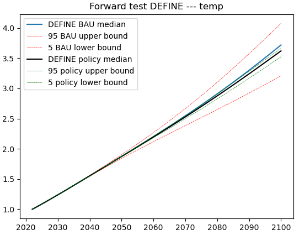
Forward scenario methodology

- Set initial conditions for all models in 2022.
- Re-estimate economic parameters using time series from 1992 to 2022.
- Set physical parameters to current (i.e. 2022) values.
- Select the n (e.g. 5) most important parameters for each model according to total Sobol index.
- Simulate each model with parameters sampled from appropriate distributions using BAU and preferred policy versions.

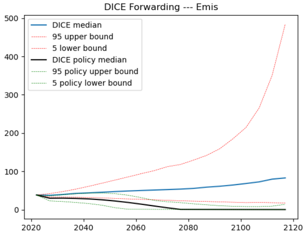
Temperature predictions

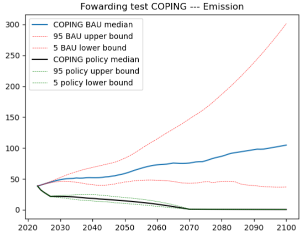


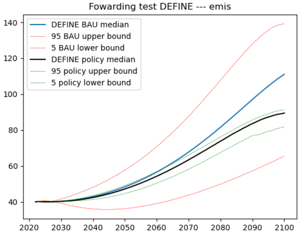




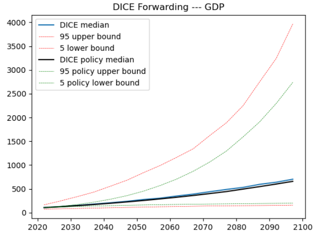
Emissions predictions

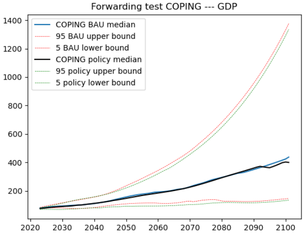


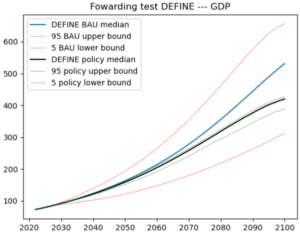




GDP predictions





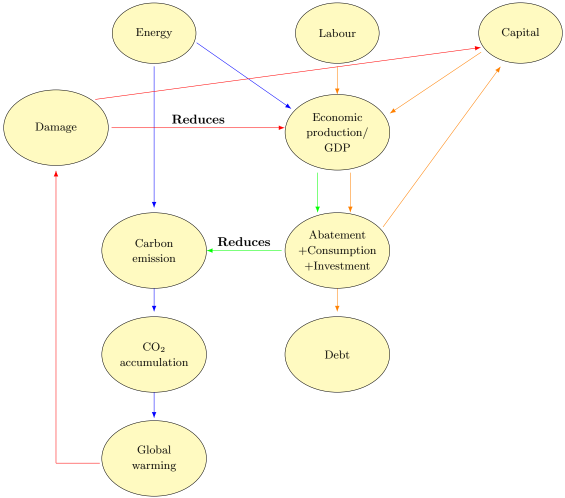


The COPING Model

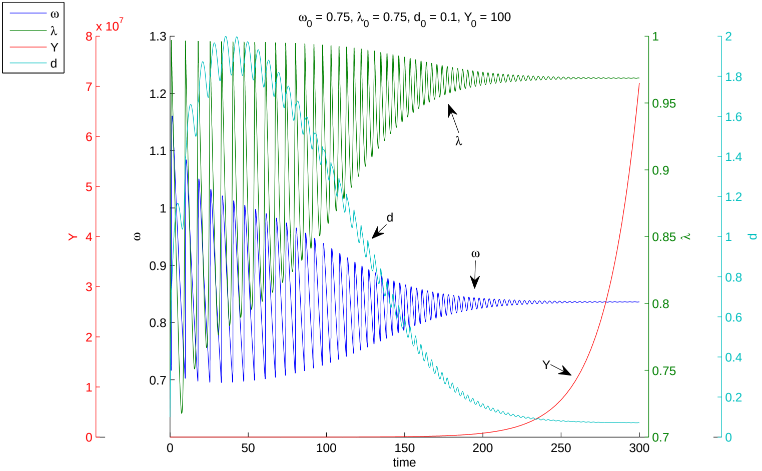
	Households	Firms		Banks	Sum
Balance Sheet					
Capital stock		pK			pK
Deposits	M^h	M^f		$-M$	
Loans		$-L$		L	
Equities	$E^b + E^f$	$-E^f$		$-E^b$	
Sum (net worth)	X^h	X^f		X^b	X
Transactions		current	capital		
Consumption	$-pC$	pC			
Investment		pI	$-pI$		
Accounting memo [GDP]		$[pY]$			
Wages	W	$-W$			
Dividends	$Di + r(L-M)$		$-Di$	$-r(L-M)$	
Interests on loans		$-rL$		rL	
Interests on deposits	$+rM^h$	$+rM^f$		$-rM$	
Financial Balances	S^h	Π	$-pI - Di$	0	
Flow of funds					
Gross Fixed Capital Formation		pI			pI
Change in Deposits	$\dot{M}^h$	$\dot{M}^f$		$-\dot{M}$	
Change in loans		$-\dot{L}$		$\dot{L}$	
Change in equities	$\dot{E}^f + \dot{E}^b$	$-\dot{E}^f$		$-\dot{E}^b$	
Column sum	S^h	$\Pi - Di$		0	pI
Change in net worth	$\dot{X}^h = S^h$	$\dot{X}^f = \Pi - Di + \left[\dot{p} - (\delta + \mathbf{D}^K + \frac{G}{\nu})p\right]K$		$\dot{X}^b = 0$	$\dot{X} = pI + \left[\dot{p} - (\delta + \mathbf{D}^K + \frac{G}{\nu})p\right]K$

Table 1: Balance sheet, transactions, and flow of funds in the economy

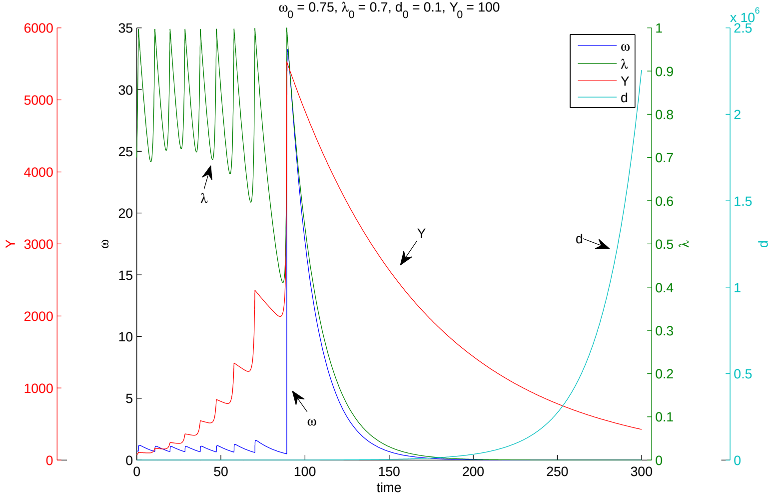
Model Schematic



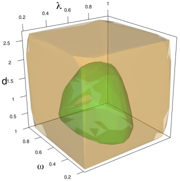
Example: convergence to the interior equilibrium in a Keen model



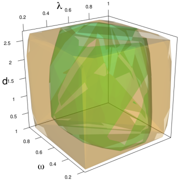
Example: explosive debt in a Keen model



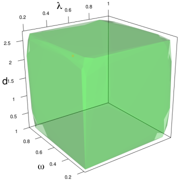
Basin of attraction of interior equilibrium - BGH (2021)



(a) $\bar{\xi} = 1.18$

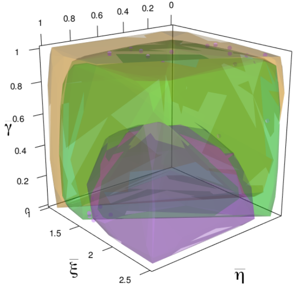


(b) $\bar{\xi} = 1.3$

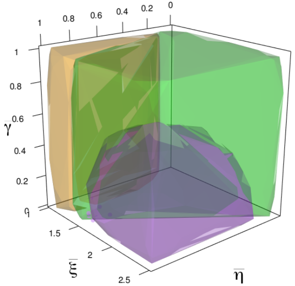


(c) $\bar{\xi} = 1.875$

Dependence on inflation parameters - BGH (2021)

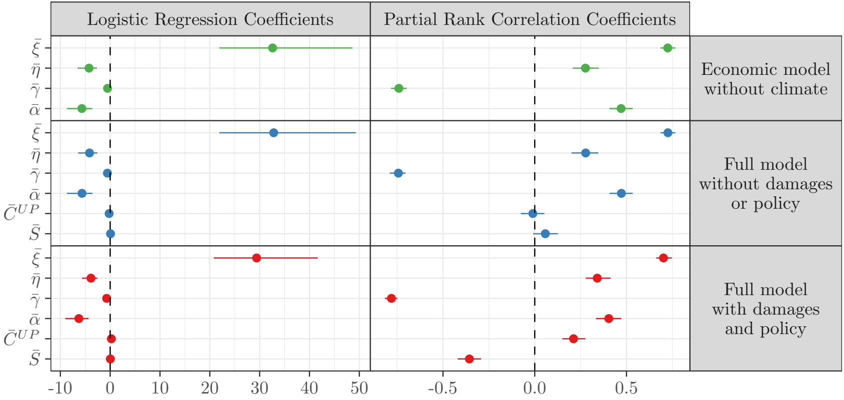


(d) $(0.9, 0.9, 0.3)$

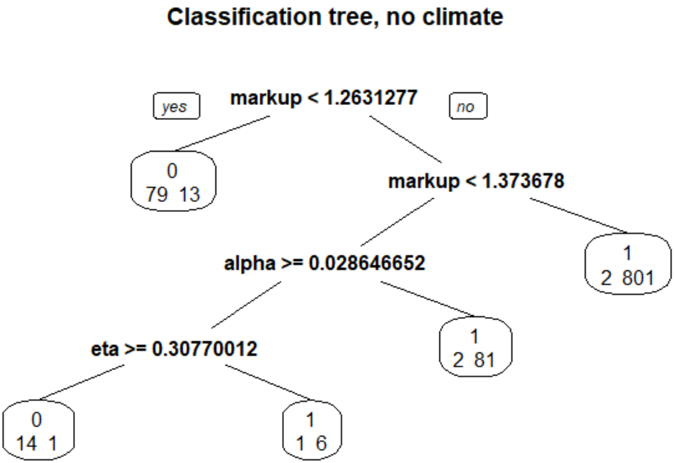


(e) $(0.675, 0.578, 1.53)$

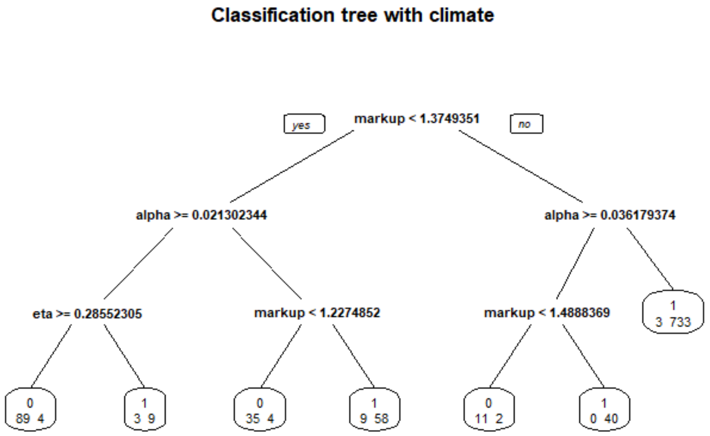
Logistic regression and partial rank correlation - BGH (2021)



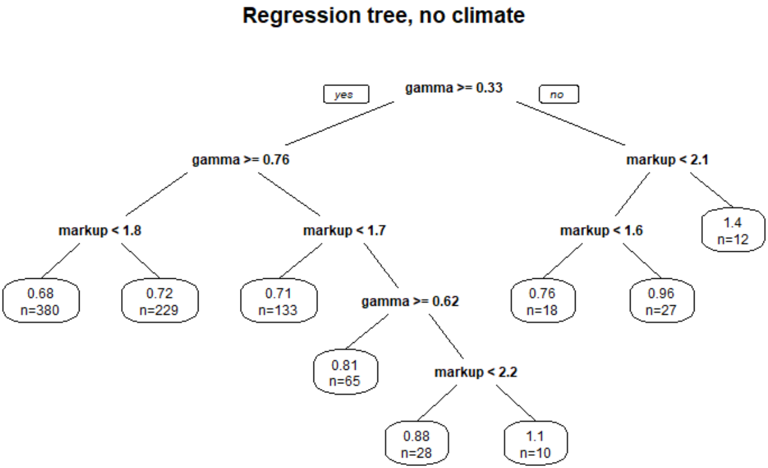
Classification tree - economic model (no climate)



Classification tree - full model



Regression tree - economic model (no climate)



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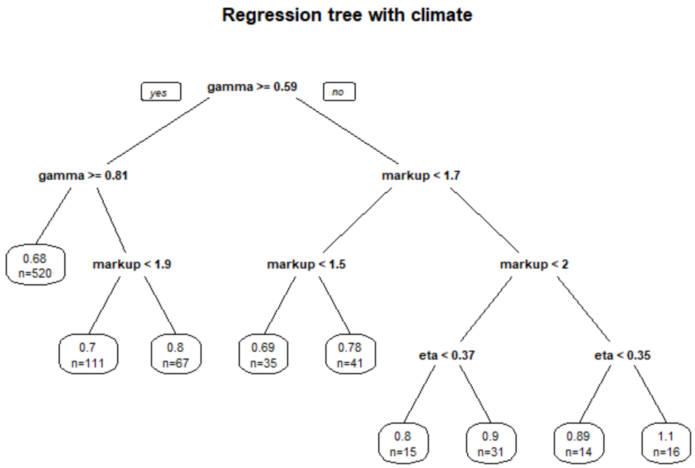
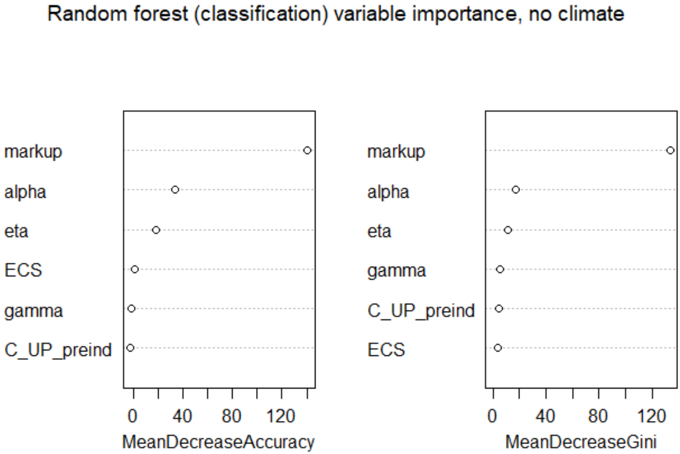


Classification Random Forest - economic model (no climate)



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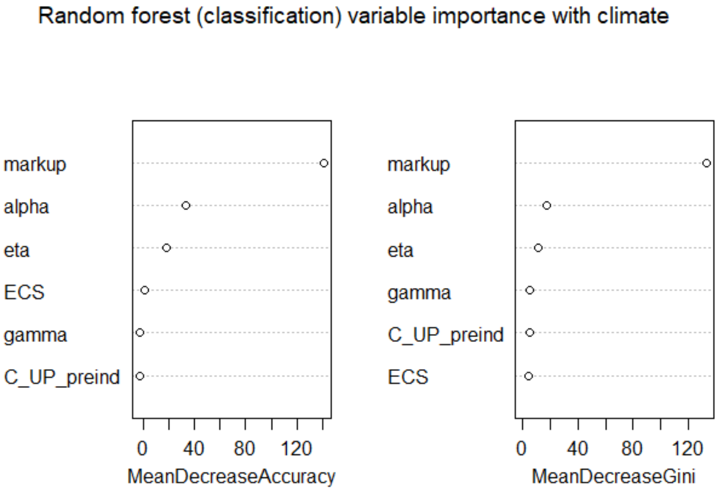

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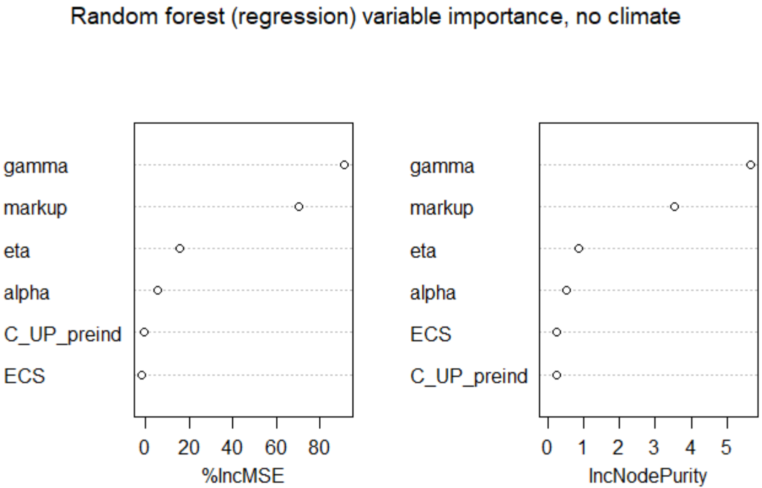
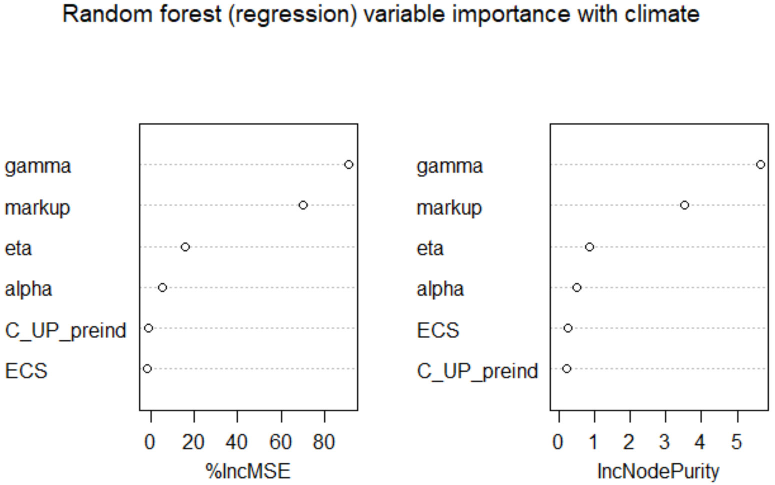
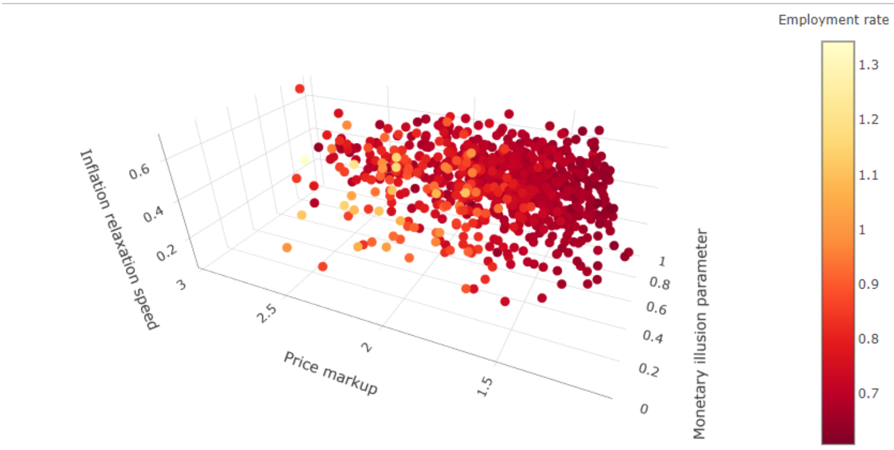


Regression Random Forest - full model



Heat map - full model



Conclusions

- Climate change is the most formidable challenge faced by the human race
- Traditional macroeconomics is ill-equipped to contribute to it
- Integration of *dynamic* models with *disequilibrium* and *slowly adjusting variables* is needed
- Finance is likely to play a fundamental role in the low-carbon transition
- Understanding parameter sensitivity of the models is key to comparing past performance and assessing predictions.
- Thank you.