Ecological and environmental macroeconomics

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Outline

1. Ecological vs environmental macroeconomics: conceptual issues
2. The DICE model
3. Ecological stock-flow consistent modelling
4. Environmental dynamic stochastic general equilibrium modelling

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1. Ecological vs environmental macroeconomics: conceptual issues

Two different traditions in analysing environmental issues from an economics point of view:

- ***Environmental economics***: Environmental problems are analysed as market failures that can be tackled by putting the right price on negative environmental externalities. This tradition relies on neoclassical economics.
- ***Ecological economics***: The economy is considered as a subsystem of the ecosystem and the implications of the laws of thermodynamics are explicitly taken into account. This tradition uses insights from many disciplines and has strong links with heterodox economics.

1. Ecological vs environmental macroeconomics: conceptual issues

- In environmental economics a **weak conception of sustainability** is adopted: natural capital (like matter, energy and land) and human-made capital are assumed to be perfectly substitutable.
- On the contrary, ecological economics adopts a **strong conception of sustainability**: substitutability is assumed to be limited.
- **Weak sustainability-**>technological innovation is the main solution to the environmental problems.
- **Strong sustainability-**> technological innovation is useful, but is not enough; more fundamental changes are necessary.

1. Ecological vs environmental macroeconomics: conceptual issues

- **Environmental macroeconomics** analyses macroeconomic issues by relying on the tradition of environmental economics.
- **Ecological macroeconomics** is a relatively recent field which analyses macroeconomic issues by combining ecological economics with heterodox macroeconomics.
- Post-Keynesian macroecononomics has played a key role in the development of ecological macroeconomics.

1. Ecological vs environmental macroeconomics: conceptual issues

Cost-benefit analysis in environmental macroeconomics

- In the context of climate policy evaluation, cost-benefit analysis suggests the identification of optimal policies through a comparison of costs and benefits.
- **Costs**: how much do we have to pay for a specific environmental policy?
- **Benefits**: how much do we benefit by addressing environmental problems through this policy?
- An optimal climate policy is a policy that weighs costs and benefits.

1. Ecological vs environmental macroeconomics: conceptual issues

Pitfalls of cost-benefit analysis

- Unidimensional approach that monetises costs and benefits and ignores the intrinsic value of nature
- Implicitly assumes that consumption per person in the future will be higher
- Ignores the beneficial economic effects of climate mitigation

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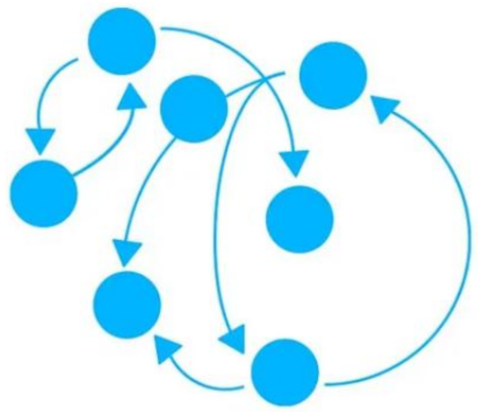
1. Ecological vs environmental macroeconomics: conceptual issues

Systems-based analysis in ecological macroeconomics

- Several dimensions are assessed at the same time. These dimensions include ecological, economic, financial and social factors. Crucially, these factors interact with each other through feedback loops that are at the heart of **system dynamics**.



- The short-run and long-run effects of specific policies are evaluated without having to discount the future values of variables. Specific attention is paid to **path dependency:** future outcomes are not independent of short-run developments.
- The **collapse of systems** is a possibility.

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1. Ecological vs environmental macroeconomics: conceptual issues

The issue of growth

The link between economic growth and environmental impact can be captured by the following equation:

Environmental impact=(Environmental impact/GDP)*GDP

Examples: CO_2 emissions, use of energy and matter, material waste, deforestation

Intensity effect

Scale effect

Relative decoupling: GDP ↑, environmental impact/GDP ↓ and envir. Impact ↑

Absolute decoupling: GDP ↑, environmental impact/GDP ↓ and envir. Impact ↓

1. Ecological vs environmental macroeconomics: conceptual issues

Environmental vs ecological macroeconomic modelling

Environmental macroeconomic models	Ecological macroeconomic models
Supply-determined output (demand might matter only in the short run)	Demand-determined output (with supply-side constraints)
Banks are financial intermediaries (when they exist)	Money is endogenous
Utility and profit maximisation	Fundamental uncertainty/bounded rationality
Income distribution does not typically matter	Income distribution interacts with economic activity
Environmental problems as an externality/cost-benefit analysis	Economy as a subsystem of the ecosystem/systems-based analysis

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2. The DICE model

- The Dynamic Integrated Climate-Economy (DICE) model that has been developed by **William Nordhaus** is the most popular Integrated Assessment Model (IAM).
- It combines an economy module, that relies on a standard neoclassical growth framework, with a climate module.
- The model has been used extensively for identifying optimal carbon pricing.

American Economic Review 2019, 109(6): 1991–2014
https://doi.org/10.1257/aer.109.6.1991

Climate Change: The Ultimate Challenge for Economics[†]

By William Nordhaus[*]

The science of economics covers a vast terrain, as is clear from the history of Nobel awards in this area. Among the many fields that have been recognized are portfolio theory to reduce investment risk, the discovery of linear programming algorithms to solve complex allocation problems, econometric methods as a way of systematically understanding history and behavior, economic growth theory, and general-equilibrium theory as the modern interpretation of the invisible hand of Adam Smith.

The award this year concerns another of the many fields of economics. It involves the spillovers or externalities of economic growth, focusing on the economics of technological change and the modeling of climate-change economics. These topics might at first view seem to live in separate universes. The truth is that they are manifestations of the same fundamental phenomenon, which is a global externality or global public good. Both involve science and technology, and both involve the inability of private markets to provide an efficient allocation of resources. They also draw on the fields mentioned above as integral parts of the theoretical apparatus needed to integrate economics, risk, technology, and climate change.

The two topics not only share a common intellectual heritage, but also are both of fundamental importance. Technological change raised humans out of Stone Age living standards. Climate change threatens, in the most extreme scenarios, to return us economically whence we came. Humans clearly have succeeded in harnessing new technologies. But humans are clearly failing, so far, to address climate change.

My colleague Paul Romer has made fundamental contributions to understanding the global externality of knowledge, and we learn of that key discovery in his essay. This essay addresses the climate-change externality—its sources, its potential impacts, and the policy tools that are available to stem the rising tides and damages that this externality will likely bring to humans and the natural world. It draws upon my writings in the area, most of which are cited in the references.

*Department of Economics, Yale University, PO Box 208268, New Haven, CT 06520 (email: william.nordhaus@yale.edu). The research underlying this essay has benefited from the contributions of innumerable teachers, collaborators, students, and institutions, many of whom are mentioned below. Because they are so numerous and their contributions are so deep, I will mention only one, who was a guiding mentor and contributor for many decades, Tjalling Koopmans. He represents the spirit of courageous innovation in many fields of economics and can stand in for the many others whose work fills the equations and pages of climate-change economics.

This article is a revised version of the lecture William Nordhaus delivered in Stockholm, Sweden, on December 8, 2018 when he received the Bank of Sweden Prize in Economic Sciences in memory of Alfred Nobel.

† Go to https://doi.org/10.1257/aer.109.6.1991 to visit the article page.

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2. The DICE model

- **Households** maximise their welfare taking into account their time preferences and the impact of consumption on their utility.
- **Firms** produce output by using capital and labour. They maximise their profits. Their investment is financed through household saving (saving causes investment).
- Firms can spend money on a **backstop technology,** which allows them to reduce carbon emissions and contribution to climate mitigation.
- There is an **abatement cost function** according to which the cost of emission reductions depends on the emission reduction rate.
- No banks and no involuntary unemployment.

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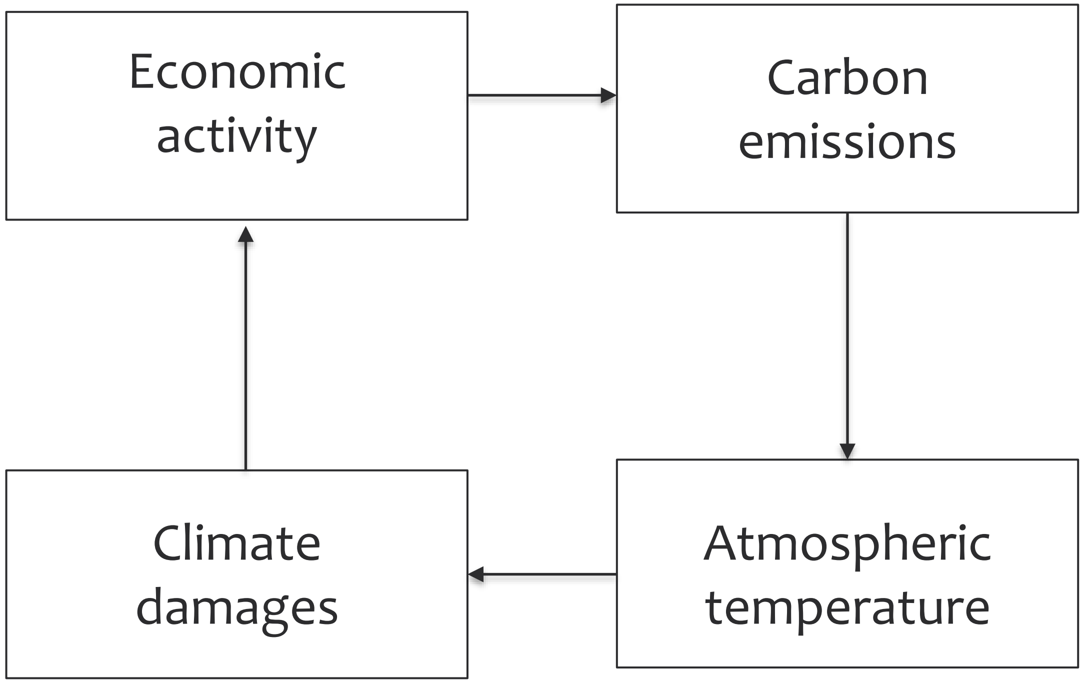
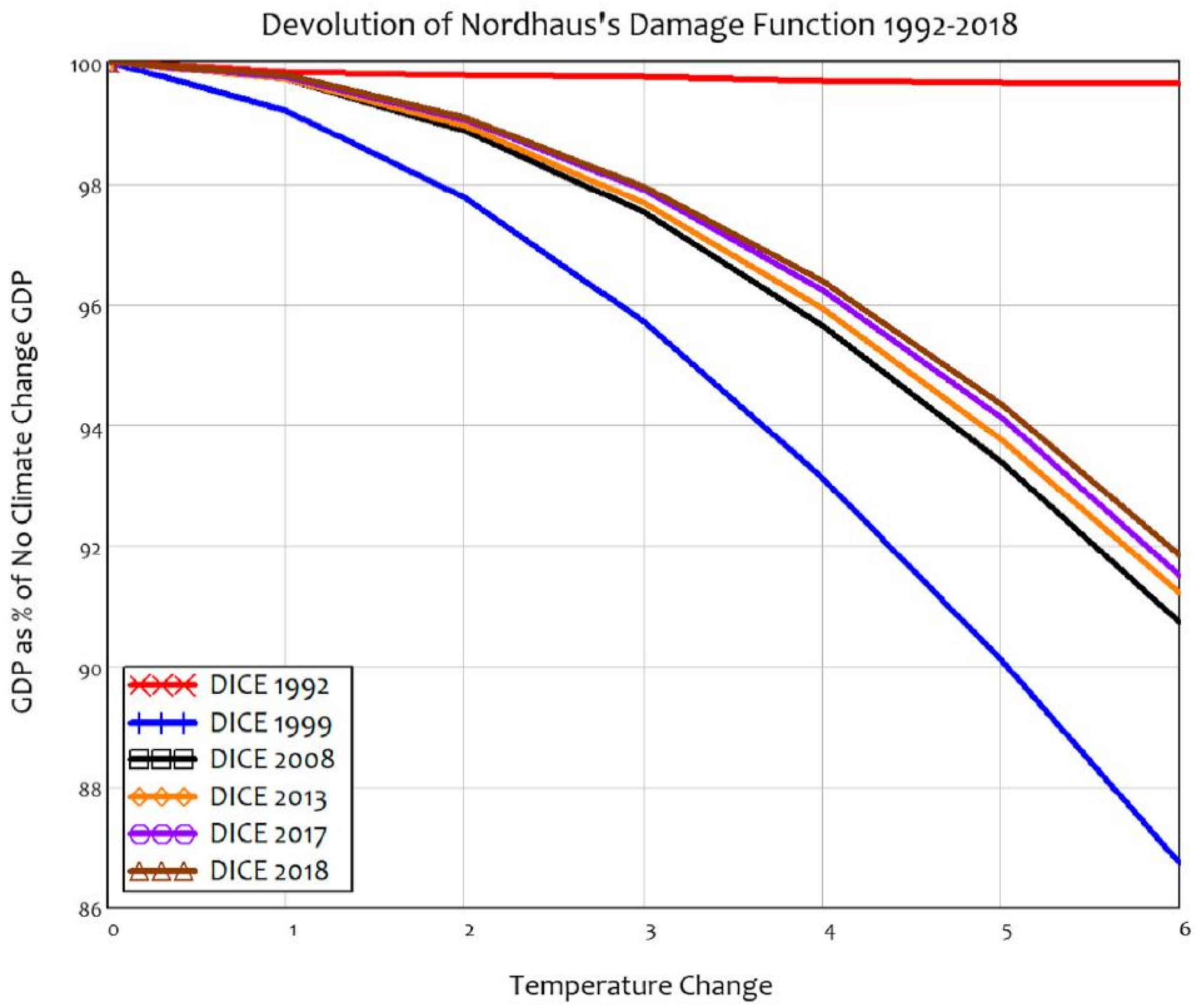
2. The DICE model



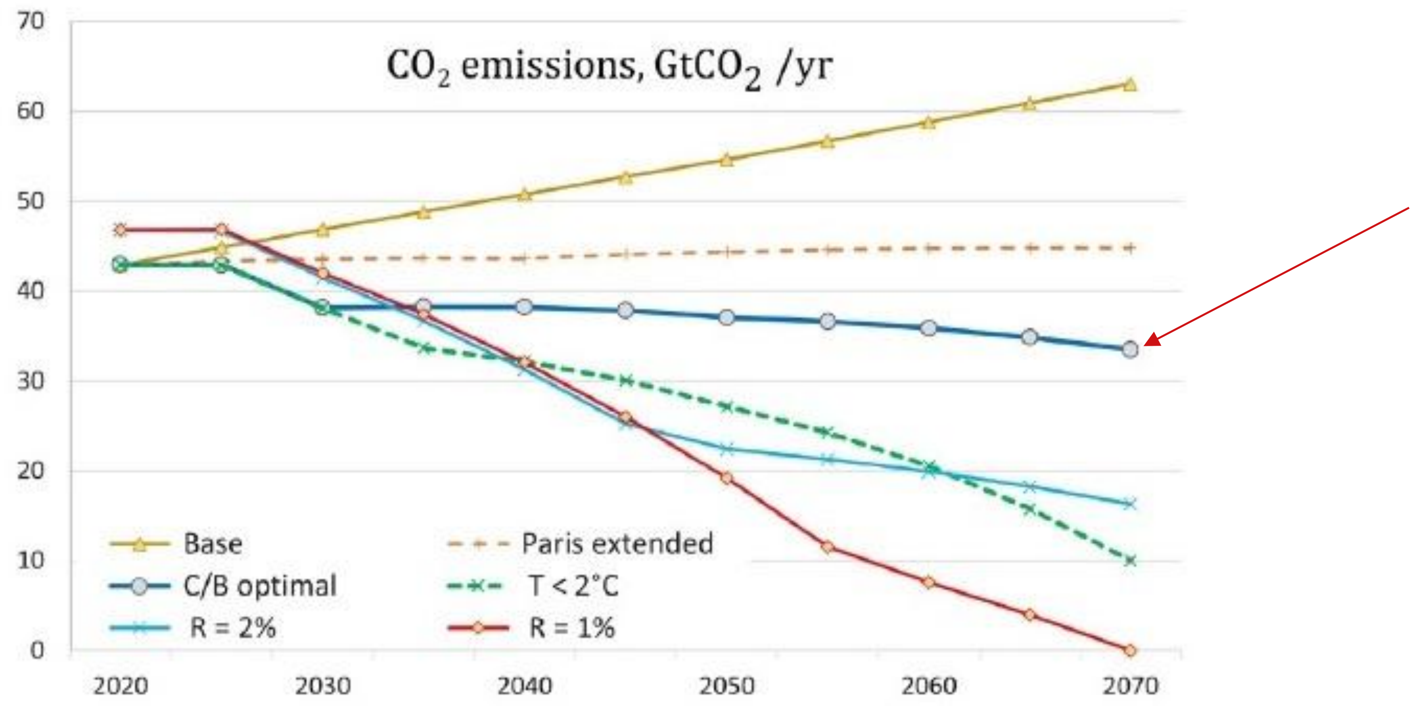
2. The DICE model



Source: Keen (2020)

2. The DICE model

Key results



Cost-benefit analysis: The **optimal carbon price** balances the present value of the **costs** of abatement and the present value of the **benefits** of reduced climate damages

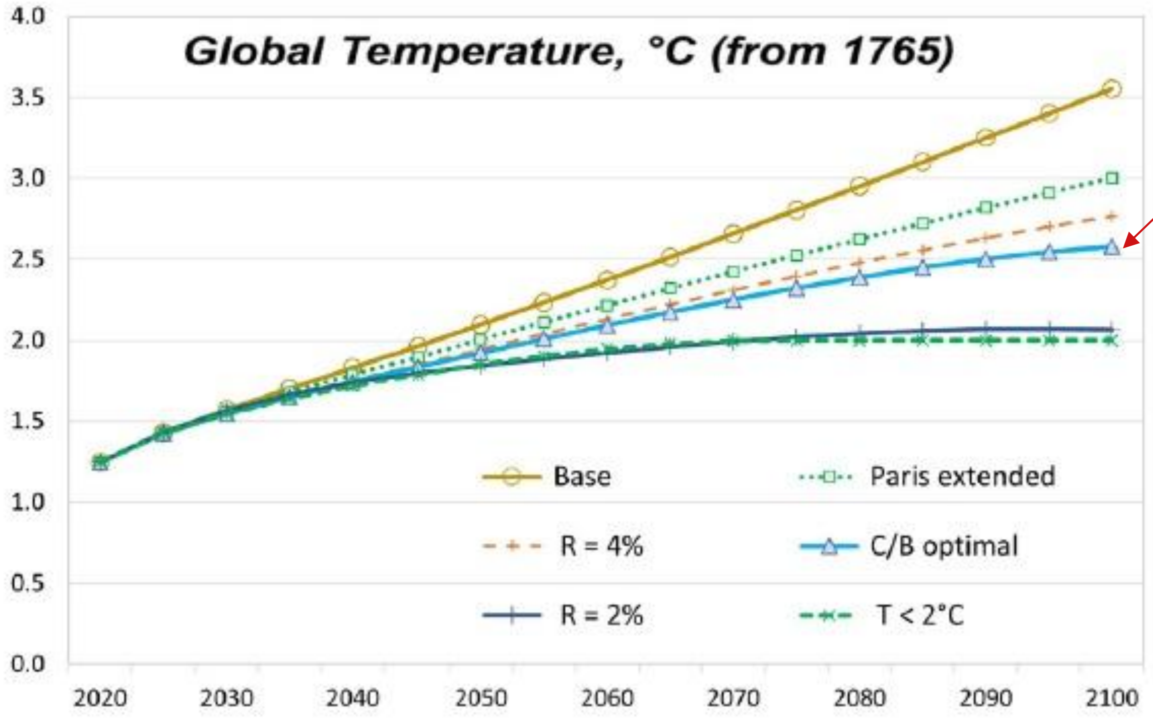
Source: Barrage and Nordhaus (2024)

2. The DICE model

Key results

Why is the optimal temperature in the model of Nordhaus so high?

- Optimistic assumptions about climate damages
- High discount of future generations' consumption
- High responsiveness of temperature to emissions



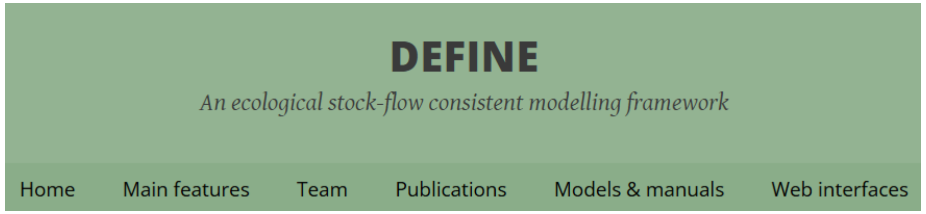
Optimal temperature pathway

Source: Barrage and Nordhaus (2024)

3. E-SFC modelling

- **Ecological stock-flow consistent (E-SFC)** models have been widely used to analyse the interactions between the economy and the ecosystem, as well as the macrofinancial implications of environmental policies.
- A distinct feature of SFC models is the emphasis that they place on the *stock-flow interactions* between macroeconomic and financial variables.
- E-SFC models have analysed the role of **green fiscal policy** (Bovari et al., 2018; Monasterolo and Raberto, 2018, 2019; Dafermos and Nikolaidi, 2019, 2022; Gourdel et al., 2024), **green monetary policy** (Dafermos et al., 2018), **green financial regulation** (Dafermos and Nikolaidi, 2021; Dunz et al., 2021) and **low growth** (Jackson and Victor, 2020).

3. E-SFC modelling



- The Dynamic Ecosystem FINance-Economy (DEFINE) model is an E-SFC model that analyses the interactions between the ecosystem, the macroeconomy and the financial system.
- **Firms** invest both in green and conventional capital and take out green and conventional loans from banks.
- **Banks** provide only a proportion of the demanded loans. Interest loan spreads are endogenous.
- **Households** receive several forms of income and invest in bonds, deposits and government securities. The wage income share depends negatively on the unemployment rate due to a bargaining power channel.
- The **government sector** invests in conventional and green capital.
- **Central banks** set the base interest rate and buy conventional/green bonds issued by firms.

3. E-SFC modelling

Balance sheet matrix

	Households	Firms	Banks	Government sector	Central banks	Total
Conventional capital		$+\Sigma K_{C(PRI)it}$		$+K_{C(GOV)t}$		$+K_{Ct}$
Green capital		$+\Sigma K_{G(PRI)it}$		$+K_{G(GOV)t}$		$+K_{Gt}$
Durable consumption goods	$+DC_t$					$+DC_t$
Deposits	$+D_t$		$-D_t$			0
Conventional loans		$-\Sigma L_{Cit}$	$+\Sigma L_{Cit}$			0
Green loans		$-\Sigma L_{Git}$	$+\Sigma L_{Git}$			0
Conventional bonds	$+\bar{p}_C b_{CHt}$	$-\bar{p}_C b_{Ct}$			$+\bar{p}_C b_{CCBt}$	0
Green bonds	$+\bar{p}_G b_{GHt}$	$-\bar{p}_G b_{Gt}$			$+\bar{p}_G b_{GCBt}$	0
Government securities	$+SEC_{Ht}$		$+SEC_{Bt}$	$-SEC_t$	$+SEC_{CBt}$	0
High-powered money			$+HPM_t$		$-HPM_t$	0
Advances			$-A_t$		$+A_t$	0
Total (net worth)	$+V_{Ht}$	$+V_{Ft}$	$+CAP_t$	$-SEC_t+K_{C(GOV)t}+K_{G(GOV)t}$	$+V_{CBt}$	$+K_{Ct}+K_{Gt}+DC_t$

Source: Dafermos and Nikolaidi (2022)

3. E-SFC modelling

Physical stock-flow matrix, matter

	Atmospheric oxygen	Carbon content of fossil energy resources	Carbon content of fossil energy reserves	Cumulative carbon dioxide emissions	Material resources	Material reserves	Socio-economic material stock	Cumulative material waste	Total
Opening stock	O_{2t-1}	RES_{CEt-1}	REV_{CEt-1}	$CO_{2cumt-1}$	RES_{Mt-1}	REV_{Mt-1}	$SEMS_{t-1}$	$WASTE_{cumt-1}$	$MATTER_T$
Exctracted matter						$-M_t$	$+M_t$		0
Discarded material stock							$-DIS_t$	$+DIS_t$	0
Recycled discarded material stock							$+REC_t$	$-REC_t$	0
Material resources converted into reserves					$-CON_{Mt}$	$+CON_{Mt}$			0
Energy resources converted into reserves		$-CON_{Et}$	$+CON_{Et}$						0
Carbon used in fossil combustion			$-CARBON_t$	$+CARBON_t$					0
Oxygen used in fossil fuel combustion	$-OXYGEN_t$			$+OXYGENt$					0
Closing stock	O_{2t}	RES_{CEt}	REV_{CEt}	CO_{2cumt}	RES_{Mt}	REV_{Mt}	$SEMS_t$	$WASTE_{cumt}$	$MATTER_T$

Note: The table refers to annual global stocks and flows. Matter is measured in gigatonnes.

Source: Dafermos, Colesanti Senni, von Jagow and Nikolaidi (forthcoming)

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3. E-SFC modelling

Physical stock-flow matrix, land

	Natural forest	Planted forest	Cropland	Pastureland	Built-up area	Other land	Total
Opening stock	FOR_{Nt-1}	FOR_{Pt-1}	$CROP_{t-1}$	$PAST_{t-1}$	$BUILT_{t-1}$	$OTHER_{Lt-1}$	$LAND_T$
Cropland-related deforestation	$-DEFOR_{Ct}$		$+DEFOR_{Ct}$				0
Pastureland-related deforestation	$-DEFOR_{Pt}$			$+DEFOR_{Pt}$			0
Planted forests-related deforestation	$-DEFOR_{PFt}$	$+DEFOR_{PFt}$					0
Other land-related deforestation	$-DEFOR_{Ot}$					$+DEFOR_{Ot}$	0
Deforestation due to built-up area	$-DEFOR_B$				$+DEFOR_{Bt}$		0
Land conversion from pastureland to cropland			$+LC_{PCt}$	$-LC_{PCt}$			0
Cropland reforestation/afforestation		$+REFOR_{Ct}$	$-REFOR_{Ct}$				0
Pastureland reforestation/afforestation		$+REFOR_{Pt}$		$-REFOR_{Pt}$			0
Cropland regenerated into natural forest	$+REGEN_{Ct}$		$-REGEN_{Ct}$				0
Pastureland regenerated into natural forest	$+REGEN_{Pt}$			$-REGEN_{Pt}$			0
Planted forest regenerated into natural forest	$+REGEN_{PFt}$	$-REGEN_{PFt}$					0
Other land regenerated into natural forest	$+REGEN_{Ot}$					$-REGEN_{Ot}$	0
Land conversion from pastureland to built-up area				$-LC_{PBt}$	$+LC_{PBt}$		0
Land conversion from cropland to built-up area			$-LC_{CBt}$		$+LC_{CBt}$		0
Land conversion from other land to cropland			$+LC_{OCt}$			$-LC_{OCt}$	0
Land conversion from other land to pastureland				$+LC_{OPt}$		$-LC_{OPt}$	0
Closing stock	FOR_{Nt}	FOR_{Pt}	$CROP_t$	$PAST_t$	$BUILT_t$	$OTHER_{Lt}$	$LAND_T$

Note: The table refers to annual global stocks and flows. Land is measured in million hectares.

Source: Dafermos, Colesanti Senni, von Jagow and Nikolaidi (forthcoming)

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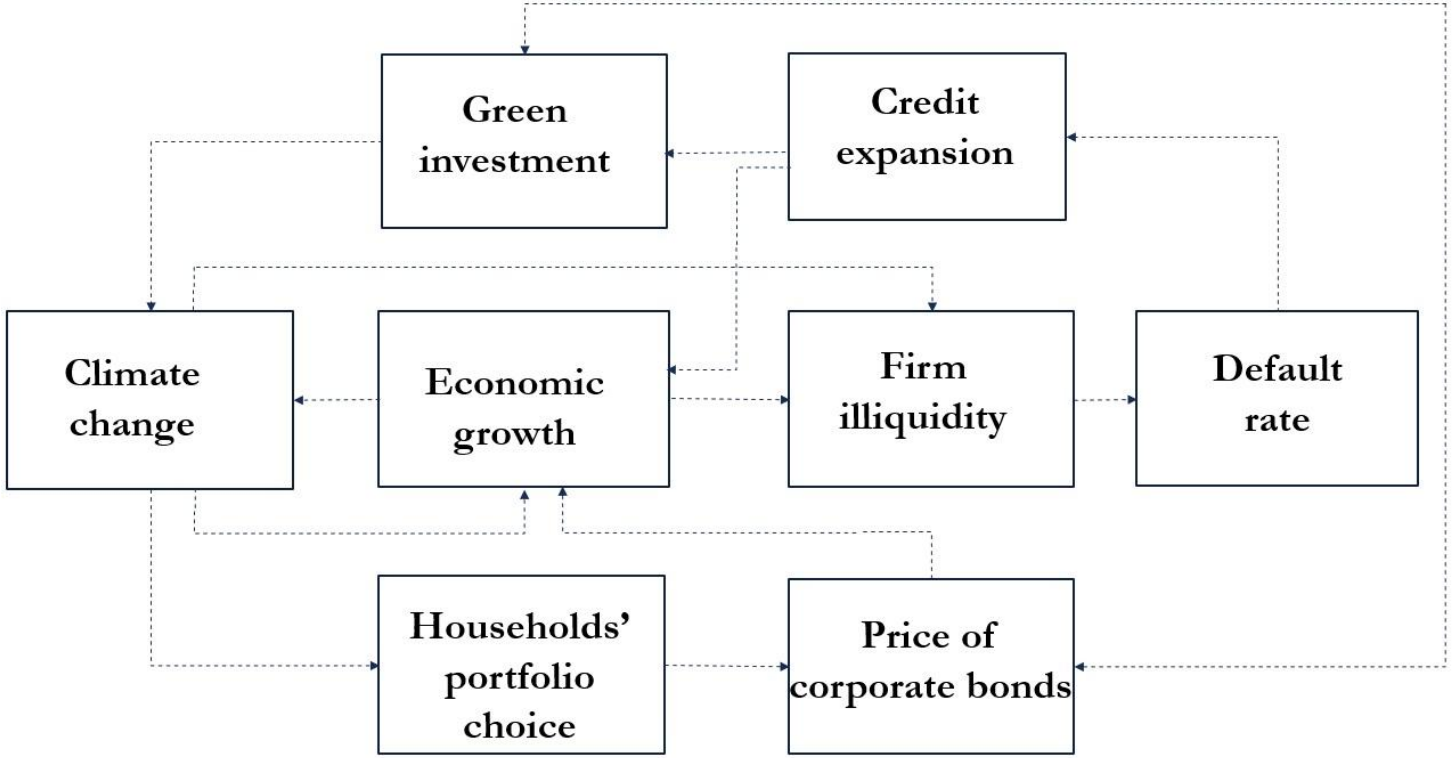
3. E-SFC modelling

Key channels through which climate change and financial stability interact in the model



Source: Dafermos, Nikolaidi and Galanis (2018)

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3. E-SFC modelling

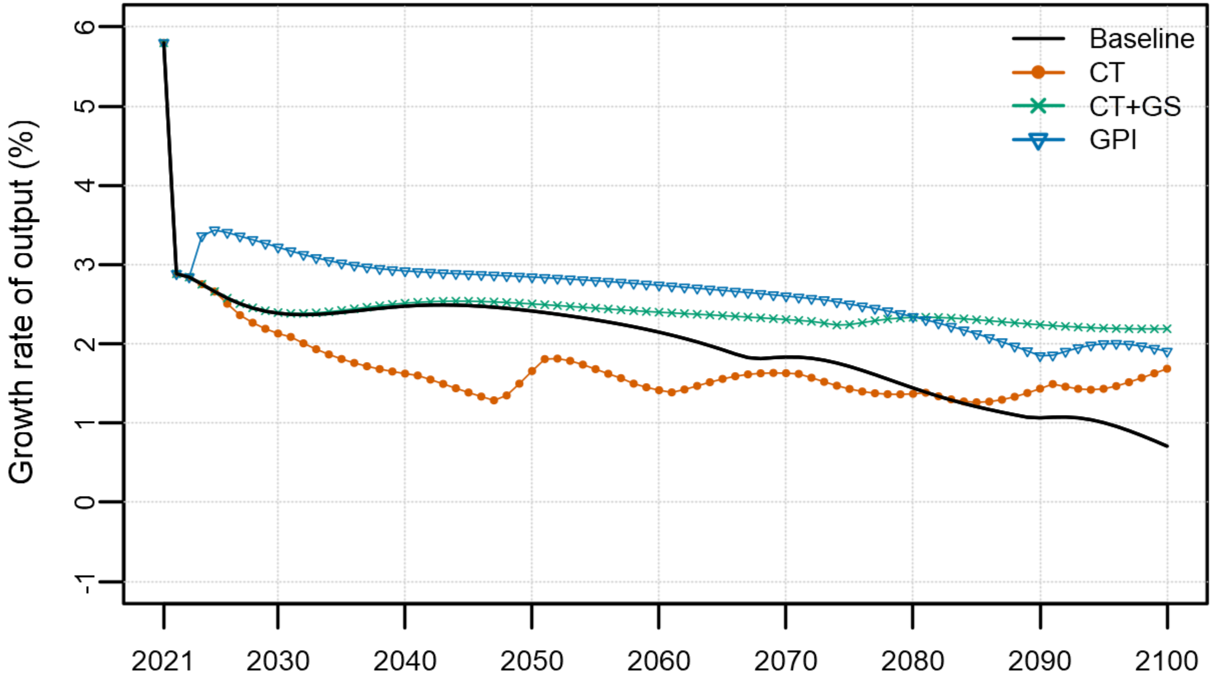
Green fiscal policies (DEFINE-GLOBAL)

- **Carbon Tax (CT):** An increase in carbon taxes without revenue recycling.
- **Carbon Tax and Green Subsidies (CT+GS):** Carbon taxes are recycled in the form of green subsidies that are provided to firms. The level of carbon taxes is the same as in the first scenario.
- **Green Public Investment (GPI):** Green public investment increases from around 0.2% to 1% of GDP per year.

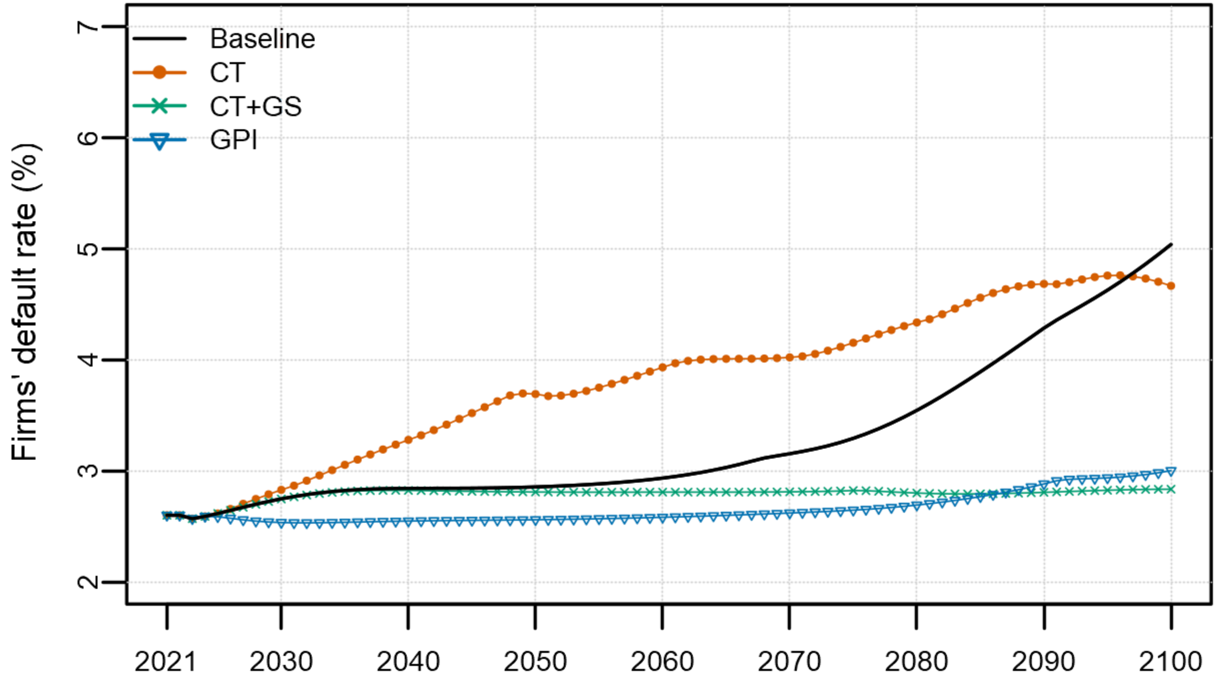
3. E-SFC modelling

Green fiscal policies (DEFINE-GLOBAL)

Growth rate of output



Default rate



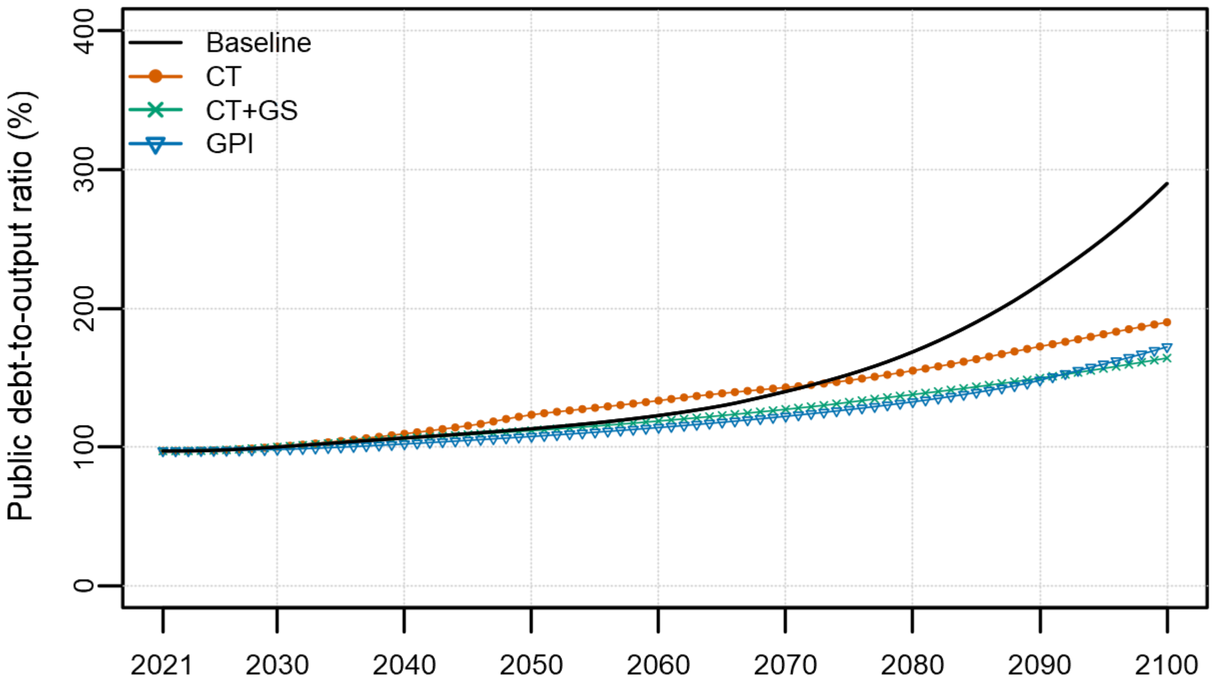
Source: Dafermos and Nikolaidi (2022)

CT: Carbon Tax
CT+GS: Carbon Tax + Green Subsidy
GPI: Green Public Investment

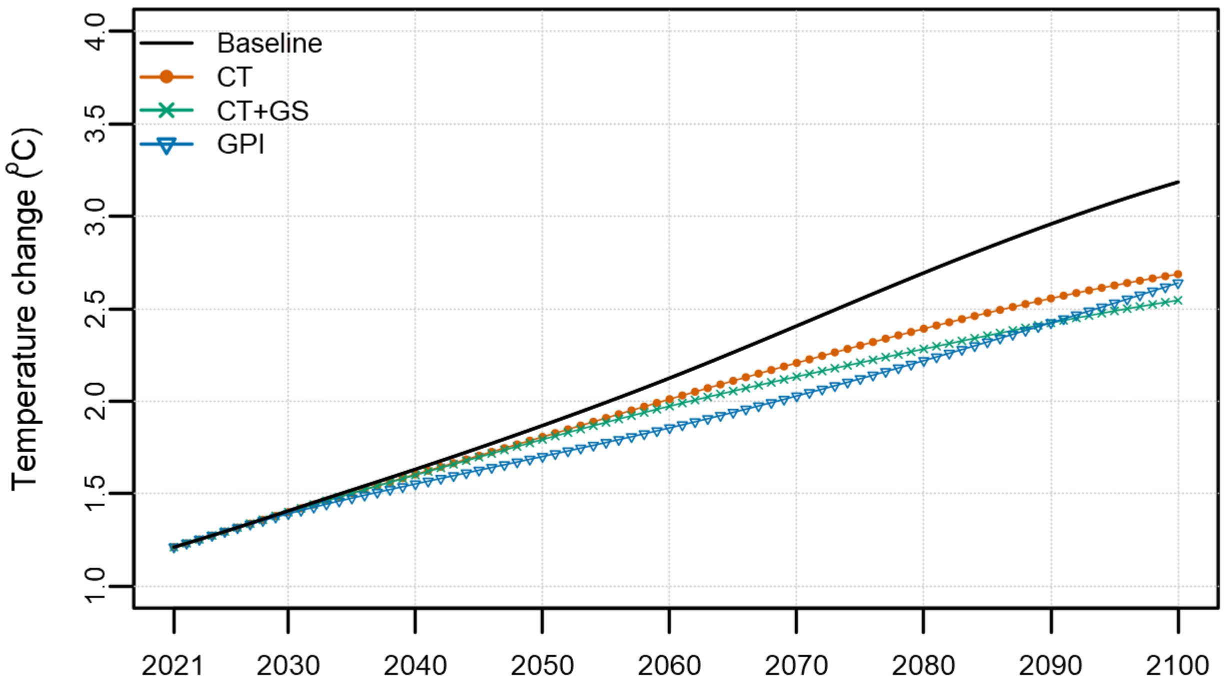
3. E-SFC modelling

Green fiscal policies (DEFINE-GLOBAL)

Public debt-to-GDP



Atmospheric temperature



Source: Dafermos and Nikolaidi (2022)

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CT: Carbon Tax
CT+GS: Carbon Tax + Green Subsidy
GPI: Green Public Investment

3. E-SFC modelling

Green fiscal policies (DEFINE-GLOBAL)

Type of indicator	Indicator	Carbon Tax		Carbon Tax+Green Subsidy		Green Public Investment	
		Short run	Long run	Short run	Long run	Short run	Long run
Ecological	Temperature	Mildly declines	Declines	Mildly declines	Declines	Mildly declines	Declines
	Waste per capita	Mildly declines	Declines	Mildly declines	Declines	Mildly declines	Mildly increases
Macroeconomic-social	Unemployment rate	Mildly increases	Increases	Mildly declines	Declines	Mildly declines	Declines
	Wage share	Mildly declines	Declines	Mildly increases	Increases	Mildly increases	Increases
Financial	Default rate	Increases	Mildly declines	Mildly declines	Declines	Mildly declines	Declines
	Banks' leverage ratio	Increases	Mildly declines	Mildly declines	Mildly declines	Mildly declines	Declines
	Public debt-to-output ratio	Increases	Declines	Declines	Declines	Declines	Declines

Source: Dafermos and Nikolaidi (2022)

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3. E-SFC modelling

Green fiscal policies (DEFINE-UK)

- **Carbon Price Increase:** The emission price in the UK is increased steadily from around £15/$MTCO_{2e}$ to over £200/$MTCO_{2e}$ by 2035.
- **Green Power Subsidy:** The government increases its GB energy power subsidy from £8.3 bn to £40 bn over 5 years and continues with this level of spending for the rest of the simulation, or until a non-fossil fuel electricity transition is achieved.
- **Housing Subsidy:** The government provides subsidies to households for green home improvements covering 40% of the cost of energy efficiency and electrification improvements.
- **Combined Scenario:** All above policies are run simultaneously.

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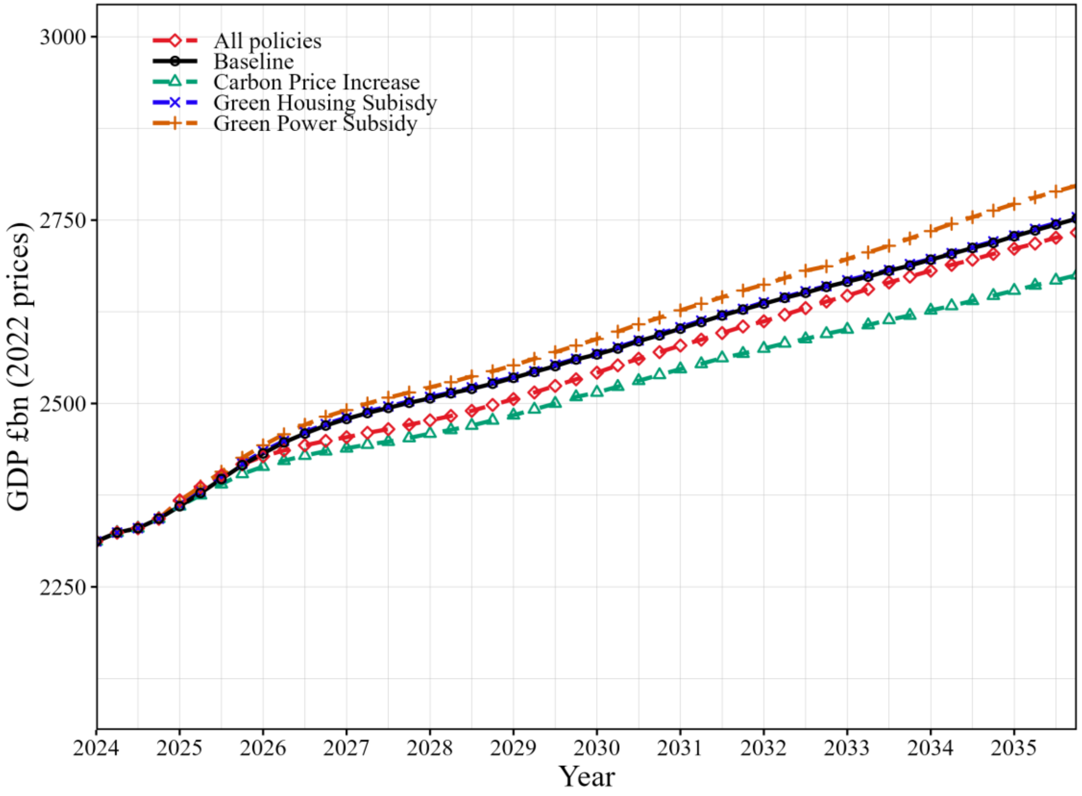
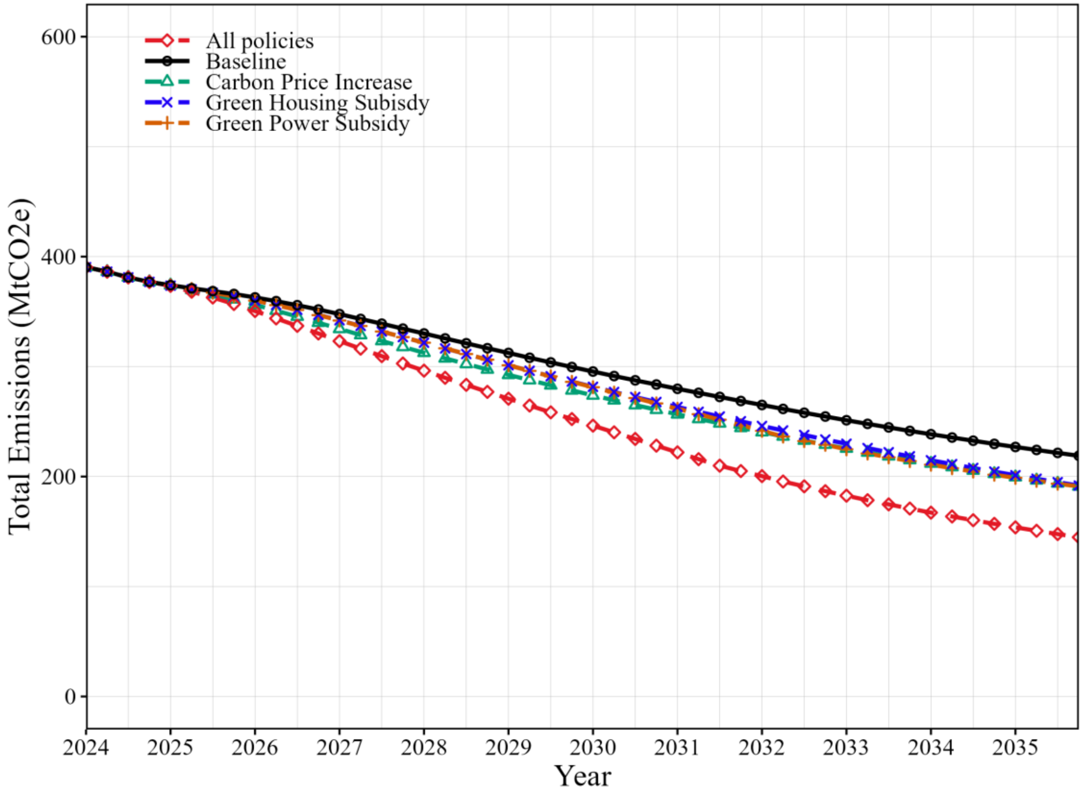
3. E-SFC modelling

Green fiscal policies (DEFINE-UK)

GDP



GHG emissions



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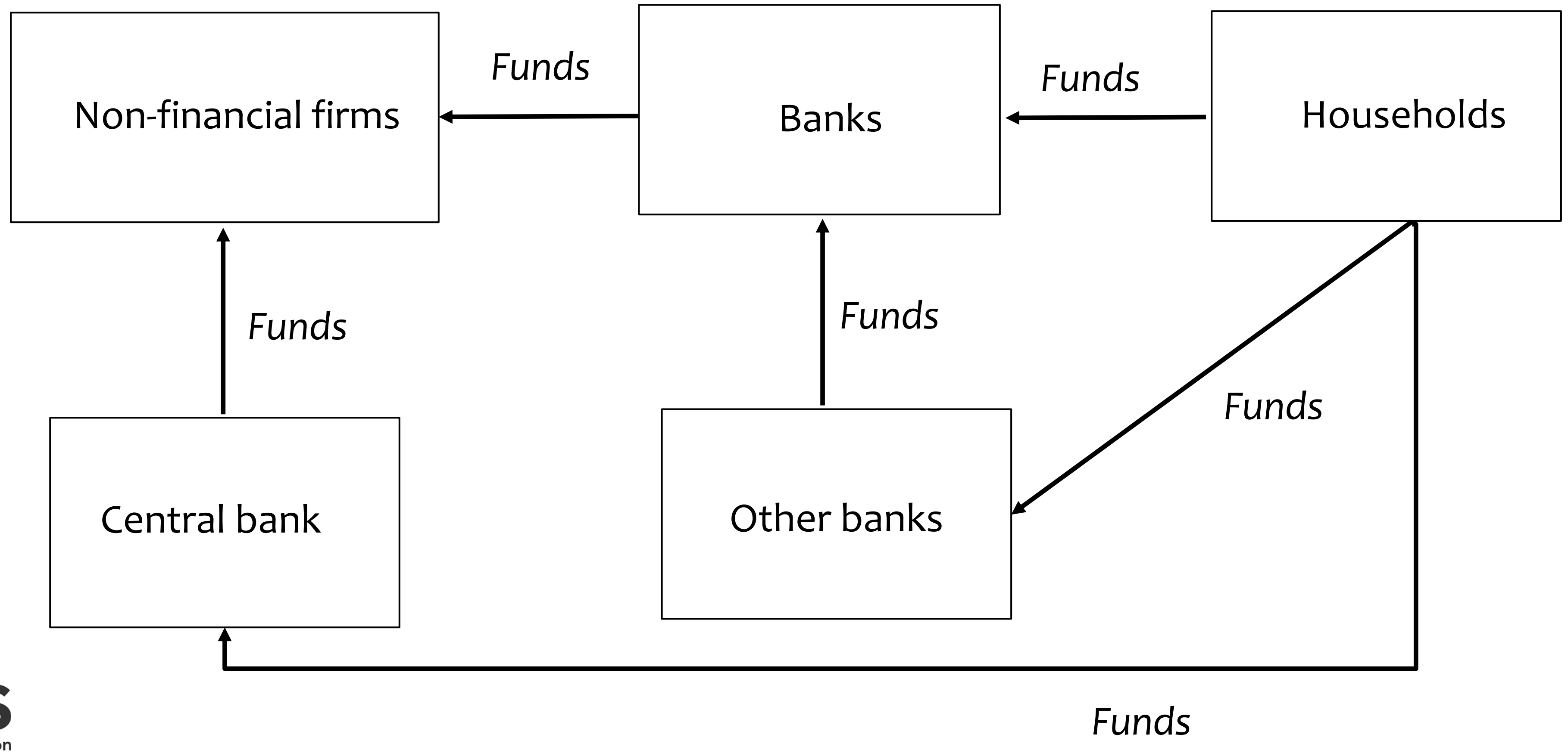
Source: George and Dafermos (forthcoming)

4. E-DSGE modelling

- **Environmental Stochastic General Equilibrium (E-DSGE)** models have been used to examine environmental issues in the context of business cycle analysis.
- A distinction can be made between: (i) **DSGE models without finance** and (ii) **DSGE models with finance.**
- In DSGE models without finance, a standard DSGE model is combined with a damage function and a carbon pricing framework. Main purpose: identify a carbon price that makes the business cycle smoother.
- In DSGE models with finance, environmental issues are examined in the context of a **financial accelerator** framework.

4. E-DSGE modelling

Financial intermediation in Gertler and Kiyotaki (2011)



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4. E-DSGE modelling

A DSGE model with financial accelerator and carbon taxes

- Diluiso et al. (2021) have developed a model that combines the financial accelerator framework with carbon taxes and climate finance policies.
- Two types of **energy producers:** low-carbon producers and fossil energy producers.
- **Banks** lend funds to firms obtained from households.
- The model includes emissions but not environmental damages.

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Climate actions and macro-financial stability: The role of central banks

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ABSTRACT

Limiting global warming to well below 2 °C may pose threats to macroeconomic and financial stability. In an estimated Euro Area New Keynesian model with financial frictions and climate policy, we study the possible perils of a low-carbon transition and evaluate the role of monetary policy and financial regulation. We show that, even for very ambitious climate targets, transition costs are moderate along a timely and gradual mitigation pathway. Inflation volatility strongly increases for disorderly climate policy, demanding a strong monetary response by central banks. In reaction to an adverse financial shock originating in the fossil sector, a green quantitative easing policy can provide an effective stimulus to the economy, but its stabilizing properties do not significantly differ from those of market neutral asset purchase programs. A financial regulation, encouraging the decarbonization of the banks' balance sheets via *ad hoc* capital requirements, can significantly reduce the severity of a financial crisis, but prolongs the recovery phase. Our results suggest that the involvement of central banks in climate actions must be carefully designed to be in compliance with their mandate and to avoid unintended trade-offs.

Through our strategy review, we will determine where and how the issue of climate change and the fight against climate change can actually have an impact on our policies.

[Christine Lagarde (2020), President of the ECB]

1. Introduction

By signing and ratifying the Paris Agreement countries agreed to limit global warming to well below 2 °C. Achieving this target requires to reach net-zero CO_2 emissions within the next 50–60 years (IPCC, 2018). According to recent estimates, this implies global emissions to decline by approximately 7% per year in a typical 1.5 °C scenario and by 3% per year in a 2 °C scenario (e.g. Höhne et al., 2020). Such strong emission reductions are historically unprecedented and partially the result of the past decade of political failure in contrasting climate change. In the absence of more stringent climate policies, global emissions are bound to keep rising (e.g. Friedlingstein et al., 2019; UNEP, 2019).[1] The current plans of expanding fossil fuel production will lead to emission levels in

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[1] While the pandemic crisis has lead to a projected decrease of 7% in carbon emissions in 2020 (see Le Quéré et al., 2020, 2021), past recessions showed a quick rebound in emissions with even higher growth rates (e.g. Peters et al., 2020).

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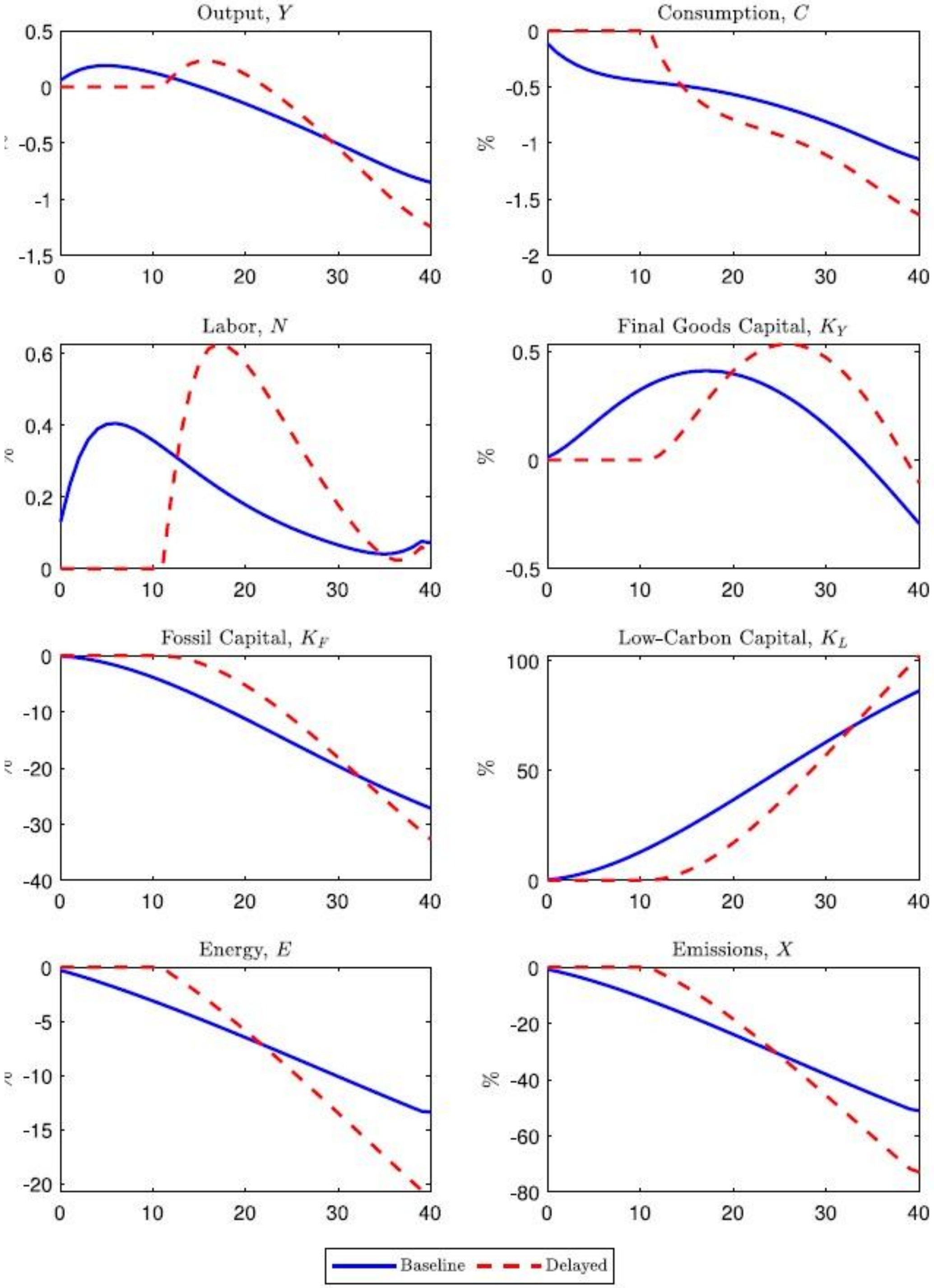
4. E-DSGE modelling

A DSGE model with financial accelerator and carbon taxes

- The figure shows the effects of a continuous increase in carbon taxes.
- Due to rational expectations, the increase in the carbon tax leads **firms to increase production** in the first years (since they expect a further increase in their production costs in the future).
- In their attempt to maximise their intertemporal utility, **workers also supply more labour and save more** (since they expect a reduction in their wages in the future).
- As a result of these developments, **inflation also declines.**



Source: Diluiso et al. (2021)
Note: *Baseline* is the orderly scenario and *Delayed* is the disorderly scenario in which the mitigation policy is implemented with a 3-year delay.

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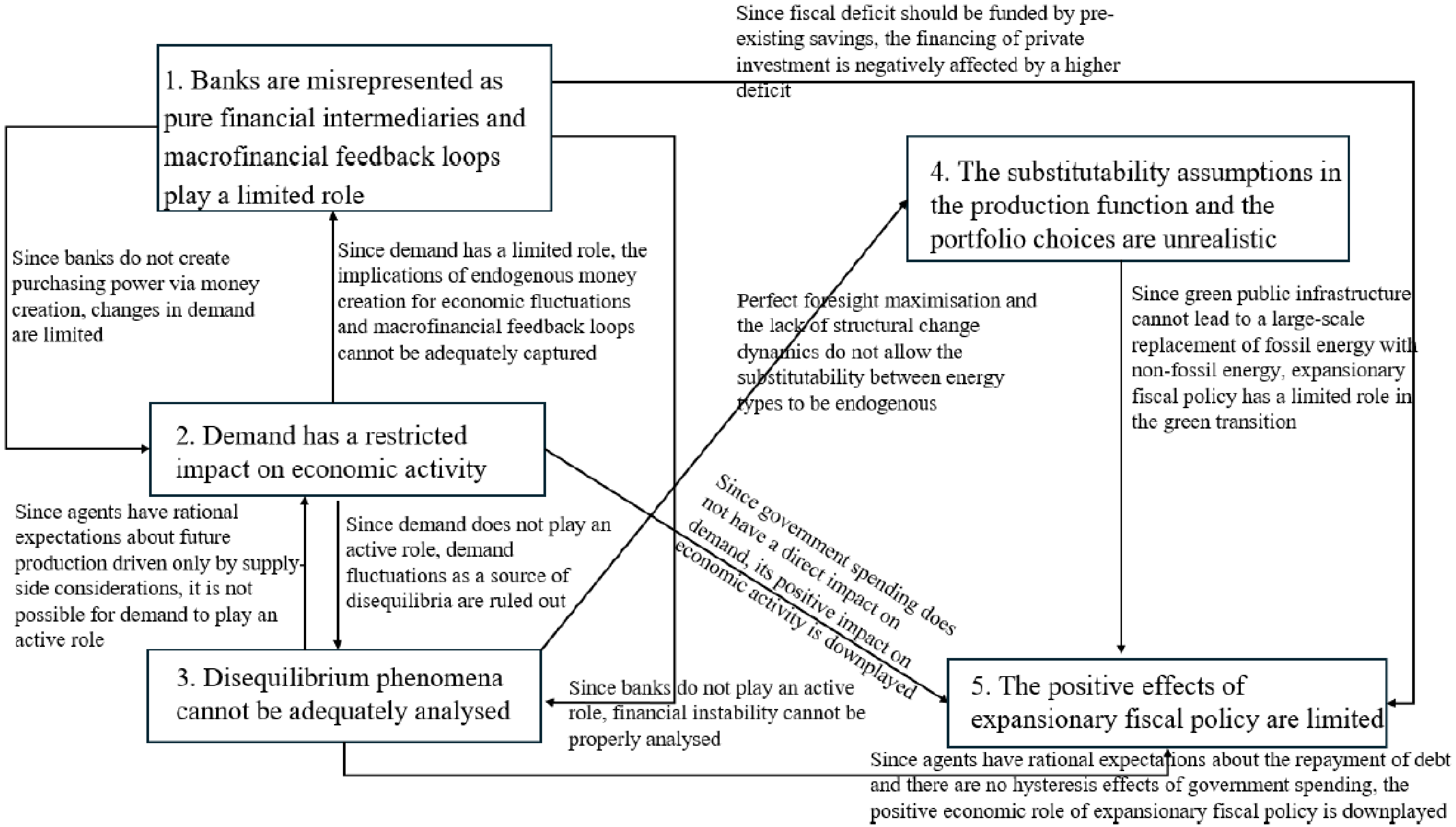
4. E-DSGE modelling

Limitations of E-DSGE models and their interconnections



Source: Dafermos, McConnell, Nikolaidi, Storm and Yanovski (2024)