Stock-flow consistent modelling and ecological macroeconomics

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Introduction

- Over the last decade, **stock-flow consistent** (SFC) modelling has become a very popular approach in heterodox macro modelling (see Caverzasi and Godin, 2015; Nikiforos and Zezza, 2017, Carnevali et al., 2019).
- The SFC approach has proved successful in formulating the complex interactions between the **financial** and the **real** spheres of the economy.
- This approach has its origins to the work of the Yale group of **James Tobin** and the Cambridge Economic Policy Group of **Wynne Godley** that used SFC structures to analyse the US and the UK economy in the 1970s and the 1980s.

Introduction

- There is currently a lot of research on **theoretical SFC modelling**.
- There is also research on **empirical SFC modelling** (for a review of country-specific models see Zezza, 2019). However, the empirical SFC literature is much less developed than the theoretical one.
- SFC models are often viewed as **alternative models to the Dynamic Stochastic General Equilibrium (DSGE) models** and **Integrated Assessment Models** (especially when they are combined with agent-based structures).
- Recently, SFC models have been used for the analysis of **ecological macroeconomic** issues. They have also received attention by **central banks** due to their ability to analyse interactions between climate change and finance (see e.g. NGFS, 2019).

Outline

1. Key features of SFC models
2. A simple ecological SFC model
3. Extending the simple model
4. Research gaps in SFC modelling and ecological macroeconomics

1. Key features of SFC models

(1) There are no black holes

'Everything comes from somewhere and goes somewhere'. This is ensured by using two matrices: (i) the balance sheet matrix and (ii) the transactions matrix.

(2) The financial and the real spheres are integrated

Following the post-Keynesian tradition on the non-neutrality of money and finance, the SFC models explicitly formulate the various links between financial and real variables.

(3) Behavioural equations are based on post-Keynesian assumptions

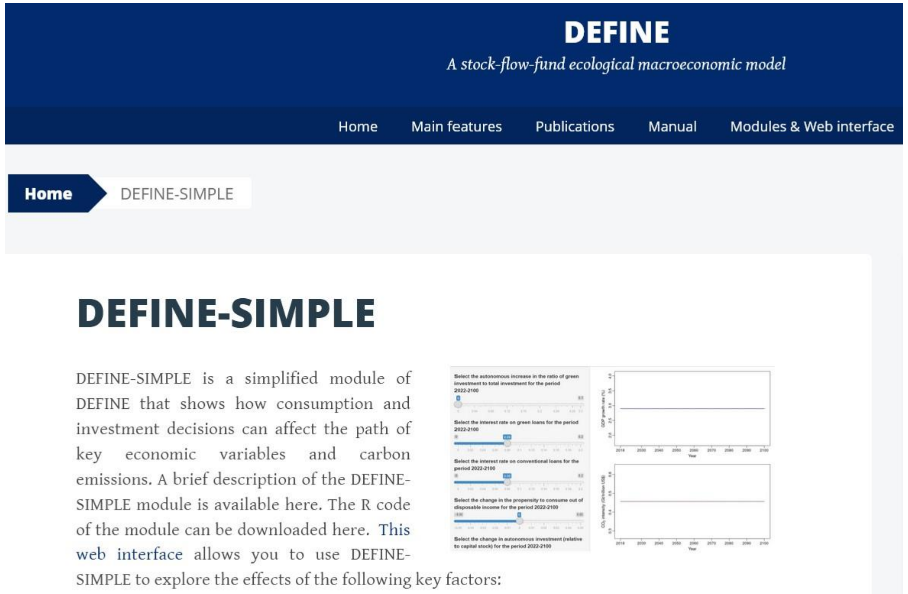
The behavioural equations (like consumption and investment functions) are built by relying primarily on post-Keynesian theories.

2. A simple ecological SFC model

- **DEFINE-SIMPLE** is a simplified module of the Dynamic Ecosystem-FINance-Economy (DEFINE) model (see Dafermos, Nikolaidi and Galanis, 2018; Dafermos and Nikolaidi, 2021).
- The model consists of three sectors: households, firms and banks.
- It has the following **ecological features**:

(a) There is a distinction between green and conventional loans/investment.

(b) Carbon intensity depends on the accumulation of green capital compared to conventional capital.



www.define-model.org

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2. A simple ecological SFC model

Households

- Households have three sources of income: wages, firms' distributed profits, bank profits and interest.
- Their **disposable income** (Y_D) is therefore equal to:

$$Y_{Dt} = s_W Y_t + DP_t + BP_t + int_D\, D_{t-1}$$

where s_W: wage share; Y: output; DP: firms' distributed profits; BP: bank profits; int_D: interest on deposits; D: deposits

- They **consume** (C) a proportion of their income and wealth:

$$C_t = c_1 Y_{Dt-1} + c_2 D_{t-1}$$

2. A simple ecological SFC model

Firms

- The **investment** rate of firms depends on their profit rate (r):

$$I_t = (\alpha_0 + \alpha_1 r_{t-1}) K_{t-1}$$

- Investment can be either green (e.g. investment in solar panels) or conventional (e.g. investment in a coal-fired plant): $I_t = I_{Ct} + I_{Gt}$
- **Green investment** is a proportion of total investment: $I_{Gt} = \beta_t I_t$
- This **proportion** is higher the more strict environmental regulation and preferences are (this is captured by β_0) and the higher is the lower the interest rate on green loans (int_G) compared to the interest rate on conventional loans (int_C) : $\beta_t = \beta_0 - \beta_1 (int_G - int_C)$

where I: investment; K: capital stock; I_G: green investment; I_C: conventional investment; β : proportion of green investment to total investment

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2. A simple ecological SFC model

Banks

- Banks provide **loans demanded by firms**. They do not impose credit rationing.
- Their profits are higher the higher is the interest rate on loans compared to the interest rate on deposits.
- All their **profits are distributed to households**. An implication of this is that an increase in the loan interest rate increases the disposable income of households and, hence, their consumption.

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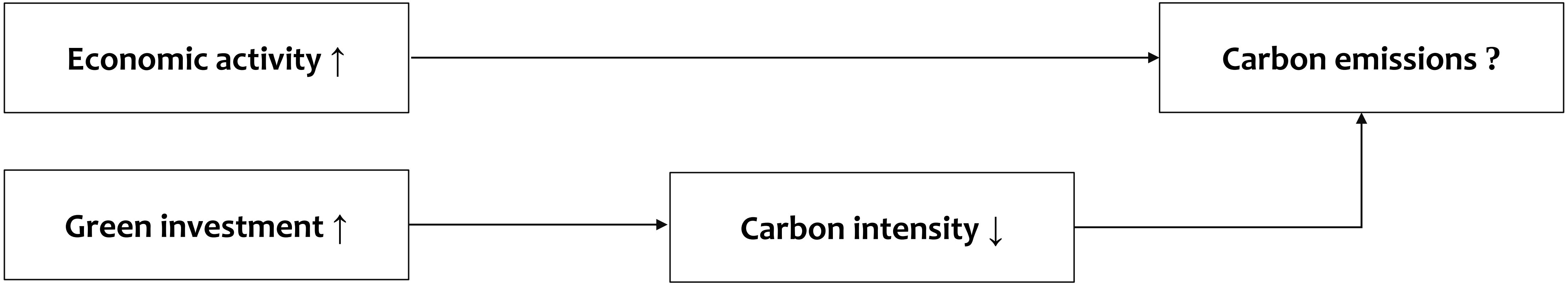
2. A simple ecological SFC model

Emissions

- Industrial **CO2 emissions** ($EMIS_{IN}$): $EMIS_{INt} = CI_t Y_t$
- **Carbon intensity** (CI): $CI_t = f\left(\overset{(-)}{K_{Gt-1} / K_{Ct-1}}\right)$

where Y: output; K_G: green capital stock; K_C: conventional capital stock



2. A simple ecological SFC model

Balance sheet matrix

	Households	Firms	Commercial banks	Total
Deposits	$+D_t$		$-D_t$	0
Green loans		$-L_{Gt}$	$+L_{Gt}$	0
Conventional loans		$-L_{Ct}$	$+L_{Ct}$	0
Green capital		$+K_{Gt}$		$+K_{Gt}$
Conventional capital		$+K_{Ct}$		$+K_{Ct}$
Total (net worth)	$+D_t$	$+V_{Ft}$	0	$+K_t$

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2. A simple ecological SFC model

Transactions matrix

	Households	Firms		Commercial banks		Total
		Current	Capital	Current	Capital	
Consumption	$-C_t$	$+C_t$				0
Green investment		$+I_{Gt}$	$-I_{Gt}$			0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$			0
Wages	$+s_W Y_t$	$-s_W Y_t$				0
Firms' profits	$+DP_t$	$-TP_t$	$+RP_t$			0
Banks' profits	$+BP_t$			$-BP_t$		0
Interest on deposits	$+int_D D_{t-1}$			$-int_D D_{t-1}$		0
Interest on green loans		$-int_G L_{Gt-1}$		$+int_G L_{Gt-1}$		0
Interest on conventional loans		$-int_C L_{Ct-1}$		$+int_C L_{Ct-1}$		0
Change in deposits	$-\Delta D_t$				$+\Delta D_t$	0
Change in green loans			$+\Delta L_{Gt}$		$-\Delta L_{Gt}$	0
Change in conventional loans			$+\Delta L_{Ct}$		$-\Delta L_{Ct}$	0
Total	0	0	0	0	0	0

$$DP_t = TP_t - RP_t$$

$$BP_t = int_C\, L_{Ct-1} + int_G\, L_{Gt-1} - int_D\, D_{t-1}$$

$$D_{redt} = L_t$$

$$D_t = D_{t-1} + Y_{Dt} - C_t$$

$$(L_{Ct} - L_{Ct-1}) + (L_{Gt} - L_{Gt-1}) = I_{Ct} + I_{Gt} - RP_t$$

$$TP_t = Y_t - s_W Y_t - int_C\, L_{Ct-1} - int_G\, L_{Gt-1}$$

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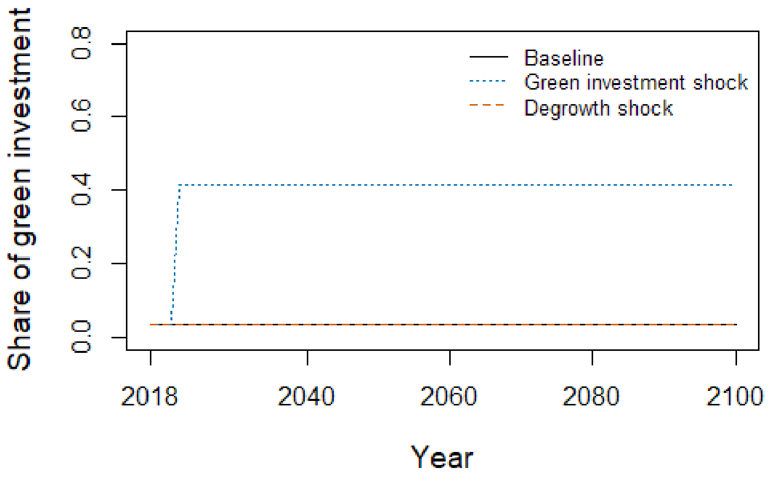
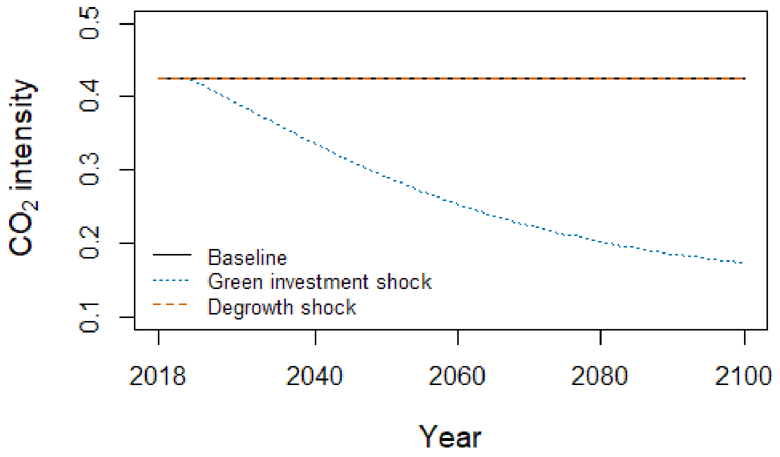
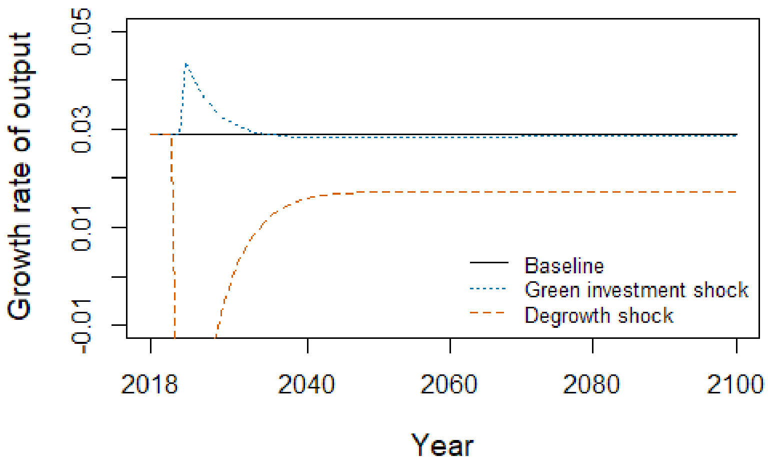
2. A simple ecological SFC model

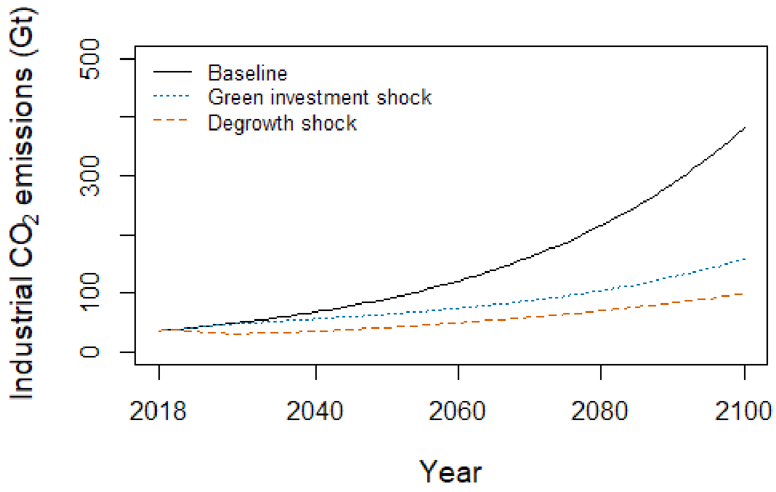


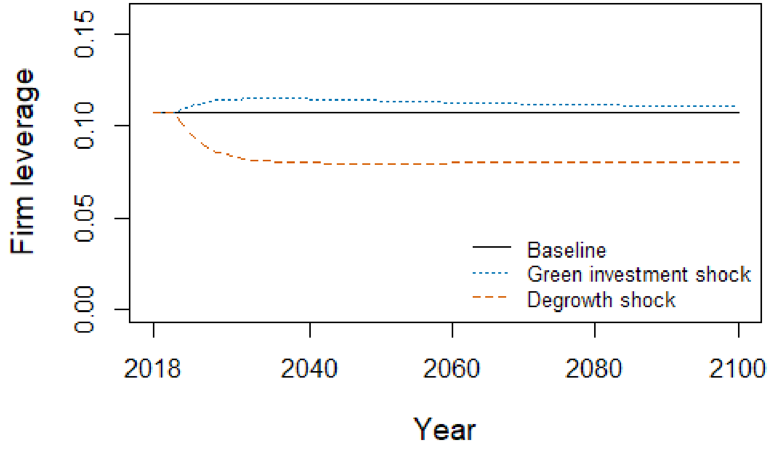


Green investment shock: Increase in the share of green investment via an increase in β_0 and int_C and a decline in int_G

Degrowth shock: Decline in the propensity to consume (c_1) and autonomous investment (a_0)







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3. Extending the simple model

Climate change

- The change in **atmospheric temperature** is driven by cumulative emissions:

$$T_{ATt} = T_{ATt-1} + t_1\left(t_2 \varphi CO2_{CUMt-1} - T_{ATt-1}\right)$$

where $CO2_{CUM}$ denotes cumulation CO_2 emissions; t_1 captures the timescale of the initial adjustment of the climate system to an increase in cumulative emissions; t_2 captures the global warming that stems from non-CO_2 greenhouse gas emissions; φ is the Transient Climate Response to cumulative carbon Emissions (TCRE) (^{o}/GtCO_2)

- Climate change can cause damages that can affect both the **supply-side** (e.g. labour productivity, capital stock, agriculture) and the **demand-side** of the economy (e.g. consumption and investment demand). Supply-side effects might be more important than demand-side effects for the **Global South.**
- **Climate damages** can be captured by non-linear functions that link damages with atmospheric temperature.

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3. Extending the simple model

Matter and energy

- Production relies on a continuous inflow of matter and energy from the ecosystem.
- These inflows can be consistently analysed using the **1st Law of Thermodynamics:** energy and matter cannot be created or destroyed.
- Two key issues can arise from the use of matter: (1) **matter depletion** and (2) **waste generation.** Both of them can have feedback effects on the economy.

3. Extending the simple model

Matter and energy

Physical flow matrix

	Material balance	Energy balance
Inputs		
Extracted matter	$+M_t$	
Non-fossil energy		$+E_{NFt}$
Fossil energy	$+CEN_t$	$+E_{Ft}$
Oxygen used for fossil fuel combustion	$+O2_t$	
Outputs		
Industrial CO_2 emissions	$-EMIS_{INt}$	
Waste	$-W_t$	
Dissipated energy		$-ED_t$
Change in socio-economic stock	$-\Delta SES_t$	
Total	0	0

- Material balance: $M_t + CEN_t + O2_t = EMIS_{INt} + W_t + \Delta SES_t$
- Energy balance: $ER_t + EN_t = ED_t$

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3. Extending the simple model

Matter and energy

Physical stock-flow matrix

	Material reserves	Non-renewable energy reserves	Cumulative CO_2 emissions	Socio-economic stock	Hazardous waste
Opening stock	REV_{Mt-1}	REV_{Et-1}	$CO2_{CUMt-1}$	SES_{t-1}	HWS_{t-1}
Additions to stock					
Resources converted into reserves	$+CON_{Mt}$	$+CON_{Et}$			
CO_2 emissions			$+EMIS_t$		
Production of material goods				$+MY_t$	
Non-recycled hazardous waste					$+hazW_t$
Reductions of stock					
Extraction/use of matter or energy	$-M_t$	$-EN_t$			
Demolished/disposed socio-economic stock				$-DEM_t$	
Closing stock	REV_{Mt}	REV_{Et}	$CO2_{CUMt}$	SES_t	HWS_t

- Material reserves: $REV_{Mt-1}+CON_{Mt}-M_t=REV_{Mt}$
- Non-renewable energy reserves: $REV_{Et-1}+CON_{Et}-EN_t=REV_{Et}$
- Cumulative CO_2 emissions: $CO2_{CUMt-1}+EMIS_t=CO2_{CUMt}$
- Socio-economic stock: $SES_{t-1}+MY_t-DEM_t=SES_t$
- Hazardous waste: $HWS_{t-1}+hazW_t=HWS_t$

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3. Extending the simple model

Green fiscal and monetary policy

- **Carbon taxes** and **green subsidies** can affect the decision of firms about how much investment they will make in green capital.
- A distinction can be made between **green public and private capital**. This allows the government sector to play a more active role in the transition to a low-carbon economy.
- A bond market can be introduced and a distinction can be made between **green** and **conventional bonds**. Central banks can affect the yield on these two different types of bonds for example by purchasing more green bonds and less conventional bonds as part of their **quantitative easing** programmes.

3. Extending the simple model

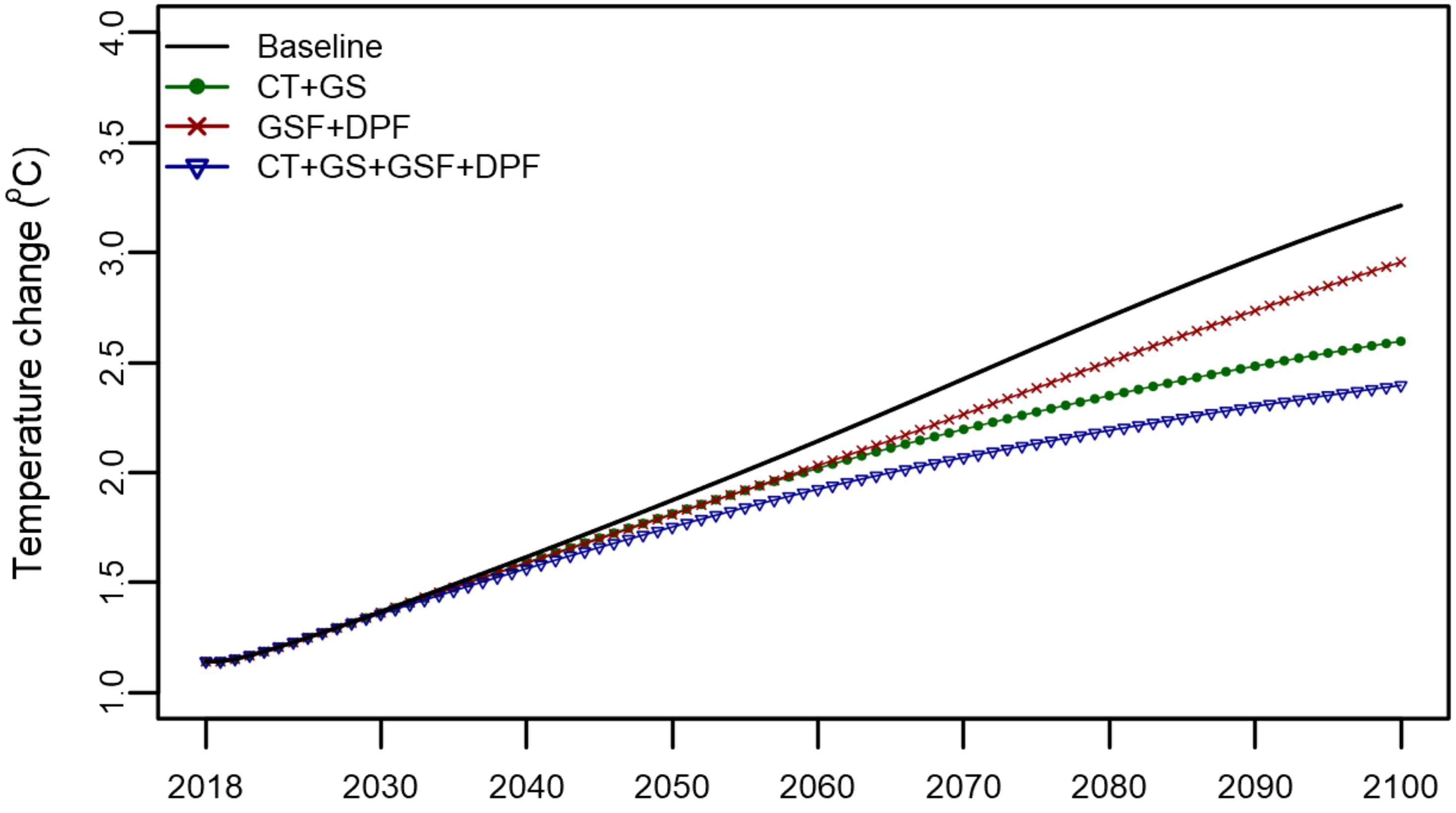
Banking sector and green financial policy

- In DEFINE-SIMPLE all loans demanded by firms are provided. In reality, however, a significant part of the loan applications is rejected.
- **Credit rationing** can be introduced to take into account the active role that banks play in financing investment projects. Credit rationing can be affected by both borrowers' and lenders' financial position.
- The introduction of credit rationing can allow the explicit analysis of green financial regulation, such as the **green supporting factor** (lower capital requirements on green loans) and the **dirty penalising factor** (higher capital requirements on carbon-intensive loans).
- It can also allow the analysis of **climate-induced financial instability**.

3. Extending the simple model

Climate policies and temperature in DEFINE

Atmospheric temperature



CT: Carbon tax
GS: Green subsides
GSF: Green supporting factor
DPF: Dirty penalising factor

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4. Research gaps in SFC modelling and ecological macroeconomics

- Ecological SFC models have been developed which focus on the role of **green fiscal policy** (Bovari et al., 2018; Monasterolo and Raberto, 2018, 2019; Dafermos and Nikolaidi, 2019), **green monetary policy** (Dafermos et al., 2018) and **green financial regulation** (Dafermos and Nikolaidi, 2021; Dunz et al., 2021) and **low growth** (Jackson and Victor, 2020).
- More work is necessary on the following issues:

1) The role of degrowth, consumption patterns and environmental regulation
2) The links between environmental policies and balance of payments constraints (see Carnevali et al., 2020)
3) The incorporation of sectoral dynamics (e.g. through input-output tables) and inequality into ecological SFC models
4) The development of country-specific ecological SFC models

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