Stock-flow consistent modelling and ecological macroeconomics

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- **Stock-flow consistent** (SFC) modelling has become a very common approach in heterodox macro modelling.
- The SFC approach has its origins in 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. It became popular after the publication of the book by Godley and Lavoie (2007).
- This approach has proved successful in formulating the complex interactions between the **financial** and the **real** spheres of the economy.

- SFC models have been used for analysing a **variety of topics**, such as financialisation, the links between growth and distribution, the macrofinancial effects of fiscal and monetary policies, as well as the interactions between trade and exchange rates (for reviews, see Caverzasi and Godin, 2015; Nikiforos and Zezza, 2017; Carnevali et al., 2019).
- Several **country-specific** SFC models have been developed that are typically used to conduct projections under different policy scenarios (e.g. Zezza and Zezza, 2022; Byrialsen et al., 2024; Mazier et al., 2024).
- SFC models are now increasingly used for the analysis of **ecological macroeconomic** issues (Dafermos and Nikolaidi, 2022; Dunz et al., 2023; Distefano and D'Alessandro, 2023; Gourdel et al., 2024).
- SFC modelling provides an accounting framework that can accommodate different **post-Keynesian theoretical assumptions**.

The aim of this lecture is two-fold:

1. To provide an introduction to the features and the methodology of SFC models. Particular emphasis will be placed on the **steps** that need to be followed in practice in order to develop, calibrate and simulate SFC models.
2. To present how **ecological aspects** can be incorporated into SFC models.

Outline

1. Features of SFC models
2. DEFINE-SIMPLE
3. DEFINE-GOV
4. Physical stocks and flows
5. Policy mixes in DEFINE
6. Conclusion

Outline

(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 flow 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 (such as the consumption and investment functions) are constructed following post-Keynesian theories.

(1) There are no black holes

Balance sheet matrix

	Households	**Firms**	**Commercial banks**	**Total**
Deposits	$+D_t$		$-D_t$	0
Loans		$-L_t$	$+L_t$	0
Capital		$+K_t$		$+K_t$
Total (net worth)	$+D_t$	$+V_{Ft}$	0	$+K_t$

(1) There are no black holes

Transactions flow matrix

	Households	Firms		Commercial banks		Total
		Current	Capital	Current	Capital	
Consumption	-C_t	+C_t				0
Firms' investment		+I_t	-I_t			0
Wages	+W_t	-W_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 loans		-$int_L L_{t-1}$		+$int_L L_{t-1}$		0
Change in deposits	-ΔD_t				+ΔD_t	0
Change in loans			+ΔL_t		-ΔL_t	0
Total	0	0	0	0	0	0

(2) The financial and the real spheres are integrated

- All SFC models have **at least one financial asset/liability**.
- Money is introduced both as a **stock** and as a **flow** variable.
- Two **examples** of the real sector-financial sector interlinkages:
  1. Financing of firms' investment (bank lending and financial markets affect the level of real investment)
  2. Asset price effects on consumption (via financial wealth) and investment (via Tobin's q).

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

- Labour and product markets do not clear through changes in wages and prices. They clear via **quantity adjustments**.
- The **pricing mechanism** only plays a clearing role in the **financial markets**.
- Although the SFC models are typically demand-led, it is possibly to introduce **supply-side** effects (by including endogenous labour productivity, debt defaults etc.).

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

- The **decisions of households** are formulated using **Davidson's** two-step decision process: The **1st step** refers to the decision about the proportion of income that will be saved. The **2nd step** refers to the way that savings are allocated between the various assets (portfolio choice).
- In many behavioural equations economic agents have **stock-flow targets** (e.g. wealth-to-income ratios, debt-to-income ratios, inventories-to-sales ratios) and **react to disequilibria** in order to achieve these targets.
- Behaviour can be different between **classes**.

Outline

E-SFC modelling

- Traditional SFC models are inconsistent with the **biophysical limits of a finite planet**.
- They ignore the fact that production and consumption are not possible without using **energy** and **matter** and they do not take into account that economic activity creates various types of **waste** that can destabilise the ecosystem.
- They also neglect other types of **environmental problems**, like the loss of biodiversity, water scarcity and deforestation.
- As a response to these limitations, several **ecological stock-flow consistent (E-SFC)** models have recently been developed.

DEFINE-SIMPLE: key features

- The steps for developing, calibrating and simulating a simple E-SFC model will be illustrated by using **DEFINE-SIMPLE**.
- DEFINE-SIMPLE is a simplified module of the **DEFINE** (Dynamic Ecosystem-FINance-Economy) model developed by Dafermos, Nikolaidi and Galanis (2017, 2018) and Dafermos and Nikolaidi (2019, 2021, 2022); for more information, see: www.define-model.org.
- DEFINE-SIMPLE is used to illustrate how **green investment** and **emissions** can be incorporated in a simple way in an SFC model.
- The model assumes that a proportion of total private investment is green and that a part of **bank loans** is used to finance this type of investment. An increase in the proportion of green capital to conventional capital leads to a decline in **carbon intensity**.

Steps in developing an SFC model

- **Step 1**: Identify the accounting structure of the model.
- **Step 2**: Specify the identities that stem from the accounting structure of the model.
- **Step 3**: Identify equations for the variables that are not defined through the accounting identities.
- **Step 4**: Put together all the equations of the model.

Step 1: Identify the accounting structure of the model

DEFINE-SIMPLE has the following **structure**:

- There are three **sectors**: firms, commercial banks and households.
- **Firms** undertake green and conventional investment by using retained profits and (green and conventional) loans. A part of firms' profits is distributed to households.
- **Commercial banks** provide firm loans by creating deposits. Banks distribute all their profits to households.
- **Households** accumulate savings in the form of deposits.
- Green investment affects **carbon intensity**. For a given carbon intensity, an increase in economic activity leads to an increase in emissions.

Step 1: Identify the accounting structure of the 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	$+K_t$

Step 1: Identify the accounting structure of the model

Transactions flow 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	+W_t	-W_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	$-\Delta D_t$				+ΔD_t	0
Change in green loans			+ΔL_{Gt}		-ΔL_{Gt}	0
Change in conventional loans			+ΔL_{Ct}		-ΔL_{Ct}	0
Total	0	0	0	0	0	0

Step 2: Specify the identities that stem from the accounting structure of the model

- Deposits: $D_t = D_{t-1} + Y_{Ht} - C_t$
- Total profits of firms: $TP_t = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1}$
- Conventional loans: $L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} - RP_t - (L_{Gt} - L_{Gt-1})$
- Profits of banks: $BP_t = int_G L_{Gt-1} + int_C L_{Ct-1} - int_D D_{t-1}$
- Deposits: $D_{redt} = L_t$
- Distributed profits: $DP_t = TP_t - RP_t$
- Output: $Y_t = C_t + I_t$
- Conventional investment: $I_{Ct} = I_t - I_{Gt}$
- Disposable income of households: $Y_{Ht} = W_t + DP_t + BP_t + int_D D_{t-1}$
- Total loans: $L_t = L_{Ct} + L_{Gt}$

Transactions flow 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	$+W_t$	$-W_t$				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

Step 2: Specify the identities that stem from the accounting structure of the model

- Capital stock: $K_t = K_{Ct} + K_{Gt}$

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	$+K_t$

Step 3: Identify equations for the variables that are not defined through the accounting identities

- Consumption expenditures: C_t
- Wage income: W_t
- Deposits (identity): D_t
- Total profits of firms (identity): TP_t
- Retained profits: RP_t
- Distributed profits (identity): DP_t
- Investment: I_t
- Green investment: I_{Gt}
- Conventional investment (identity): I_{Ct}
- Capital stock (identity): K_t
- Green capital stock: K_{Gt}
- Conventional capital stock: K_{Ct}
- Loans (identity): L_t
- Green loans: L_{Gt}
- Conventional loans (identity): L_{Ct}
- Profits of banks (identity): BP_t

Step 3: Identify equations for the variables that are not defined through the accounting identities

- Consumption expenditures: $C_t = c_1 Y_{Ht-1} + c_2 D_{t-1}$
- Wage income: $W_t = s_W Y_t$
- Retained profits: $RP_t = s_F TP_t$
- Investment: $I_t = (\alpha_0 + \alpha_1 r_{t-1}) K_{t-1}$
- Rate of profit: $r_t = TP_t / K_t$

where Y_{Ht}: disposable income, D_t: deposits, Y_t: output, TP_t: total profits of firms, K_t: capital stock

Step 3: Identify equations for the variables that are not defined through the accounting identities

- Green investment: $I_{Gt} = \beta_t I_t$
- Share of green investment in total investment: $\beta_t = \beta_0 - \beta_1 \left(int_G - int_C \right)$
- Green capital stock: $K_{Gt} = K_{Gt-1} + I_{Gt}$
- Conventional capital stock: $K_{Ct} = K_{Ct-1} + I_{Ct}$
- Green loans: $L_{Gt} = L_{Gt-1} + I_{Gt} - \beta_t RP_t$

where I_t: investment , int_G: interest rate on green loans, int_C: interest rate on conventional loans, I_{Ct}: conventional investment, RP_t retained profits of firms

Step 3: Identify equations for the variables that are not defined through the accounting identities

Emissions:

- Fossil CO_2 emissions: $EMIS_{Ft} = CI_t Y_t$
- Carbon intensity: $CI_t = CI_{\max} - \frac{CI_{\max} - CI_{\min}}{1 + ci_1 e^{-ci_2 (K_{Gt-1}/K_{Ct-1})}}$

Auxiliary equations:

- Potential output: $Y_t^* = vK_t$
- Capacity utilisation: $u_t = Y_t / Y_t^*$
- Growth rate of output: $g_{Yt} = (Y_t - Y_{t-1}) / Y_{t-1}$
- Leverage ratio: $lev_t = L_t / K_t$

where Y_t: output, K_{Gt}: green capital stock, K_{Ct}: conventional capital stock, K_t: capital stock, L_t: firms' loans

Step 4: Put together all the equations of the model

- The equations of DEFINE-SIMPLE are listed in Appendix A in Dafermos and Nikolaidi (2024).

Steps in calibrating and simulating an SFC model

- **Step 1**: Specify the first-period equations.
- **Step 2**: Identify parameter values and initial values for the endogenous variables
- **Step 3**: Check stock-flow consistency.
- **Step 4**: Design the simulation exercises.

Step 1: Specify the first-period equations

- To properly calibrate parameter values and initial values for endogenous variables, it is necessary to take explicitly into account **all the equations of the model**.
- If **arbitrary** or data-driven values are assigned to all parameters or initial values of the variables without considering the equations of the model, it is very likely that the model will follow an implausible dynamic pathway.
- This would happen because our calibration would not take into account the **implicit simplifications** that the model makes about the relationship between the variables included in the model.

Step 1: Specify the first-period equations

- To derive parameter values and initial values for the endogenous variables that are consistent with the model structure, we first need to write down the **first-period equations of the model**.
- When we do that we should address the fact that some variables are **lagged** in the model and, if we start running the model in period $t = 1$, we will not have values for these variables in period $t = 0$.
- To deal with that, we take into account that for each **variable** x_t we have $x_t = x_{t-1}(1+g_{xt})$ where g_{xt} is the growth rate of this variable in period t. Therefore, $x_{t-1} = x_t/(1+g_{xt})$.
- Writing this equation for $t = 1$, we get $x_{t=0} = x_{t=1}/(1+g_{xt=1})$. The latter formula should therefore be used for all variables that have a **lag** in the equations of the model.

Step 1: Specify the first-period equations

First-period equations	Step	Type of variable/parameter specified	Equations in the code for period t=1
$Y_{Ht=1} = W_{t=1} + DP_{t=1} + BP_{t=1} + int_D \frac{D_{t=1}}{1+g_{Dt=1}}$ (A.1)'	2b	Model-constrained variable	$Y_{Ht=1} = W_{t=1} + DP_{t=1} + BP_{t=1} + int_D \frac{D_{t=1}}{1+g_{Dt=1}}$
$W_{t=1} = s_W Y_{t=1}$ (A.2)'	2b	Model-constrained variable	$W_{t=1} = s_W Y_{t=1}$
$C_{t=1} = c_1 \frac{Y_{Ht=1}}{1+g_{YHt=1}} + c_2 \frac{D_{t=1}}{1+g_{Dt=1}}$ (A.3)'	2d	Model-constrained parameter	$c_1 = \frac{C_{t=1} - c_2 D_{t=1}/(1+g_{Dt=1})}{Y_{Ht=1}/(1+g_{YHt=1})}$
$D_t = \frac{D_{t=1}}{1+g_{Dt=1}} + Y_{Ht} - C_t$ (A.4)'	-	-	$-$
$Y_{t=1} = C_{t=1} + I_{t=1}$ (A.5)'	2a	Model-constrained variable	$C_{t=1} = Y_{t=1} - I_{t=1}$
$TP_{t=1} = Y_{t=1} - W_{t=1} - int_{LC} \frac{L_{Ct=1}}{1+g_{LCt=1}} - int_{LG} \frac{L_{Gt=1}}{1+g_{LGt=1}}$ (A.6)'	2b	Model-constrained variable	$TP_{t=1} = Y_{t=1} - W_{t=1} - int_{LC} \frac{L_{Ct=1}}{1+g_{LCt=1}} - int_{LG} \frac{L_{Gt=1}}{1+g_{LGt=1}}$
$RP_{t=1} = s_F TP_{t=1}$ (A.7)'	2d	Model-constrained parameter	$s_F = \frac{RP_{t=1}}{TP_{t=1}}$
$DP_{t=1} = TP_{t=1} - RP_{t=1}$ (A.8)'	2b	Model-constrained variable	$DP_{t=1} = TP_{t=1} - RP_{t=1}$
$I_{t=1} = (\alpha_0 + \alpha_1 r_{t=1}) \frac{K_{t=1}}{1+g_{Kt=1}}$ (A.9)'	2d	Model-constrained parameter	$\alpha_0 = \frac{I_{t=1}}{K_{t=1}(1+g_{Kt=1})} - \alpha_1 r_{t=1}$
$r_{t=1} = \frac{TP_{t=1}}{K_{t=1}}$ (A.10)'	2b	Model-constrained variable	$r_{t=1} = \frac{TP_{t=1}}{K_{t=1}}$
$I_{Gt=1} = \beta_{t=1} I_{t=1}$ (A.11)'	2a	Model-constrained variable	$\beta_{t=1} = \frac{I_{Gt=1}}{I_{t=1}}$
$\beta_{t=1} = \beta_0 - \beta_1 (int_G - int_C)$ (A.12)'	2d	Model-constrained parameter	$\beta_0 = \beta_{t=1} + \beta_1 (int_G - int_C)$
$I_{Ct=1} = I_{t=1} - I_{Gt=1}$ (A.13)'	2a	Model-constrained variable	$I_{Ct=1} = I_{t=1} - I_{Gt=1}$
$K_{Gt=1} = \frac{K_{Gt=1}}{1+g_{KGt=1}} + I_{Gt=1}$* (A.14)'	2b	Model-constrained variable	$K_{Gt=1} = \frac{1+g_{KGt=1}}{g_{KGt=1}} I_{Gt=1}$
$K_{Ct=1} = \frac{K_{Ct=1}}{1+g_{KCt=1}} + I_{Ct=1}$** (A.15)'	2b	Model-constrained variable	$K_{Ct=1} = \frac{1+g_{KCt=1}}{g_{KCt=1}} I_{Ct=1}$
$K_{t=1} = K_{Ct=1} + K_{Gt=1}$ (A.16)'	2b	Model-constrained variable	$K_{t=1} = K_{Ct=1} + K_{Gt=1}$

* Using $K_{Gt=1} = \frac{K_{Gt=1}}{1+g_{KGt=1}} + I_{Gt=1}$, we get $K_{Gt=1} = \frac{1+g_{KGt=1}}{g_{KGt=1}} I_{Gt=1}$

** Using $K_{Ct=1} = \frac{K_{Ct=1}}{1+g_{KCt=1}} + I_{Ct=1}$, we get $K_{Ct=1} = \frac{1+g_{KCt=1}}{g_{KCt=1}} I_{Ct=1}$

Step 1: Specify the first-period equations

First-period equations	Step	Type of variable/parameter specified	Equations in the code for period t=1
$L_{Gt=1} = \frac{L_{Gt=1}}{1+g_{LGt=1}} + I_{Gt=1} - \beta_t RP_{t=1}$ (A.17)'	2b	Model-constrained variable	$L_{Gt=1} = \frac{1+g_{LGt=1}}{g_{LGt=1}}(I_{Gt=1} - \beta_t RP_{t=1})$
$L_{Ct=1} = \frac{L_{Ct=1}}{1+g_{LCt=1}} + I_{Ct=1} + I_{Gt=1} - RP_{t=1} - (L_{Gt=1} - \frac{L_{Gt=1}}{1+g_{LGt=1}})$*** (A.18)'	2c	Model-constrained variable	$RP_{t=1} = I_{t=1} - \frac{g_{Lt=1}L_{t=1}}{1+g_{Lt=1}}$
$L_{t=1} = L_{Ct=1} + L_{Gt=1}$ (A.19)'	2c	Model-constrained variable	$L_{Ct=1} = L_{t=1} - L_{Gt=1}$
$BP_{t=1} = int_{LC}\frac{L_{Ct=1}}{1+g_{LCt=1}} + int_{LG}\frac{L_{Gt=1}}{1+g_{LGt=1}} - int_D\frac{D_{t=1}}{1+g_{Dt=1}}$ (A.20)'	2b	Model-constrained variable	$BP_{t=1} = int_{LC}\frac{L_{Ct=1}}{1+g_{LCt=1}} + int_{LG}\frac{L_{Gt=1}}{1+g_{LGt=1}} - int_D\frac{D_{t=1}}{1+g_{Dt=1}}$
$D_{redt=1} = L_{t=1}$ (A.21)'	2a	Model-constrained variable	$D_{t=1} = L_{t=1}$
$EMIS_{Ft=1} = CI_{t=1}Y_{t=1}$ (A.22)'	2a	Model-constrained variable	$CI_{t=1} = \frac{EMIS_{Ft=1}}{Y_{t=1}}$
$CI_{t=1} = CI_{\max} - \frac{CI_{\max}-CI_{\min}}{1+ci_1 e^{-ci_2(\frac{K_{Gt=1}}{1+g_{KG}}/\frac{K_{Ct=1}}{1+g_{KC}})}}$ (A.23)'	2d	Model-constrained parameter	$ci_1 = (\frac{CI_{\max}-CI_{\min}}{CI_{\max}-CI_{t=1}} - 1)e^{ci_2(\frac{K_{Gt=1}}{1+g_{KG}}/\frac{K_{Ct=1}}{1+g_{KC}})}$
$Y^*_{t=1} = vK_{t=1}$ (A.24)'	2d	Model-constrained parameter	$v = Y^*_{t=1}/K_{t=1}$
$u_{t=1} = Y_{t=1}/Y^*_{t=1}$ (A.25)'	2a	Model-constrained variable	$Y^*_{t=1} = Y_{t=1}/u_{t=1}$
$g_{Yt=1} = g^*$ (A.26)'	2a	Model-constrained variable	$g_{Yt=1} = g^*$
$lev_{t=1} = L_{t=1}/K_{t=1}$ (A.27)'	2b	Model-constrained variable	$lev_{t=1} = L_{t=1}/K_{t=1}$

*** Using $L_{Ct=1} = \frac{L_{Ct=1}}{1+g_{LCt=1}} + I_{Ct=1} + I_{Gt=1} - RP_{t=1} - (L_{Gt=1} - \frac{L_{Gt=1}}{1+g_{LGt=1}})$ and Eqs. (A.11) and (A.19), we get $L_{t=1} = \frac{L_{t=1}}{1+g_{Lt=1}} + I_{t=1} - RP_{t=1}$

Question for discussion

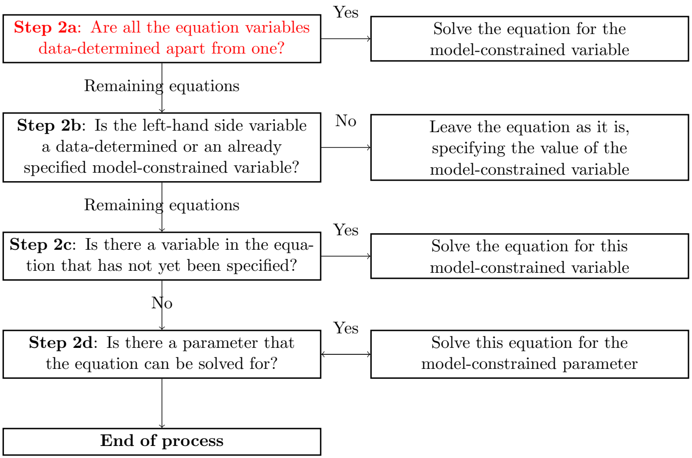
Suppose that you have data for output (Y_t), consumption (C_t), investment (I_t), household disposable income (Y_{Ht}), deposits (D_t), the growth rate of disposable income (g_{YH}), the growth rate of deposits (g_D), emissions ($EMIS_{Ft}$) and carbon intensity (CI_t). Would it make sense to use all this data to calibrate the equations below?

- $Y_{t=1} = C_{t=1} + I_{t=1}$
- $C_{t=1} = c_1 \frac{Y_{Ht=1}}{1+g_{YH}} + c_2 \frac{D_{t=1}}{1+g_D}$
- $EMIS_{Ft=1} = CI_{t=1} Y_{t=1}$

Step 2: Identify parameter values and initial values for the endogenous variables

- For the calibration, it is necessary to use a specific **country** or a group of countries as a reference.
- Based on the **GDP identity**, specify which variables of this identity will be calibrated using data and which variable will be used as a residual in the GDP identity.
- Identify all the **financial assets/liabilities** of the model and use real-world data for all of them, apart from one that should be specified via an accounting identity.
- In DEFINE-SIMPLE, we use the following **data-determined variables**: output (Y_t), investment (I_t), green investment (I_{Gt}), loans (L_t), the rate of capacity utilisation (u_t), the growth rate of output (g_{Yt}) and emissions ($EMIS_{Ft}$).

Step 2a: Identify parameter values and initial values for the endogenous variables



Step 2a: Identify parameter values and initial values for the endogenous variables

First-period equations	Step	Type of variable/parameter specified	Equations in the code for period t=1
$Y_{Ht=1} = W_{t=1} + DP_{t=1} + BP_{t=1} + int_D \frac{D_{t=1}}{1+g_{Dt=1}}$ (A.1)'			
$W_{t=1} = s_W Y_{t=1}$ (A.2)'			
$C_{t=1} = c_1 \frac{Y_{Ht=1}}{1+g_{YHt=1}} + c_2 \frac{D_{t=1}}{1+g_{Dt=1}}$ (A.3)'			
$D_t = \frac{D_{t=1}}{1+g_{Dt=1}} + Y_{Ht} - C_t$ (A.4)'			
$Y_{t=1} = C_{t=1} + I_{t=1}$ (A.5)'	2a	Model-constrained variable	$C_{t=1} = Y_{t=1} - I_{t=1}$
$TP_{t=1} = Y_{t=1} - W_{t=1} - int_{LC} \frac{L_{Ct=1}}{1+g_{LCt=1}} - int_{LG} \frac{L_{Gt=1}}{1+g_{LGt=1}}$ (A.6)'			
$RP_{t=1} = s_F TP_{t=1}$ (A.7)'			
$DP_{t=1} = TP_{t=1} - RP_{t=1}$ (A.8)'			
$I_{t=1} = (\alpha_0 + \alpha_1 r_{t=1}) \frac{K_{t=1}}{1+g_{Kt=1}}$ (A.9)'			
$r_{t=1} = \frac{TP_{t=1}}{K_{t=1}}$ (A.10)'			
$I_{Gt=1} = \beta_{t=1} I_{t=1}$ (A.11)'	2a	Model-constrained variable	$\beta_{t=1} = \frac{I_{Gt=1}}{I_{t=1}}$
$\beta_{t=1} = \beta_0 - \beta_1 (int_G - int_C)$ (A.12)'			
$I_{Ct=1} = I_{t=1} - I_{Gt=1}$ (A.13)'	2a	Model-constrained variable	$I_{Ct=1} = I_{t=1} - I_{Gt=1}$
$K_{Gt=1} = \frac{K_{Gt=1}}{1+g_{KGt=1}} + I_{Gt=1}$* (A.14)'			
$K_{Ct=1} = \frac{K_{Ct=1}}{1+g_{KCt=1}} + I_{Ct=1}$** (A.15)'			
$K_{t=1} = K_{Ct=1} + K_{Gt=1}$ (A.16)'			

* Using $K_{Gt=1} = \frac{K_{Gt=1}}{1+g_{KGt=1}} + I_{Gt=1}$ we get $K_{Gt=1} = \frac{1+g_{KGt=1}}{g_{KGt=1}} I_{Gt=1}$

** Using $K_{Ct=1} = \frac{K_{Ct=1}}{1+g_{KCt=1}} + I_{Ct=1}$ we get $K_{Ct=1} = \frac{1+g_{KCt=1}}{g_{KCt=1}} I_{Ct=1}$

Step 2a: Identify parameter values and initial values for the endogenous variables

First-period equations	Step	Type of variable/parameter specified	Equations in the code for period t=1
$L_{Gt=1} = \frac{L_{Gt=1}}{1+g_{LGt=1}} + I_{Gt=1} - \beta_t RP_{t=1}$ (A.17)'			
$L_{Ct=1} = \frac{L_{Ct=1}}{1+g_{LCt=1}} + I_{Ct=1} + I_{Gt=1} - RP_{t=1} - (L_{Gt=1} - \frac{L_{Gt=1}}{1+g_{LGt=1}})$*** (A.18)'			
$L_{t=1} = L_{Ct=1} + L_{Gt=1}$ (A.19)'			
$BP_{t=1} = int_{LC}\frac{L_{Ct=1}}{1+g_{LCt=1}} + int_{LG}\frac{L_{Gt=1}}{1+g_{LGt=1}} - int_D\frac{D_{t=1}}{1+g_{Dt=1}}$ (A.20)'			
$D_{redt=1} = L_{t=1}$ (A.21)'	2a	Model-constrained variable	$D_{t=1} = L_{t=1}$
$EMIS_{Ft=1} = CI_{t=1} Y_{t=1}$ (A.22)'	2a	Model-constrained variable	$CI_{t=1} = \frac{EMIS_{Ft=1}}{Y_{t=1}}$
$CI_{t=1} = CI_{\max} - \frac{CI_{\max} - CI_{\min}}{1+ci_1 e^{-ci_2(\frac{K_{Gt=1}}{1+g_{KG}}/\frac{K_{Ct=1}}{1+g_{KC}})}}$ (A.23)'			
$Y^*_{t=1} = vK_{t=1}$ (A.24)'			
$u_{t=1} = Y_{t=1}/Y^*_{t=1}$ (A.25)'	2a	Model-constrained variable	$Y^*_{t=1} = Y_{t=1}/u_{t=1}$
$g_{Yt=1} = g^*$ (A.26)'	2a	Model-constrained variable	$g_{Yt=1} = g^*$
$lev_{t=1} = L_{t=1}/K_{t=1}$ (A.27)'			

*** Using $L_{Ct=1} = \frac{L_{Ct=1}}{1+g_{LCt=1}} + I_{Ct=1} + I_{Gt=1} - RP_{t=1} - (L_{Gt=1} - \frac{L_{Gt=1}}{1+g_{LGt=1}})$ and Eqs. (A.11) and (A.19), we get $L_{t=1} = \frac{L_{t=1}}{1+g_{Lt=1}} + I_{t=1} - RP_{t=1}$

Step 2: Identify parameter values and initial values for the endogenous variables

For the **parameters** that have not been identified through the previous steps, options include:

- econometric estimation of parameters;
- use of values from real-world data;
- use of values from other studies;
- use of reasonable values.

Step 2: Identify parameter values and initial values for the endogenous variables

To summarise, we have made the following categorisation of variables and parameters:

- **Data-determined variables**: These are variables whose initial values are directly determined using data.
- **Model-constrained variables**: These are variables whose values are determined based on constraints imposed by the model equations once real-world data has been used.
- **Model-constrained parameters**: These are parameters whose values are determined based on constraints imposed by the model equations once real-world data has been used.
- **Free parameters**: These parameters can take any values.

Step 3: Check stock-flow consistency

- In order for your model to be **consistent** you need to ensure that:
  1. in the **initial period** all the stocks in the model satisfy the restrictions of the balance sheet matrix;
  2. the **identities** from the transactions flow matrix and balance sheet matrix are correctly written;
  3. the **adding-up constraints** are satisfied (if your model includes portfolio allocation).

- In the numerical simulations, consistency is checked by verifying that the **redundant equation** is satisfied.

Step 4: Design the simulation exercises

Simulations can be run in several different ways. Some options are listed below.

- **Option 1**: Consider the special case in which all the variables grow at the same rate in the first period (i.e. the model is at the steady state). Then a shock can be imposed and we can check how the dynamic pathway of the model is affected by the shock.
- **Option 2**: Modify some of the equations of DEFINE-SIMPLE by introducing some non-linearities (e.g. in the investment function) which increase the possibility that the model will generate some sort of cyclical behaviour.
- **Option 3**: Keep the model out-of-the-steady state and impose a shock. This would generate more realistic results. However, it would be more difficult to isolate the effects of the shock compared to the case in which the model is at a steady state.

Outline

DEFINE-GOV: key features

- DEFINE-GOV extends DEFINE-SIMPLE by introducing a **government sector** that collects taxes (including carbon taxes), provides green subsidies and undertakes consumption expenditures. This allows the analysis of specific green fiscal policies.
- DEFINE-GOV consists of four sectors: firms, households, banks and the government.
- Compared to DEFINE-SIMPLE, firms' **share of green investment** in total investment is not only affected by the difference between the interest rate on green loans and conventional loans. It is also a positive function of carbon taxes and green subsidies.

Step 1: Identify the accounting structure of the model

Government securities are held by households (SEC_{Ht}) and commercial banks (SEC_{Bt}).

Balance sheet matrix

	Households	**Firms**	**Commmercial banks**	**Government**	**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		$+K_{Ct}$			$+K_{Ct}$
Government securities	$+SEC_{Ht}$		$+SEC_{Bt}$	$-SEC_t$	0
Total (net worth)	$+V_{Ht}$	$+V_{Ft}$	0	$-SEC_t$	$+K_t$

Step 1: Identify the accounting structure of the model

The government pays interest on government securities, undertakes consumption spending and provides **green subsidies**. It also collects **taxes** from firms and households.

Transactions flow matrix

	Households	Firms		Commercial banks		Government	Total
		Current	Capital	Current	Capital		
Private consumption expenditures	$-C_{(PRI)t}$	$+C_{(PRI)t}$					0
Government consumption expenditures		$+C_{(GOV)t}$				$-C_{(GOV)t}$	0
Green investment		$+I_{Gt}$	$-I_{Gt}$				0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$				0
Wages	$+W_t$	$-W_t$					0
Green subsiidies		$+SUB_t$				$-SUB_t$	0
Taxes	$-T_{Ht}$	$-T_{Ft}-T_{Ct}$				$+T_t$	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
Interest on government securities	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$	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
Change in government securities	$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$	$+\Delta SEC_t$	0
Total	0	0	0	0	0	0	0

Step 2: Specify the identities that stem from the accounting structure of the model

Households

- Deposits: $D_t = D_{t-1} + Y_{Ht} - C_{(PRI)t} - (SEC_{Ht} - SEC_{Ht-1})$
- Gross disposable income of households: $Y_{HGt} = W_t + DP_t + BP_t + int_D D_{t-1} + int_S SEC_{Ht-1}$
- Net disposable income of households: $Y_{Ht} = Y_{HGt} - T_{Ht}$

Firms

- Total net profits of firms: $TP_t = TP_{Gt} - T_{Ft} - T_{Ct} + SUB_t$
- Total gross profits of firms: $TP_{Gt} = Y_t - W_t - int_C L_{Ct-1} - int_G L_{Gt-1}$
- Output: $Y_t = C_{(PRI)t} + I_t + C_{(GOV)t}$
- Conventional loans: $L_{Ct} = L_{Ct-1} + I_{Ct} + I_{Gt} - RP_t - (L_{Gt} - L_{Gt-1})$

Transactions flow matrix

	Households	Firms		Commercial banks		Government	Total
		Current	Capital	Current	Capital		
Private consumption expenditures	$-C_{(PRI)t}$	$+C_{(PRI)t}$					0
Government consumption expenditures		$+C_{(GOV)t}$				$-C_{(GOV)t}$	0
Green investment		$+I_{Gt}$	$-I_{Gt}$				0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$				0
Wages	$+W_t$	$-W_t$					0
Green subsiidies		$+SUB_t$				$-SUB_t$	0
Taxes	$-T_{Ht}$	$-T_{Ft}-T_{Ct}$				$+T_t$	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
Interest on government securities	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$	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
Change in government securities	$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$	$+\Delta SEC_t$	0
Total	0	0	0	0	0	0	0

Step 2: Specify the identities that stem from the accounting structure of the model

Banks

- Profits of banks: $BP_t = int_C L_{Ct-1} + int_G L_{Gt-1} + int_S SEC_{Bt-1} - int_D D_{t-1}$
- Government securities held by banks: $SEC_{Bt} = D_t - L_{Gt} - L_{Ct}$

Government

- Government securities: $SEC_t = SEC_{t-1} + int_S SEC_{t-1} - T_t + SUB_t + C_{(GOV)t}$

Horizontal constraints

- Distributed profits: $DP_t = TP_t - RP_t$
- Government securities held by banks (redundant identity): $SEC_{Bredt} = SEC_t - SEC_{Ht}$

Transactions flow matrix

	Households	Firms		Commercial banks		Government	Total
		Current	Capital	Current	Capital		
Private consumption expenditures	$-C_{(PRI)t}$	$+C_{(PRI)t}$					0
Government consumption expenditures		$+C_{(GOV)t}$				$-C_{(GOV)t}$	0
Green investment		$+I_{Gt}$	$-I_{Gt}$				0
Conventional investment		$+I_{Ct}$	$-I_{Ct}$				0
Wages	$+W_t$	$-W_t$					0
Green subsiidies		$+SUB_t$				$-SUB_t$	0
Taxes	$-T_{Ht}$	$-T_{Ft}-T_{Ct}$				$+T_t$	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
Interest on government securities	$+int_S SEC_{Ht-1}$			$+int_S SEC_{Bt-1}$		$-int_S SEC_{t-1}$	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
Change in government securities	$-\Delta SEC_{Ht}$				$-\Delta SEC_{Bt}$	$+\Delta SEC_t$	0
Total	0	0	0	0	0	0	0

Step 2: Specify the identities that stem from the accounting structure of the model

Balance sheet matrix

- Wealth of households: $V_{Ht} = SEC_{Ht} + D_t$
- Capital stock: $K_t = K_{Ct} + K_{Gt}$

	Households	Firms	Commmercial banks	Government	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		$+K_{Ct}$			$+K_{Ct}$
Government securities	$+SEC_{Ht}$		$+SEC_{Bt}$	$-SEC_t$	0
Total (net worth)	$+V_{Ht}$	$+V_{Ft}$	0	$-SEC_t$	$+K_t$

Step 3: Identify equations for the variables that are not defined through the accounting identities

Firms

- Investment: $I_t = (\alpha_0 + \alpha_1 r_{t-1}) K_{t-1}$
- Green investment: $I_{Gt} = \beta_t I_t$
- Share of green investment in total investment:
  $\beta_t = \beta_0 - \beta_1 (int_G - int_C) + \beta_2 tucn_{t-1} + \beta_3 gov_{SUB}$
- Total unit cost of producing non-renewable energy: $tucn_t = ucn + \tau_C \omega$
- Green capital stock: $K_{Gt} = K_{Gt-1} + I_{Gt}$

where r_t: rate of profit, K_t: capital stock, int_G: interest rate on green loans, int_C: interest rate on conventional loans, gov_{SUB}: green subsidy rate, ucn: Pre-tax unit cost of producing non-renewable energy (USD trillion/EJ), τ_C: carbon tax (USD trillion/$GtCO_2$), ω: CO_2 intensity of fossil energy

Step 3: Identify equations for the variables that are not defined through the accounting identities

Government

- Government consumption expenditures: $C_{(GOV)t} = gov_C Y_{t-1}$
- Green government subsidies: $SUB_t = gov_{SUB} I_{Gt-1}$
- Revenues from carbon taxes: $T_{Ct} = \tau_C EMIS_{Ft-1}$

where Y_t: output, gov_C: share of government expenditure in output, gov_{SUB}: green subsidy rate, I_{Gt}: green investment, τ_C: carbon tax (USD trillion/GtCO$_2$), $EMIS_{Ft}$: fossil emissions

Step 3: Identify equations for the variables that are not defined through the accounting identities

Emissions

- Fossil CO_2 emissions: $EMIS_{Ft} = CI_t Y_t$
- Carbon intensity: $CI_t = CI_{\max} - \frac{CI_{\max} - CI_{\min}}{1 + ci_1 e^{-ci_2 (K_{Gt-1}/K_{Ct-1})}}$

where Y_t: output, K_{Gt}: green capital stock, K_{Ct}: conventional capital stock

Step 4: Put together all the equations of the model

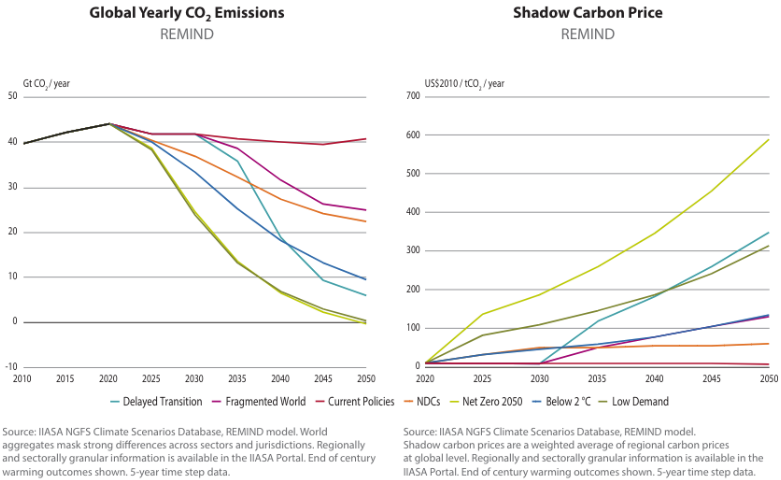
- The equations of DEFINE-GOV are listed in Appendix B in Dafermos and Nikolaidi (2024).

The **NGFS scenarios** have been developed by the central banking community to explore different levels of transition and physical risks depending on what climate policies might be implemented in the coming decades. They include:

- Three orderly scenarios
- One disorderly scenario
- Two hot house world scenarios

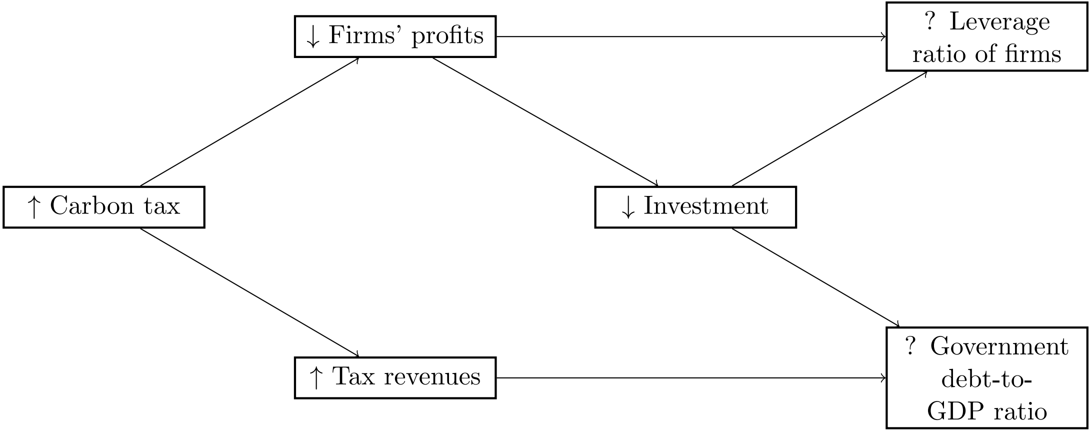
Orderly scenarios assume climate policies are introduced early and become gradually more stringent. Both physical and transition risks are relatively subdued.

- The **Net Zero 2050** scenario limits global warming to 1.4°C through stringent climate policies and innovation, reaching global net zero CO2 emissions around 2050.
- The **Below 2°C** scenario gradually increases the stringency of climate policies, limiting global warming to 1.6°C.



Source: NGFS (2023)

Transmissions channels of an increase in carbon taxes in DEFINE-GOV



Outline

The importance of physical stocks and flows

- An integrated incorporation of environmental aspects into an SFC model requires the use of **additional matrices**, apart from the transactions and the balance sheet ones.
- The **physical flow matrix** captures the flows of energy and matter.
- The **physical stock-flow matrix** captures the interaction between physical stocks and flows.
- These matrices go back to the work of **Georgescu-Roegen (1971)** and rely on the laws of thermodynamics.

Physical flow matrix for energy and matter

	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		
Fossil CO_2 emissions	$-EMIS_{Ft}$	
Waste	$-W_t$	
Dissipated energy		$-ED_t$
Change in socio-economic stock	$-\Delta SES_t$	
Total	0	0

Note: Energy and matter are measured in EJ and Gt, respectively.

Physical stock-flow matrix for energy, matter and carbon

	Material reserves	Fossil energy reserves	Cumulative CO_2 emissions	Socio-economic stock	Cumulative hazardous waste
Opening stock	REV_{Mt-1}	REV_{Et-1}	$CO2_{CUMt-1}$	SES_{t-1}	HW_{CUMt-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	$-M_t$	$-E_{Ft}$			
Demolished/disposed socio-economic stock				$-DEM_t$	
Closing stock	REV_{Mt}	REV_{Et}	$CO2_{CUMt}$	SES_t	HW_{CUMt}

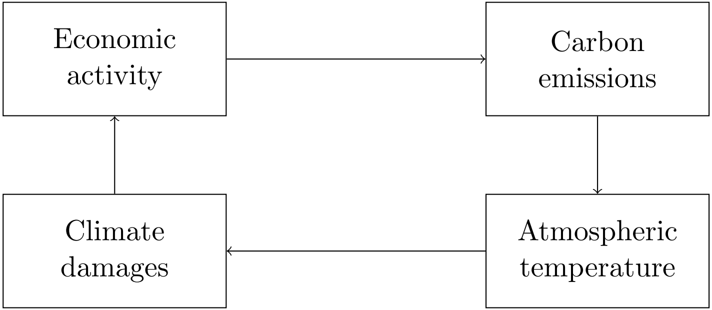
Note: Energy and matter are measured in EJ and Gt, respectively.

Emissions

- **Fossil CO_2 emissions** ($EMIS_{Ft}$) are generated when fossil fuels (E_{Ft}) are utilised to produce energy: $EMIS_{Ft}=\omega_t(1\text{-}seq_t)E_{Ft}$
- **Land CO_2 emissions** are generated when the forest carbon stock and the industrial roundwood stock decline.
- **Atmospheric temperature** (T_{ATt}) is a positive function of cumulative carbon emissions (CO2_{CUMt}): $T_{ATt}=T_{ATt-1}+t_1(t_2\varphi CO2_{CUMt-1}\text{-}T_{ATt-1})$

where ω_t: CO_2 intensity; seq_t: proportion of sequestrated 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: Transient Climate Response to cumulative carbon Emissions (TCRE) (^{o}C/GtCO_2)

Emissions, temperature and damages



Damages

- The feedback effects of the environment on the economy can be incorporated through **damage functions**.
- In **mainstream environmental models** the damages are confined to the supply side and tend to be optimistic.
- In **SFC models** damages refer both to the demand and the supply side and tend to be more pessimistic.
- The incorporation of damages remains a very challenging task and we are still far from formulating them properly.

Physical stock-flow matrix for water

	Water resources	Available water stock	Embodied water stock	Polluted water stock	**Total**
Opening stock	$RES_{W\,t-1}$	AWS_{t-1}	EWS_{t-1}	PWS_{t-1}	
Resources converted into available stock	$-CON_{W\,t}$	$+CON_{W\,t}$			0
Water treatment		$+TW_t$		$-TW_t$	0
Embodied water stock converted into resources	$+CON_{WS\,t}$		$-CON_{WS\,t}$		0
Consumptive water use		$-WU_t$	$+WU_t$		0
Water pollution		$-PW_t$		$+PW_t$	0
Closing stock	$RES_{W\,t}$	AWS_t	EWS_t	PWS_t	

Note: Water is measured in km^3.

Physical stock-flow matrix for land

	Natural forest	Planted forest	Regenerated natural forest	Cropland	Pastureland	Built-up area	Other land	Total
Opening stock	FOR_{Nt-1}	FOR_{Pt-1}	FOR_{REGt-1}	$CROP_{t-1}$	$PAST_{t-1}$	$BUILT_{t-1}$	$OTHER_{Lt-1}$	$LAND_T$
Cropland-related deforestation	$-DEF_{C}t$			$+DEF_{Ct}$				0
Pastureland-related deforestation	$-DEF_{Pt}$				$+DEF_{Pt}$			0
Planted forests-related deforestation	$-DEF_{PFt}$	$+DEF_{PFt}$						0
Other-land-related deforestation	$-DEF_{Ot}$						$+DEF_{Ot}$	0
Deforestation due to built-up area	$-DEF_{B}$					$+DEF_{Bt}$		0
Land conversion from pastureland to cropland				$+LC_{PCt}$	$-LC_{PCt}$			0
Cropland reforestation/afforestation		$+REF_{Ct}$		$-REF_{Ct}$				0
Pastureland reforestation/afforestation		$+REF_{Pt}$			$+REF_{Pt}$			0
Cropland regenerated into natural forest			$+REG_{Ct}$	$-REG_{Ct}$				0
Pastureland regenerated into natural forest			$+REG_{Pt}$		$-REG_{Pt}$			0
Planted forest regenerated into natural forest		$-REG_{PFt}$	$+REG_{PFt}$					0
Other land regenerated into natural forest			$+REG_{Ot}$				$-REG_{Ot}$	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
Closing stock	FOR_{Nt}	FOR_{Pt}	FOR_{REGt}	$CROP_t$	$PAST_t$	$BUILT_t$	$OTHER_{Lt}$	$LAND_T$

Note: Land is measured in million hectares.

Outline

Mainstream vs SFC models

Mainstream models	**SFC (and other post-Keynesian) 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
Mitigation represents only a cost	Mitigation is both a cost and a source of income
Environmental problems as an externality/cost-benefit analysis	Economy as a subsystem of the ecosystem/Systems-based analysis

The DEFINE 1.1 model consists of two big blocks and various sub-blocks.

Ecosystem

- Matter, waste and recycling
- Energy
- Emissions and climate change
- Ecological efficiency and technology

Macroeconomy and financial system

- Output determination
- Firms
- Households
- Banks
- Government sector
- Central banks

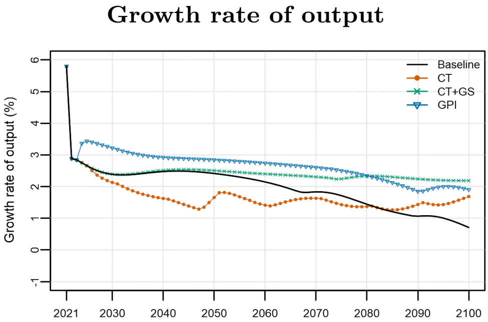
Baseline scenario

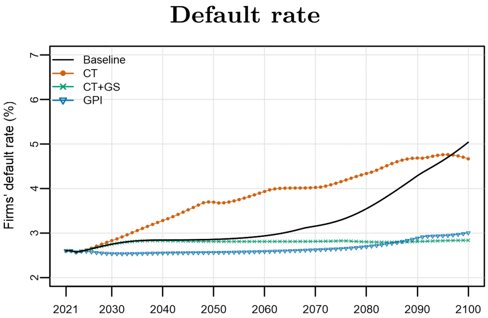
- We use a combination of calibration and estimation techniques. For example, we **econometrically** estimate some functions (such as investment, consumption and loans) using panel data for the global economy.
- We run the model for the period 2021-2100.
- Our baseline scenario corresponds to IPCC's SSP2 and SSP3 mitigation scenarios with temperature equal to about 3.2 degrees at the end of the century.

Green fiscal policies

1. **Carbon Tax (CT)**: An increase in carbon taxes after 2024, without revenue recycling.
2. **Carbon Tax+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.
3. **Green Public Investment (GPI)**: Green public investment increases after 2024 from around 0.2% to 0.8% of GDP per year.

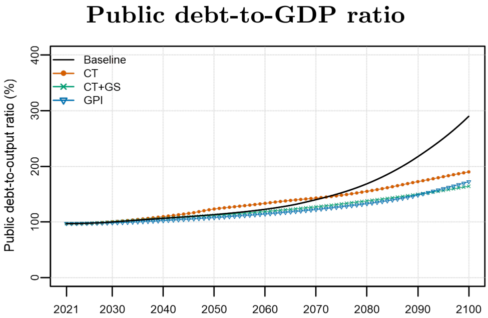
Green fiscal policies

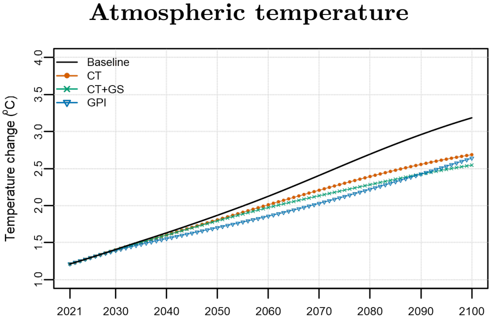




Source: Dafermos and Nikolaidi (2022)
CT: Carbon Tax
CT+GS: Carbon Tax + Green Subsidy
GPI: Green Public Investment

Green fiscal policies





Source: Dafermos and Nikolaidi (2022)
CT: Carbon Tax
CT+GS: Carbon Tax + Green Subsidy
GPI: Green Public Investment

Green fiscal policies

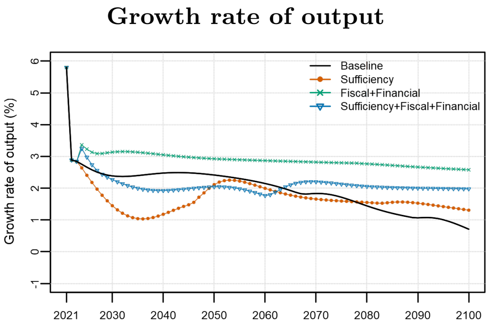
Type of indicator	Indicator	Carbon Tax		Carbon Tax+Green Subsidy		Green Public Investment	
		Short run	Long run	Short run	Long run	Short run	Long run
Ecological	Temperature	Mildly declines	Declines	Mildly declines	Declines	Mildly declines	Declines
	Waste per capita	Mildly declines	Declines	Mildly declines	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

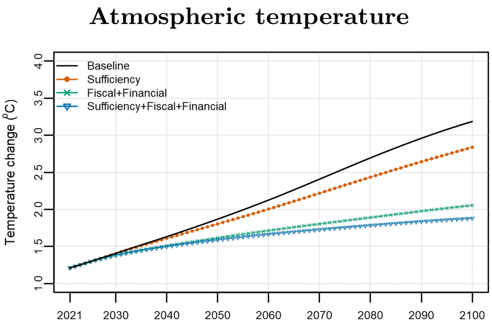
Source: Dafermos and Nikolaidi (2022)

Sufficiency policies and climate policy mixes

- **Sufficiency scenario**: Policies that reduce consumption are introduced gradually over the period 2024-2100 and lead to a reduction in the propensities to consume by 15% in 2100 compared to their 2024 levels (this is combined with a reduction in working hours).
- Two climate policy mixes:
  1. **Fiscal+Financial scenario**: We combine green fiscal policies and green monetary/financial policies.
  2. **Sufficiency+Fiscal+Financial scenario**: We combine the sufficiency policies with the macroeconomic and financial policies of the previous scenario.

Sufficiency policies and climate policy mixes





Source: Dafermos and Nikolaidi (2022)

Sufficiency policies and climate policy mixes

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

Source: Dafermos and Nikolaidi (2022)

Outline

- SFC models constitute a flexible tool for analysing complex issues that involve an active role of **finance**.
- They have the capacity to form a solid alternative to DSGE models.
- However, more **progress** needs to be made in the way that these models are calibrated, validated and simulated.

Areas for future research in E-SFC modelling:

- Degrowth, consumption patterns and environmental regulation
- Links between environmental policies and balance of payments constraints
- Sectoral dynamics (e.g. through input-output tables) and inequality
- Country-specific E-SFC models
- Global North-Global South interactions and global climate justice