Climate change, financial stability and monetary policy

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- **Climate change** is likely to have severe effects on the stability of the **financial system**.
- So far, most quantitative analyses have concentrated on the transition risks (see e.g. Carbon Tracker Initiative, 2011; Comerford and Spiganti, 2015; Battiston et al., 2016; Plantinga and Scholtens, 2016).
- Much less attention has been paid to the impact of climate change on financial stability as a result of its **economic damages** (physical risks).

Two key physical risks for the financial system:

- The increase in temperature and the economic catastrophes caused by climate change could reduce the **profitability** of firms and could deteriorate their financial position. Accordingly, debt defaults could arise which would lead to **systemic bank losses**.
- Lower firm profitability combined with global warming-related damages can affect the **confidence** of investors, inducing a rise in liquidity preference and a **fire sale** of the financial assets issued by the corporate sector.

- In this paper, we develop an **ecological macroeconomic model** that sheds light on these financial stability effects of climate change.
- The model builds on the stock-flow-fund model of Dafermos et al. (2017) which relies on a novel synthesis of the stock-flow consistent approach (see Burgess et al., 2016) with the flow-fund model of Georgescu-Roegen (1971, ch. 9; 1979; 1984).
- Our model permits a more detailed examination of the financial stability effects of climate change compared to Dietz et al. (2016). In particular, our framework includes (i) a detailed analysis of the interlinkages between **financial flows** and **assets/liabilities**, (ii) a **portfolio** structure with multiple financial assets and (iii) **money endogeneity** and the feedback effects of finacial instability on economic activity.

- An additional contribution of this paper is that it examines how monetary policy could reduce the risks imposed on the financial system by climate change.
- Drawing on the recent discussions about the potential use of monetary policy in tackling climate change (see e.g. Werner, 2012; Campiglio, 2016), we examine the extent to which a global **green quantitative easing (QE)** programme could ameliorate the financial distress caused by climate change.

Outline

Outline

The 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

Physical flow matrix

	Material balance	Energy balance
Inputs		
Extracted matter	$+M$	
Renewable energy		$+ER$
Non-renewable energy	$+CEN$	$+EN$
Oxygen	$+O2$	
Outputs		
Industrial CO_2 emissions	$-EMIS_{IN}$	
Waste	$-W$	
Dissipated energy		$-ED$
Change in socio-economic stock	$-\Delta SES$	
Total	0	0

Physical stock-flow matrix

	Material reserves	Non-renewable energy reserves	Atmospheric CO_2 concentration	Socio-economic stock	Hazardous waste
Opening stock	REV_{M-1}	REV_{E-1}	$CO2_{AT-1}$	SES_{-1}	HWS_{-1}
Additions to stock					
Resources converted into reserves	$+CONV_M$	$+CONV_E$			
CO_2 emissions			$+EMIS$		
Production of material goods				$+MY$	
Non-recycled hazardous waste					$+hazW$
Reductions of stock					
Extraction	$-M$	$-EN$			
Net transfer to oceans/biosphere			$+(\phi_{11}-1)CO2_{AT-1}+\phi_{21}CO2_{UP-1}$		
Demolished/disposed material goods				$-DEM$	
Closing stock	REV_M	REV_E	$CO2_{AT}$	SES	HWS

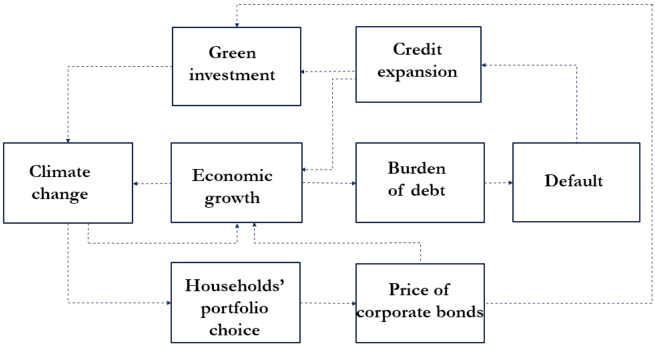
Transactions flow matrix

	Households	Firms		Commercial banks		Government sector	Central banks		Total
		Current	Capital	Current	Capital		Current	Capital	
Consumption	$-C$	$+C$							0
Government expenditures		$+G$				$-G$			0
Conventional investment		$+I_C$	$-I_C$						0
Green investment		$+I_G$	$-I_G$						0
Wages	$+wN$	$-wN$							0
Taxes	$-T_H$	$-T_F$				$+T$			0
Firms' profits	$+DP$	$-TP$	$+RP$						0
Commercial banks' profits	$+BP_D$			$-BP$	$+BP_U$				0
Interest on deposits	$+int_D D_{-1}$			$-int_D D_{-1}$					0
Capital depreciation		$-\delta K_{-1}$	$+\delta K_{-1}$						0
Interest on conventional loans		$-int_C L_{C-1}$		$+int_C L_{C-1}$					0
Interest on green loans		$-int_G L_{G-1}$		$+int_G L_{G-1}$					0
Interest on conventional bonds	$+coupon_C b_{CH-1}$	$-coupon_C b_{C-1}$					$+coupon_C b_{CCB-1}$		0
Interest on green bonds	$+coupon_G b_{GH-1}$	$-coupon_G b_{G-1}$					$+coupon_G b_{GCB-1}$		0
Interest on government securities	$+int_S SEC_{H-1}$			$+int_S SEC_{B-1}$		$-int_S SEC_{-1}$	$+int_S SEC_{CB-1}$		0
Interest on advances				$-int_A A_{-1}$			$+int_A A_{-1}$		0
Central bank's profits						$+CBP$	$-CBP$		0
Δdeposits	$-\Delta D$				$+\Delta D$				0
Δconventional loans			$+\Delta L_C$		$-\Delta L_C$				0
Δgreen loans			$+\Delta L_G$		$-\Delta L_G$				0
Δconventional bonds	$-p_C \Delta b_{CH}$		$+p_C \Delta b_C$					$-p_C \Delta b_{CCB}$	0
Δgreen bonds	$-p_G \Delta b_{GH}$		$+p_G \Delta b_G$					$-p_G \Delta b_{GCB}$	0
Δgovernment securities	$-\Delta SEC_H$				$-\Delta SEC_B$	$+\Delta SEC$		$-\Delta SEC_{CB}$	0
Δadvances					$+\Delta A$			$-\Delta A$	0
Δhigh-powered money					$-\Delta HPM$			$+\Delta HPM$	0
Defaulted loans			$+DL$		$-DL$				0
Total	0	0	0	0	0	0	0	0	0

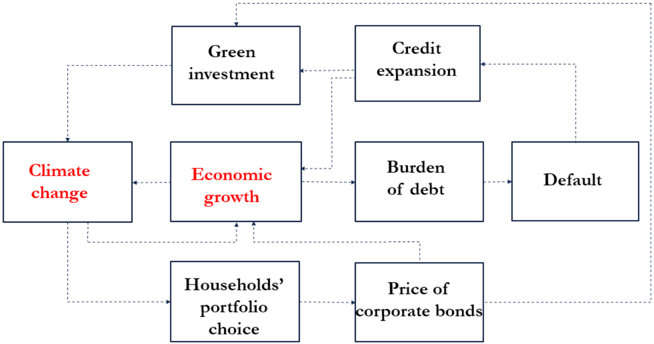
Balance sheet matrix

	Households	Firms	Commercial banks	Government sector	Central banks	Total
Conventional capital		$+K_C$				$+K_C$
Green capital		$+K_G$				$+K_G$
Durable consumption goods	$+DC$					$+DC$
Deposits	$+D$		$-D$			0
Conventional loans		$-L_C$	$+L_C$			0
Green loans		$-L_G$	$+L_G$			0
Conventional bonds	$+p_C b_{CH}$	$-p_C b_C$			$+p_C b_{CCB}$	0
Green bonds	$+p_G b_{GH}$	$-p_G b_G$			$+p_G b_{GCB}$	0
Government securities	$+SEC_H$		$+SEC_B$	$-SEC$	$+SEC_{CB}$	0
High-powered money			$+HPM$		$-HPM$	0
Advances			$-A$		$+A$	0
Total (net worth)	$+V_H$	$+V_F$	$+K_B$	$-SEC$	$+V_{CB}$	$+K_C + K_G + DC$

Channels through which climate change and financial stability interact in the model



Channels through which climate change and financial stability interact in the model



Climate change damages

- Industrial CO_2 emissions ($EMIS_{IN}$) are generated when the non-renewable energy resource (EN) is utilised in order to produce energy: $EMIS_{IN} = \omega EN$
- The stock of CO_2 that remains in the atmosphere relies on the carbon cycle.

CO_2 concentration in the **atmosphere**:

$$CO2_{AT} = EMIS + \phi_{11} CO2_{AT-1} + \phi_{21} CO2_{UP-1}$$

CO_2 concentration in the **upper ocean/biosphere**:

$$CO2_{UP} = \phi_{12} CO2_{AT-1} + \phi_{22} CO2_{UP-1} + \phi_{32} CO2_{LO-1}$$

CO_2 concentration in the **lower ocean**:

$$CO2_{LO} = \phi_{23} CO2_{UP-1} + \phi_{33} CO2_{LO-1}$$

Climate change damages

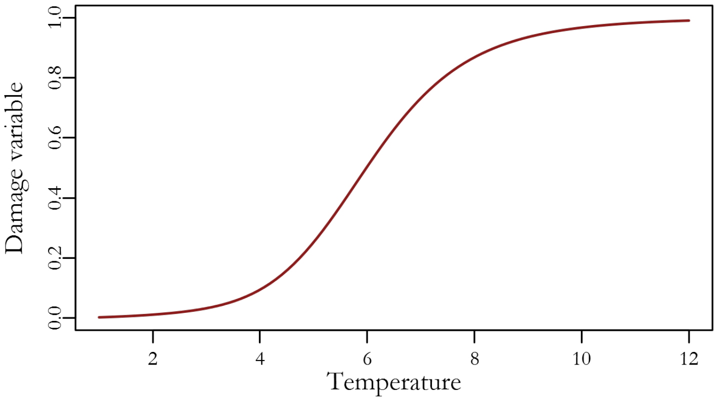
- We define the following **damage variable** (D_T) that takes values between 0 (no damage) and 1 (full damage):

$$D_T = 1 - \frac{1}{1 + \eta_1 T_{AT} + \eta_2 T_{AT}^2 + \eta_3 T_{AT}^{6.754}}$$

- The damage variable is a function of the atmospheric temperature (T_{AT}). The higher the temperature the higher the damage.
- The damage variable affects (1) labour productivity, (2) labour force, (3) capital depreciation, (4) capital productivity and (5) the components of aggregate demand (consumption and investment).

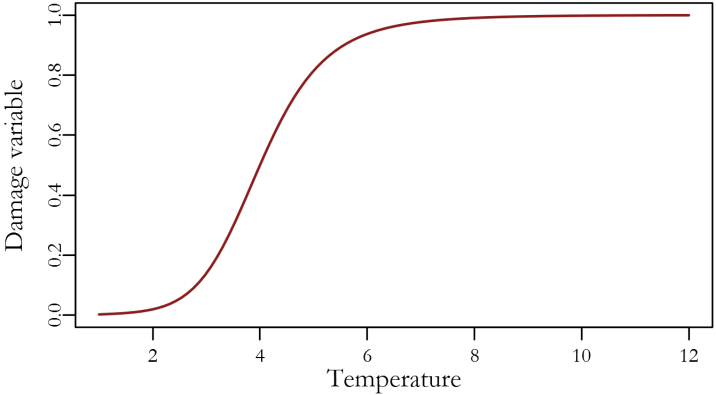
Climate change damages

Damage function (Weitzman, 2012)

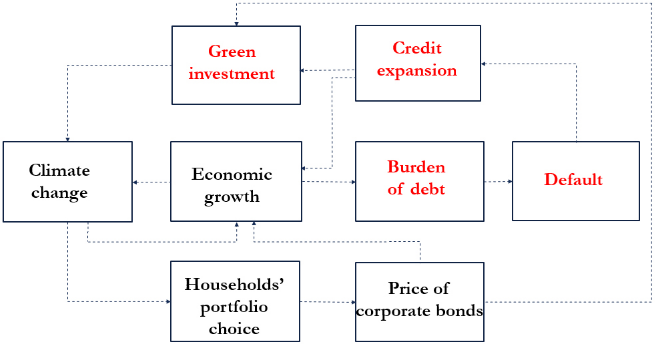


Climate change damages

Damage function (Dietz and Stern, 2015)



Channels through which climate change and financial stability interact in the model



Credit rationing and bank leverage

- **Degree of credit rationing for conventional loans** (CR_C):

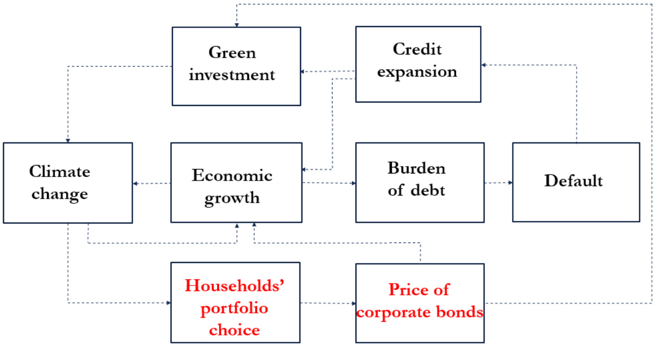
$$CR_C = r_0 + r_1 def_{-1} + r_2 lev_{B-1}$$

- **Degree of credit rationing for green loans** (CR_G):

$$CR_G = l_0 + l_1 def_{-1} + l_2 lev_{B-1}$$

where *def* is the rate of default and lev_B is banks' leverage ratio.

Channels through which climate change and financial stability interact in the model



The portfolio choice of households

$$\begin{bmatrix} \frac{SEC_H}{V_{HF-1}} \\ \frac{B_{CH}}{V_{HF-1}} \\ \frac{B_{GH}}{V_{HF-1}} \\ \frac{D}{V_{HF-1}} \end{bmatrix} = \begin{bmatrix} \lambda_{10} \\ \lambda_{20} \\ \lambda_{30} \\ \lambda_{40} \end{bmatrix} + \begin{bmatrix} \lambda'_{10} \\ \lambda'_{20} \\ \lambda'_{30} \\ \lambda'_{40} \end{bmatrix} D_{T-1} + \begin{bmatrix} \lambda_{11} & \lambda_{12} & \lambda_{13} & \lambda_{14} \\ \lambda_{21} & \lambda_{22} & \lambda_{23} & \lambda_{24} \\ \lambda_{31} & \lambda_{32} & \lambda_{33} & \lambda_{34} \\ \lambda_{41} & \lambda_{42} & \lambda_{43} & \lambda_{44} \end{bmatrix}$$

$$\begin{bmatrix} int_S \\ yield_{C-1} \\ yield_{G-1} \\ int_D \end{bmatrix} + \begin{bmatrix} \lambda_{15} \\ \lambda_{25} \\ \lambda_{35} \\ \lambda_{45} \end{bmatrix} \frac{Y_{H-1}}{V_{HF-1}}$$

where SEC_H denotes government securities, B_{CH} denotes conventional bonds, B_{GH} denotes green bonds, D denotes deposits, V_{HF} is household wealth and Y_H is household income.

Green investment

- **Share of desired green investment in total investment** (β):

$$\beta = \beta_0 + \beta_1 - \beta_2[sh_{L-1}(int_G - int_C) + (1 - sh_{L-1})(yield_{G-1} - yield_{C-1})] + \beta_3 D_{T-1}$$

where $\beta_0 + \beta_1$ captures the rise in green investment, for example, due to carbon price policies and green regulation, int_G is the interest rate on green loans, int_C is the interest rate on conventional loans, $yield_G$ is the yield on green bonds, $yield_C$ is the yield on conventional bonds and sh_L is the share of loans in total firm liabilities.

Green investment and finance

- Firms finance green investment via (1) retained profits; (2) bonds; (3) bank loans.
- The proportion of green investment funded via bonds increases as the yield on bonds declines.
- There is credit rationing: only a proportion of the demanded loans are provided by banks.

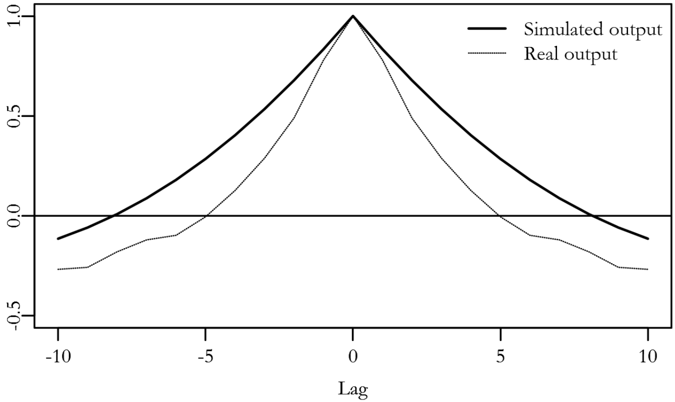
Outline

1. Structure and equations of the model
2. Calibration and validation
3. Simulation results I: climate change and financial stability
4. Simulation results II: green QE
5. Conclusion

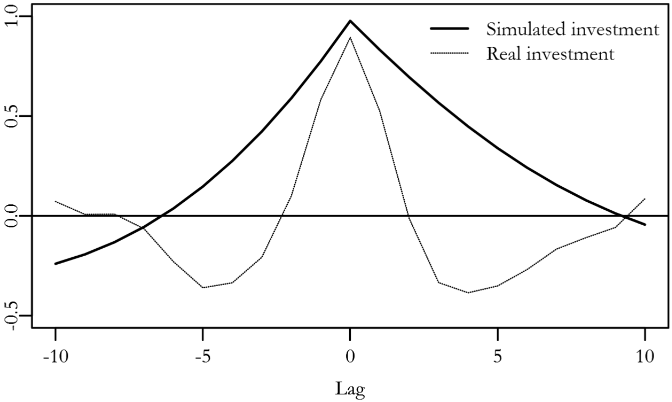
Baseline scenario:

- Very slow transition to a low-carbon economy and no financial collapse in the next decades.
- Economic growth is around 2.7-2.8% till 2050.
- Share of renewable energy increases (from 14% in 2015) to 18% in 2050.
- Energy intensity improves by 30% till 2050.
- Labour force becomes 4.5 bn people in 2050.
- Cumulative green investment in the period 2015-2050 is equal to around USD 35 trillion.
- The price of conventional bonds remains close to its current level till 2050.

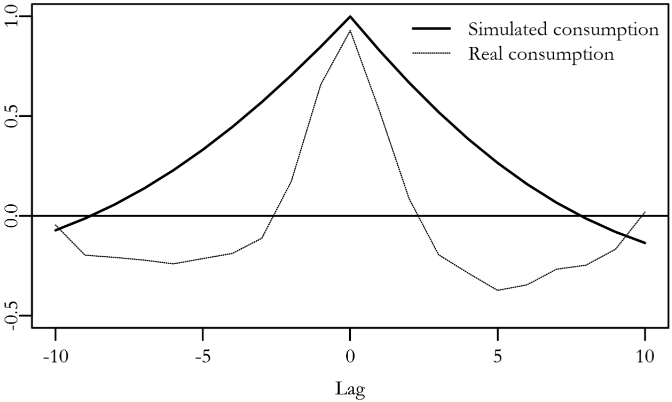
Cross-correlation: output



Cross-correlation: investment

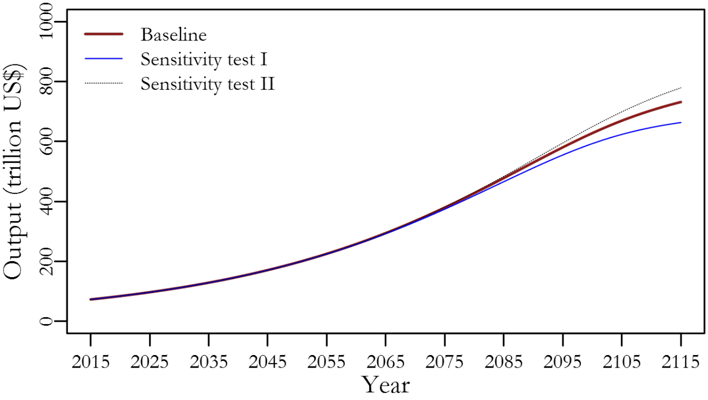


Cross-correlation: consumption

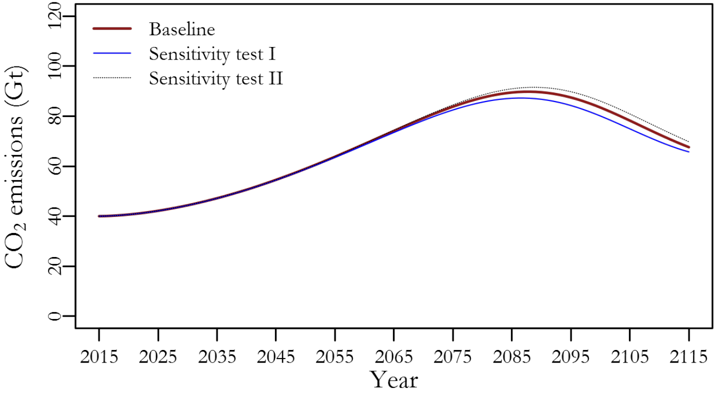


Outline

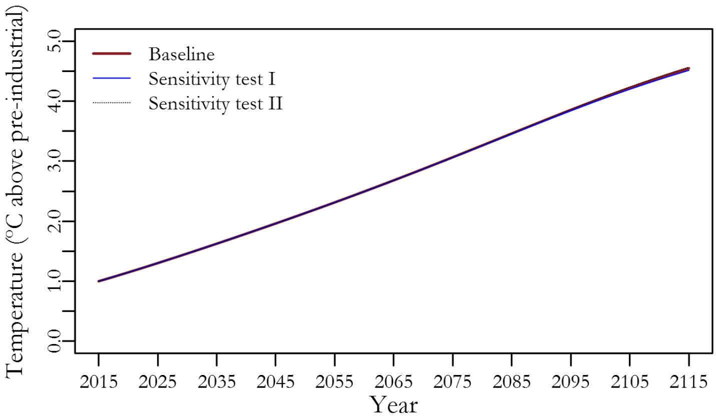
Output


Baseline
Sensitivity test I
Sensitivity test II
Output (trillion US$)
0
200
400
600
800
1000
2015
2025
2035
2045
2055
2065
2075
2085
2095
2105
2115
Year

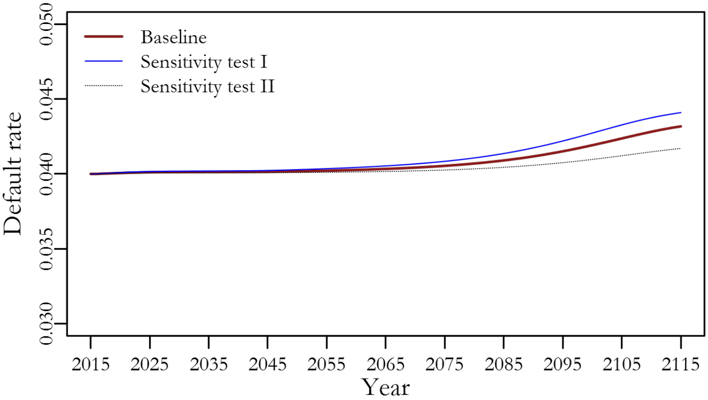
CO_2 emissions



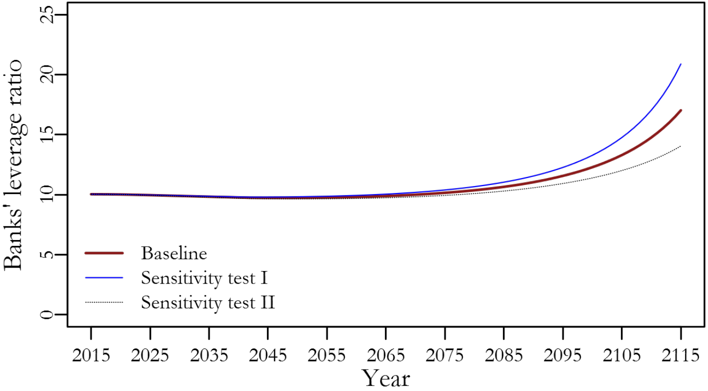
Atmospheric temperature



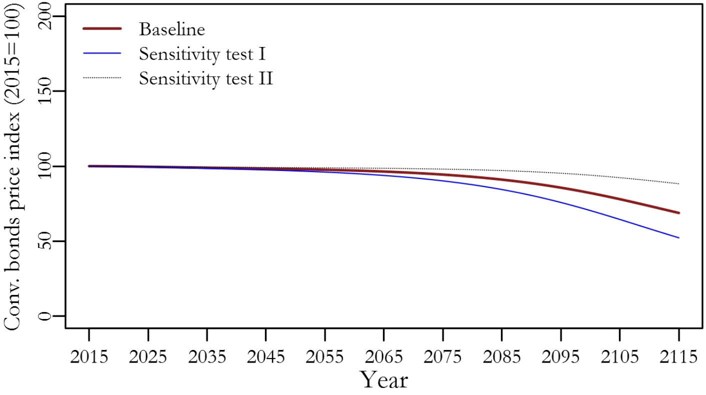
Default rate



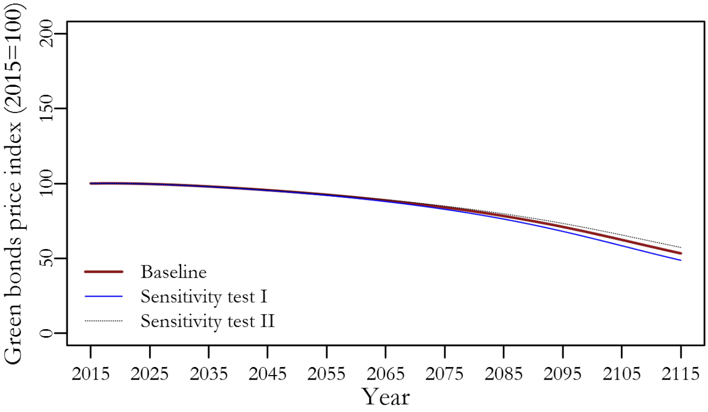
Banks' leverage ratio



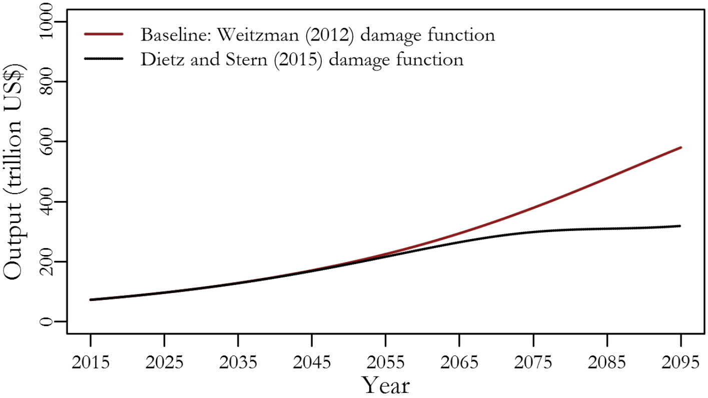
Conventional bonds price index



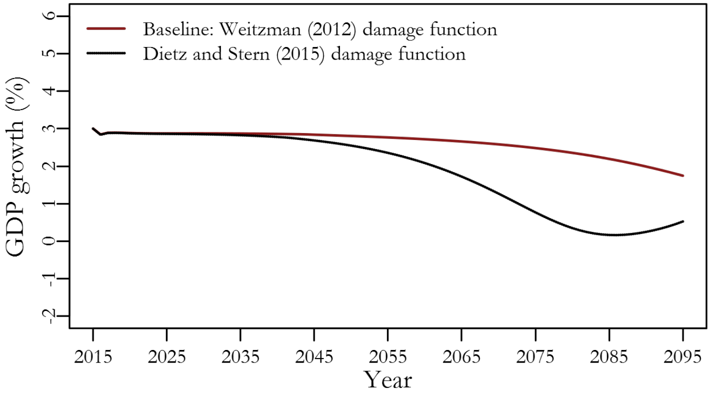
Green bonds price index



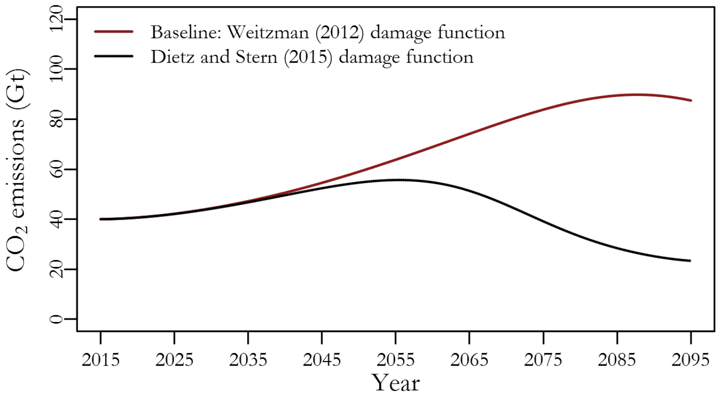
Output

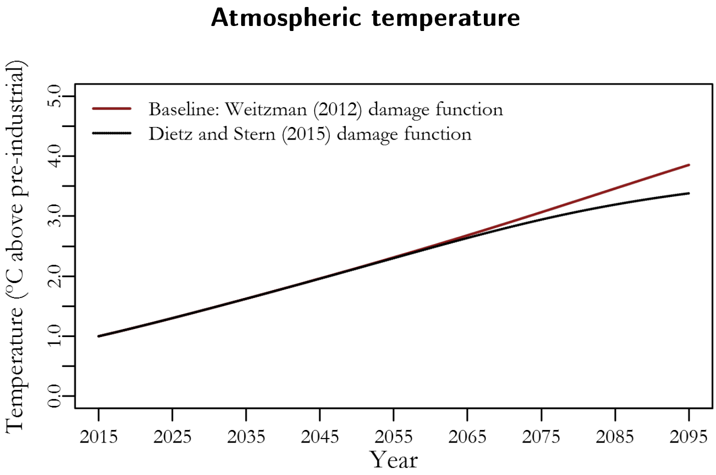

Baseline: Weitzman (2012) damage function
Dietz and Stern (2015) damage function
Output (trillion US$)
0
200
400
600
800
1000
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year

Growth rate of output

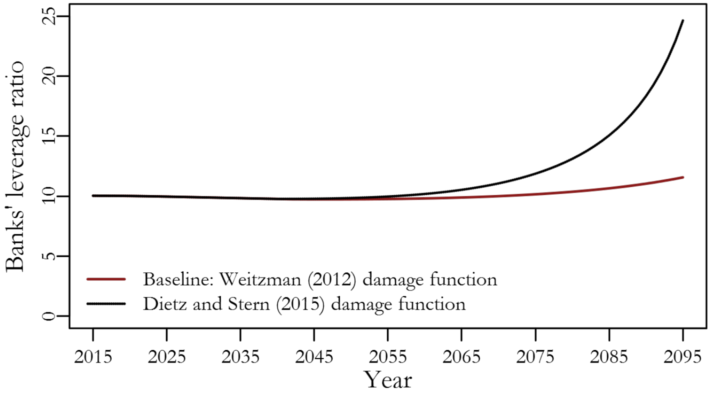


CO_2 emissions

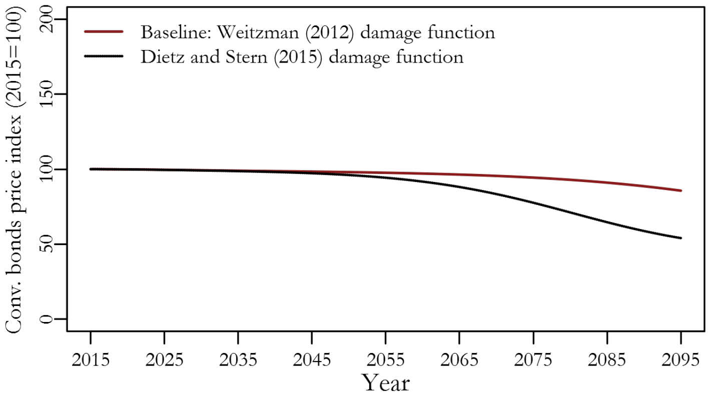



Atmospheric temperature
Baseline: Weitzman (2012) damage function
Dietz and Stern (2015) damage function
Temperature (°C above pre-industrial)
0.0
1.0
2.0
3.0
4.0
5.0
2015
2025
2035
2045
2055
2065
2075
2085
2095
Year

Banks' leverage ratio



Conventional bonds price index



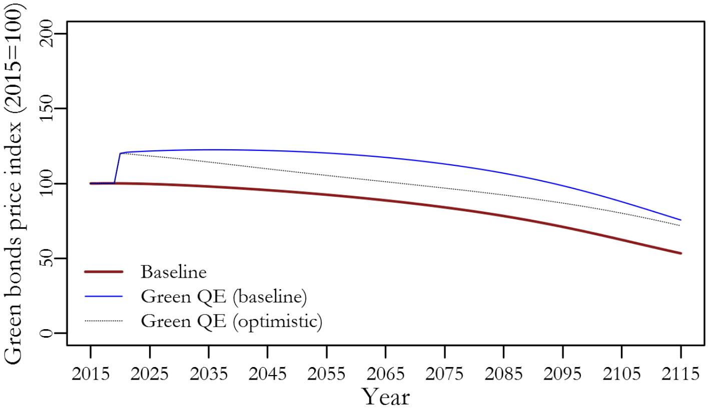
Outline

- We suppose that in 2020 central banks around the globe announce that they will purchase 20% of the outstanding **green bonds** and they commit themselves that they will keep the same share of the green bond market over the next decades.
- In 2020 this translates into an amount equal to around USD 180 billion.
- We also assume that the proportion of conventional corporate bonds held by central banks remains equal to its current level.

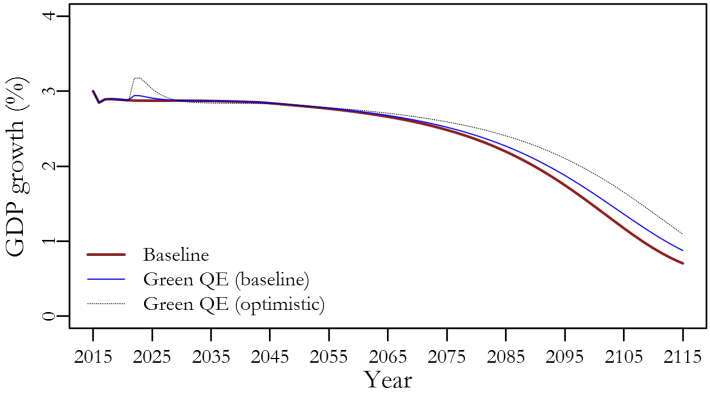
Green QE affects green investment by reducing the **yield on green bonds**. This has two key effects:

- Firms' desired investment in green technologies increases.
- Firms increase the amount of green investment that is funded via the bond market.

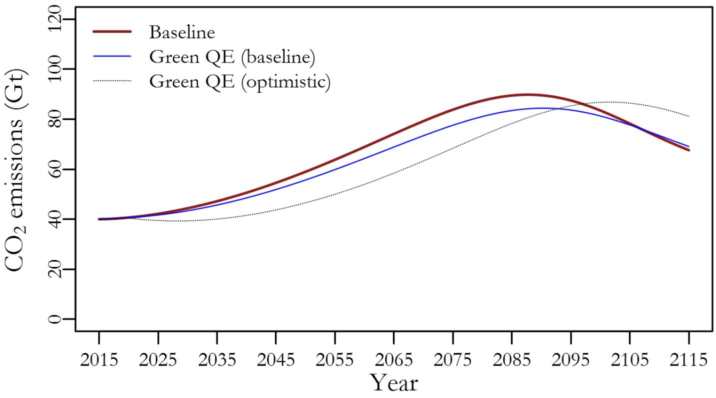
Green bonds price index



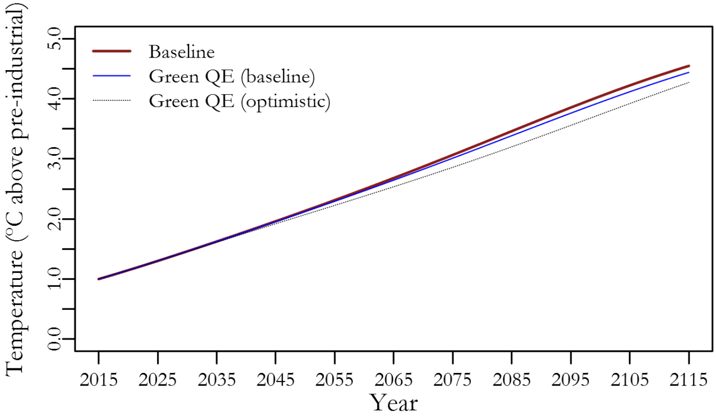
Growth rate of output



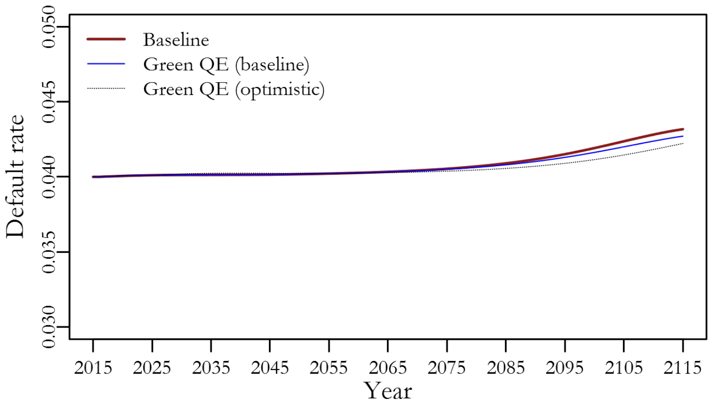
CO_2 emissions



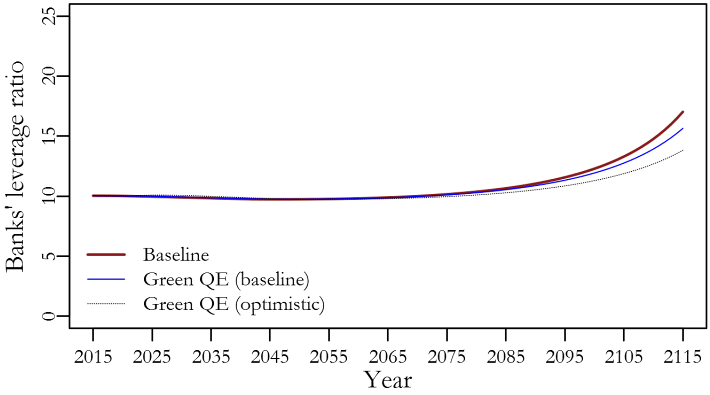
Atmospheric temperature



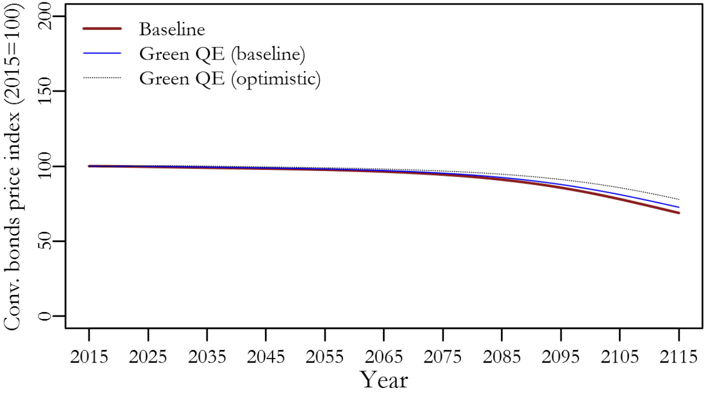
Default rate



Banks' leverage ratio



Conventional bonds price index



Outline

- By destroying the **capital of firms** and reducing their **profitability**, climate change is likely to increase gradually the burden of debt of firms, leading to a higher rate of default that could harm both the financial and the non-financial corporate sector.
- The damages caused by climate change can lead to a **portfolio reallocation** that can cause a gradual decline in the price of corporate bonds.
- A green QE programme can reduce climate-induced financial instability and restrict global warming. However, **green QE** does not turn out to be by itself capable of preventing a substantial increase in atmospheric temperature.