Coping with the Collapse: A Stock-Flow Consistent, Monetary Macro-dynamics of Global Warming

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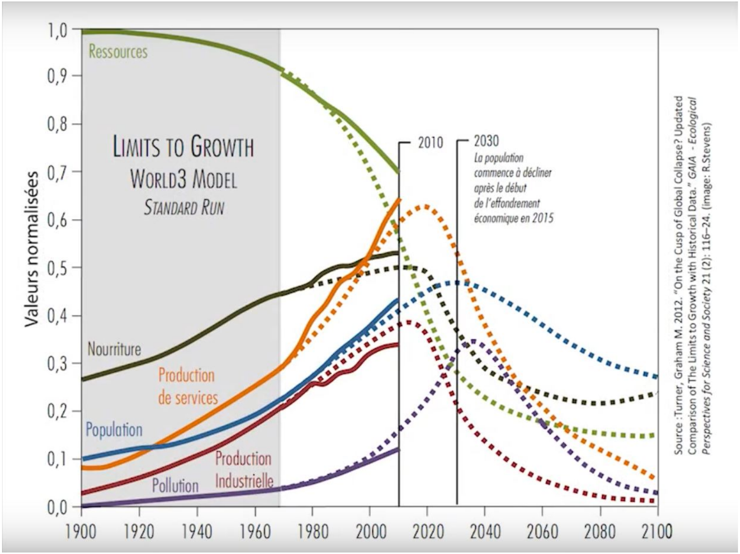
Outlines

Introduction

- *The Limits to Growth* was published (Meadows et al., 1972 and Meadows et al., 1974).
- Turner (2008, 2012, 2014) and Hall and Day (2009) tend to confirm the LtG standard run scenarios.

Introduction

Sustainable path or collapse?



Introduction

- Consistent with increasing capital costs and net energy (the decline of energy returned on energy invested, EROI).
- Growing scarcity of natural resources (energy, minerals, water...), while climate change plays little role, if any. (Caveat: Pollution).
- The question of whether global warming might *per se* induce a similar breakdown of the world economy (cf. COP 21).

Introduction

Paper's framework

- We explicitly model the financial side of the world economy in order to assess the possible negative feedback of debt on the ability of the world economy to cope with the collapse.
- Pivotal role of private debt.
- Losses due to environmental damages force the global productive sector to invest a growing part of its wealth in restoring and maintaining capital.
- The persistent level of debt may endanger the world economic engine itself as it is based on the promise of future wealth creation.

Introduction

Paper's framework

- Depending upon the speed at which labor productivity increases compared to the severity of global warming, the shrink of investment induced by the burden of private debt may prevent the world economy from further adapting to the climate turmoil, leading ultimately to a collapse around the end of the twenty-first century.
- The global collapse captured in this paper can be interpreted as the result of a debt-deflation depression in the sense given to this concept by Irving Fisher (1933).
- That part of the world economy might be on the verge of falling into a liquidity trap is illustrated, today, by the two “lost decades” of Japan, of course, but also the recessionary state of the Southern part of the Eurozone, obstinately negative long-term interest rates on international financial markets and, last but not least, the brutal contraction of the world nominal GDP in 2015 (-6%, IMF (2016)).

Introduction

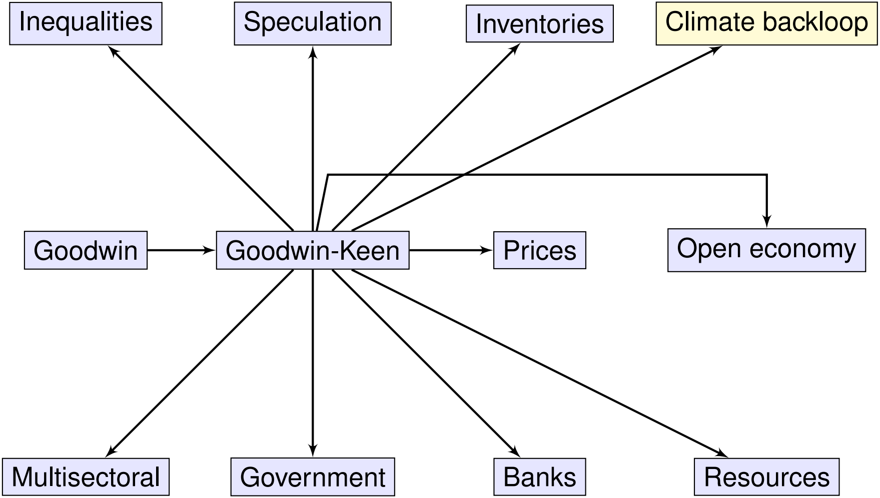
Paper's framework

- These paradoxes may be viewed as signals of the translation of a secular decline induced by biophysical constraints into the financial sphere.

GEMMES

GEneral Monetary Multisectoral Macrodynamics for the Ecological Shifts

GEMMES


Inequalities
Speculation
Inventories
Climate backloop
Goodwin
Goodwin-Keen
Prices
Open economy
Multisectoral
Government
Banks
Resources

Outlines

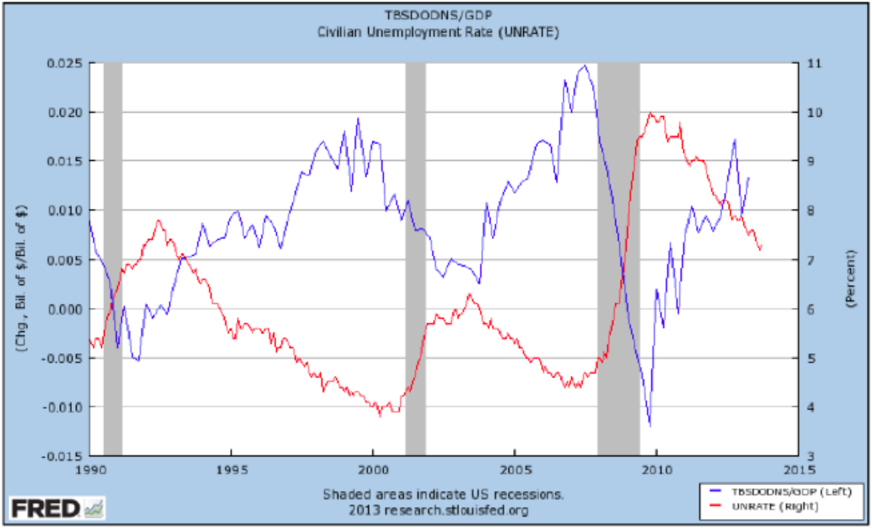
The Keen (1995) Model

Overview

1. Since the financial crisis of 2007-2009, the ideas of Hyman Minsky around the intrinsic instability of a monetary market economy have experienced a significant revival.
2. Goodwin (1967): Lotka-Volterra logic of the wage share and the employment rate.
3. Keen (1995): 'Black Swan' event, or a Minsky moment can occur.
4. Investment financed by endogenous money creation.

The Keen (1995) Model

Private debt matters



The Keen (1995) Model

Stock and Flow consistent model

Balance Sheet	Households	Firms		Banks	Government	Sum
Capital stock		K				K
Loan		$-D$		D		
Sum (net worth)		X^f		X^b		X
Transactions		*current*	*capital*			
Consumption	$-C$	C				
Investment		I	$-I$			
Government spend.		G			$-G$	
Memo [GDP]		$[GDP]$				
Wages	W	$-W$				
Interests on debt		$-rD$		rD		
Firms' net profit		$-\Pi$	Π			
Financial Balances			$-\dot{D}$	Π^b		
Flow of funds						
Investment		I				I
Change in Loans		$-\dot{D}$		$\dot{D}$		
Column sum		Π		$\dot{D}$		I
Change in Net worth		$\dot{X}^f = \Pi + (\dot{p} - \delta p)K$		$\dot{X}^b = \Pi^b$		$\dot{X}$

Table: Stock-Flow Table

The Keen (1995) Model

The model

λ: the employment rate.

$$\lambda := \frac{L}{N}.$$

L: the labor force, and N: the total population.

$$\frac{\dot{N}}{N} = \beta.$$

a: the labor productivity.

$$\frac{\dot{a}}{a} = \alpha.$$

w: the wage per worker, $W = wL$: the total wage, ω: the wage share ad Y: the production.

$$\omega = \frac{W}{Y} = \frac{wL}{aL} = \frac{w}{a}$$

The Keen (1995) Model

The model

K: the stock of capital.

$$\dot{K} = I - \delta K.$$

The Leontief production function

$$\begin{aligned} Y &= \min\left(\frac{K}{\nu}, aL\right) \\ &= \frac{K}{\nu} = aL. \end{aligned}$$

The Keen (1995) Model

The model

D: the aggregate debt.

$$\dot{D} = I - \Pi.$$

with$\Pi := Y - W - rD$: the real profit of the firm, and r: the interest rate.

π: the profit-to-production ratio.

$$\pi = \frac{\Pi}{Y}.$$

d: the debt-production ratio.

$$d = \frac{D}{Y}.$$

The Keen (1995) Model

Aggregate behaviours

- The Short-term Phillips Curve (Mankiw, 2010).

$$\frac{\dot{w}}{w} = \phi(\lambda).$$

- The Investment Function : it evolves positively with the profit share.

$$\frac{I}{Y} = \kappa\left(\pi\right).$$

The Keen (1995) Model

The three-dimensional system

One can retrieve the following set of equations:

$$
\begin{aligned}
\dot{\omega} &= \omega \left[\phi(\lambda) - \alpha\right] \\
\dot{\lambda} &= \lambda \left[\frac{\kappa(\pi)}{\nu} - \delta - \alpha - \beta\right] \\
\dot{d} &= d \left[r - \frac{\kappa(\pi)}{\nu} + \delta\right] + \kappa(\pi) - (1 - \omega)
\end{aligned}
$$

The Keen (1995) Model

Aggregate behaviours

- Phenomenological approach: $\phi(.)$ and $\kappa(.)$ are empirically estimated.
- Sonnenschein-Mantel-Debreu (1975): anything can happen.
- Agent-based model.

The Keen (1995) Model

Equilibria analysis

Three long run equilibria exist:

- An unstable equilibrium at $(0, 0, d_0)$
- A good equilibrium locally stable
- A bad equilibrium locally stable

Simulations - good equilibrium with finite debt

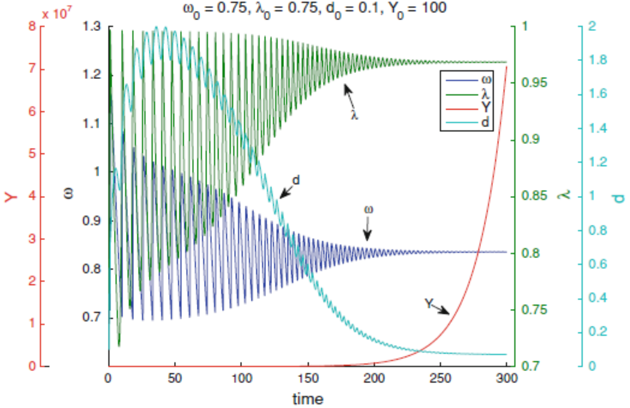


Fig. 4 Employment, wages, debt and output as functions of time converging to a stable equilibrium with finite debt in the Keen model

Simulations - bad equilibrium with infinite debt

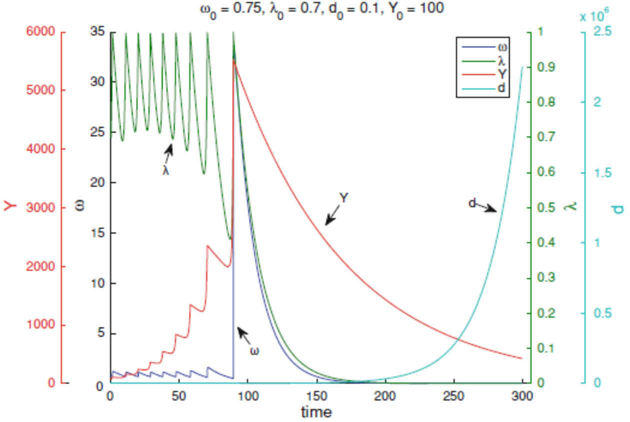
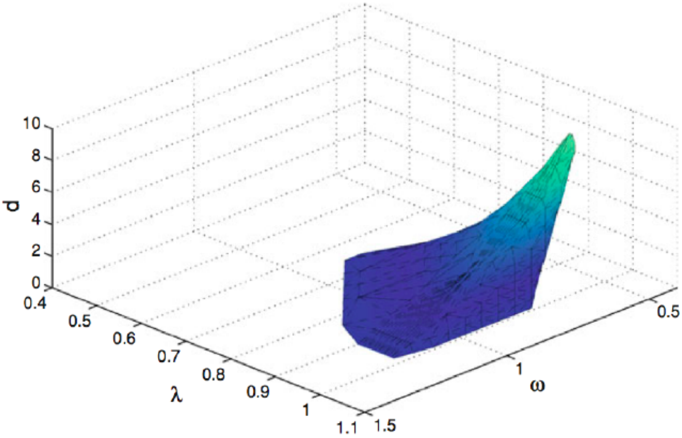


Fig. 5 Employment, wages, debt and output as functions of time converging to a stable equilibrium with infinite debt in the Keen model

Basin of Attraction



The Keen (1995) Model

Possible outcome induced by climate change

- Depending upon the basin of attraction where the state of the economy is driven by climate damages, the ultimate breakdown may occur as the inescapable consequence of the business as usual trajectory.

Outlines

Macroeconomic model for climate change

- Modelling:
  - The macroeconomics is borrowed from Keen (1995).
    - Stock-Flow consistent.
    - Phenomenological functions.
  - The climate feed-back loop is in line with Nordhaus' DICE model (2013).
- Estimation
  - Calibration of the climate and public policy modules in line with Norhdaus' DICE model (2013).
  - Macroeconomic module estimation in progress: panel analysis to benefit wider volatility.

Macroeconomic model for climate change

Production, capital and debt accumulation

The real output

$$Y = (1 - \mathbf{D})\frac{K}{\nu}.$$

The investment function with abatement cost

$$I = (\kappa(\pi) - \mu G)Y.$$

Population grows according to a UN scenario,

$$\frac{\dot{N}}{N} = q\left(1 - \frac{N}{M}\right).$$

The wage dynamic evolves according to a short-term Phillips curve

$$\frac{\dot{w}}{w} = \Phi(\lambda) + \gamma i.$$

The price dynamics,

$$\begin{aligned} i &= \frac{\dot{p}}{p}, \\ &= \eta_p(m\omega - 1) + i_{LT}. \end{aligned}$$

Macroeconomic model for climate change

Impact of climate change

As an example, for deterministic exponential scenario, climate change positively impact the share of wages

$$\begin{aligned}\frac{\dot{\omega}}{\omega} &= \frac{\dot{w}}{w} - \frac{\dot{a}}{a} + \frac{\dot{\mathbf{D}}}{1-\mathbf{D}} - i \\ &= \phi(\lambda) - \alpha + \frac{\dot{\mathbf{D}}}{1-\mathbf{D}} - (1-\gamma)i.\end{aligned}$$

Macroeconomic model for climate change

	Households	Firms		Banks	Sum
Balance Sheet					
Capital stock		$+p_t K_t$			$+p_t K_t$
Loan		$-D_t$		$+D_t$	
Sum (net worth)		X_t^f		X_t^b	X_t
Transactions		current	capital		
Consumption	$-p_t C_t$	$+p_t C_t$			
Investment		$+p_t I_t$	$-p_t I_t$		
Accounting memo [GDP]		$[p_t Y_t(1 - \mathbf{D}_t)]$			
Wages	$+W_t$	$-W_t$			
Interests on debt		$-rD_t$		$+rD_t$	
Firms' net profit		$-\Pi_t$	$+\Pi_t$		
Dividends	$+Di_t$		$-Di_t$		
Financial Balances			$-\dot{D}_t$	$+\Pi_t^b$	
Flow of funds					
GFCF		$+p_t I_t$			$+p_t I_t$
Change in Loans		$-\dot{D}_t$		$+\dot{D}_t$	
Column sum		$\Pi_t - Di_t$		$\dot{D}_t$	$p_t I_t$
Change in Net worth		$\dot{X}_t^f = \Pi_t - Di_t + (\dot{p}_t - \delta p_t)K_t$		$\dot{X}_t^b = \Pi_t^b$	$\dot{X}_t$

Table: Balance sheet, transactions, and flow of funds for a three-sector economy.

Macroeconomic model for climate change

Productivity

- The Business as usual Scenario

$$\frac{\dot{a}}{a} = \alpha$$

- The Burke et al.(2015) Scenario

$$\frac{\dot{a}}{a} = \alpha_1 T_\alpha + \alpha_2 T_\alpha^2$$

- The Kaldor-Verdoorn (2002) Scenario

$$\frac{\dot{a}}{a} = \alpha + \eta g$$

- The Gordon (2014) Scenario - productivity growth is 1,3%

Outlines

Global emissions are the sum of industrial and land-use emissions

$$E := E_{ind} + E_{land},$$

where industrial emissions depend on output,

$$E_{ind} := Y\sigma(1-n),$$

with,

$$\begin{aligned} \frac{\dot{\sigma}}{\sigma} &= -g_\sigma \\ \frac{\dot{g}_\sigma}{g_\sigma} &= \delta_{g_\sigma} \text{ with } \delta_{g_{sigma}} < 0 \end{aligned}$$

and the land-use emissions,

$$\frac{\dot{E}_{land}}{E_{land}} = \delta_E \text{ with } \delta_E < 0$$

Climate Module

CO_2 Accumulation

The CO_2 evolves according to a three-layer model, the atmosphere (AT), the upper ocean (UP) and the lower ocean (LO),

$$\begin{pmatrix} \dot{CO_2}^{AT} \\ \dot{CO_2}^{UP} \\ \dot{CO_2}^{LO} \end{pmatrix} = \begin{pmatrix} E \\ 0 \\ 0 \end{pmatrix} + \begin{pmatrix} -\phi_{12} & \phi_{12}\frac{C_{AT_{eq}}}{C_{UP_{eq}}} & 0 \\ \phi_{12} & -\phi_{12}\frac{C_{AT_{eq}}}{C_{UP_{eq}}} - \phi_{23} & \phi_{23}\frac{C_{UP_{eq}}}{C_{LO_{eq}}} \\ 0 & \phi_{23} & -\phi_{23}\frac{C_{UP_{eq}}}{C_{LO_{eq}}} \end{pmatrix} \begin{pmatrix} CO_2^{AT} \\ CO_2^{UP} \\ CO_2^{LO} \end{pmatrix}.$$

Climate Module

Radiative Forcing

Radiative forcing is the sum of the radiative forcing due to CO_2 and other gases,

$$F := F_{ind} + F_{exo},$$

with,

$$\begin{aligned} F_{ind}(t) &= \frac{F_{2\times CO_2}}{\log(2)} \log\left(\frac{C_{CO_{2(t)}}}{C_{CO_{2(t0)}}}\right), \\ \dot{F}_{exo} &= \delta_{F_{exo}} F_{exo} \left(1 - \frac{F_{exo}}{F_{exo}^{max}}\right). \end{aligned}$$

Climate Module

Temperature Increase

The temperature dynamics is a two-layer model, with T being the mean atmospheric temperature deviation with respect to its value in 1900 and T_0 represents the deep-ocean temperature deviation.

$$
\begin{aligned}
C\dot{T} &= F - (RF)T - \gamma^*(T - T_0) \\
C_0\dot{T}_0 &= \gamma^*(T - T_0)
\end{aligned}
$$

Climate Module

Damage Function (1/2)

- The Nordhaus's Damage function (2013),

$$\mathbf{D} = 1 - \frac{1}{1 + \pi_1 T + \pi_2 T^2}$$

- The Weitzman's (2010) and Dietz-Stern's (2015) Damage functions,

$$\mathbf{D} = 1 - \frac{1}{1 + \pi_1 T + \pi_2 T^2 + \pi_3 T^{6.754}}$$

  - In Weitzman (2010), π_3 is calibrated so that $\mathbf{D} = 50\%$ whenever $T = 6$.
  - In Dietz-Stern (2015), π_3 is calibrated so that $\mathbf{D} = 50\%$ whenever $T = 4$.

Climate Module

Damage Function (2/2)

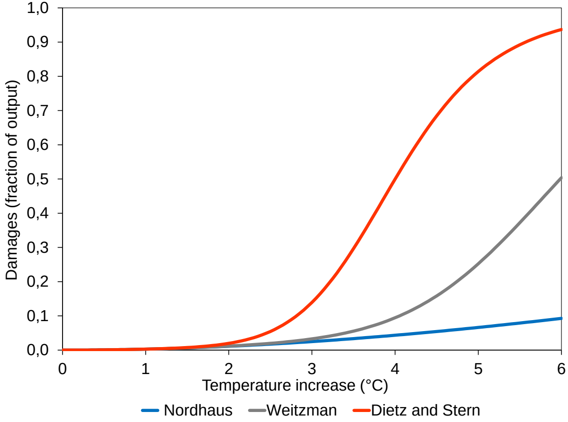


Figure: Comparison of the proposed Damage functions as percentage of output.

Outlines

Public Policy Module

Abatement Costs

The abatement cost

$$G := \theta_1 n^{\theta_2}$$

with θ_1 and θ_2 borrowed from Nordhaus (2013). n, the reduction rate of emissions implied by the abatement cost evolves according to,

$$n = \min\left\{\left(\frac{p_c}{p_{BS}}\right)^{\frac{1}{\theta_2 - 1}} ; 1\right\}.$$

Prices are exogenously given so that,

$$\begin{aligned} \frac{\dot{p_{BS}}}{p_{BS}} &= \delta_{p_{BS}}, \text{ with } \delta_{p_{BS}} < 0 \\ \frac{\dot{p_C}}{p_C} &= \delta_{p_C}, \text{ with } \delta_{p_C} > 0 \end{aligned}$$

Outlines

Numerical Simulations

Scenarios - Baseline Calibration

Parameter	Value
Y_{init}	64.4565
N_{init}	4.5510
ω_{init}	0.5849
λ_{init}	0.6910
d_{init}	1.4393
p_{init}	1
η_p	0.0819
markup	1.610
Monetary illusion	-
δ	0.0625
ν	2.8956
r	0.0303
dfi	0.1672
α	0.0226

Numerical Simulations

The BAU Scenario

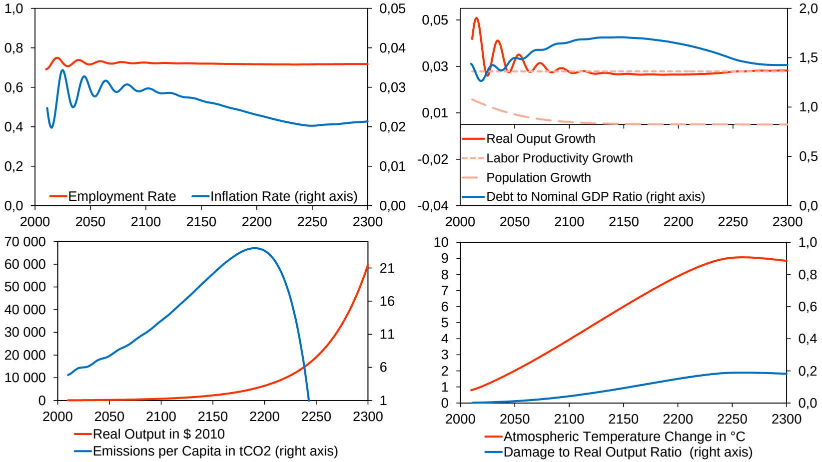


Figure: Trajectories of the main simulation outputs in the BAU case.

Numerical Simulations

The BAU Scenario

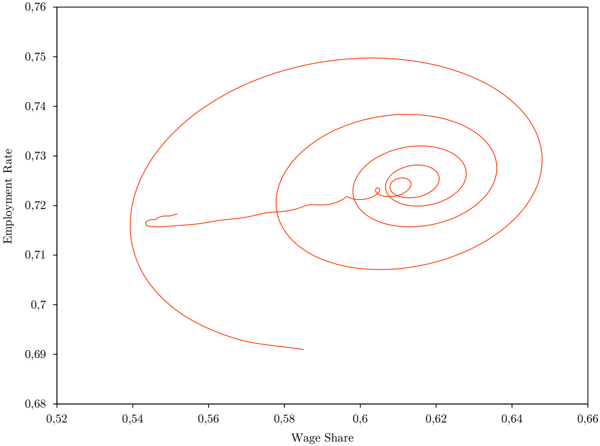


Figure: Trajectories of the main simulation outputs in the BAU case.

Numerical Simulations

The BAU Scenario

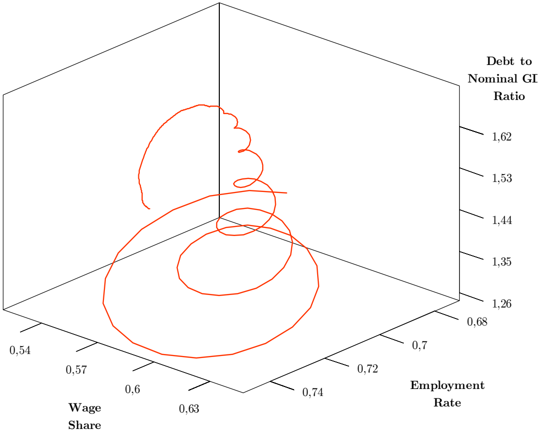


Figure: Trajectories of the main simulation outputs in the BAU case.

Numerical Simulations

The BAU Scenario - Values

GDP Real Growth 2100 (wrt 2010)	1053%
t CO_2 per capita (2050)	7.72
Temperature change in 2100	$+3.94\ ^\circ C$
CO_2 concentration 2100	968.98 ppm

Table: Key values of the world economy by 2100 — the exogenous case.

Numerical Simulations

The Kaldor-Verdoorn Scenario

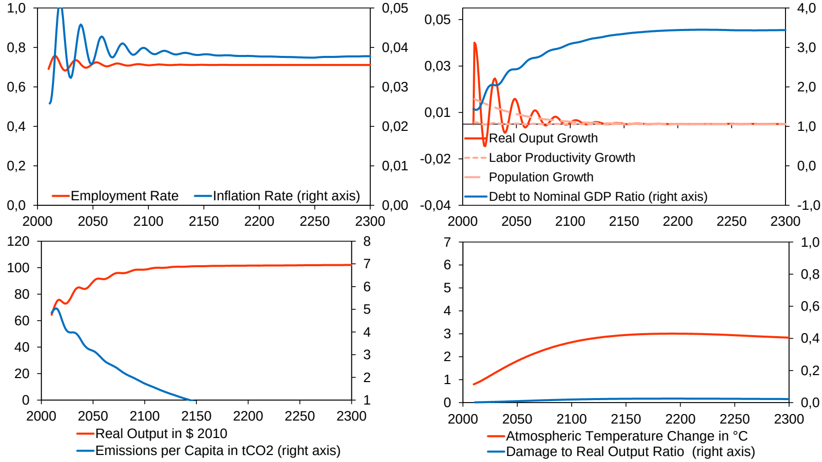


Figure: Trajectories of the main simulation outputs in the Kaldor-Verdoorn case.

Numerical Simulations

The Kaldor-Verdoorn Scenario

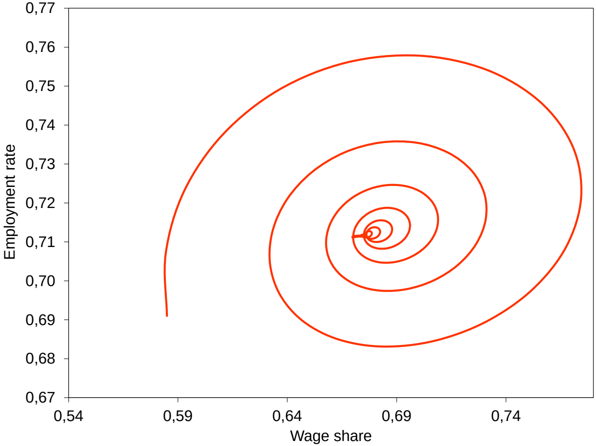


Figure: Trajectories of the main simulation outputs in the Kaldor-Verdoorn case.

Numerical Simulations

The Kaldor-Verdoorn Scenario - Values

GDP Real Growth 2100 (wrt 2010)	53%
t CO_2 per capita (2050)	3.17
Temperature change in 2100	$+2.63\ ^\circ C$
CO_2 concentration 2100	521.09 ppm

Table: Key values of the world economy by 2100 — the Kaldor-Verdoorn case.

Numerical Simulations

The Burke et al. (2015) Scenario

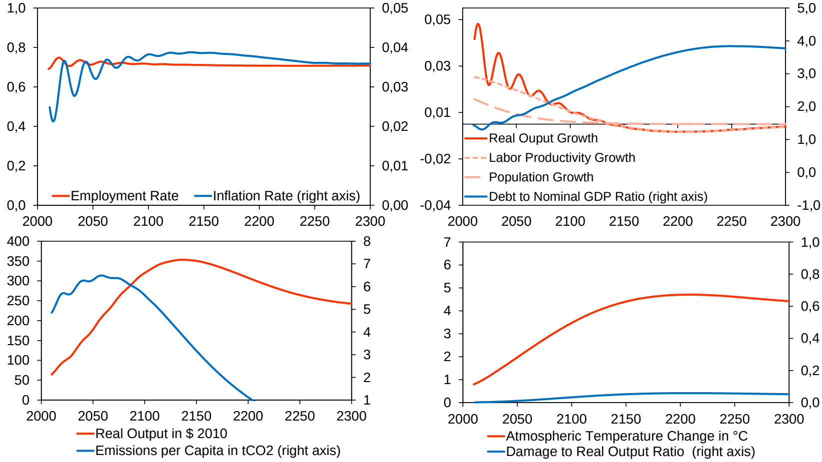


Figure: Trajectories of the main simulation outputs in the Burke et al. (2015) case.

Numerical Simulations

The Burke et al. (2015) Scenario

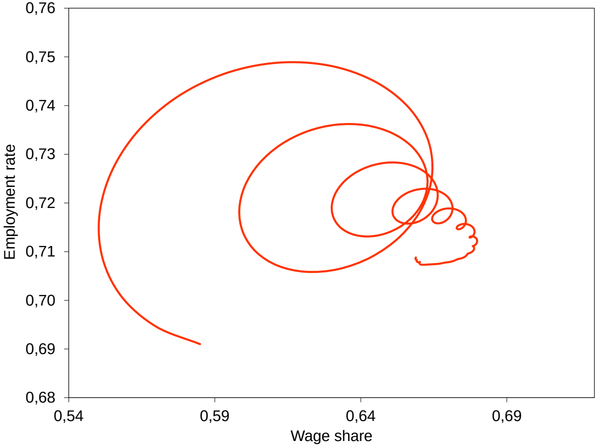


Figure: Trajectories of the main simulation outputs in the Burke et al. (2015) case.

Numerical Simulations

The Burke et al. (2015) Scenario - Values

GDP Real Growth 2100 (wrt 2010)	397%
t CO_2 per capita (2050)	6.29
Temperature change in 2100	$+3.48\,^{\circ}$C
CO_2 concentration 2100	744.49 ppm

Table: Key values of the world economy by 2100 — The Burke et al. (2015) case.

Numerical Simulations

The Weitzman Scenario

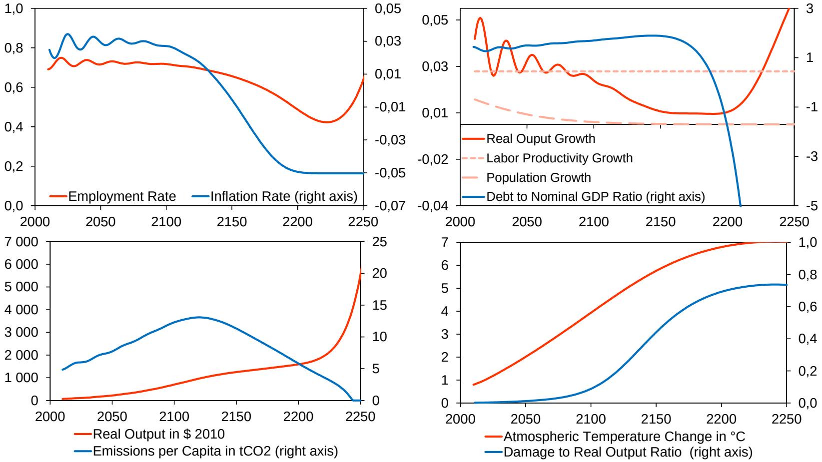


Figure: Trajectories of the main simulation outputs in the Weitzman case.

Numerical Simulations

The Weitzman Scenario

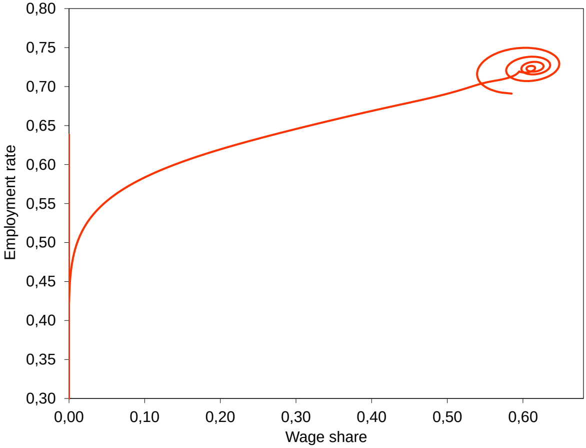


Figure: Trajectories of the main simulation outputs in the Weitzman case.

Numerical Simulations

The Weitzman Scenario - Values

GDP Real Growth 2100 (wrt 2010)	987%
t CO_2 per capita (2050)	7.72
Temperature change in 2100	$+3.93\ ^{\circ}C$
CO_2 concentration 2100	958.17 ppm

Table: Key values of the world economy by 2100 — the Weitzman case.

Numerical Simulations

The Dietz-Stern Scenario

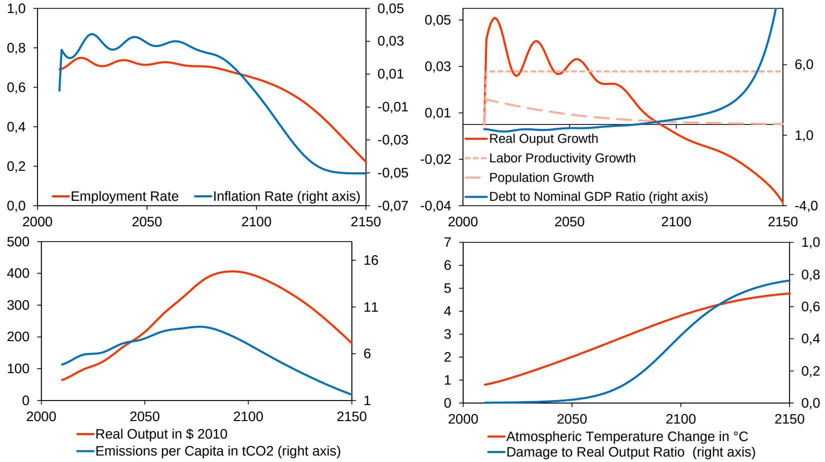


Figure: Trajectories of the main simulation outputs in the Dietz-Stern case.

Numerical Simulations

The Dietz-Stern Scenario

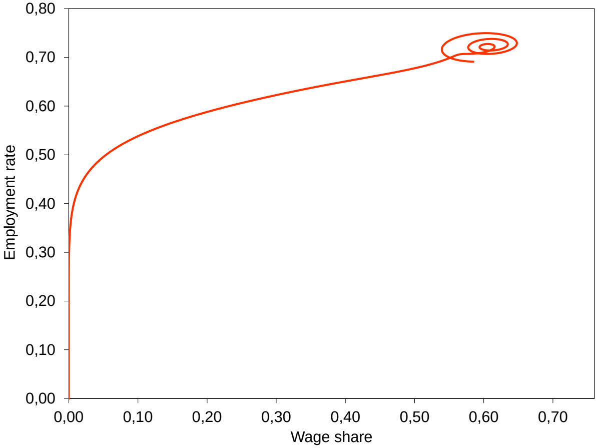


Figure: Trajectories of the main simulation outputs in the Dietz-Stern case.

Numerical Simulations

The Dietz-Stern Scenario - Values

GDP Real Growth 2100 (wrt 2010)	495%
t CO_2 per capita (2050)	7.72
Temperature change in 2100	$+3.84\ ^\circ C$
CO_2 concentration 2100	860.53 ppm

Table: Key values of the world economy by 2100 — the Dietz-Stern case.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern Scenario

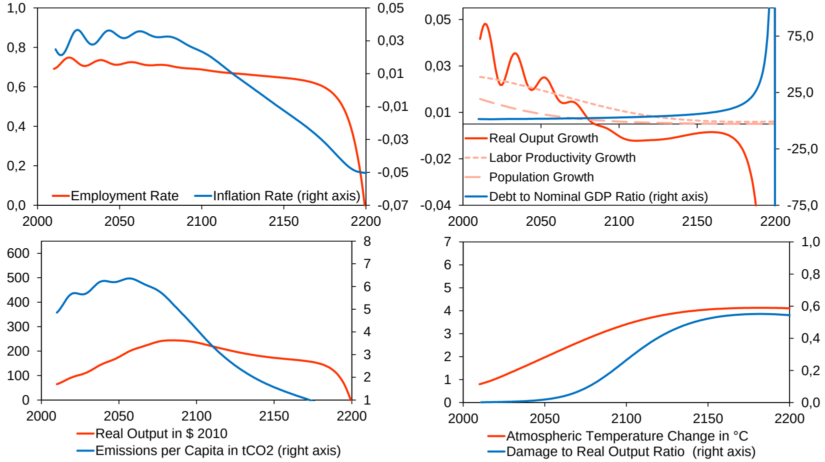


Figure: Trajectories of the main simulation outputs in the Combined Burke *et al.* and Dietz-Stern case.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern Scenario

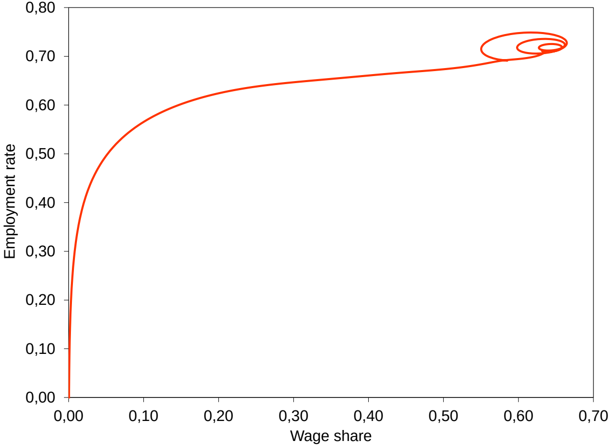


Figure: Phase portrait in the Combined Burke *et al.* and Dietz-Stern case

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Values

GDP Real Growth 2100 (wrt 2010)	265%
t CO_2 per capita (2050)	6.23
Temperature change in 2100	$+3.41$ °C
CO_2 concentration 2100	708.98 ppm

Table: Key values of the world economy by 2100 — The Combined Burke *et al.* and Dietz-Stern case.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Demographic

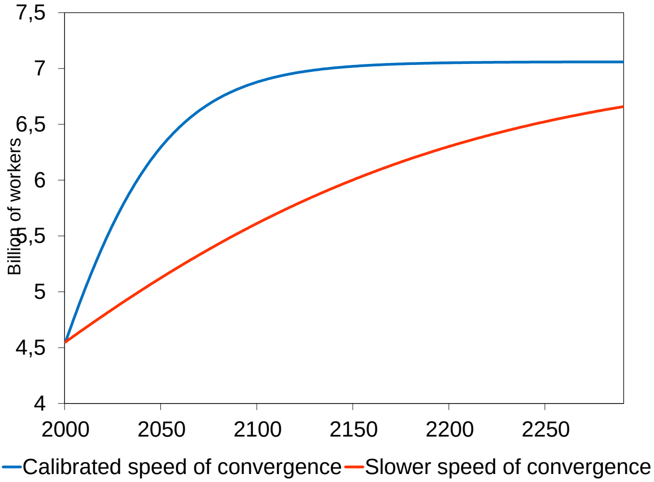


Figure: Trajectories of the main simulation outputs in the Combined Burke *et al.* and Dietz-Stern - Demographic.

Numerical Simulations

The Combined Burke-Dietz Scenario - Demographic

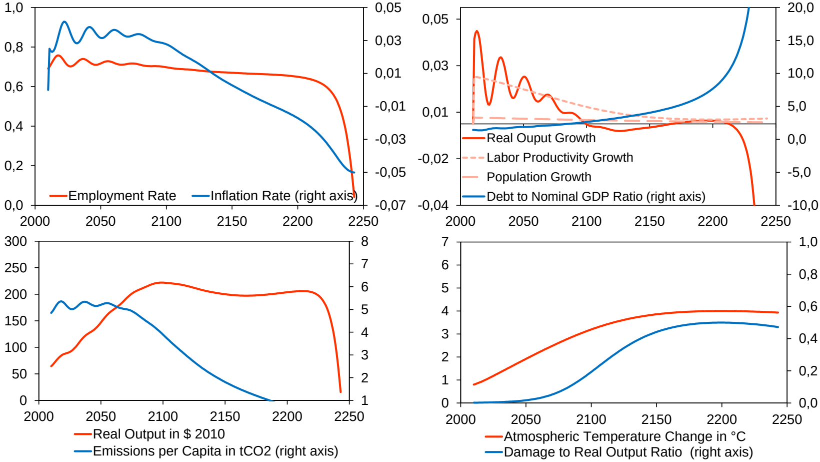


Figure: Trajectories of the main simulation outputs in the Combined Burke *et al.* and Dietz-Stern - Demographic.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Demographic - Values

GDP Real Growth 2100 (wrt 2010)	244%
t CO_2 per capita (2050)	5.21
Temperature change in 2100	$+3.20\ ^{\circ}C$
CO_2 concentration 2100	660.37 ppm

Table: Key values of the world economy by 2100 — the Combined Burke *et al.* and Dietz-Stern - Demographic.

Numerical Simulations

Price of Carbon

- we find the initial condition in 2010 that the growth rate that match with the 2015 and 2055 values (2005 $US 12 and 29 t/$CO_2$ respectively)

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price

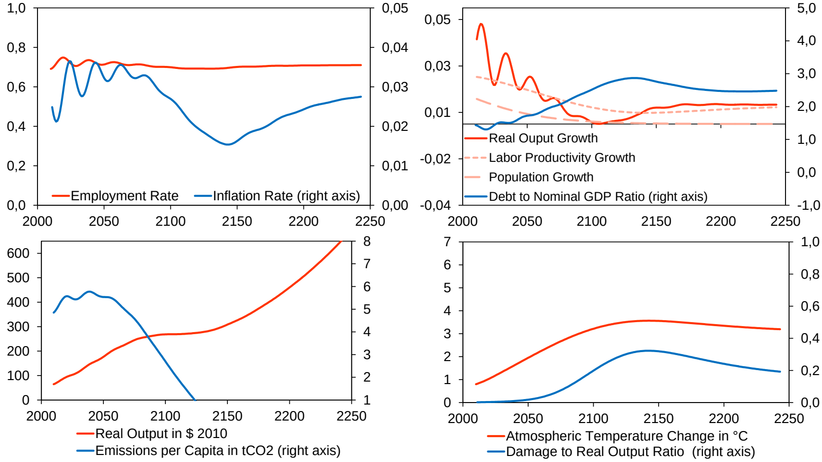


Figure: Trajectories of the main simulation outputs in rhe Combined Burke *et al.* and Dietz-Stern - Carbon Price.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price

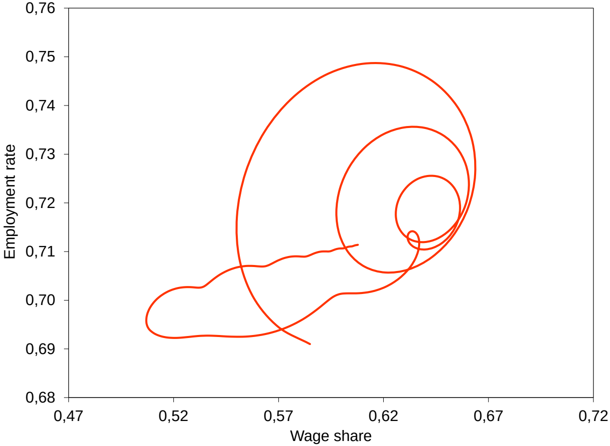


Figure: Trajectories of the main simulation outputs in the Combined Burke *et al.* and Dietz-Stern - Carbon Price.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price- Values

GDP Real Growth 2100 (wrt 2010)	3.17%
t CO_2 per capita (2050)	5.54
Temperature change in 2100	$+3.22\,^{\circ}C$
CO_2 concentration 2100	643.77 ppm

Table: Key values of the world economy by 2100 — the Combined Burke *et al.* and Dietz-Stern- Carbon Price.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price - Sensitivity of

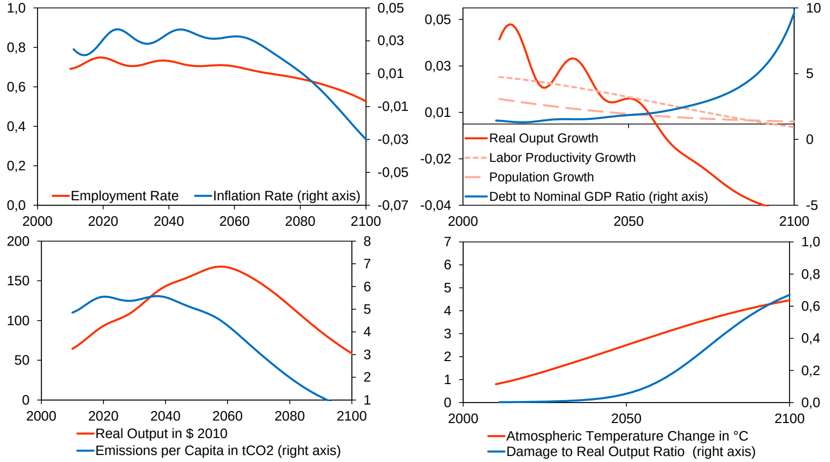


Figure: Trajectories of the main simulation outputs in the Combined Burke-Dietz Scenario - Carbon Price case.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price- Values

GDP Real Growth 2100 (wrt 2010)	-9.1%
t CO_2 per capita (2050)	5.00
Temperature change in 2100	$+4.4552°C$
CO_2 concentration 2100	549.78 ppm

Table: Key values of the world economy by 2100 — the Combined Burke *et al.* and Dietz-Stern - Carbon Price.

Numerical Simulations

Price of Carbon 2

- we find the initial condition in 2010 that the growth rate that match with the 2015 and 2055 values (2005 $US 74 and 306 t/CO2 respectively)

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price 2 - Sensitivity

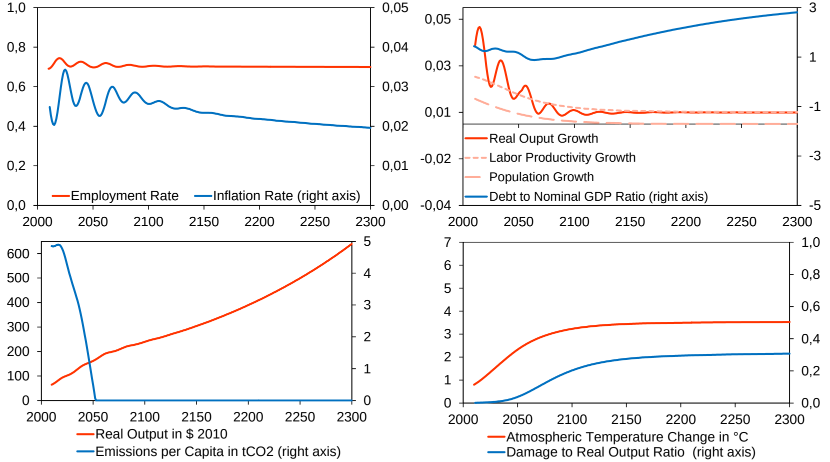


Figure: Trajectories of the main simulation outputs in the Combined Burke *et al.* and Dietz-Stern - Carbon Price 2 - Sensitivity of 6 case.

Numerical Simulations

The Combined Burke et al. and Dietz-Stern - Carbon Price- Values

GDP Real Growth 2100 (wrt 2010)	272%
t CO_2 per capita (2050)	0.49
Temperature change in 2100	$+3.2293°C$
CO_2 concentration 2100	397.98 ppm

Table: Key values of the world economy by 2100 — the Combined Burke *et al.* and Dietz-Stern - Carbon Price.

Numerical Simulations

Objective 1.5

- According to the 2015 climate meeting, held in Paris, the universal agreement's main goal is to stay, in this century, within the + 2 C of temperature anomaly and to drive efforts to limit even further to + 1.5C above pre-industrial levels.

Numerical Simulations

Objective + 1.5° C

	Sensitivity of 1.5		Sensitivity of 2.9	
	Init price of 15	Init price of 80	Init price of 15	Init price of 80
Price in 2015	18.58	86.27	65.50	144.32
Price in 2020	23.00	93.04	286.02	260.35
Price in 2050	82.93	146.35	xxx	xxx

Table: Price in order to prevent the temperature anomaly to reach the + 1.5° ceiling in 2100, prices are in 2005 US$/t CO_2.

Outlines

Further Work

Further work

- To model non-renewable energy, natural resource scarcity.
- To introduce the public sector.
- To refine the statistical framework.
- To distinguish the agricultural from the industrial production.
- To precise the determination of the damage functions.

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Thank you for your attention.

développeur d'avenirs durables