Carbon Pricing and Public Spending in a Stock-Flow Consistent, Monetary Macro-dynamics of Global Warming

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Energy and Prosperity Chair

Summary

1 Introduction

2 Context

3 II. The set-up

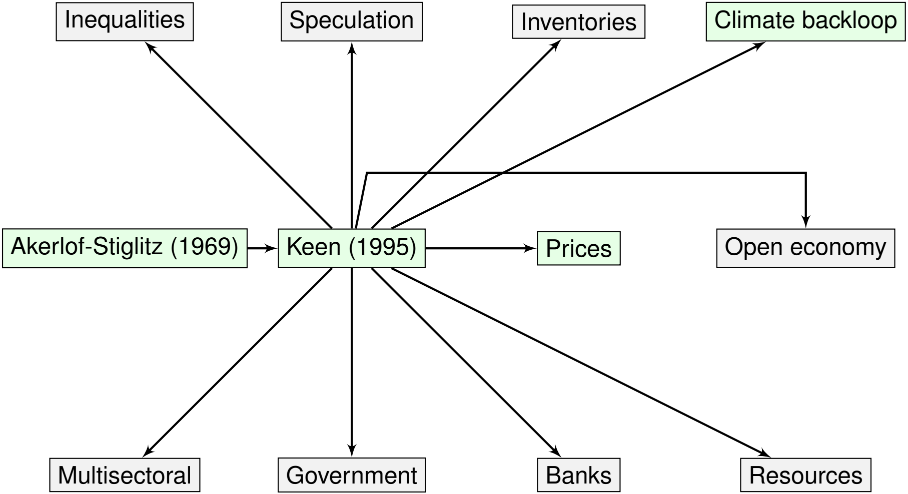
4 Climate prospective

5 Adding public intervention (2017)

GEMMES
GEneral Monetary Multisectoral Macrodynamics for the Ecological Shifts

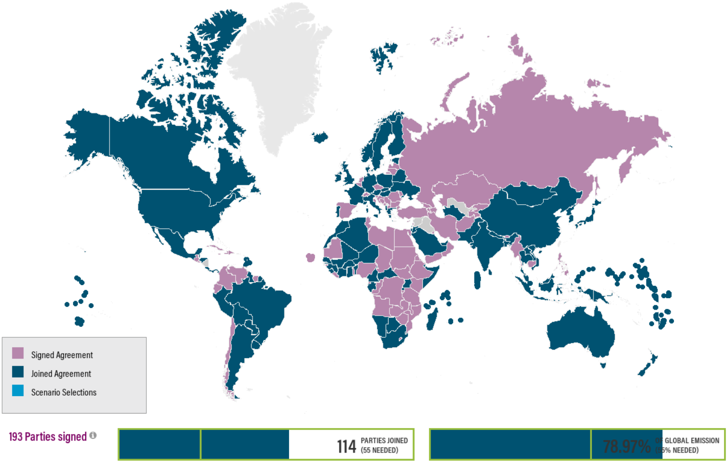
GEMMES

Overview of the research project



Introduction

Climate change as a milestone for the XXIst century



Introduction

The 2008 crisis: a revival of Minsky's theory of financial instability

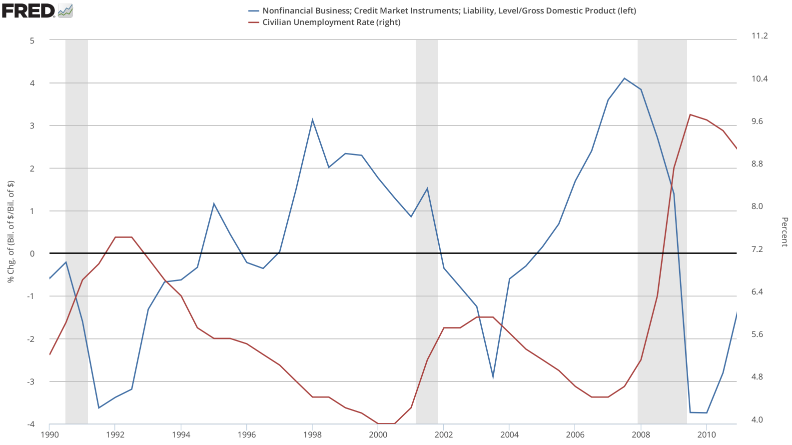


Figure: Time series of the private debt ratio and employment rate in the United States over the period 1990-2010.

- Fankhauser-Stern (MIT press, 2016)
  ... we should seek a dynamic economics where we tackle directly issues involving pace and scale of change in the context of major and systemic risks.
- Blanchard (PIIE, 2016):
  I see the current DSGE models as seriously flawed...
- Romer (2016):
  For more than three decades, macroeconomics has gone backwards...
- Kocherlakota (2016):
  ...we simply do not have a settled successful theory of the macroeconomy. The choices made 25-40 years ago - made then for a number of excellent reasons - should not be treated as written in stone or even in pen.

1. Combine two sources of global instabilities (climate and finance) in a minimal dynamic framework to shed some prospective light on the climate-economy interactions

2. Identify the instability factors and their transmission channels (in particular the pivotal role of private debt)

3. Provide public policy guidance for the implementation of the objective to contain global warming as close as possible to $+1.5^{\circ}C$ and "‘well below” $+2^{\circ}C$

Summary

1 Introduction

2 Context
- The Keen model (1995)[?]
- The DICE model (2013)[?]

3 II. The set-up

4 Climate prospective

5 Adding public intervention (2017)

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3 II. The set-up

4 Climate prospective

5 Adding public intervention (2017)

Context – The Keen model (1995)[?]

Theoretical elements

- Minimal (bounded) rationality
- Endogenous business cycles as in Akerlof-Stiglitz (1969).
- Mathematical formalization of Minsky's ideas
  - Lotka-Volterra relationship linking the employment rate to the wage share
  - Dynamics of corporates' private debt.
  - Short-term Phillips curve (Mankiw (2010), Krugman (2014), Gordon (2016))
  - Investment as a function of profit share
- Multiplicity of long-term equilibria:
  - A Solovian steady-state equilibrium
  - A bad attractor leading to a breakdown in the long-run.
  - Their asymptotic local stability becomes key.

Context – The Keen model (1995)[?]

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 and Y, the real production define ω, the wage share:

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

Context – The Keen model (1995)[?]

The model

K: capital.

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

Leontief production function

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

But CES (McIsaac et al. 2016), Putty-Clay (Giraud-Lojkine, 2017)...

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.

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

Context – The Keen model (1995)[?]

Aggregate behaviours

- The Short-term Phillips Curve (Mankiw, 2010 and Krugman, 2014).

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

- The Investment Function : an increasing function of the profit share and output.

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

Context – The Keen model (1995)[?]

The three-dimensional system

One can retrieve the following 3-dim. non-linear system:

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

Context – The Keen model (1995)[?]

Aggregate behaviors

- Phenomenological approach: $\phi(.)$ and $\kappa(.)$ are empirically estimated.
- Sonnenschein-Mantel-Debreu (1975): “anything can happen”. (“Emergence”.)

Context – The Keen model (1995)[?]

Convergence to the locally asymptotically stable steady-state equilibrium

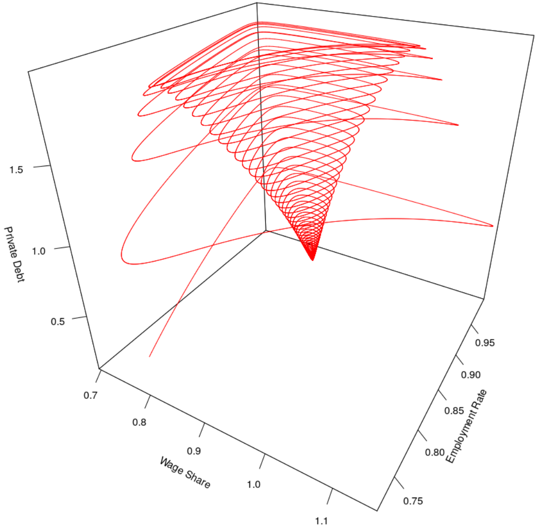

Figure: Phase diagram in the Keen model (1995)[?].

Context – The Keen model (1995)[?]

Viability analysis through the basin of attraction

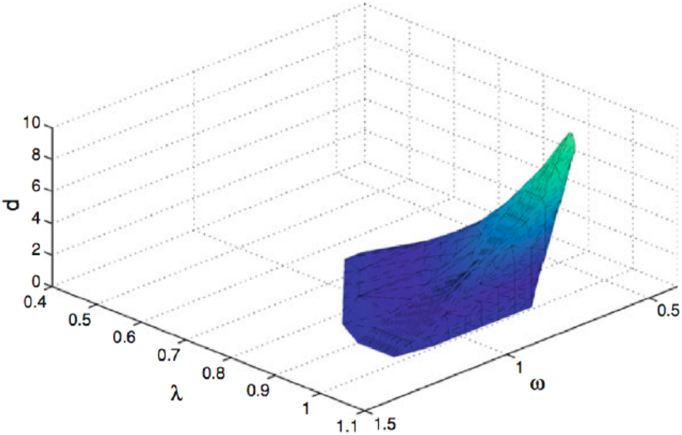

Figure: Basin of attraction of the desirable steady-state in the Keen model. Source: Grasselli *et al.* (2012)[?]

Context – The Keen model (1995)[?]

Stock-Flow consistency

	Households	Firms		Banks	Sum
Balance Sheet					
Capital stock		K			K
Deposits	M^h	M^f		$-M$	
Loans		$-L$		L	
Sum (net worth)	X^h	X^f		X^b	X
Transactions		current	capital		
Consumption	$-C$	C			
Investment		I	$-I$		
Accounting memo [GDP]		$[Y]$			
Wages	W	$-W$			
Interests on deposits	rM^h	rM^f		$-rM$	
Interests on loans		$-rL$		rL	
Financial Balances	S^h	Π	$-I$	S^b	
Flow of funds					
Gross Fixed Capital Formation		I			I
Change in Deposits	$\dot{M}^h$	$\dot{M}^f$		$-\dot{M}$	
Change in loans		$-\dot{L}$		$\dot{L}$	
Column sum	S^h	Π		S^b	I
Change in net worth	$\dot{X}^h = S^h$	$\dot{X}^f = \Pi - \delta K$		$\dot{X}^b = \Pi^b$	$\dot{X}$

Table: Balance sheet, transactions, and flow of funds in the economy

Summary

1 Introduction

2 Context
- The Keen model (1995)[?]
- The DICE model (2013)[?]

3 II. The set-up

4 Climate prospective

5 Adding public intervention (2017)

Context – The DICE model (2013)[?]

A seminal model of IAMs

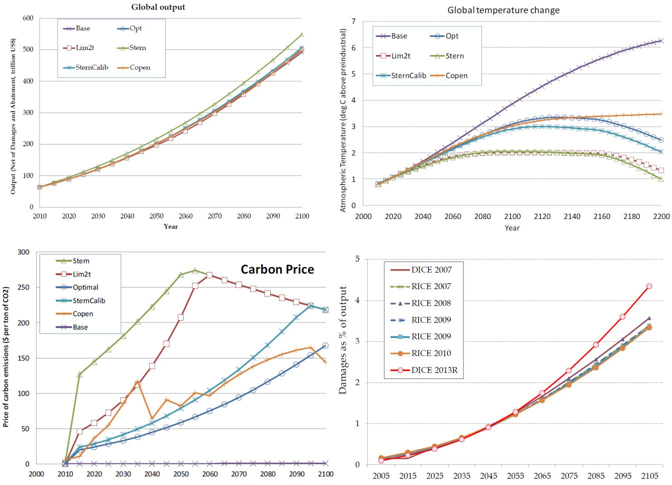

Figure: Trajectories from the model Dynamic Integrated Climate Economy (DICE). Source: Nordhaus (2013)[?].

Summary

1 Introduction

2 Context

3 II. The set-up
- The macroeconomic framework
- The climate module
- Climate damages and mitigation
- Wrap-up: stock-flow consistent table
- Numerical analysis

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5 Adding public intervention (2017)

Taking advantage of two prominent models:

- The macrodynamics of Keen (1995)[?] refined with:
  - Price dynamics under imperfect competition (Grasselli *et al.* (2014)[?])
  - Sigmoïd pattern of the global workforce (UN population scenarios (2015)[?])
  - Dividends payments of firms to households
  - Public spending and taxes, hence, public debt.

- The DICE climate backloop of Nordhaus (2013)[?] refined with:
  - More convex damage functions (Weitzman (2011)[?], Dietz *et al.* (2015)[?])
  - Allocation of environmental damage between:
    1. Output
    2. Capital accumulation (Dietz *et al.* (2015)[?])
    3. Labor productivity (Burke *et al.* (2015)[?])

Summary

1 Introduction

2 Context

3 II. The set-up
- The macroeconomic framework
- The climate module
- Climate damages and mitigation
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- Numerical analysis

4 Climate prospective

5 Adding public intervention (2017)

II. The set-up – The macroeconomic framework

- Absent any public intervention, a 4-dim. system:

$$\begin{cases} \dot{\omega} & = \omega \left[\Phi(\lambda) - (1-\gamma) i(\omega) - \frac{\dot{a}}{a} \right] \\ \dot{\lambda} & = \lambda \left[\frac{\dot{Y}}{Y} - \frac{\dot{a}}{a} - \frac{\dot{N}}{N} \right] \\ \dot{d} & = d \left[r - \left(\frac{\dot{Y}}{Y} + i(\omega) \right) \right] + \kappa(\pi) + \Delta(\pi) - (1-\omega) \\ \dot{N} & = qN \left(1 - \frac{N}{PN} \right) \end{cases}$$

- with the following auxiliary variables:

$$\begin{aligned} \pi &= 1 - \omega - rd \\ \frac{\dot{Y}}{Y} &= \frac{\kappa(\pi)}{\nu} - \delta \\ i(\omega) &= \eta_p (m\omega - 1) + c \end{aligned}$$

- Estimated over a reconstructed world economy (85% of the "real" world economy).

II. The set-up – The macroeconomic framework

Convergence toward a steady-state without climate change

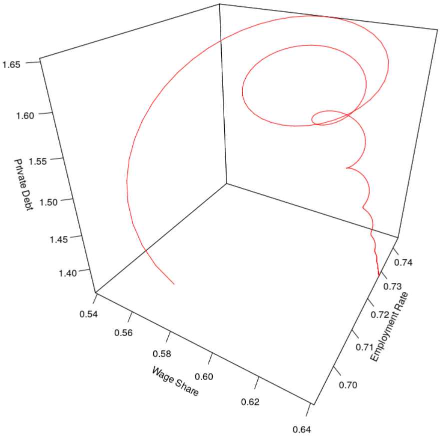

Figure: Phase diagram in the absence of climate damage.

Summary

1 Introduction

2 Context

3 II. The set-up
- The macroeconomic framework
- The climate module
- Climate damages and mitigation
- Wrap-up: stock-flow consistent table
- Numerical analysis

4 Climate prospective

5 Adding public intervention (2017)

II. The set-up – The climate module

Physical process overview

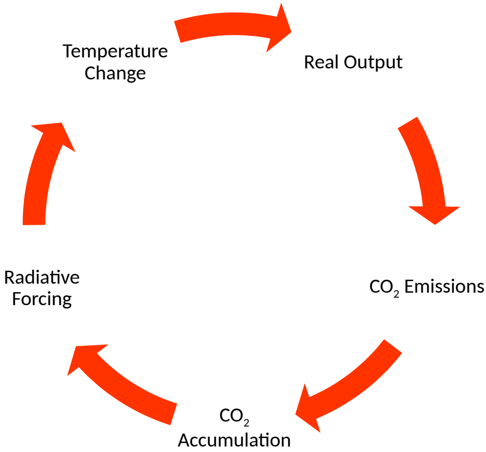

Figure: Climate-economy interactions diagram.

II. The set-up – The climate module

CO_2 emissions

Global CO_2 emissions are the sum of two contributions: $E := E_{ind} + E_{land}$

- Endogenous industrial emissions:

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

  - Proportional to real output Y
  - Emission intensity of the economy: σ
  - Emissions reduction rate: n

- Exogenous emissions linked to land-use change E_{land}

II. The set-up – The climate module

CO_2 accumulation (1/2)

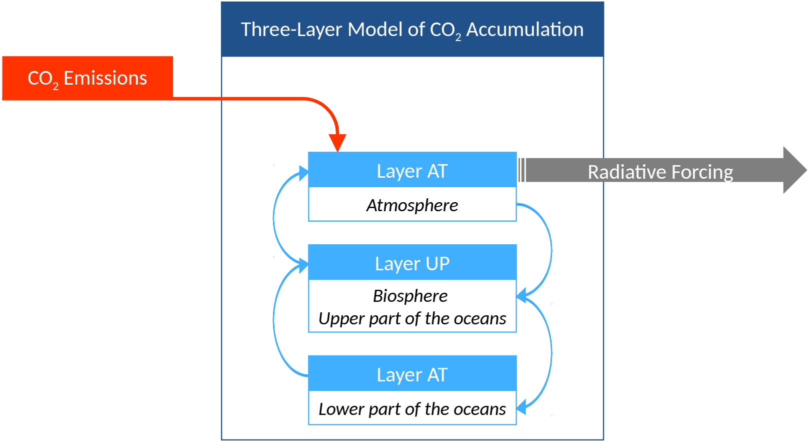

Figure: CO_2 accumulation in a three-layer model.

II. The set-up – The climate module

Temperature change (1/2)

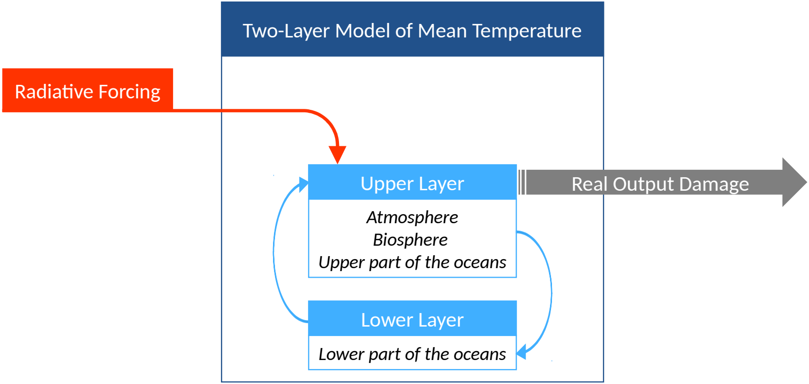

Figure: Dynamics of temperature.

Summary

1 Introduction

2 Context

3 II. The set-up
- The macroeconomic framework
- The climate module
- Climate damages and mitigation
- Wrap-up: stock-flow consistent table
- Numerical analysis

4 Climate prospective

5 Adding public intervention (2017)

II. The set-up – Climate damages and mitigation

Environmental damages due to global warming (2/2)

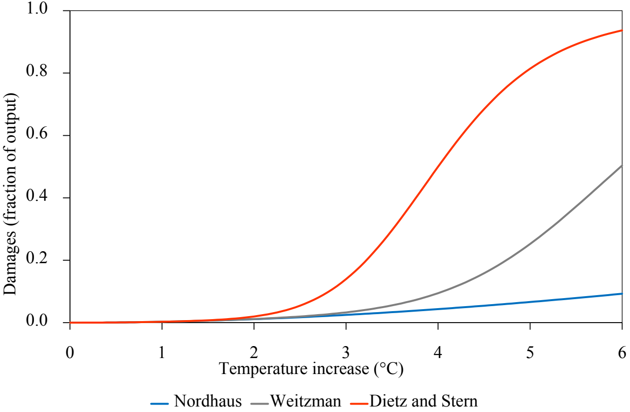

Figure: Comparison of the shape of covered damage functions.

II. The set-up – Climate damages and mitigation

Allocation of environmental damages between output flows and capital stock

- Allocation of damages according to:
  - Damages on capital stock:

$$\mathbf{D}^{\mathrm{K}} := f_K\,\mathbf{D}$$

  - Damages on output flows:

$$\mathbf{D}^{\mathrm{Y}} := 1 - \frac{1-\mathbf{D}}{1-\mathbf{D}^{\mathrm{K}}}$$

- Introduction of damages in the macroeconomic model:
  - Capital accumulation:

$$K := I - (\delta + \mathbf{D}^{\mathrm{K}})K$$

  - Production function:

$$Y := (1-\mathbf{D}^{\mathrm{Y}})\frac{K}{\nu}$$

II. The set-up – Climate damages and mitigation

Environmental damages on labor productivity

- Alternate definition of the damage function introduced by Burke *et al.* (2015)[?] as a quadratic alteration of the labor productivity.

- Endogenous labor productivity growth:

$$\frac{\dot{a}}{a} := \alpha_1 T_a + \alpha_2 T_a^2$$

- If it gets hot, we're less productive!

II. The set-up – Climate damages and mitigation

Mitigation effort

- Emission reduction rate n set by public authorities (cf. Nordhaus (2013)[?]):
  - Exogenous trajectories of the carbon price p_C
  - Exogenous decreasing trajectories of the backstop technology p_{NC}
  - Arbitrage relationship:

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

- Real abatement costs CO_2 GY depending on emission intensity σ with $G := \theta_1 n^{\theta_2}$

II. The set-up – Climate damages and mitigation

Abatement cost of carbon

- The burden of mitigation efforts = the abatement cost of carbon: $G := \theta_1 \sigma p_{BS} n^{\theta_2}$
- This cost is entirely borne by firms:
  - Effective Gross Capital Fixed Formation: $I^{ef} := (\kappa(\pi) - \mu G) Y$
  - Accumulation of capital:

$$\begin{aligned} \dot{K} &:= I^{ef} - \delta K \\ &= \kappa(\pi) Y - \left(\delta + \mathbf{D}^K + \frac{\mu}{\nu} G\right) K \end{aligned}$$

  - Dynamics of private debt:

$$\dot{D} := pI + \Delta(\pi) pY - \Pi$$

Summary

1 Introduction

2 Context

3 II. The set-up
- The macroeconomic framework
- The climate module
- Climate damages and mitigation
- Wrap-up: stock-flow consistent table
- Numerical analysis

4 Climate prospective

5 Adding public intervention (2017)

II. The set-up – Wrap-up: stock-flow consistent table

Stock-flow consistency

	Households	Firms		Banks	Sum
Balance Sheet					
capital		pK			pK
Deposits	M^h	M^f		$-M$	
Loans		$-L$		L	
Equities	$E^b + E^f$	$-E^f$		$-E^b$	
Sum (net worth)	X^h	X^f		X^b	X
Transactions		current	capital		
Consumption	$-pC$	pC			
Investment		pI	$-pI$		
Accounting memo [GDP]		$[pY]$			
Wages	W	$-W$			
Dividends	$Di + r(L - M)$		$-Di$	$-r(L - M)$	
Interests on loans		$-rL$		rL	
Interests on deposits	$+rM^h$	$+rM^f$		$-rM$	
Financial Balances	S^h	Π	$-pI - Di$	0	
Flow of Funds					
Gross Fixed Capital Formation		pI			pI
Change in deposits	$\dot{M}^h$	$\dot{M}^f$		$-\dot{M}$	
Change in loans		$-\dot{L}$		$\dot{L}$	
Change in equities	$\dot{E}^f + \dot{E}^b$	$-\dot{E}^f$		$-\dot{E}^b$	
Column sum	S^h	$\Pi - Di$		0	pI

Table: Balance sheet, transactions, and flow of funds in the economy

Summary

1 Introduction

2 Context

3 II. The set-up
- The macroeconomic framework
- The climate module
- Climate damages and mitigation
- Wrap-up: stock-flow consistent table
- Numerical analysis

4 Climate prospective

5 Adding public intervention (2017)

II. The set-up – Numerical analysis

Bifurcations of the steady-state due to temperature change

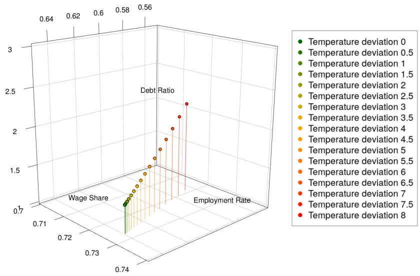

Figure: Damages on output and capital stock.

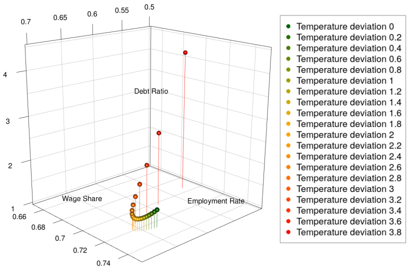

Figure: Damages on capital and labor productivity.

II. The set-up – Numerical analysis

Basin of attraction of the steady-state

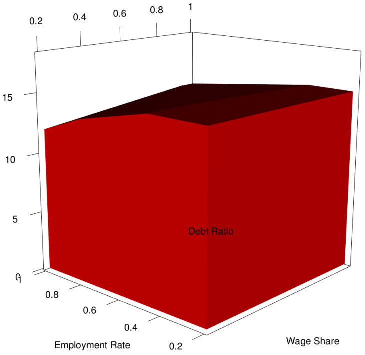

Figure: Without climate change.

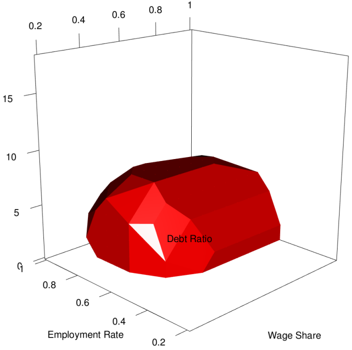

Figure: Damages on capital and labor productivity.

Summary

1 Introduction

2 Context

3 II. The set-up

4 Climate prospective
- Scope of analysis
- Low mitigation constraint
- Using a carbon-price instrument

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Summary

1 Introduction

2 Context

3 II. The set-up

4 Climate prospective
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- Low mitigation constraint
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5 Adding public intervention (2017)

Climate prospective – Scope of analysis

Design of the prospective scenarios

- Prospective analysis through 5 classes of scenarios:

Scenario	**Baseline**	**Nordhaus**	**Weitzman**	**Burke**	**Stern**
Damage Type	-	Nordhaus	Weitzman	Weitzman	Stern
On output	-	Yes	Yes	-	-
On capital	-	-	Yes	Yes	Yes
On labor productivity	-	-	-	Yes	Yes

- Using a carbon-price instrument:

1. Low-constraining paths
2. Paths compatible with the **limitation of global warming of of the Paris Agreement** (+2°C, as close as possible to the +1.5°C)
3. Proposal of minimal paths for public policy implementation

Summary

1 Introduction

2 Context

3 II. The set-up

4 Climate prospective
- Scope of analysis
- Low mitigation constraint
- Using a carbon-price instrument

5 Adding public intervention (2017)

Climate prospective – Low mitigation constraint

An imperious need for public involvement (1/2).

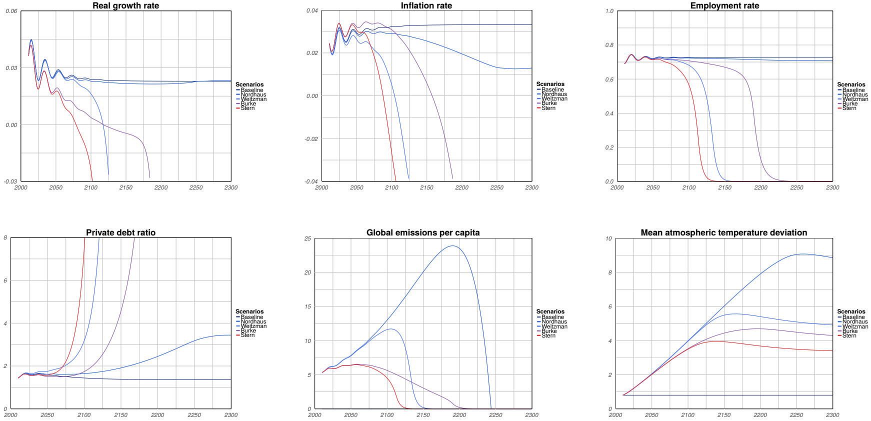


Figure: Trajectories of the main macroeconomic and climate variables.

Climate prospective – Low mitigation constraint

An imperious need for public involvement (2/2).

Scenario	Baseline	Nordhaus	Weitzman	Burke	Stern
Average real GDP growth wrt 2010-2100	2.81%	2.75%	2.62%	1.73%	1.15%
Private debt ratio in 2100	1.44	1.65	3.19	1.73	7.50
CO_2 emissions per capita in 2050	-	7.82 t CO_2	7.77 t CO_2	6.41 t CO_2	5.26 t CO_2
Temperature change in 2100	-	+3.98°C	+3.96°C	+3.52°C	+3.49°C
CO_2 concentration in 2100	-	975 ppm	960 ppm	753 ppm	732 ppm

Table: Key values of the world economy.

Summary

1 Introduction

2 Context

3 II. The set-up

4 Climate prospective
- Scope of analysis
- Low mitigation constraint
- Using a carbon-price instrument

5 Adding public intervention (2017)

Climate prospective – Using a carbon-price instrument

Achieving the +2° C target – Stability vs Indebtedness trade-offs.

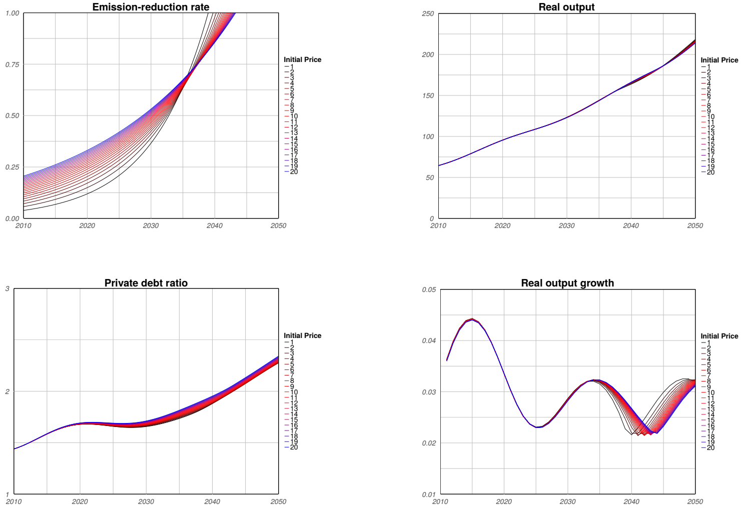


Figure: Weitzman scenario - trajectories of some key economic variables obtained with minimal carbon price paths.

Climate prospective – Using a carbon-price instrument

Achieving the +2° C target – Initial carbon-price of 1 (1/2).

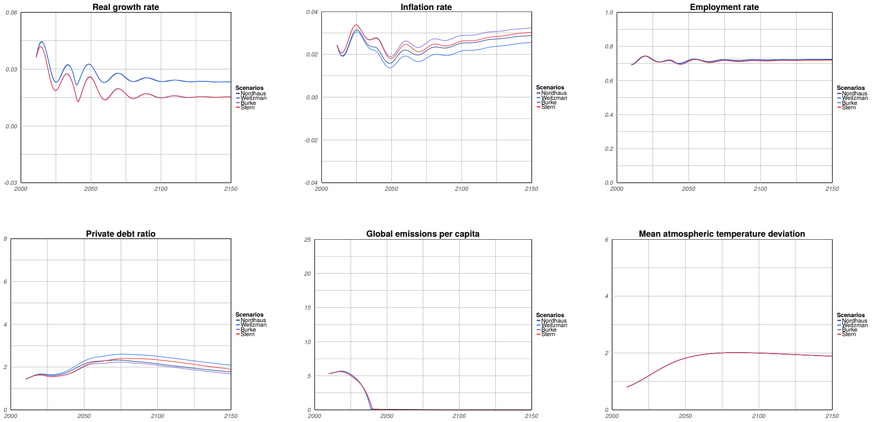


Figure: Trajectories of the main macroeconomic and climate variables.

Climate prospective – Using a carbon-price instrument

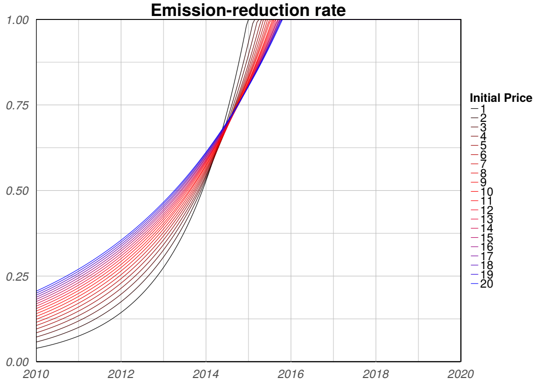
Achieving the +2° C target – Initial carbon-price of 1 (2/2).

Scenario	Baseline	Nordhaus	Weitzman	Burke	Stern
Average real GDP growth wrt 2010-2100	2.81%	2.79%	2.78%	2.08%	2.07%
Private debt ratio in 2100	1.44	2.15	2.50	2.08	2.34
CO_2 emissions per capita in 2050	-	0.07 t CO_2	0.07 t CO_2	0.07 t CO_2	0.07 t CO_2
Temperature change in 2100	-	+2.00° C	+2.00° C	+2.00° C	+2.00° C
CO_2 concentration 2100	-	396 ppm	396 ppm	396 ppm	396 ppm

Table: Key values of the world economy.

Climate prospective – Using a carbon-price instrument

Achieving the +1.5° C target – Stability vs Indebtedness trade-offs.



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1 Introduction

2 Context

3 II. The set-up

4 Climate prospective

5 Adding public intervention (2017)
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Adding public intervention (2017)

A recalibration

- Climate backloop recalibrated according to Nordhaus (2016) : `http://cowles.yale.edu/sites/default/files/files/pub/d20/d2057.pdf`
- *The study confirms past estimates of likely rapid climate change over the next century if there are not major climate-change policies. It suggests that it will be extremely difficult to achieve the 2C target of international agreements even if ambitious policies are introduced in the near term. The required carbon price needed to achieve current targets has risen over time as policies have been delayed.*

Adding public intervention (2017)

A recalibration- 2

- Climate sensitivity 3.1 and strongerr inertia of CO_2 in the atmosphere.
- Radiative forcing for other GHG following IPCC.
- If GHG emissions stop at 01/01/2016, temperature rise is **+1.9096**.
- Adding soils' contribution to CO_2 leads to **+1.9755**.
- If industrial emissions stop at 01/01/2018, temperature rise becomes **+2.0327**.

- Conclusion : without negative emissions, it is already too late for the 2°C target.

Summary

1 Introduction

2 Context

3 II. The set-up

4 Climate prospective

5 Adding public intervention (2017)
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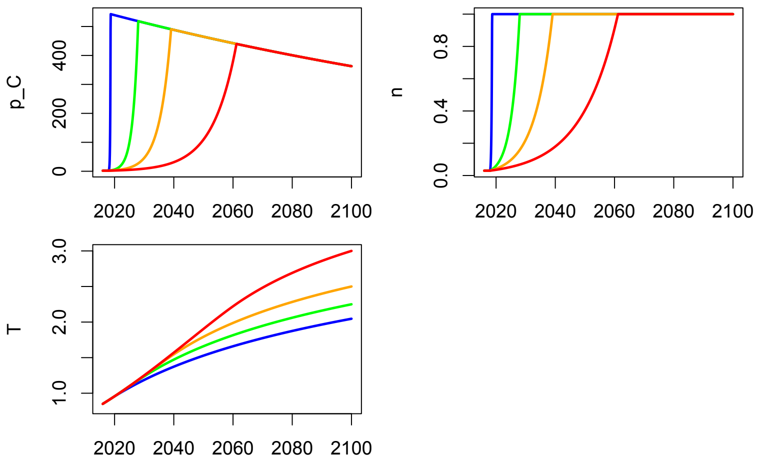
Adding public intervention (2017)

- Volontarist policy starts at 01/01/2018.
- Carbon pricing, p_C, in *US*\$2015 per ton CO_2-e.
- Abatement cost, $n = 1$: transition towards zero-carbon completed.

Couleurs :

- Closest achievable path to $+2^\circ$ – Completed transition date: August 2018!;
- +2.25 – Completed transition date: Jan 2028;
- +2.5 – Completed transition date: Feb 2039;
- +3 – Completed transition date: March 2061.

Adding public intervention (2017)



Summary

1 Introduction

2 Context

3 II. The set-up

4 Climate prospective

5 Adding public intervention (2017)
- Carbon pricing
- Public spending and taxes

Adding public intervention (2017)

Changes in the model

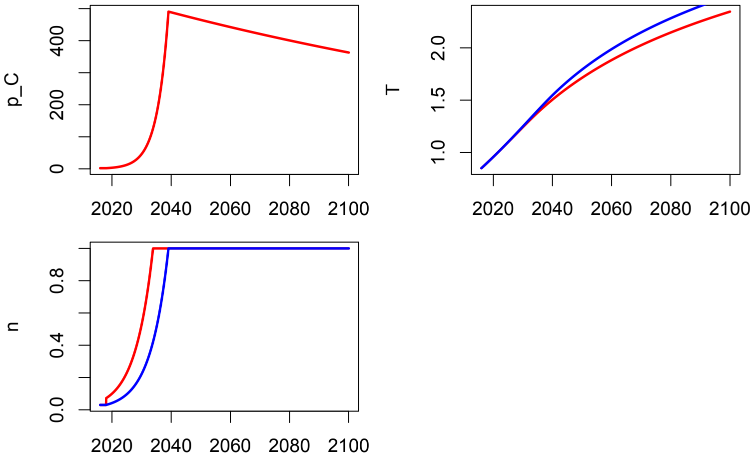
- Public subsidies : 95% of abatement costs.
- Carbon tax: p_c.
- Public debt serviced at r.
- r: Taylor rule (1993).
- Suppose labor prod. grows at 2% + Dietz-Stern damages.

- Courtesy of public intervention, transition can be completed in Dec 2033 instead of Feb 2039.
- Temperature rise in 2100 $+2.346^{\circ}$C.
- But temperature keeps rising after 2100... ! (though at slower pace than without public spending)

- Blue: without public intervention;
- Red: with public intervention.

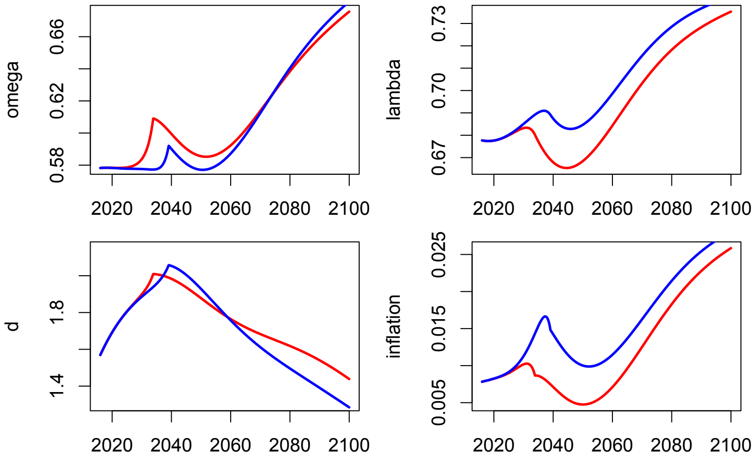
Adding public intervention (2017)

Public intervention speeds the energy shift (the Dietz-Stern case)



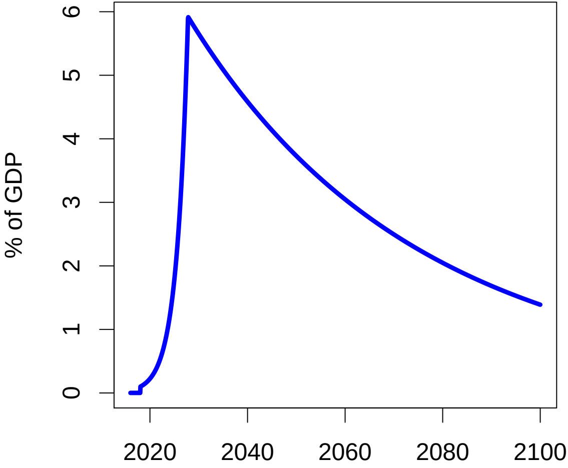
Adding public intervention (2017)

State intervention reduces unemployment and inflation



Adding public intervention (2017)

What about public debt?



Adding public intervention (2017)

What about the interest rate?