Endogenous Abatement Technology

G. Benmir[1] and J. Roman[2]

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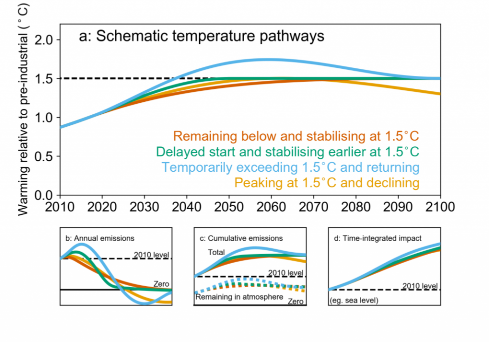
[1]London School of Economics and Political Science
[2]Paris-Dauphine University - PSL Research University

Main question:

What are the business cycle and long-term implications of fiscal and macro-financial policies aimed at achieving the net-zero target?

Introduction

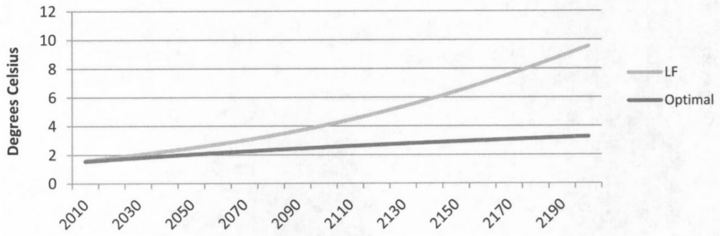
IPCC Pathways



Source: IPCC Special Report - *Global Warming of 1.5°C*

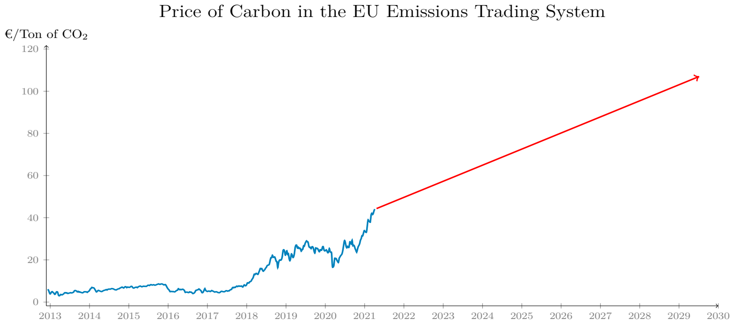
Temperature Mitigation

Laissez-faire versus optimal environmental policy



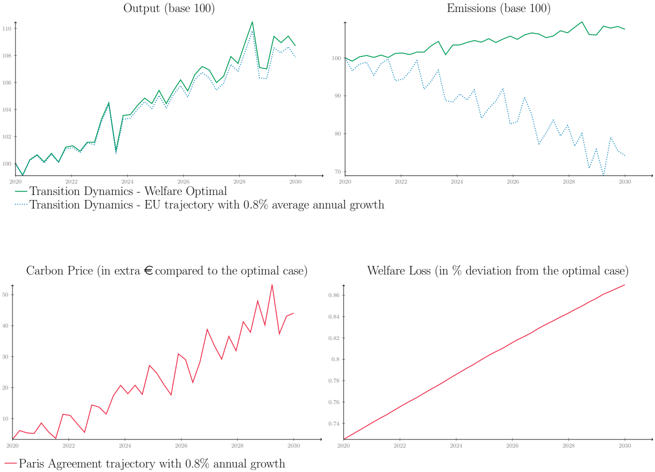
Source: Golosov & al. (2014)

Carbon Price (ETS)



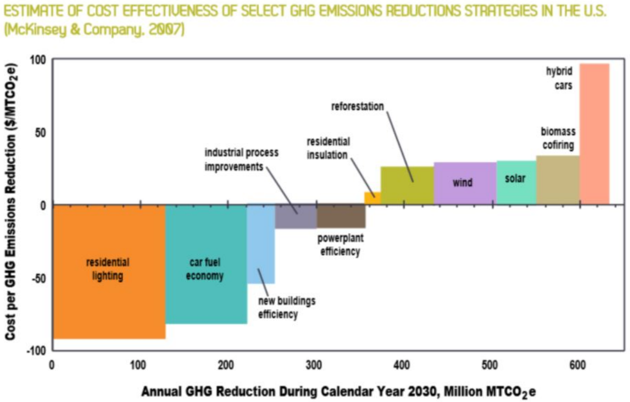
Source: Ember Climate

Impact on Welfare



Source: Benmir and Roman [2020]

Abatement Technologies



Climate & Finance Nexus

- Growing awareness of risks associated with climate change and the challenges it poses for the conduct of monetary and macroprudential policies
  - Network for Greening the Financial System
  - ECB strategy review
  - Research at the BIS, SF Fed...

Where We Stand

- Need for alternatives to **aggressive fiscal policy** to meet climate goals

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- Need for alternatives to **aggressive fiscal policy** to meet climate goals
- **Steering R&D** might be complementary and more efficient solution (welfare)
- Willingness of **financial authorities** to take part in this challenge

Objectives of the paper

1. **Empirically** investigating the role of fiscal and macro financial policies with respect to emissions reduction and steering green R&D, respectively.

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2. Providing a framework with **endogenous green abatement** and **financial intermediaries**

3. Assessing the role of **macro-financial policies** in steering green technological growth (Green R&D)

Contribution

Empirical:

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3. **Financial Intermediaries:** Queralto (2019) ⇒ The green innovation is financed by banks

Takeaways

1. Implementing an environmental fiscal policy consistent with the EU climate goals, while contributing to achieving the desired emission reduction goal, it **induces welfare losses**, and it could have **side-effect** on green innovation

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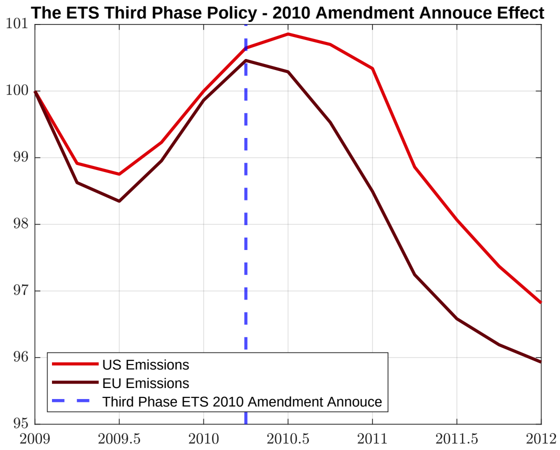
1. Implementing an environmental fiscal policy consistent with the EU climate goals, while contributing to achieving the desired emission reduction goal, it **induces welfare losses**, and it could have **side-effect** on green innovation

2. **Efficient abatement technology** would help achieve CO_2 emissions reduction targets. However, the net-zero target requires increasingly higher levels of abatement technologies.

3. **The three macro-financial policies** are shown to be able to steer R&D and reduce the carbon price overtime

Empirical Motivation

Emissions Pathways EU versus US



Diff-in-Diff

Our diff-in-diff data-set is based on a balanced US and EU dataset from 2000 to 2019 (quarterly basis):

$$ln(E_i) = \alpha + \beta_1 Policy_i + \beta_2 Treatment_i + \beta_3 (Treatment_i \times Policy_i) + \sum_i \beta_i X_i + error_i$$

- Emissions (we use spline to transform date from annual to quarterly frequency),
- R&D patents,
- Long-term loans,
- Macro aggregate (GDP, trade-balance, oil price, population, deflator, ...)

Please note: Synthetic diff-in-diff (Under construction)

ETS Price Impact on Emissions: Diff-in-diff

ln(Emissions per capita) (quarterly)	(1)	(2)	(3)	(4)	(5)	(6)
Policy (Q2 2010)	-0.0614**	-0.0111	0.0186	0.0649***	0.0496**	-0.0170
	(0.0309)	(0.0261)	(0.0276)	(0.0166)	(0.0198)	(0.0350)
Treatment (EZ)	-1.369***	-1.230***	-1.269***	-1.300***	-1.160***	-1.727***
	(0.0861)	(0.0986)	(0.0947)	(0.0741)	(0.0673)	(0.253)
Diff-in-diff Estimator	-0.0730***	-0.112***	-0.121***	-0.191***	-0.137***	-0.0932**
	(0.0276)	(0.0225)	(0.0229)	(0.0255)	(0.0266)	(0.0420)
ln(GDP per capita)	-1.032***	-0.534***	-0.581***	-1.150***	-0.895***	
	(0.168)	(0.202)	(0.187)	(0.184)	(0.152)	
ln(R&D Green) 4 lags		-0.178***				
		(0.0366)				
ln(R&D Green) 8 lags			-0.205***		-0.194***	-0.0957***
			(0.0371)		(0.0377)	(0.0336)
Trade Balance (Goods)				-0.105***	-0.120***	-0.0757***
				(0.0165)	(0.0233)	(0.0276)
Trade Balance (Services)				-0.277***	0.0430	0.168
				(0.0468)	(0.0727)	(0.103)
ln(Oil Price)					-0.00104	0.00745
					(0.0114)	(0.0112)
ln(Consumption per capita)						-1.009***
						(0.335)
ln(Gov Spending per capita)						-0.322
						(0.212)
ln(Investment per capita)						0.127
						(0.111)
Constant	9.159***	10.00***	10.03***	8.947***	9.520***	6.908***
	(0.129)	(0.208)	(0.184)	(0.166)	(0.200)	(0.560)
Observations	160	152	144	160	144	144

Newey-West standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

PANEL OLS

Our panel data-set is based on a balanced EU zone area (19 countries) data from 2008 to 2019 (quarterly basis – 870 obs) and includes:

$$GreenPatent_{i,t} = \beta_1 ETS_{i,t} + \beta_2 FI_{i,t} + \sum_i \beta_i X_{i,t} + T_t + State_i + error_{i,t}$$

- Green R&D patents,
- ETS carbon price,
- Long-term loans,
- Different controls (time, country, GDP, population, subsidies, ...).

Green Innovation Drivers: Panel OLS on EZ

Green R&D	(1)	(2)	(3)
ETS Price Level (1 year lag)	22.65*		
	(12.92)		
Long-term Loan (1 year lag)	0.0801***		
	(0.0149)		
ETS Price Level (2 years lag)		7.882*	
		(4.167)	
Long-term Loan (2 years lag)		0.0990***	
		(0.0140)	
ETS Price Level (3 years lag)			7.761**
			(3.724)
Long-term Loan (3 years lag)			0.112***
			(0.0140)
GDP per capita	1.502***	1.474***	1.442***
	(0.290)	(0.350)	(0.422)
Constant	-772.8**	-392.9***	-389.4***
	(339.0)	(119.8)	(119.9)
Observations	772	700	628
R-squared	0.969	0.970	0.968
Time fixed effect	Y	Y	Y
Country fixed effect	Y	Y	Y

Robust standard errors in parentheses
*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Green Innovation and ETS: Thresholds Effects

Green R&D	(1)	(2)	(3)	(4)	(5)
ETS Price > 5	9.351				
	(27.77)				
ETS Price > 10		13.84			
		(30.19)			
ETS Price > 15			-142.7*		
			(82.42)		
ETS Price > 20				-142.7*	
				(82.42)	
ETS Price > 25					-105.0*
					(58.73)
Long-term Loan (1 year lag)	0.0781***	0.0781***	0.0781***	0.0781***	0.0781***
	(0.0146)	(0.0146)	(0.0146)	(0.0146)	(0.0146)
GDP per capita	1.566***	1.566***	1.566***	1.566***	1.566***
	(0.292)	(0.292)	(0.292)	(0.292)	(0.292)
Constant	-172.2***	-176.7***	-162.8***	-162.8***	-162.8***
	(38.05)	(41.19)	(46.63)	(46.63)	(46.63)
Observations	790	790	790	790	790
R-squared	0.968	0.968	0.968	0.968	0.968
Time fixed effect	Y	Y	Y	Y	Y
Country fixed effect	Y	Y	Y	Y	Y

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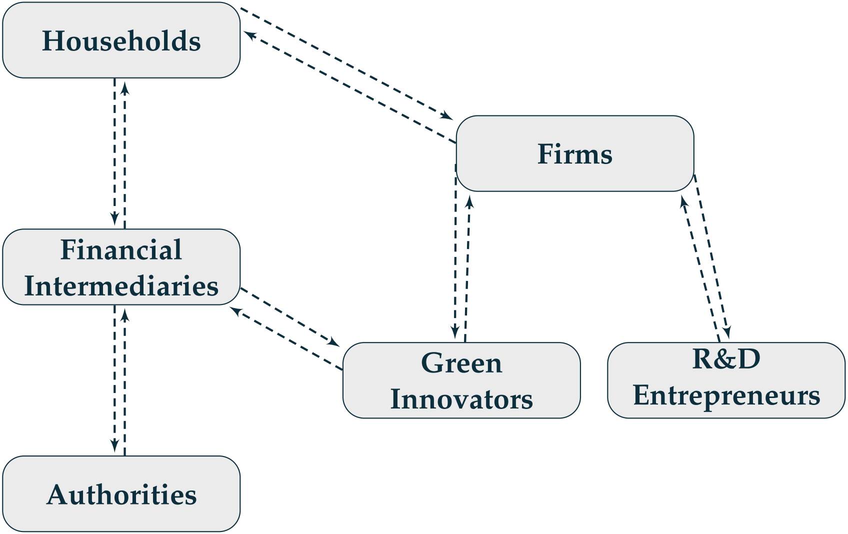
A Green Endogenous Macro-Finance Model

Model


Households
Firms
Financial Intermediaries
Green Innovators
R&D Entrepreneurs
Authorities

HOUSEHOLDS

The household maximize their lifetime welfare subject to a budget constraint:

$$\max_{\{C_t, I_t, K_{t+1}, L_t, B_{t+1}\}} E_t \sum_{i=0}^{\infty} \beta^i \left[\frac{(C_{t+i} - hC_{t+i-1})^{1-\sigma}}{1-\sigma} - \frac{\chi}{1+\varphi} L_{t+i}^{1+\varphi} \right], \tag{1}$$

s.t.

$$C_t + B_{t+1} + I_t + f(K_t, I_t) = W_t L_t + \sum_k W s_{t,k} \bar{L} s^k + T_t + R_t B_t + R_t^K K_t \tag{2}$$

$$K_{t+1} = (1-\delta) K_t + I_t \tag{3}$$

Global R&D

Ideas are endogenous in our setup:

$$A_{t+1,s} = \underbrace{\phi_{RD,s}}_{\text{Prob. of success}} \left(A_{t,s} + \underbrace{RD_{t,s}}_{\text{R\&D patents}}\right), \tag{4}$$

Entrepreneurs can produce new potential firm by employing materials and skilled workers as inputs, according to the following production function:

$$RD_{t,s} = \underbrace{N_{t,s}^{\eta_s}}_{\text{R\&D Expenditure}} \left(\underbrace{A_{t,s}}_{\text{Spillovers}} Ls_{t,s}\right)^{1-\eta}, \eta_g \in (0,1), \tag{5}$$

To produce idea, firms pay them the profits made:

$$MC_t = \Pi_t, \tag{6}$$

The Firm Production

Our production function is subject to productivity climate damages:

$$Y_t = \underbrace{A_{t,s}^{\frac{1}{\theta-1}}}_{\text{R\&D}} \underbrace{d(T_t^o)}_{\text{Damages}} K_{t-1}^{\alpha} L_t^{1-\alpha}$$

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- Vivid debate around the specification of the damage function: Nordhaus (2017), Dietz (2015), Weitzman (2012)

$$d(T_t^o) = ae^{-(bT_t^{o2})}$$

Climate Dynamics

- The temperature law of motion reads:

$$T_t^o = v_1^o(v_2^o X_{t-1} - T_{t-1}^o) + T_{t-1}^o$$

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$$X_t = (1-\gamma_d)X_{t-1} + E_t + E^*$$

- The flow of emissions can be reduced by means of an abatement technology specific to each sector

$$E_t = \underbrace{(1-\mu_t)}_{\text{Abatement}} \underbrace{\varphi}_{\text{Intensity}} Y_t$$

Firms – Abatement and R&D

Thus the profits of our representative intermediate firms reads:

$$\Pi_t = \underbrace{P_t Y_t - W_t L_t - R_t^K K_t}_{\text{Standard output input cost}} - \underbrace{f(\mu_t) Y_t}_{\text{Abat. Cost}} - \underbrace{\tau_{et} E_t}_{\text{Env. Policy}} \tag{7}$$

We recall the direct abatement effort costs

$$f(\mu_t) = \left(\int_0^{A_{t,g}} f(\mu_{jt})^{\frac{1}{\theta_3}} dj \right)^{\theta_3} \tag{8}$$

where

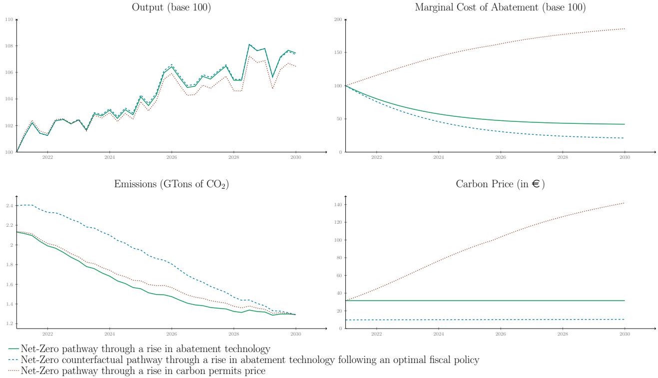
$$f(\mu_{jt}) = \theta_1 \mu_{jt}^{\theta_2},\ \theta_1 > 0, \theta_2 > 1 \tag{9}$$

with θ_1 and θ_2 representing the cost efficiency of abatement parameters. θ_3 is the elasticity of abatement to green innovation.

$$f(\mu_t) = \frac{\theta_1 \mu_t^{\theta_2}}{A_{t,g}^{\theta_3}} \tag{10}$$

Abatement Efficiency and Net-Zero: The Case $A_{t,g} = \Gamma_t^{A_g} \epsilon_t^{A_g}$ is Exogenous

Net-Zero Transition Pathways - 2030



Green Innovators

When green innovation is endogenous, ideas are created as following:

$$A_{t+1,g} = \underbrace{\phi_{RD,g}}_{\text{Prob. of success}} (A_{t,g} + \underbrace{RD_{t,g}}_{\text{Green patents}}), \tag{11}$$

Where,

$$RD_{t,g} = \underbrace{N_{t,g}^{\eta_g}}_{\text{Green Expenditure}} (\underbrace{A_{t,g}}_{\text{Spillovers}} Ls_{t,g})^{1-\eta}, \eta_g \in (0,1), \tag{12}$$

The entrepreneur has no funds to finance the sunk cost MC_t^e in each sector. To obtain funds, he or she issues equity to banks $Q_{t,e}$:

$$Q_{t,e} = MC_t^e, \tag{13}$$

Financial Intermediaries

- Banks hold financial claims ($S_{e.t}$) on green innovators:

$$\underbrace{Q_{t,e}S_{t,e}}_{\text{Assets}} = \underbrace{N_t + B_t}_{\text{Liabilities}}$$

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- The banks receive $R_{t,e}$ the gross rate of return on a unit of the bank's claims on green innovators:

$$R_{e,t} = \frac{\phi_{RD_g}(\overbrace{Z_t}^{\text{Abat. Cost}} + \overbrace{Q_{t,e}}^{\text{Price of green claims}})}{Q_{t-1,e}}.$$

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- Regulatory constrain:

$$\underbrace{V_t}_{\text{Value of banks net worth}} \geq \underbrace{\lambda Q_{t,e}S_{t,e}}_{\text{Capital requirements}}$$

Estimation, business cycle, and long-term transition pathways simulations

Estimation

- We perform a Bayesian estimation relying on the Kalman filter and MCMC techniques (over 20 000 draws)
- We estimate 4 shocks: Output, Emission, Global R&D, and Green Innovation
- We use quarterly data on GDP, Emissions, Global R&D Patents, and Green R&D Patents for the Euro Zone

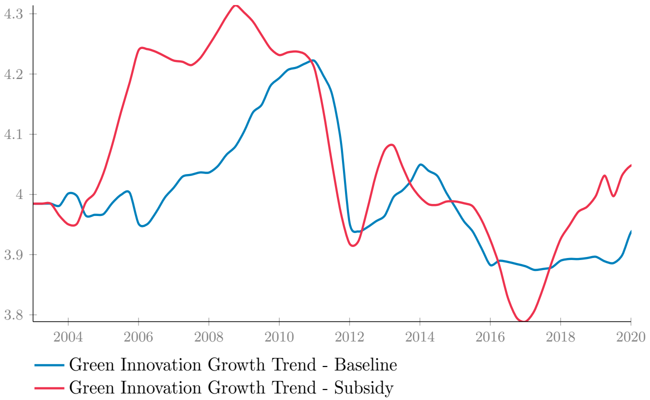
Prior and Posterior Distribution

		Prior distributions			Posterior distributions
		Shape	Mean	Std.	Mean *[0.050;0.950]*
Shock processes:					
Std. productivity	σ_A	$\mathcal{IG}_1$	0.001	0.005	0.0061 *[0.0050 ; 0.0071]*
Std. emission	σ_E	$\mathcal{IG}_1$	0.001	0.005	0.0082 *[0.0070 ; 0.0093]*
Std. R&D	σ_{A_s}	$\mathcal{IG}_1$	0.001	0.005	0.0352 *[0.0307 ; 0.0401]*
Std. green innovation	σ_{A_g}	$\mathcal{IG}_1$	0.001	0.005	0.0451 *0.0392 ; 0.0512]*
AR(1) productivity	ρ_A	$\mathcal{B}$	0.50	0.20	0.9641 *[0.9349 ; 0.9934]*
AR(1) emission	ρ_E	$\mathcal{B}$	0.50	0.20	0.9796*[0.9636 ; 0.9983]*
AR(1) R&D	ρ_{A_s}	$\mathcal{B}$	0.50	0.20	0.5456 *[0.3704 ; 0.7129]*
AR(1) green innovation	ρ_{A_g}	$\mathcal{B}$	0.50	0.20	0.9237 *[0.8509 ; 0.9832]*
Endogenous growth parameters:					
Trend slope	$\gamma_y - 1$	$\mathcal{G}$	0.005	0.001	0.0043*[0.0029 ; 0.0058]*
Green innovation trend slope	$\gamma_{A_g} - 1$	$\mathcal{G}$	0.01	0.002	0.0100 *[0.0067 ; 0.0132]*
R&D investment exogenous trend	γ_{V_s}	$\mathcal{N}$	1	0.20	1.0020 *[1.0011 ; 1.0027]*
Green investment exogenous trend	γ_{V_g}	$\mathcal{N}$	1	0.20	1.0097 *[0.9951 ; 1.0276]*
R&D investment elasticity	η_g	$\mathcal{B}$	0.15	0.20	0.0721 *[0.0001 ; 0.1501]*
Green investment elasticity	η_s	$\mathcal{B}$	0.125	0.20	0.1088 *[0.0001 ; 0.2170]*
Log-marginal data density					666.668864

Notes: $\mathcal{B}$ denotes the Beta, $\mathcal{IG}_1$ the Inverse Gamma (type 1), $\mathcal{N}$ the Normal, and $\mathcal{G}$ the Gamma distribution.

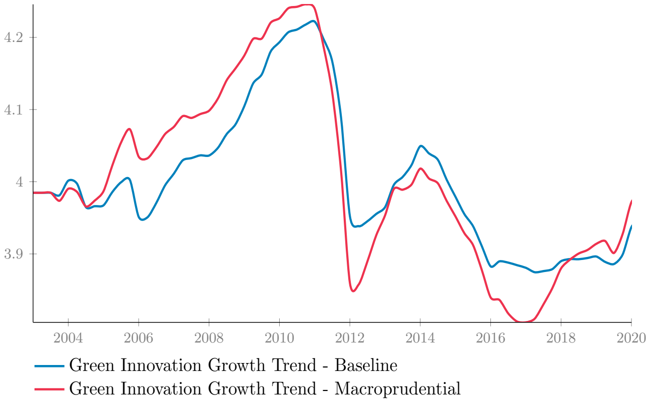
Business Cycle Analysis: Subsidies

Figure: Counterfactual Subsidy Exercise.



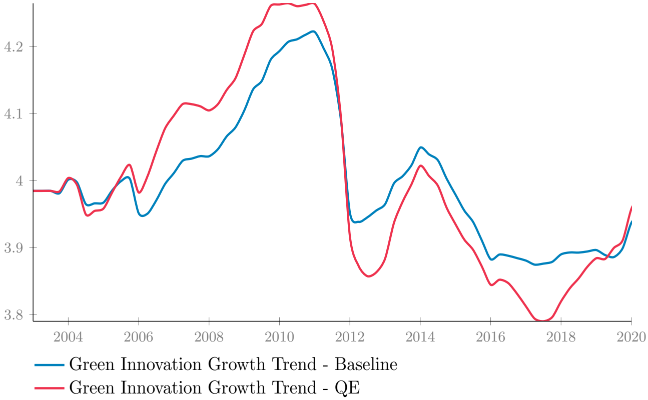
Business Cycle Analysis: Macroprudential Policy ($\text{Macropru}_t = 1 - \lambda(E_t - \bar{E})\}$)

Figure: Counterfactual Macroprudential Exercise.



Business Cycle Analysis: QE ($QE_t = \phi^{\Psi}(E_t - \bar{E})$)

Figure: Counterfactual QE Exercise.

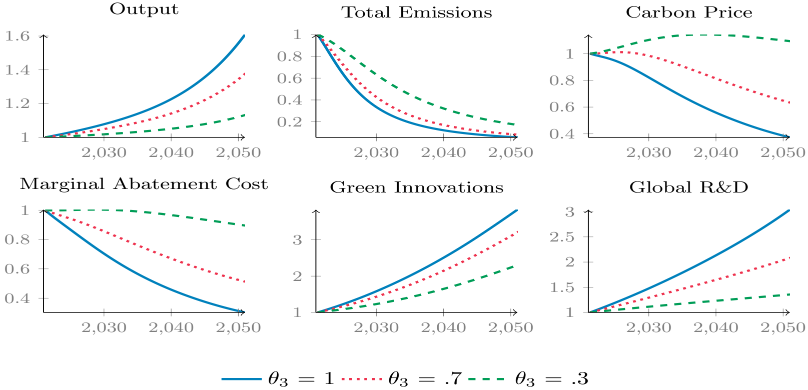


UNDER CONSTRUCTION

- Counterfactuals with smart macropru and QE policies (occasionally binding constraint):
  - $\text{Macropru}_t = max\{1, (1 - \lambda(E_t - \bar{E}))\}$
  - $\text{QE}_t = min\{0, \phi^{\Psi}(E_t - \bar{E})\}$

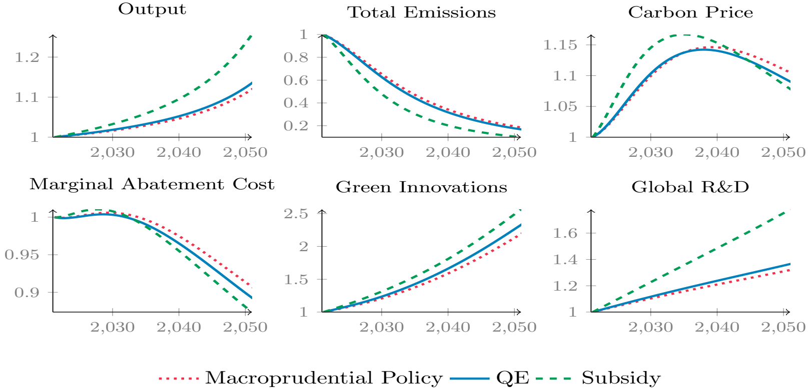
Net-Zero Transition Pathways Analysis

Figure: The Net-Zero Transition Pathway Under Different Abatement to Green Technology Elasticities θ_3.



Net-Zero Transition Pathways Analysis

Figure: The Net-Zero Transition Pathway Under The Three Macro-Financial Policies (with $\theta_3 = .3$).



Takeaway

1. The ETS price contributes to reducing emissions and steering green R&D. However, when the price is too high, the impact is negative.
2. Long-term loans appears to have played a significant positive role in steering green R&D.
3. Efficient abatement technology (i.e. greener technologies) would help achieve CO2 emissions reduction targets. However, the net-zero target requires increasingly higher levels of abatement technologies.
4. Macro-financial policies would help steer green innovation over the business cycle.
5. While Financial subsidies are found to be more effective over the long-run.

Thank you for your attention

Thank you!