GHG Emissions Control and Monetary Policy

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Motivation

- Pervasive effects on the economy of environmental policies: additional costs of abatement of greenhouse gas (GHG) emissions affect directly and/or indirectly agents' decisions and attitude toward uncertainty
- Two channels: (i) the emissions permit price which can be variable or not, according to the regime adopted (price vs. quantity regulation); (ii) the abatement cost borne by firms
- In the short- to medium-term, environmental targets and economic activity are portrayed as being in conflict with one another
- Need for a full understanding of the impact of GHG emissions control policies in an economy with uncertainty, imperfect price adjustments and lack of perfect competition

Motivation

- Environmental policy as a form of fiscal policy: the government sells emission permits according to a cap-and-trade scheme or taxes emissions
- Central bank responsible for setting the nominal interest rate
- The policy actions undertaken
  - shape the trade-off between environmental quality and economic efficiency
  - are likely to condition the business cycle behavior of an economy whose equilibrium is already distorted by imperfect competition and nominal rigidities
- Different areas of interventions cannot be considered in isolation

Research Questions

- How are monetary and environmental policies intertwined?
- What impact has emission control policy on the optimal monetary policy response to shocks?
- How do different monetary policy strategies affect optimal environmental policy?

Related Literature I

- Quite vast literature on optimal monetary policy... no environmental aspects (of course!): e.g. Khan et al. (2003), Schmitt-Grohé and Uribe (2004a, 2007), Faia (2008, 2009, 2012), Benigno and Woodford (2005), Woodford (2002), Erceg et al. (2000), Faia et al. (2014). An early attempt in Annicchiarico and Di Dio (2015).
- However, optimal monetary and fiscal policies are studied in conjunction; e.g. Schmitt-Grohé and Uribe (2004) and Schmitt-Grohé and Uribe (2007)

Two typical results in the plain NK model:

- "The optimal long-run inflation target is zero in this model *no matter how large* the steady-state distortions may be" (Woodford 2003, p. 462)
- As real shocks occur the price level should be largely stabilized

Related Literature II

- Environmental policy under uncertainty (e.g. Newell and Pizer 2003, Jotzo and Pezzey 2007; Kelly 2005)
- Few papers scratch the surface of the vast business cycle literature, incorporating pollution and environmental policy
- Questions addressed in RBC and NK models:
  - How can environmental policy adjust to business cycles? (Heutel 2012, Angelopoulos et al. 2010, 2013)
  - How do different types of environmental policies perform with business cycles? (Fischer and Springborn 2011; Annicchiarico and Di Dio 2015; Ganelli and Tervala 2011; Dissou and Karnizova 2016)

Related Literature III

Some findings:

- Ramsey environmental tax and quota procyclical
- cap policy leads to lower volatility of economic variables than does the tax policy
- intensity target policy can achieve the emissions goal at the lowest expected costs
- staggered price adjustment alters significantly the performance of the environmental policy regime put in place

Preview I: The Way We Do

- A plain vanilla New Keynesian model extended to allow for pollutant emissions, abatement technology and environmental damage
- Four cases: (i) social planner problem; (ii) Ramsey planner choosing jointly monetary and environmental policy; (iii) Ramsey planner controlling monetary policy under different environmental policy instruments (i.e. carbon tax vs. cap); (iv) Ramsey planner deciding on environmental policy given monetary policy
- Source of uncertainty: productivity shock

Preview I: The Way We Do

Structure of a NK Model

Households: decisions on consumption and risk free assets

Perfectly competitive final good producers: producers combine intermediate goods with a CES technology

Monopolistically competitive intermediate good sector: producers face nominal rigidities, employs labor

A monetary authority controlling the risk-free nominal interest rate

Preview I: The Way We Do

Structure of a NK Model Embodying Environmental Aspects

Households: decisions on consumption and risk free assets

Perfectly competitive final good producers: producers combine intermediate goods with a CES technology

Monopolistically competitive intermediate good sector: polluting producers face nominal rigidities, employs labor , embarks on abatement costs and suffer from the negative externality related to environmental damage of pollution

A government deciding over environmental policy

A monetary authority controlling the risk-free nominal interest rate

Preview II: Distortions

Three distortions in the economy:

(i) **monopolistic competition**, which generates an average markup of prices over marginal costs $\rightarrow$ lowers output with respect to the efficient economy

(ii) **costs of price adjustments** (Rotemberg 1982) $\rightarrow$ these absorb resources and distort relative prices across states

(iii) **negative externality of pollution** on production$\rightarrow$ lowers output

Rationales for the conduct of monetary and environmental policies

Preview III: Social Planner and Positive Productivity Shock

- Only one distortion: **negative externality of pollution**
- 2 forces at work:
  - a temporary increase in productivity leads to demand a cleaner environment $\rightarrow$higher abatement effort, and so lower negative externality of pollution on production
  - labor is more productive, therefore the opportunity cost of a major abatement effort increases $\rightarrow$ higher negative externality of pollution on production
- Under a reasonable parametrization of the model, the latter effect dominates the former $\rightarrow$ emissions move procyclically in response to a positive productivity shock

Preview IV: Ramsey Planner and Positive Productivity Shock

Three distortions:

- **negative externality of pollution**:
  - labor is more productive, therefore the opportunity cost of a major abatement effort increases $\rightarrow$ higher negative externality of pollution on production
  - BUT, more resources are available to abate emissions per unit of output $\rightarrow$ lower negative externality of pollution on production
- **monopolistic competition**:
  - the marginal cost component related to the manufacturing of goods goes down, BUT the overall marginal cost (embedding environmental policy and abatement cost) can increase or not depending on the environmental policy in place $\rightarrow$ extra marginal cost can be transferred to households via markups
- **costs of price adjustments**:
  - Deviations from price stability are costly and subtract resources from consumption and abatement

Preview V: Ramsey Planner - Results

- In the decentralized equilibrium a compromise among all the distortions that characterize the economy must be found
- Results depend on
  - the instruments in hand
  - the intensity of the distortions (i.e. imperfect competition, costly price adjustment and negative environmental externality)
  - the way distortions interact
- Emissions can be pro-cyclical or not
- Inflation is not always stabilized

The Model

Final Good Sector

The final good Y_t is produced by perfectly competitive firms, using the intermediate inputs with CES technology:

$$Y_t = \left[\int_0^1 Y_{j,t}^{(\theta-1)/\theta} dj \right],$$

with $\theta > 1$ constant elasticity of substitution.
The demand schedule from profits maximization is $Y_{j,t} = \left(P_{j,t}/P_t\right)^{-\theta} Y_t$,
where $P_t = \left(\int_0^1 P_{j,t}^{1-\theta} dj \right)^{1/(1-\theta)}$

The Model

Intermediate Good Sector I

There is a continuum $j \in [0,1]$ of **monopolistically competitive firms**. The typical firm j hires $L_{j,t}$ labor inputs to produce intermediate good $Y_{j,t}$, according to:

$$Y_{j,t} = \Lambda_t A_t L_{j,t},$$

A_t productivity which evolves as $\log A_t = (1-\rho_A)\log A + \rho_A \log A_{t-1} + \varepsilon_{A,t}$, with $0 < \rho_A < 1$ and $\varepsilon_{A,t} \sim i.i.d.\ N(0, \sigma_A^2)$ and Λ_t is a **damage** coefficient that captures the impact of climate change on output:

$$\Lambda_t = \exp(-\chi(M_t - \tilde{M})),$$

where M_t is the stock of pollution in period t, $\tilde{M}$ is the pre-industrial stock level and $\chi > 0$ measures the intensity of this **negative externality**

The Model

Intermediate Good Sector II

Emissions at firm level, $Z_{j,t}$, are related to output and depend on the **abatement effort**, $U_{j,t}$

$$Z_{j,t} = (1 - U_{j,t})\,\varphi Y_{j,t}, \;\; \varphi > 0, \quad 0 \leq U_{j,t} \leq 1.$$

The abatement technology employs the final good and is related to abatement effort and individual firm's output. Cost of emission abatement $\mathcal{C}_A$:

$$\mathcal{C}_A(U_{j,t}, Y_{j,t}) = \phi_1 U_{j,t}^{\phi_2} Y_{j,t}, \;\; \phi_1 > 0, \quad \phi_2 > 1.$$

Emissions are costly to producers and the **unit cost of emissions**, p_Z, depends on the **environmental regime**.

The Model

Intermediate Good Sector III

- Each producer faces a marginal cost of the type

$$MC_t = \Psi_t + \phi_1 U_t^{\phi_2} + p_{Z,t} \left(1 - U_t\right) \varphi,$$

The Model

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- Ψ_t: component related to the extra units of labor needed to manufacture an additional unit of output (declines if A increase, increases if the damage increases)

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- $\phi_1 U_t^{\phi_2}$: component related to the extra abatement effort

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- $p_{Z,t} \left(1 - U_t\right) \varphi$: component related to the extra purchase of emission permits (or tax payments)

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- $\phi_1 U_t^{\phi_2}$: component related to the extra abatement effort
- $p_{Z,t} \left(1 - U_t\right) \varphi$: component related to the extra purchase of emission permits (or tax payments)
- the last two components increase with A under an optimal environmental policy and with a cap, but stay constant with a carbon tax.

The Model

Intermediate Good Sector IV: The New Keynesian Phillips Curve - NKPC

- FOC wrt $P_{j,t}$ under **adjustment costs of the Rotemberg type**:
  $\frac{\gamma}{2}\left(\frac{P_{i,t}}{P_{i,t-1}} - 1\right)^2 Y_t \rightarrow$ NKPC

  $$1 - \theta + \theta MC_t - \gamma\left(\Pi_t - 1\right)\Pi_t + \gamma E_t Q^R_{t,t+1}\left(\Pi_{t+1} - 1\right)\Pi_{t+1}\frac{Y_{t+1}}{Y_t} = 0,$$

  $\Pi_t = P_t / P_{t-1}$; $Q^R_{t,t+1}$ stochastic discount factor.

The Model

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- Current inflation related to expected future rate of inflation and to marginal cost (depending on productivity, abatement, emission regulation and externality of pollution!)

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- Current inflation related to expected future rate of inflation and to marginal cost (depending on productivity, abatement, emission regulation and externality of pollution!)
- With $\gamma = 0$

$$MC=\frac{\theta-1}{\theta}$$

The Model

Intermediate Good Sector V: The New Keynesian Phillips Curve - NKPC

- Using the definition of (gross) price markup:

$$Markup_t = \frac{P_t}{MC_t^N} = \frac{1}{MC_t}$$

The Model

Intermediate Good Sector V: The New Keynesian Phillips Curve - NKPC

- Using the definition of (gross) price markup:

$$Markup_t = \frac{P_t}{MC_t^N} = \frac{1}{MC_t}$$

- The re-formulated NKPC:

$$Markup_t = \frac{\theta}{\theta - 1 + \gamma\left[\left(\Pi_t - 1\right)\Pi_t - E_t Q^R_{t,t+1}\left(\Pi_{t+1} - 1\right)\Pi_{t+1}\frac{Y_{t+1}}{Y_t}\right]}$$

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- The markup is variable because of price stickiness$\rightarrow$ The monetary authority has a temporary control over it (by means of inflation)

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- The markup is variable because of price stickiness$\longrightarrow$ The monetary authority has a temporary control over it (by means of inflation)
- With $\gamma = 0$

$$Markup = \frac{\theta}{\theta - 1}$$

The Model

Households

Households derive utility from consumption C_t and disutility from labor L_t:

$$E_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \mu_L \frac{{L_t}^{1+\eta}}{1+\eta} \right), \ \eta \geq 0, \ \mu_L > 0, \, 0 < \beta < 1,$$

β: discount factor, η: inverse of the Frisch elasticity of labor supply; μ_L: disutility of labor. The flow budget constraint:

$$P_t C_t + R_t^{-1} B_{t+1} = B_t + W_t L_t + D_t - P_t T_t,$$

B_{t+1}: riskless one-period bonds paying one unit of the *numéraire* in $t+1$,; R_t: gross nominal return on riskless bonds purchased in t; T_t: lump-sum transfers; D_t: dividends from ownership of firms.

The Model

Resource Constraint and Emissions

- Resource constraint of the economy

$$Y_t = C_t + \underbrace{\frac{\gamma}{2}\left(\Pi_t - 1\right)^2 Y_t}_{\text{price adj. cost}} + \underbrace{\phi_1 U_t^{\phi_2} Y_t}_{\text{abatement cost}} .$$

The Model

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- Total emissions

$$Z_t = \int_0^1 Z_{j,t}\,dj = \left(1 - U_t\right)\varphi \int_0^1 Y_{j,t}\,dj = \left(1 - U_t\right)\varphi Y_t .$$

The Model

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$$Z_t = \int_0^1 Z_{j,t} dj = (1 - U_t)\, \varphi \int_0^1 Y_{j,t} dj = (1 - U_t)\, \varphi Y_t.$$

- Pollutant emissions accumulate in the environment:

$$M_t = (1 - \delta_M) M_{t-1} + Z_t + \tilde{Z},$$

$0 < \delta_M < 1$: natural decay rate; $\tilde{Z}$: non-industrial emissions

The Model

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- The government budget is always balanced:

$$T_t = p_{Z_t} Z_t,$$

i.e. revenues from environmental policy are transferred to households

Planner Solution

Social planner problem:

$$\max_{\{L_t, U_t, M_t\}_{t=0}^{\infty}} E_0 \left\{ \sum_{t=0}^{\infty} \beta^t \left[\log \left(\underbrace{\Lambda_t A_t L_t \left(1 - \phi_1 U_t^{\phi_2}\right)}_{C_t} \right) - \mu_L \frac{{L_t}^{1+\eta}}{1+\eta} \right] \right\},$$

$$s.t.$$

$$M_t = (1 - \delta_M) M_{t-1} + (1 - U_t)\, \varphi \Lambda_t A_t L_t + \tilde{Z}$$

The social planner solution corresponds to the Pareto efficient equilibrium

Parametrization

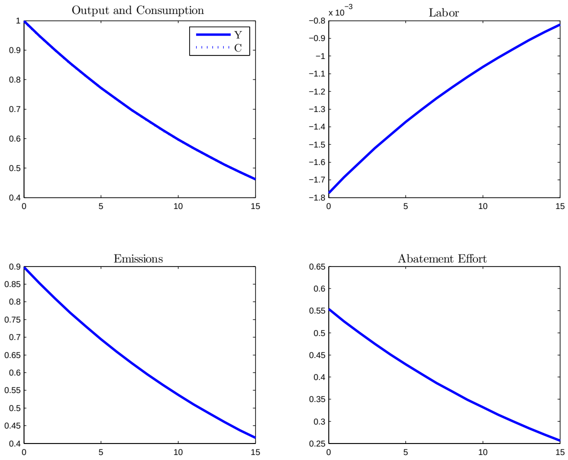
The model frequency is quarterly

Parameter	Description
$\beta = 0.99$	discount factor
$\eta = 1$	inverse of the Frisch elasticity
$\theta = 6$	elasticity of substitution
$\gamma = 58.25$	price adjust. cost parameter
$A = 5.0363$	technology level (scale parameter)
$\mu_L = 24.9015$	disutility of labor (scale parameter)
$\rho_A = 0.9$	shock persistence
$\delta_M = 0.0021$	decay rate
$\varphi = 0.1235$	emission intensity (consistent with RICE-2010 simulations)
$\phi_1 = 0.0485$	abatement technology parameter (scale parameter)
$\phi_2 = 2.8$	abatement technology parameter
$\chi = 0.000457$	damage parameter (consistent with RICE-2010 simulations)

Solution Method

- Perturbation method: The dynamic responses of the Ramsey plan are computed by taking second-order approximations of the set of first-order conditions around the deterministic steady state (Judd 1998; Schmitt-Grohé and Uribe 2004)

Figure 1: Dynamic Responses to a One Percent Increase in Productivity - Social Planner



Ramsey Policy

- By optimal (Ramsey) policy we mean a policy in which policy variables are set so as to maximize social welfare under the constraints represented by the market economy general equilibrium conditions more
- The Ramsey planner is able to commit to the contingent policy rule (i.e. ex-ante commitment to a feedback policy so as to have the ability to dynamically adapt the policy to the changed economic conditions)
- Timeless perspective: at time t=0 the economy has long been operating under an optimal policy. In choosing optimal policy, the Ramsey planner honors commitments made in the past

Ramsey Policy

- **Optimal Environmental and Monetary Policy**: The Ramsey planner decides on R and p_Z (or analogously on Z)
- **Optimal Monetary Policy**: The Ramsey planner decides on R, while environmental policy is set according to a cap or to tax on emissions
- **Optimal Environmental Policy**: The Ramsey planner decides on p_Z (or analogously on Z), while R obeys to an interest rate feedback rule

Optimal Steady State Inflation

- In steady state the optimal inflation rate is zero: the Ramsey planner will find it optimal to fully neutralize the distortion induced by the costs on price adjustment which reduces the overall resources available and creates a wedge between aggregate demand and output
- Nominal adjustment costs reduce the resource available for abatement (and so for damage reduction...)

Optimal Steady State of the Price on Emission Permit

- In steady state the optimal level of abatement is positive since the Ramsey planner internalizes the negative externality of pollution on productivity. This result, in turn, delivers a positive value for the price on emission permits, $p_{Z,t}$ (or equivalently of a tax on emissions)

Steady-State Solution

	Social Planner	Ramsey	Ramsey $\theta = 1000$
Y	1	0.9141	1.000
C	0.9997	0.9140	0.9997
L	0.2	0.1828	0.2000
Z	0.1046	0.1039	0.1046
U	0.1534	0.0798	0.1534
p_z		0.01162	0.0377
Π		1	1
M	57.3089	56.9879	57.3089
Welfare	-49.8285	-50.5881	-49.8285

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Figure 2a: Dynamic Responses to a One Percent Increase in Productivity - Ramsey Monetary and Environmental Policy

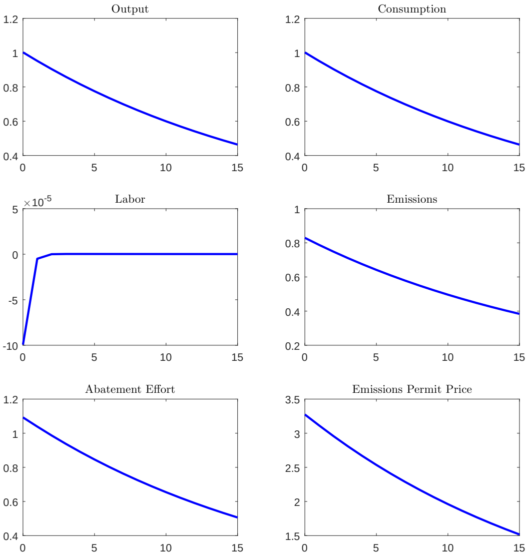
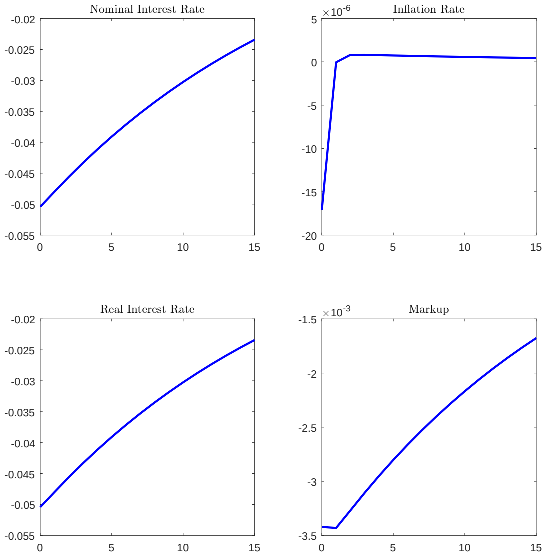


Figure 2b: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary and Environmental Policy



Impulse Responses to a 1% Productivity Shock

- Output and consumption immediately increase, while labor decreases
- The optimal response of emissions is positive, but mitigated by the hike in the price of emissions permit which, in turn, induces a surge in the abatement effort
- The nominal interest rate decreases and inflation falls on impact, but less than proportionally. The resulting real interest rate factor, R_t/Π_{t+1}, declines, showing that the Ramsey planner will opt to optimally respond to this shock with an accommodative monetary policy
- The Ramsey planner tends to generate the conditions under which it is optimal for firms to set lower markups, temporarily reducing the distortions due to the lack of competition and increasing the resources available for consumption and abatement

Figure 3a: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary and Environmental Policy - Sensitivity

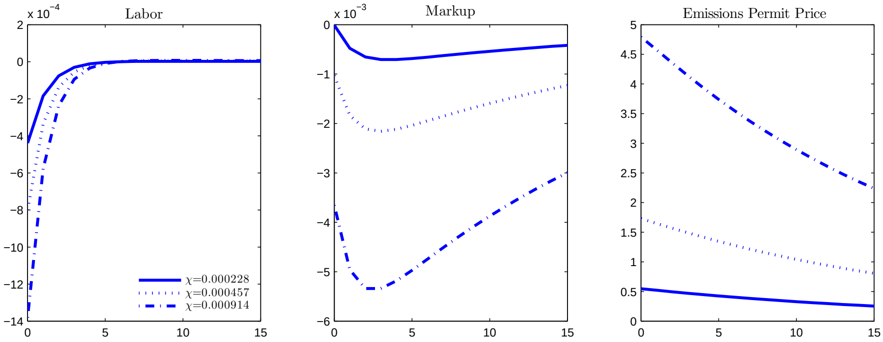


Figure 3b:Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary and Environmental Policy - Sensitivity

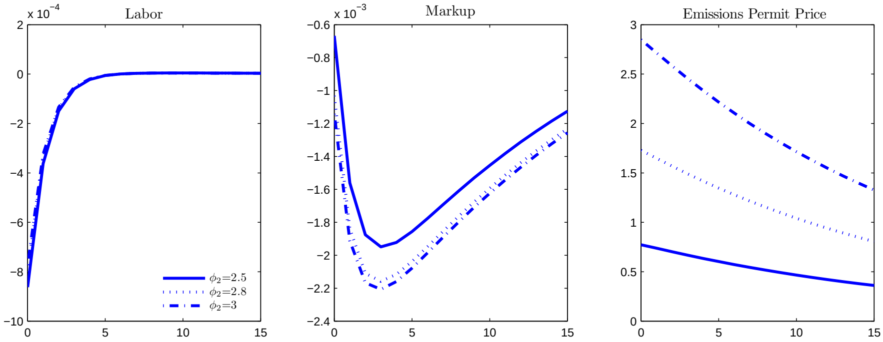


Figure 3c: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary and Environmental Policy - Sensitivity

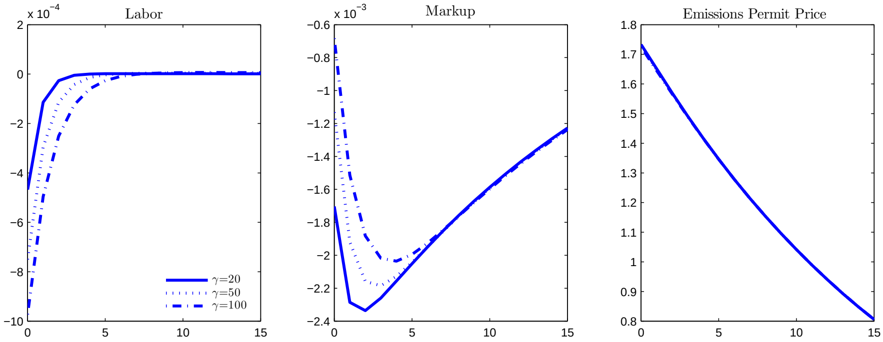


Figure 3d: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary and Environmental Policy - Sensitivity

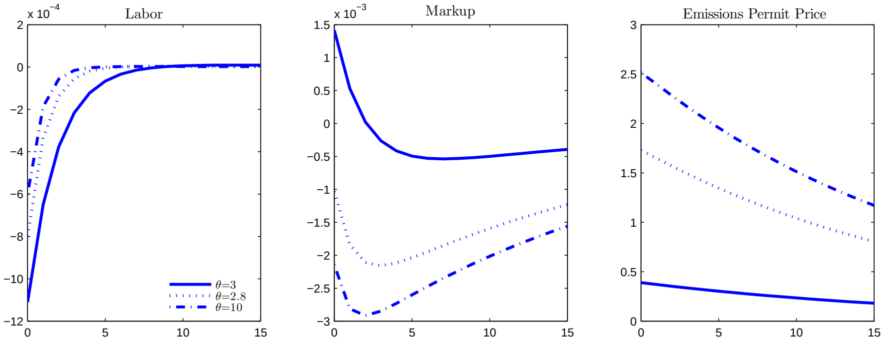


Figure 4a: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy

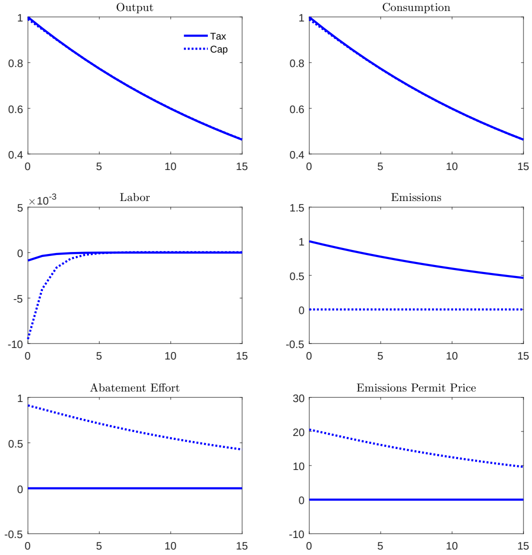
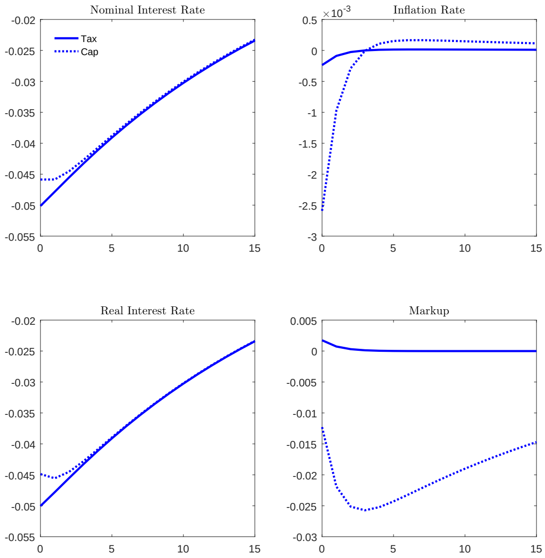


Figure 4b: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy



Impulse Responses to a 1% Productivity Shock

Ramsey Monetary Policy

- Emissions expand only under a carbon tax, while with a cap scheme the abatement effort and the permits price increase
- Deviations from price stability in response to the shock in a cap scheme: first deflation and then inflation (as before...)
- Under a carbon tax, the Ramsey planner will only induce a slight deflation combined with a higher markup... here emissions increase and so the negative externality of pollution becomes an issue

Figure 5: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy with Carbon Tax

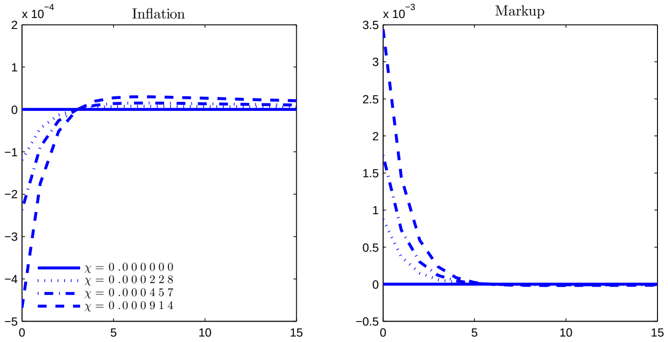


Figure 6a: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy with Cap - Sensitivity

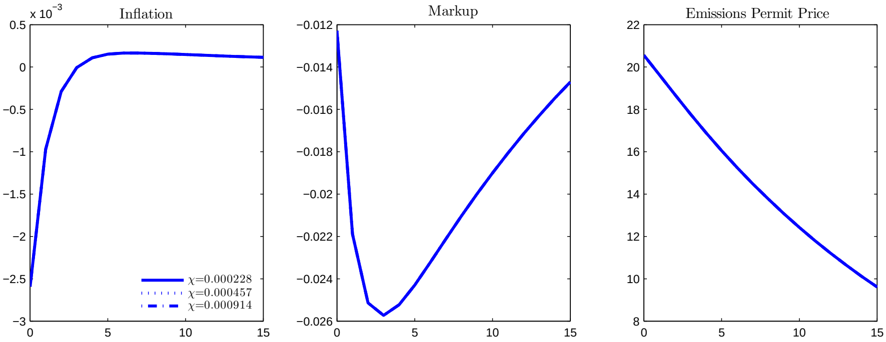


Figure 6b: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy with Cap - Sensitivity

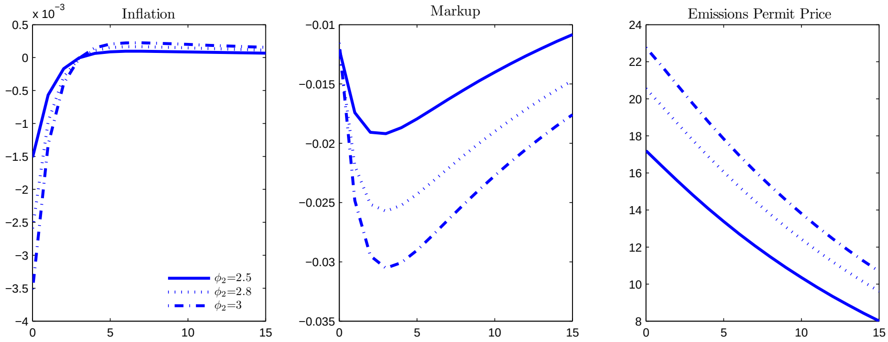


Figure 6c: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy with Cap - Sensitivity

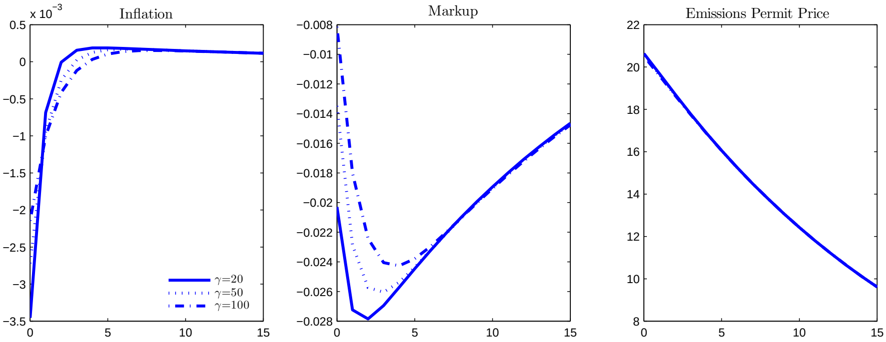


Figure 6d: Dynamic Responses to 1% Increase in Productivity - Ramsey Monetary Policy with Cap - Sensitivity

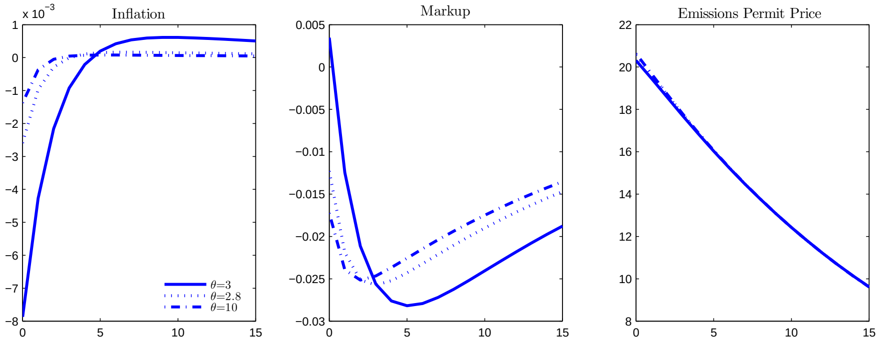


Figure 7a: Dynamic Responses to 1% Increase in Productivity - Ramsey Environmental Policy

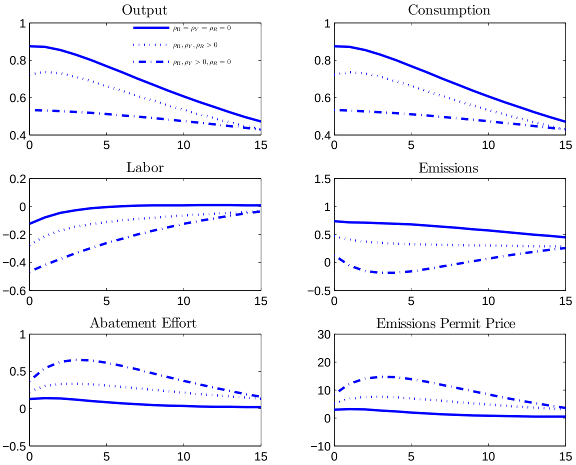
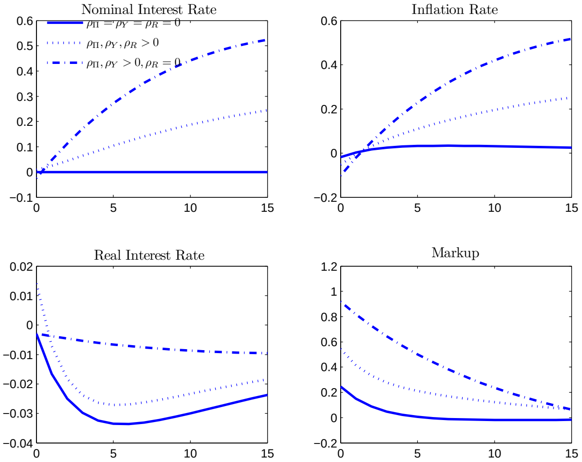


Figure 7b: Dynamic Responses to 1% Increase in Productivity - Ramsey Environmental Policy



Impulse Responses to a 1% Productivity Shock

- Response of output, consumption and emissions much lower than before
- The markup now increases: the Ramsey planner has no access to monetary instrument not directly controlling the markup via inflation path
- Monetary policy conduct influences intensively the way in which the Ramsey planner sets environmental policy
- When there is a positive reaction of the interest rate to output and inflation, the opportunity cost of a major abatement reduces so emissions initially increase and then temporarily decline to slowly revert back to their initial steady-state level $\rightarrow$ emissions become countercyclical, reducing even further the damage of pollution on productivity.

Conclusions

- Climate actions are likely to have pervasive effects on the conduct of agents and on the compliance costs borne by firms, as well as economic variables tend to affect the quality of the environment and therefore the performance of mitigation policies
- We study the optimal environmental and monetary policy mix in a New Keynesian model with pollutant emissions, abatement technology and environmental damage
- Environmental and monetary policies are strongly intertwined: their interaction is determined by the intensity of the distortions to be addressed
- Further research needed

Related Projects

- Theoretical model with oligopolistic markets and endogenous market structure to study the effects mitigation schemes on market structure
- Theoretical model with two-interdependent economies to highlight the international aspects of environmental policies
- Construction of a large-scale DSGE model embodying environmental variables for policy analysis

Ramsey Problem

- Fairly rich model: it is not possible to reduce the constraints to the Ramsey problem into a simple implementability constraint and a resource constraint
- Multi-stage approach:
  - efficiency conditions for households and firms, along with budget and resource constraints
  - reduce the number of constraints to the Ramsey problem
  - write the problem so that it is inherently stationary (i.e. augmented Lagrangian...)
  - maximize expected utility subject to these constraints
  - find the monetary policy actions which lead these outcomes to be the result of a dynamic equilibrium
- Timeless perspective: "start up" dynamics ignored

back to Ramsey problem