A General Equilibrium Approach to Carbon Permit Banking

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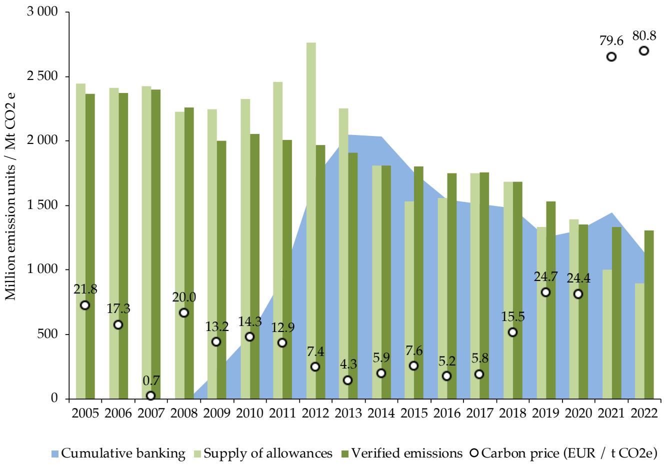
Motivations – (1) The emission trading system

- The emission trading system (ETS) is a market-based approach implemented by regulators to adjust and reduce carbon emissions.
- The regulator sets a limit, or "cap", on the total amount of emissions allowed within a specific jurisdiction or industry.
- The emission cap is expressed in terms of a specific number of permits. Each permit represents the right to emit a certain amount of carbon dioxide.
- Companies can strategically manage their emissions over time through *permit banking*.

Motivations – (2) The importance of permit banking



Sources: European Environment Agency and European Commission. Cumulative banking is defined as the difference between the allowances allocated for free, auctioned or sold plus international credits surrendered or exchanged from 2008 to 2022 minus the cumulative emissions. MtCO2e: million tons of CO2 equivalent.

Motivations – (3) Environmental targets vs. economic outcomes

- In the coming years, the EU-ETS is expected to play a critical role in the Union's efforts to reach the goals of the Paris Agreement.
- "In the short term, the surplus risks undermining the orderly functioning of the carbon market. In the longer term it could affect the ability of the ETS to meet more demanding emission reduction targets cost-effectively."

  European Commission
- A comprehensive economic assessment is crucial in designing and implementing effective environmental policies: it enables policymakers to strike a balance between environmental and economic targets.

This paper

- Objective:

  Propose a general equilibrium framework to assess the macroeconomic effects of various cap policies in the presence of permit banking.

- How?
  1. We develop and estimate an environmental real business cycle (E-RBC) model for the European Union.
  2. We introduce an emission trading system with permit banking.
  3. We quantify "going green" via projections up to 2060.

Related literature

- Relates to the literature on permit banking, which recognizes its importance in achieving cost-effective emissions reductions and providing flexibility to regulated entities: e.g., Liski and Montero, 2005, Fell et al., 2012, Holland and Moore, 2013, Kollenberg, 2016, 2019, Perino and Willner, 2016, Lintunen and Kuusela, 2018, Hitzemann and Uhrig-Homburg, 2018, Quemin and Trotignon, 2021.
- Complements the burgeoning literature on climate issues using microfounded structural models: e.g., Fischer and Springborn (2011), Heutel (2012), Golosov et al. (2014), Dissou and Karnizova (2016), Annicchiarico and Di Dio (2015, 2017), Annicchiarico et al. (2018), Barrage (2020), Carattini et al. (2021), Diluiso et al. (2021), Jondeau et al. (2022), Finkelstein Shapiro and Metcalf (2023), Gibson and Heutel (forth.).

Contributions

We make three **contributions** w.r.t. the literature:

- **Methodological**. We develop a quantitative and tractable macro-climate model for the European Union economy featuring an ETS market with permit banking.
- **Empirical**. We estimate this nonlinear macro-climate model by applying full-information methods to monthly EU data.
- **Policy applied**. We assess the macroeconomic effects of recent decisions or regulations on the ETS, already implemented or announced by the European Parliament, and quantify the role of permit banking.

Model

Overview

- **Households**: maximize intertemporal utility by choosing consumption, hours worked, and capital accumulation.
- **Firms**: hire labor services and physical capital to produce a homogeneous final good. Firms' activities generate CO_2 emissions.
- **Regulatory authority**: implements a cap policy that gives firms the legal right to pollute a certain amount, which depends on the number of pollution permits issued. These permits are bankable, i.e., they can be stored for future use.

Firms

- Firm $j \in [0, 1]$ produces a homogeneous good using the following production function:

$$y_{j,t} = \varepsilon_{a,t} k_{j,t-1}^{\alpha} n_{j,t}^{1-\alpha},$$

where $\alpha \in (0, 1)$ denotes the capital share and $\varepsilon_{a,t}$ is the total factor productivity shock common to all firms.

- Firms generate CO_2 emissions, denoted by $e_{j,t}$, which accumulate to increase the stock of pollutants in the air:

$$e_{j,t} = \eta \left(1 - \mu_{j,t}\right) y_{j,t}^{1-\gamma},$$

where $\mu_{j,t}$ represents the effort to abat emissions, $1 - \gamma$ is the elasticity of emissions with respect to output, and η is a scale parameter.

Firms and the regulation

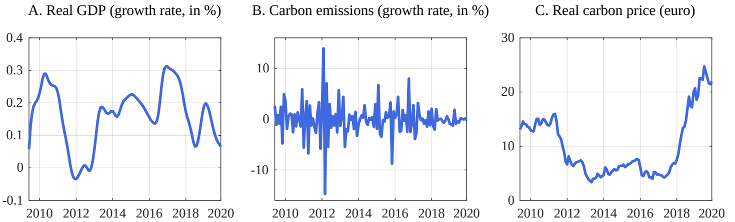
- The regulator sets an emission cap and issues a quantity of permits ϑ_t consistent with that cap.
$$\vartheta_t = \varepsilon_{\vartheta,t}\bar{\vartheta},$$
where $\varepsilon_{\vartheta,t}$ is a shock that makes the effective permit supply time-varying.
- The law of motion of firm j's bank of permits $b_{j,t}$ is given by:
$$b_{j,t} = b_{j,t-1} + \vartheta_{j,t} - e_{j,t}.$$
- Non-borrowing constraint: firms are not allowed to borrow permits from the future, such that:
$$b_{j,t} \geq 0.$$

Inference

Data

The observable variable matrix:

$$\begin{bmatrix} \text{Real GDP growth rate} \\ \text{Carbon emission growth rate} \\ \text{Real carbon price} \end{bmatrix} = 100 \times \begin{bmatrix} \Delta \log(y_t) \\ \Delta \log(e_t) \\ p_{e,t} \end{bmatrix}. \tag{1}$$



Sources: Organization for Economic Cooperation and Development (GDP and deflator), Emissions Database for Global Atmospheric Research (carbon emissions), and International Carbon Action Partnership (carbon price).

Estimation

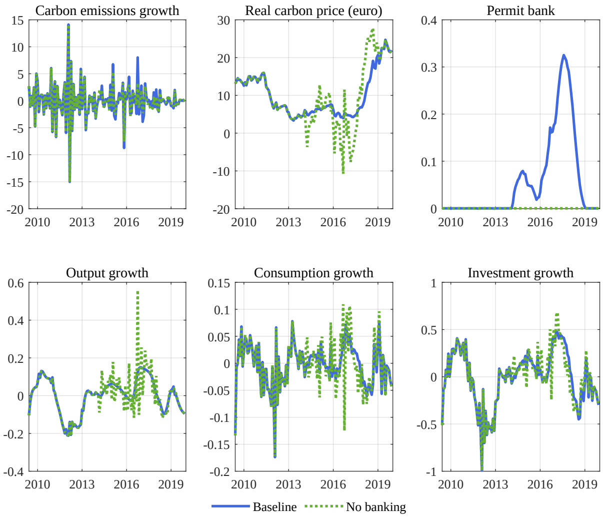
The parameters are estimated using the full information maximum likelihood methodology (inversion filter).

	Parameter	Estimates
Panel A: Structural parameters		
Inv. of elasticity of substitution in consumption	σ	2.744 *[0.00]*
Inv. of Frisch labor supply elasticity	ν	1.927 *[0.00]*
Habit formation	φ	0.728 *[0.00]*
Elasticity of emissions with respect to output	$1-\gamma$	0.821 *[0.00]*
Abatement effort	μ	0.202 *[0.00]*
Adjustement cost on investment	ψ	5.926 *[0.00]*
Adjustement cost on abatement	κ	0.027 *[0.00]*
Panel B: Shock processes		
AR(1) productivity	ρ_a	0.949 *[0.00]*
AR(1) abatement cost	ρ_μ	0.908 *[0.00]*
AR(1) permit supply	ρ_ϑ	0.941 *[0.00]*
Std dev. productivity	σ_a	0.001 *[0.00]*
Std dev. abatement	σ_μ	0.221 *[0.00]*
Std dev. permit supply	σ_ϑ	0.031 *[0.00]*
Log likelihood		663.050

Note: P-values are in brackets (null hypothesis of being equal to zero).

Counterfactual exercise

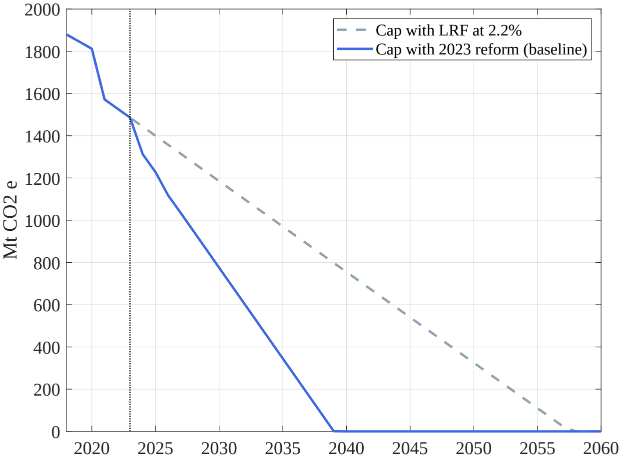
- Counterfactual exercise to understand the importance of the nonlinearities generated by intertemporal banking of permits.
- Plugging the smoothed shocks obtained from the estimated baseline model into an alternative version without permit banking.
- Accounting for permit banking is crucial for correctly studying the interaction between a cap policy and the economy.



Policy implications of permit banking

Baseline scenario (I)

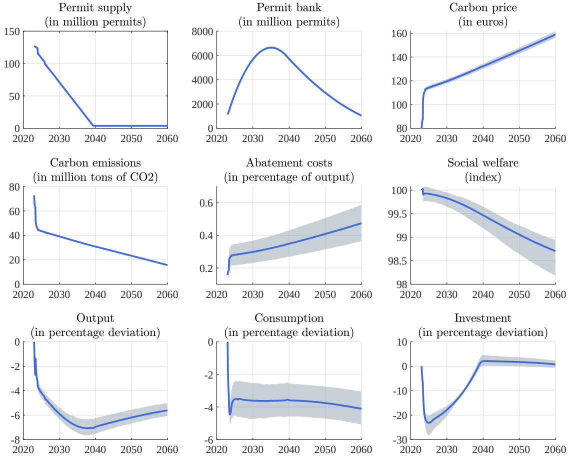
Figure: European-Union emission trading system cap



Baseline scenario (II)

- **Result 1:** The baseline cap scenario leads to (i) a strong increase in permit banking until 2035 (before fading after that date), (ii) a doubling of the carbon price, and (iii) an average output loss of approximately 6% by 2060.

Baseline scenario under the 2023 EU-ETS cap reform

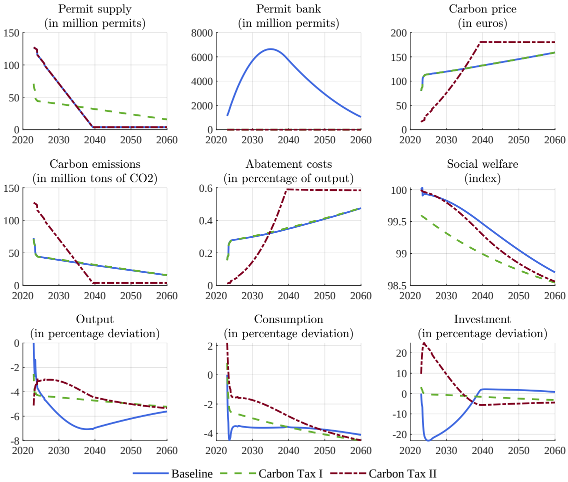


Cap policy vs. carbon tax

- **Result 2:** A policymaker can achieve the same emission reduction path as under cap policy by setting a carbon price that accounts for firms' forward-looking behavior implied by the ETS. This choice allows her to save 1.3% of GDP on average until 2060, at the cost of deteriorating social welfare.

- **Result 3:** Forgetting permit banking leads to (i) a significant underestimation of the macroeconomic effects of policy tightening and (ii) an incorrect carbon emission path. The latter misleadingly suggests that achieving net-zero emissions would occur by 2040.

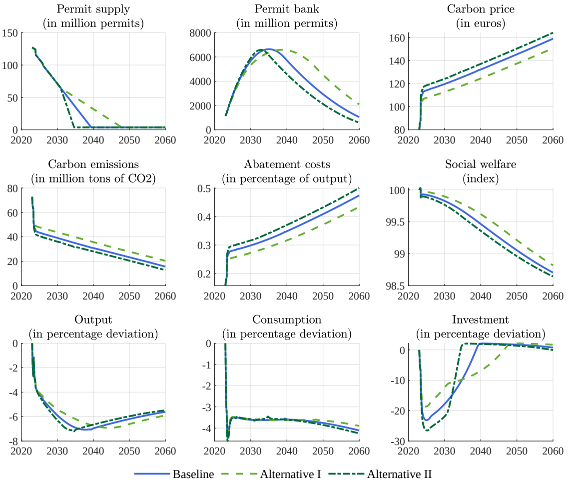
Cap policy versus carbon tax



What about after 2030? (I)

- No indication of the characteristics of Phase 5 which will begin in 2031.
- Two credible alternative scenarios that differ after this date: (i) decreasing LRF to 2.2% and (ii) increasing LRF to 10% to reach a cap of virtually 0 in 2035.
- Decreasing the LRF is less restrictive for firms that reduce their emissions less and store their permits longer.

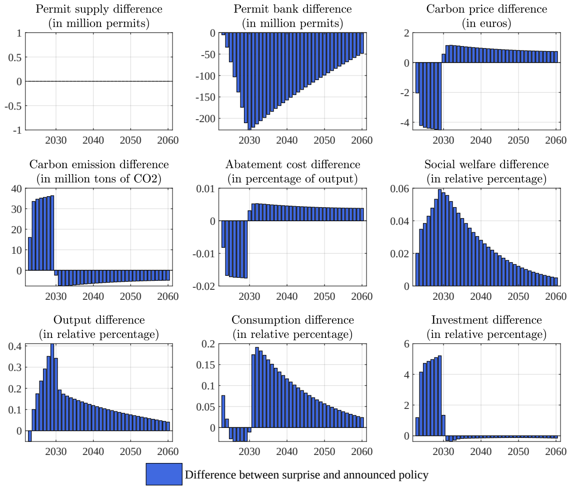
Cap policy versus carbon tax



What about after 2030? (II)

- Not only does the amount of an announced regulatory change matter but also the timing of this announcement.
- Comparison of a pre-announced scenario with a surprise one.
- **Result 4:** Announcing a policy in advance allows agents to modify their behavior accordingly, thus reducing emissions from the day of the announcement and not at the time of its implementation.

Cap policy versus carbon tax



The market stability reserve (I)

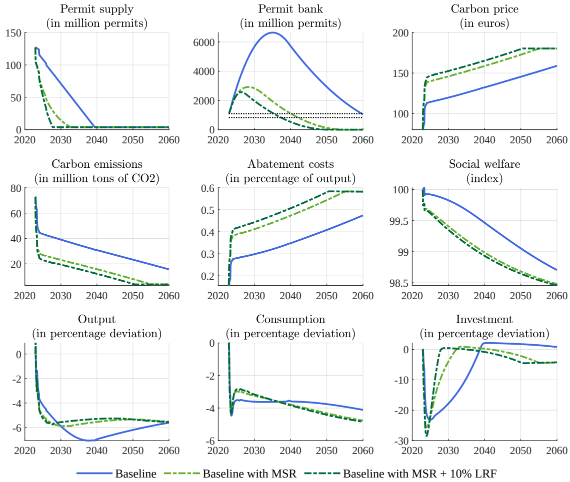
- The MSR functions by triggering adjustments to annual auction volumes if the requirements based on the level of the aggregate bank of allowances are met. Total number of allowances in circulation (TNAC) is used.
- If TNAC is between 833 million and 1,096 million, the difference between TNAC and 833 million is transferred to the reserve.
- If TNAC is above 1,096 million, the number of allowances to be placed in the reserve amounts to 24% of TNAC.
- If TNAC is less than 400 million, 100 million allowances should be released from the reserve and auctioned off.
- In our framework, this translates in:

$$\vartheta_t = \varepsilon_{\vartheta,t}\bar{\vartheta} - 1_{\{(b_t > \underline{b}) \cap (b_t < \bar{b})\}} \frac{b_t - \underline{b}}{12} - 1_{\{b_t > \bar{b}\}} \tau \frac{b_t}{12}$$

The market stability reserve (II)

- **Result 5:** The market stability reserve is a powerful tool to slow down firms' banking of permits and thus reduce emissions more quickly. By combining it with a higher LRF (e.g, 10%), the net-zero objective would be achieved in 2050, with an average GDP cost of approximately 5.3% and an average consumption cost of approximately 3.9%.

Cap policy versus carbon tax



Concluding remarks

- We investigate the general equilibrium effects of permit banking during the transition to a low-carbon economy.
- Our projection exercises underscore the critical role of permit banking in shaping the policy outcomes.
- The 2023 cap reform would lead to a strong increase in permit banking until 2035, a doubling of the carbon price, and an average GDP loss of approximately 5.3% or 6% (depending on whether we account for the market stability reserve) by 2060.
- Importantly, forgetting about permit banking when assessing cap policies would lead to both a significant underestimation of the total macroeconomic effects and an inaccurate representation of the carbon emission trajectory.

Thank you for your attention!

Appendix

Households

Household $i \in [0,1]$ maximizes its sequence of present and future utility flows that depend positively on consumption $c_{i,t}$ and negatively on hours worked $n_{i,t}$:

$$\mathrm{E}_t \sum_{s=0}^{\infty} \beta^s \left\{ \frac{(c_{i,t+s} - \varphi c_{t+s-1})^{1-\sigma} - 1}{1-\sigma} - \chi \frac{n_{i,t+s}^{1+\nu}}{1+\nu} \right\},$$

subject to the sequence of real budget constraints

$$c_{i,t} + x_{i,t} + \mathcal{A}_{i,t}^{x} \leq w_t n_{i,t} + d_{i,t} + r_{k,t} k_{i,t-1},$$

where $x_{i,t}$ is investment, $d_{i,t}$ is the equity payout received from the ownership of firms, and w_t is the real wage, $k_{i,t}$ is physical capital rented to the firm at the rental rate $r_{k,t}$, and $\mathcal{A}_{i,t}^{x}$ represents adjustment costs on investment

$\beta \in (0,1)$: subjective discount factor, φ: external habit formation, σ: the inverse of the elasticity of substitution in consumption, $\nu > 0$: the inverse of the Frisch labor supply elasticity, and χ: a scale parameter.

Firms II

- Substituting carbon-intensive technologies with low-carbon technologies is costly. The cost of abatement technology (in proportion to output) is given by (Nordhaus, 2014):

$$\mathcal{A}^{\mu}_{j,t} = \varepsilon_{\mu,t}\theta_1 \left[\mu_{j,t}^{\theta_2} + \frac{\kappa}{2}\left(\frac{\mu_{j,t}}{\mu_{j,t-1}} - 1\right)^2 \mu_{j,t-1} \right] y_{j,t}.$$

- Firms maximize their intertemporal profits:

$$\mathrm{E}_t \sum_{t=s}^{\infty} \Omega_{t,t+s}\{y_{j,t+s} - w_{t+s}n_{j,t+s} - r_{k,t+s}k_{j,t+s-1} - p_{e,t+s}\vartheta_{j,t+s} - \mathcal{A}^{\mu}_{j,t+s}\},$$

subject to the several production constraints. $\Omega_{t,t+s}$ is the stochastic discount factor that converts future payoffs into current values.

Regulatory authority and market clearing

- The regulatory authority sets a cap $\bar{\vartheta}$ on the maximum level of emissions and creates permits for each unit of emissions allowed under the cap:

$$\vartheta_t = \varepsilon_{\vartheta,t}\bar{\vartheta},$$

where $\varepsilon_{\vartheta,t}$ is a shock that makes the effective permit supply time-varying.

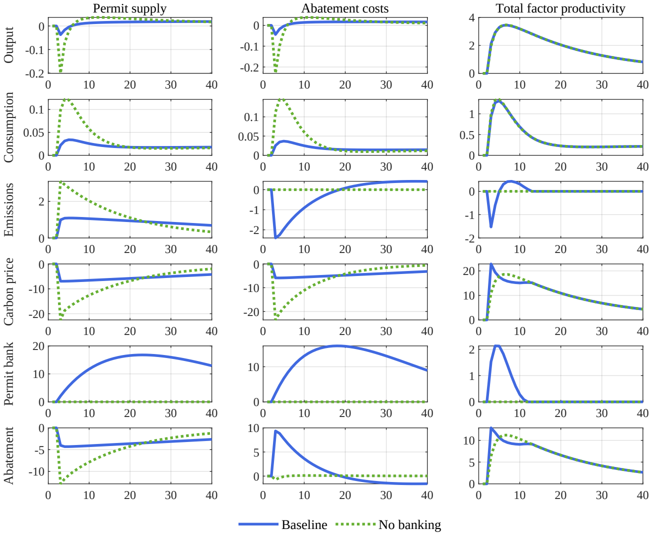
- The aggregate resource constraint of the economy:

$$\int_{j=0}^{1} y_{j,t}\mathrm{d}j = \int_{i=0}^{1}\int_{j=0}^{1}\left(c_{i,t} + x_{i,t} + p_{e,t}\vartheta_{j,t} + \mathcal{A}^{x}_{i,t} + \mathcal{A}^{\mu}_{j,t}\right)\mathrm{d}i\mathrm{d}j$$

Model solution

- The non-negativity constraint on the bank of permits introduces nonlinearity and creates de facto two regimes.
- Thus, we rely on the piecewise linear perturbation approach proposed by Guerrieri and Iacoviello (2015), which is a variant of the extended perfect-foresight path method proposed by Fair and Taylor (1983).
- The occasionally binding constraint can be handled as different regimes of the same model: under one regime, the occasionally binding constraint is slack, and under the other regime, the same constraint is binding.

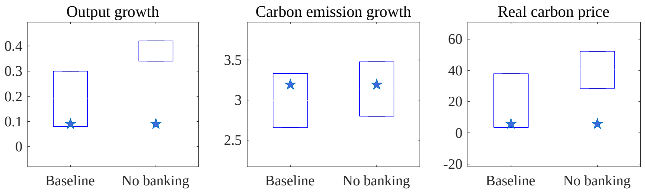
Impulse response functions



Counterfactual exercise II

- A model without banking leads to higher volatility for most variables.
- Firms that are not allowed to store permits are unable to insure themselves against fluctuations.
- Accounting for permit banking is crucial for correctly studying the interaction between a cap policy and the economy.

Empirical and model-implied standard errors



Note: The two models were simulated 300 times for 127 periods (same size as the data sample). The stars represent the values obtained from the data. The rectangles represent the range of values simulated from the baseline model.