Carbon Pricing, Border Adjustment and Renewable Energy Investment: a Network approach

Mar Delgado-Téllez[⋆] Javier Quintana[§] Daniel Santabárbara[§]

[⋆] ECB [§] Banco de España

The views expressed in this presentation are those of the authors and **do not** necessarily represent the views of the Bank of Spain, the ECB and the Eurosystem.

In this paper

- What is the effect of a **€100 carbon tax per CO_2 equivalent tonne** emitted in the EU?

→ What is the reduction of **CO_2 emissions**?
  - How much is due to fall in production, change in consumption or change in inputs?

→ Is there import-related carbon leakage?
  - Could a carbon border adjustment mechanism avoid it?

→ How much does the carbon tax incentive green energy investments?
  - Does it drive an electrification process?

- We use a dynamic multi-sector model with production and investment networks and a renewable energy sector.

Related Literature

- **Carbon pricing desired features** (IMF, 2019): wide-ranging coverage of emissions; alignment of carbon prices with mitigation objectives; predictable steady increase over time of carbon prices; and efficient use of the fiscal funds generated.

- Effects of different carbon pricing strategies and carbon leakage:
  - **Ex-post**. Econometric models using historical data find limited carbon leakage (perhaps due to low carbon pricing).
  - **Ex-ante**. Model simulations calibrated with empirical data. Böhringer et al. (2022); Felbermayr et al. (2020); Zachmann and McWilliams (2020), and Yu et al. (2021): carbon leakage depends on: stringency of carbon pricing, geographical scope or magnitude of trade and fossil fuel supply elasticities.

Literature Review

- **Carbon border adjustment**
  - **Reduces leakages** but depends on sectoral coverage, reference emissions, number of countries implementing, and trade elasticities (Böhringer et al., 2022; Antimiani et al., 2016; Fouré et al., 2016; Schinko et al., 2014; Burniaux et al., 2013).
  - **or little leakage reduction** (Zachmann and McWilliams, 2020). Ernst et al. (2022) it can benefit 'dirty' domestic sectors (cost of imports increases → shift towards domestic demand). Weitzel et al. (2012) it could strategically used when 'dirty' domestic sectors are cleaner than abroad.
- Ernst et al. (2022) with a environmental multi-sector dynamic general equilibrium model, with three regions, **assess alternative designs** of carbon pricing and CBAM, **but** without retaliatory measures and renewables investment.
- **Endogenous energy transition**: O'Ryan et al. (2020) analyses the impact of four alternative energy mix scenarios for Chile for 2030 in a CGE model environment.

Model

Model

- Multi-sector, multi-country dynamic model
- Firms use labor, capital, energy and other intermediate inputs.
  - Intermediate input and investment networks.

⇒ Increasing costs, lower production and import substitution.

- Energy sector with endogenous renewable investment.
  - Calibrate the relative value of green and brown electricity.

⇒ Carbon tax increases eneregy prices: incentives for renewable capacity.

⇒ Attenuates increase of energy costs (capture price)

- EU sets a carbon tax to the use of polluting inputs.

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Production Side

- Firms produce with **((KL)E)MS)** structure.

1. Value added:

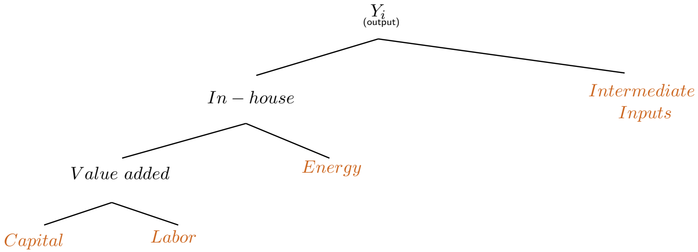
   Capital and labor

2. Energy

3. Material and services from other firms

- Aggregated under CES

- *Energy - VA complementarity*



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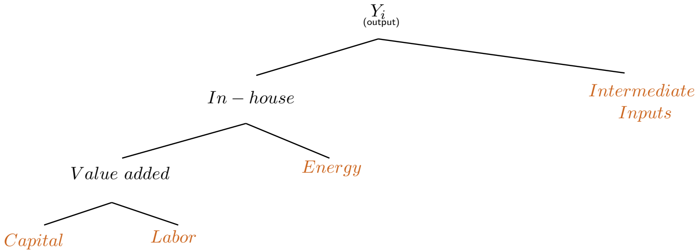

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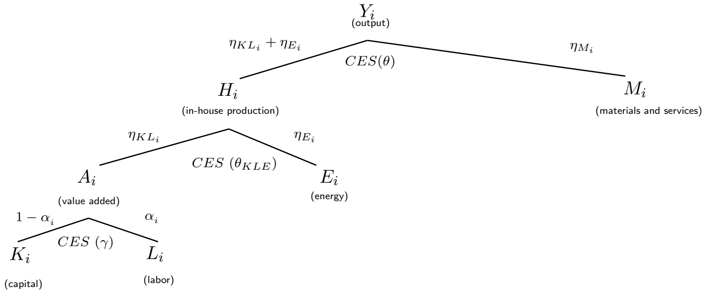


Production Side

- Firms combine output from other sectors to produce:

1. Investment bundle, K_i
2. Intermediate Inputs bundle, M_i

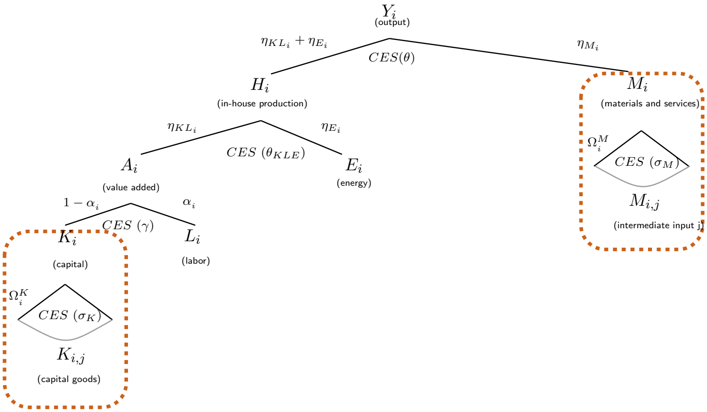
   Weight matrices, Ω_i^K and Ω_i^M

   CES with elasticities, σ^K and σ^M

- Firms combine different local varieties of each sector:

   Importance of each local variety, $\Lambda_{i,j}^K$ and $\Lambda_{i,j}^M$

   CES with trade elasticities, ξ_j.



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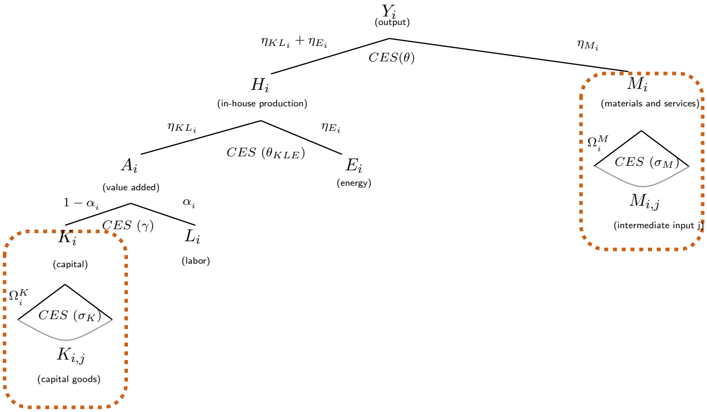

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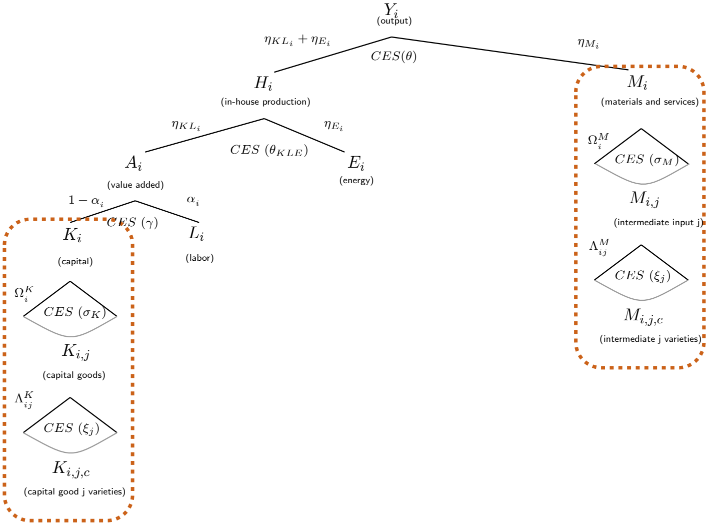

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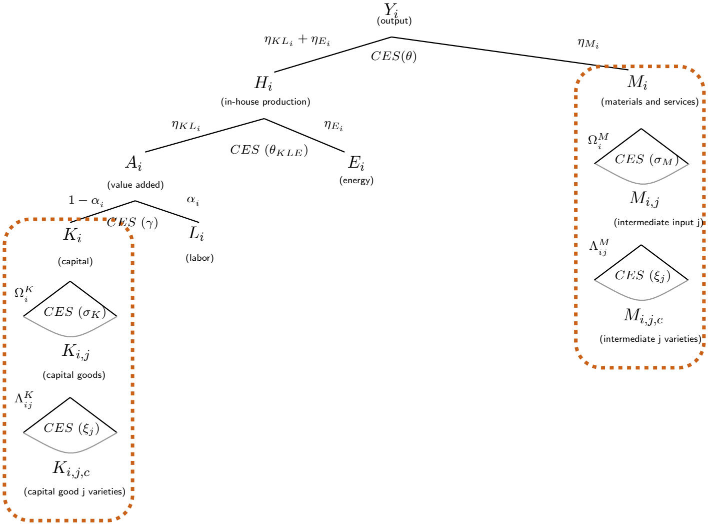


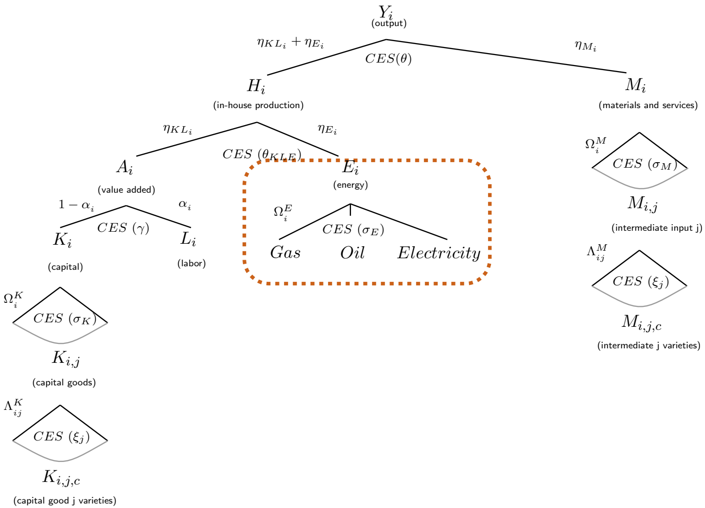
Production Side

- Firms use fossil fuels and electricity as energy inputs.

  Weight matrix Ω_i^E

  Elasticity of substitution σ^E

- Electricity is produced from green or brown sources



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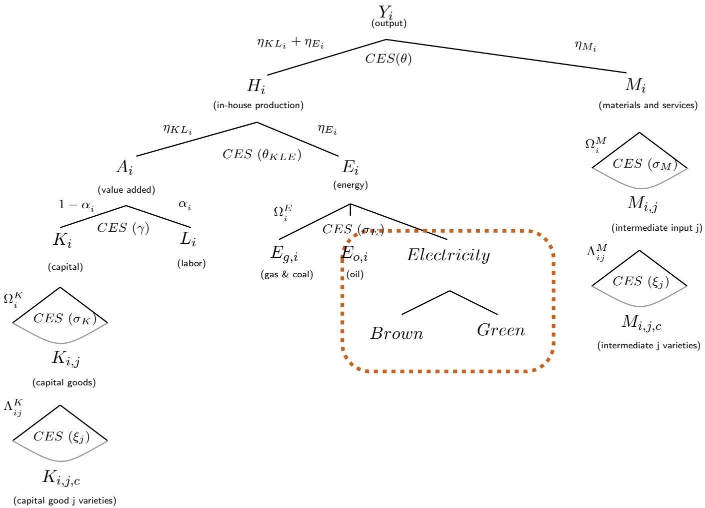
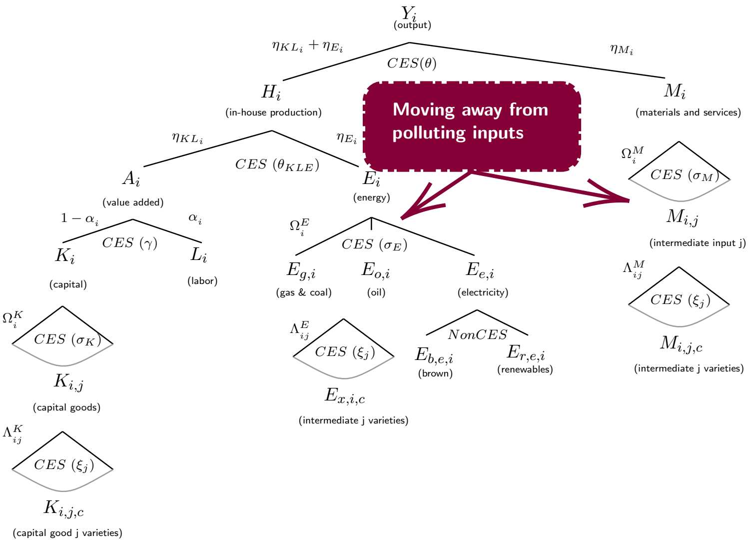


The Carbon Tax in the Production Function



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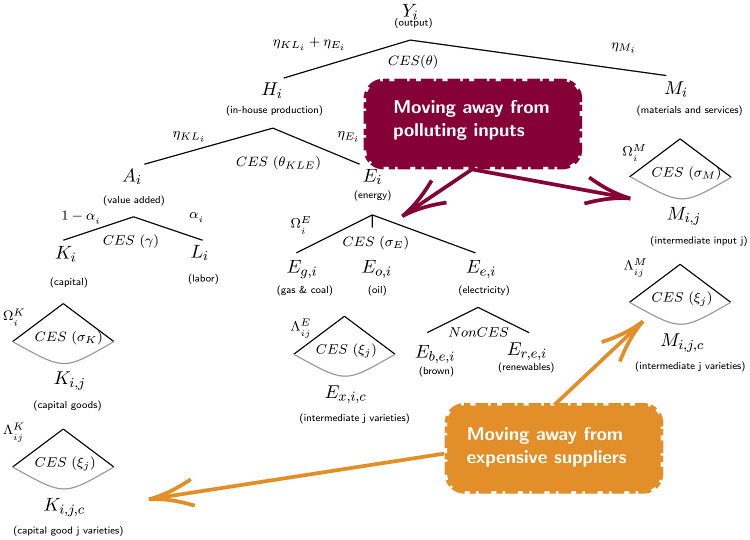

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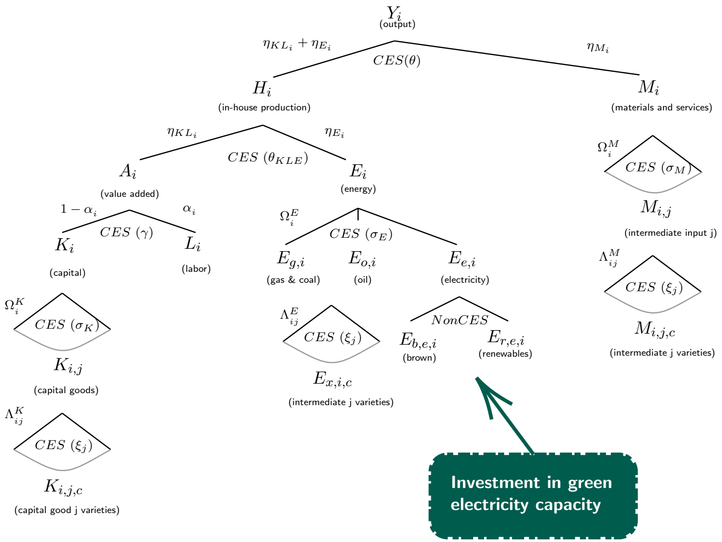


Electricity Market

- Electricity can be produced from fossil fuels (brown) or green sources.

Brown electricity

- Standard CES production
  - Intermediate inputs
  - Variable costs
  - Adjustable production
- Dispatchable supply
- CO_2 emissions

Green electricity

- AK-type production function
  - Only capital
  - Zero marginal cost
  - Pre-set production
- Non dispatchable
- No CO_2 emissions

Electricity market

Market design:

1. Electricity price equals to the marginal cost most expensive technology *(merit based order)*.

⇒ Complete pass-through of carbon tax to electricity prices.

2. Green producers *captures* only a fraction of average electricity price.

⇒ Capture price share decreases with percentage of green generation (cannibalization risk).

⇒ Renewables displace (more expensive) fossil fuels and reduce marginal costs.

3. Average electricity price as the average price of both sources.

Electricity market

Alternative interpretation:

What is the **elasticity of substitution** between brown and green for consumers?

- **Non constant** elasticity of substitution:

→ Very **large** with a small share of *green* electricity: it crowds *brown* electricity.

- ▷ 1 additional green MWh crowds out 1 brown MWh

→ Very **low** with high share of *green* generation

- ▷ Brown electricity has been crowded out in the hours/days/months that green electricity is generated.

Electricity market

Our approach:

- Estimate relationship between wholesale electricity price and share of *green* generation using hourly data.

1. Compute residual of wholesale electricity prices from the expected price conditional on natural gas prices

2. Fit the residuals with respect to share of *green* generation.

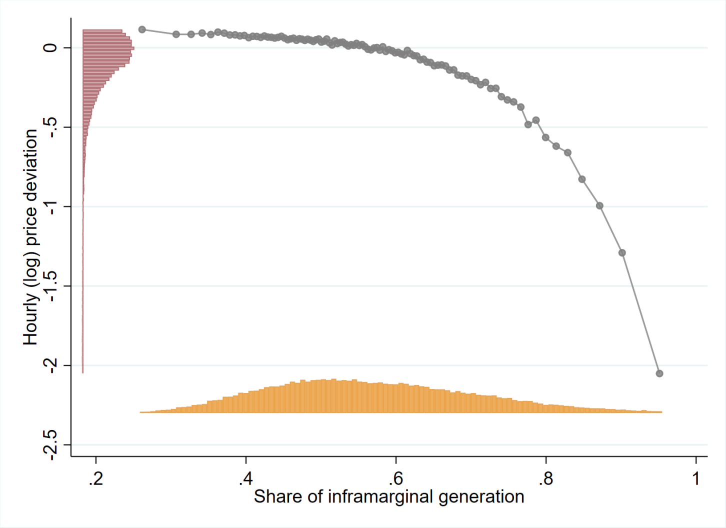
- Project hourly prices to annual prices using the distribution of sun and wind hours.

3. Find the parameter ϱ for

$$P^{g}_{c,t} = P^{b}_{c,t} \cdot \left(1 - S^{\varrho}_{c,t}\right) \tag{1}$$

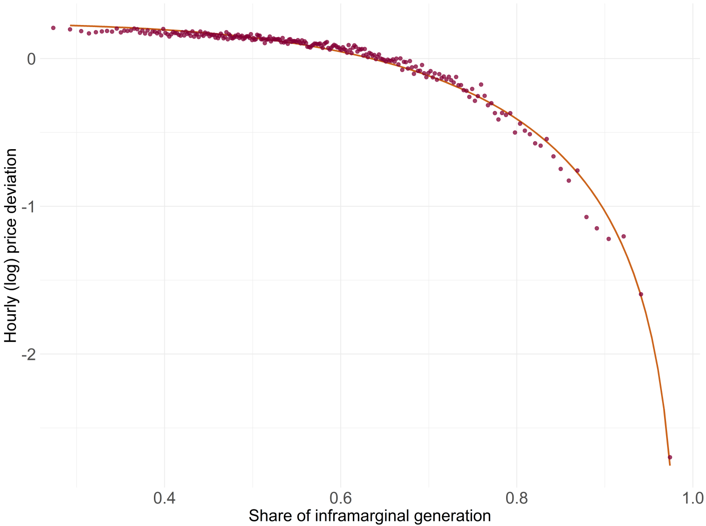
- This gives us the implicit relative value between *green* and *brown* energy.

Electricity market



Bin scatter of hourly log price deviations with respect to expected price of electricity conditional on natural gas price and share of *inframarginal* generation.

Electricity market



Bin scatter of hourly log price deviations with respect to expected price of electricity conditional on natural gas price and $\ln(1 - S^{2.5})$.

Electricity market

Electricity market and carbon pricing in our model

1. Carbon tax increases marginal cost of *brown* electricity sector.

$\rightarrow$ Increases the price that electricity producers receive.

2. Incentives to invest in additional *green* generation.

$\rightarrow$ Green electricity producers capture a lower share of average fossil-based electricity.

$\rightarrow$ Green electricity attenuates the rise of average electricity price.

New equilibrium:

- *Green* electricity producers capture a lower fraction (because of higher share) of a higher price of electricity.

Investment and Labor

- Sectors invest in a bundle of goods produced by the other sectors of the economy:

$$K_{i,t+1} = (1-\delta_i)\cdot K_{i,t} + I_{i,t} - \frac{\varsigma}{2}\left(\frac{K_{i,t+1}}{K_{i,t}} - 1\right)^2 \cdot K_{i,t}$$

$$I_i = \left(\sum_{j=1}^{S} \Omega_{i,j}^{K} \cdot I_{i,j}^{\frac{\sigma_K - 1}{\sigma_K}}\right)^{\frac{\sigma_K}{\sigma_K - 1}} \quad \text{where } I_{ij} = \left(\sum_{h=1}^{C} \lambda_{ijh}^{K} I_{ijh}^{\frac{\xi_j - 1}{\xi_j}}\right)^{\frac{\xi_j}{\xi_j - 1}}$$

- Labor is imperfectly mobile across sectors with an elasticity υ.

$$L_i = \omega_L \left(\frac{W_i}{W_c}\right)^{\upsilon} \cdot L_c$$

Households

Households' preferences are represented by the function

$$U = \mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\log C_t - \frac{L_t^{1+\frac{1}{\mu}}}{1+\frac{1}{\mu}} \right) \tag{2}$$

where μ is the Frisch elasticity of labor supply and β the discount factor.

$$C_i = \left(\sum_{j=1}^{S} \Omega_{i,j}^{C} C_{c,j}^{\frac{\sigma_C - 1}{\sigma_C}} \right)^{\frac{\sigma_C}{\sigma_C - 1}} \qquad C_{ij} = \left(\sum_{h=1}^{C} \lambda_{ijh}^{C} C_{ijh}^{\frac{\xi_j - 1}{\xi_j}} \right)^{\frac{\xi_j}{\xi_j - 1}} \tag{3}$$

Budget constraint:

$$P_c^C \cdot C_c + P_c^K \cdot I_c = W_c \cdot L_c + \Pi_c + \tau_c \tag{4}$$

Parameters

Variable		Value	Source
θ,	Input elasticities	.9	B&F (2021), Atalay (2017)
$\sigma_K, \sigma_M, \sigma_E$		.2	
γ		.9	
σ_C		.9	
θ_{KLE}		.5	Bohringer and Rivers (2017)
ξ	Trade elasticity	2	Boehm et al. (2019)
Ω, λ, α,η	Expenditure shares, and production parameters		ICIO OECD
Ω^K, δ	Investment matrix and dep. rate		KLEMS, ICIO OECD
ϱ	Renewable price canibalisation	2.5	
ς	Capital adjustment cost	.4	Vom Lehm & Winberry (2022)
η	Frisch elasticity	1	
β	Discount rate	.95	
υ	Labor adjustment cost	1	Horvath (2000)

Taxes

- **Carbon tax**

  EU firms and consumers pay additional τ^{CT} for fossil fuel inputs.

- **Border adjustment**

  EU firms and consumers pay additional τ^{BT} for third countries goods according to CO_2 emissions.

- **Export subsidy**

  EU firms receive τ^{Subs} for exports equal to CT burden.

- **Retaliation**

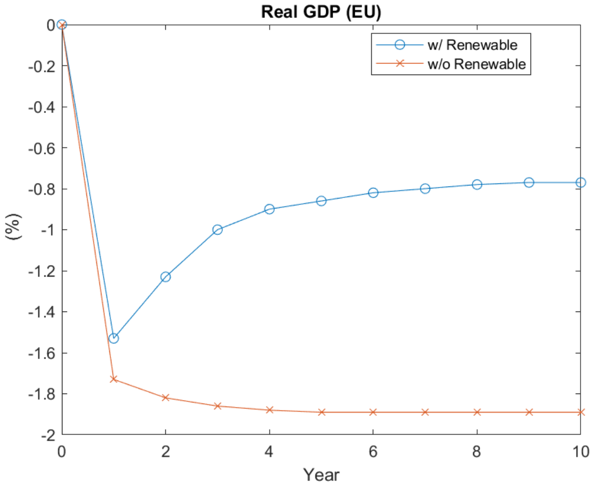
  EU exports to third countries pay τ^{Ret} tariff. Equal aggregate amount than EU border adjustment paid by foreign firms.

Results

Carbon tax

- Impact of a 100€/$\mathrm{CO_2}$tonne
- Assessment with and without endogenous renewable investment.

Impact of 100€/tonne carbon tax.



- Considering endogenous investment in renewable electricity reduces the economic impact of the carbon tax.

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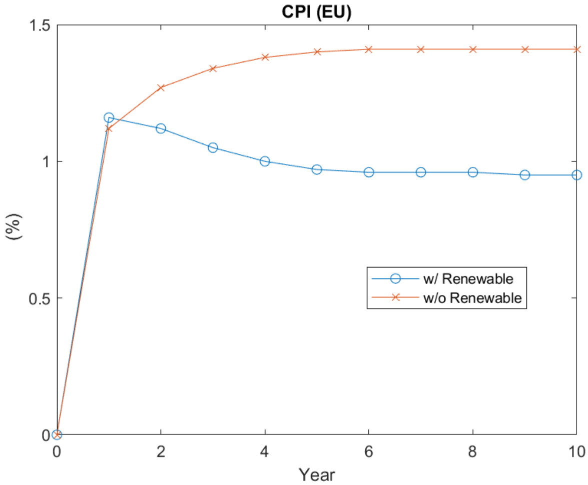

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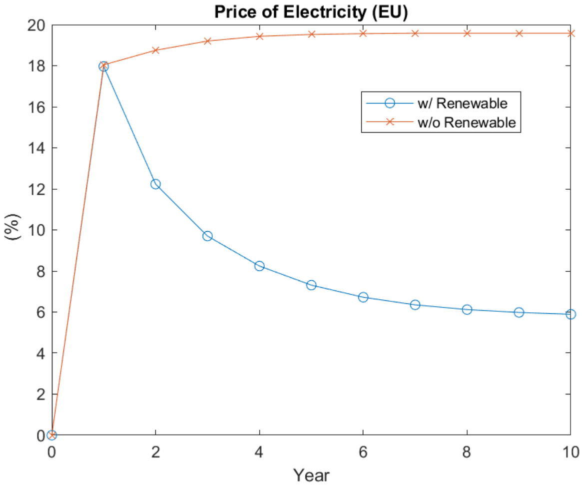

- **Main mechanism:** additional investment in green electricity attenuates the increase in the cost of energy.

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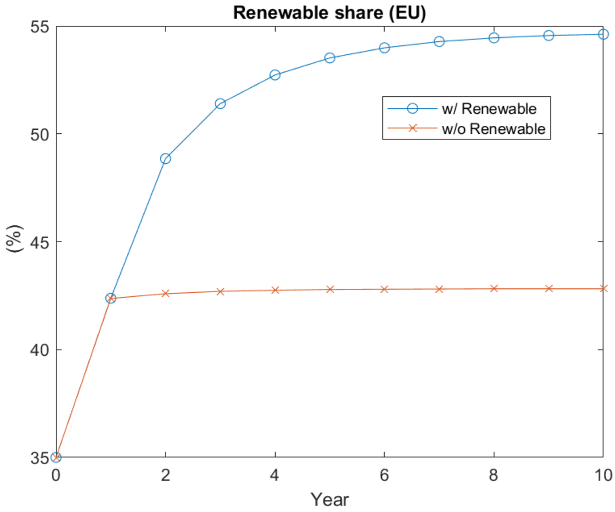

Impact of 100€/tonne carbon tax.

	European Union	
In percentage	w/o Renew.	w/ Renew
Real GDP	−1.9	−0.7
CPI	1.4	1.0
Exports	−2.0	−1.8
Exports (ex. Energy)	−1.5	−1.4
Imports	−3.2	−3.0
Imports (ex. Energy)	−1.1	−0.7
Export price (ex. Energy)	1.4	1.1
Import price (ex. Energy)	0.4	0.1
Tax revenue	0.7	0.1
CO_2 emissions	−13.1	−15.7
Electricity price	19.8	5.8
Renewable change	0.0	11.4

- Considering the incentives to invest in renewable energy cuts GDP by $\sim 2/3$

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In percentage	European Union w/o Renew.	European Union w/ Renew
CO_2 emissions	−13.1	−15.7
Carbon footprint (prod.)	−11.7	−15.4
Carbon leakage (prod.)	1.4	0.3
CO_2 contribution		
due to production level	−1.9	−0.7
due to sectoral reassig.	−4.9	−4.8
due to inputs subst.	−2.2	−3.9
due to energy	−2.5	−2.4
due to renewables	0	−3.8
Renewable change	0.0	11.4
CO_2 emissions (RoW)	0.1	0.2
CO_2 emissions (World)	−0.9	−1.0

- Renewable energies reduce further emissions; but doing so through cleaner electricity instead of production fall.

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- RoW emissions increase: lower fossil demand in EU lowers global prices.

Carbon Border Adjustment Mechanism

- Introduction of equivalent tariff to imports
- Impact on carbon leakage and trade patterns
- Assessment with and without endogenous renewable investment.

Impact of Carbon Border Adjustment Mechanism (w/o Renewables).

	European Union	
In percentage	CT	CT+CBAM
Real GDP	−1.9	−2.3
CPI	1.4	1.7
Exports	−2.0	−2.7
Exports (ex. Energy)	−1.5	−2.2
Imports	−3.2	−4.6
Imports (ex. Energy)	−1.1	−2.5
Export price (ex. Energy)	1.4	1.7
Import price (ex. Energy)	0.4	1.5
Tax revenue	0.7	1.0
CO_2 emissions	−13.1	−14.2
Electricity price	19.8	21.1
Renewable change	0.0	0.0

	European Union	
In percentage	CT	CT+CBAM
CO_2 emissions	−13.1	−14.2
Carbon footprint (prod.)	−11.7	−14.0
Carbon leakage (prod.)	1.4	0.2
CO_2 reduction contribution		
due to production level	−1.9	−2.3
due to sectoral reassignment	−4.9	−4.8
due to inputs substitution	−2.2	−2.8
due to energy	−2.5	−2.6
due to renewables	0	0
Renewable change	0.0	0.0
CO_2 emissions (RoW)	0.1	0.0
CO_2 emissions (World)	−0.9	−1.1

- CBAM closes the carbon leakage, but it has an additional negative effect on GDP.

Impact of Carbon Border Adjustment Mechanism (w/o Renewables).

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due to renewables	0	0
Renewable change	0.0	0.0
CO_2 emissions (RoW)	0.1	0.0
CO_2 emissions (World)	−0.9	−1.1

- CBAM protects some local upstream industries (metal, plastics) but increases the cost of inputs for sectors with very integrated GVCs

Impact of Carbon Border Adjustment Mechanism (with Renewables).

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Export price (ex. Energy)	1.1	1.3
Import price (ex. Energy)	0.1	1.3
Tax revenue	0.7	1.0
CO_2 emissions	−15.7	−16.0
Electricity price	5.8	6.3
Renewable change	11.4	11.7

	European Union	
In percentage	CT	CT+CBAM
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Renewable change	11.4	11.7
CO_2 emissions (RoW)	0.2	0.1
CO_2 emissions (World)	−1.0	−1.2

- Environmental gains from CBAM are weaker in the case with endogenous renewable investment, but additional cost in GDP remains.

Conclusions

Conclusions

- A **carbon tax** is a powerful instrument to reduce $\mathrm{CO_2}$ emissions in the EU
  - Carbon footprint reduction mostly due to consumption and input demand reallocation, and partly to production fall.
  - Carbon leakage due to input sourcing diversion from third countries.
- **Carbon border adjustment mechanism** reduces carbon leakage but does not reverse economic losses
  - Carbon tax affects energy-intensive intemediate input producers like chemicals and metals.
  - Introduction of CBAM reverses losses in these sectors but increases costs for input importer sectors, like computer or vehicle manufacturing.
  - Overall, marginally negative effect on GDP but positive effect over carbon leakage.
- **Renewables** are key to achieve reduction costs and minimize transition costs
  - Carbon tax increases investment incentive for green electricity generation.
  - Green energy boosts investment demand in the short run and attenuates the hike of the price of electricity in the medium term.

Thank you!

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