BBVA Research

Carbon emission cycles in the U.S.: greening through browning?

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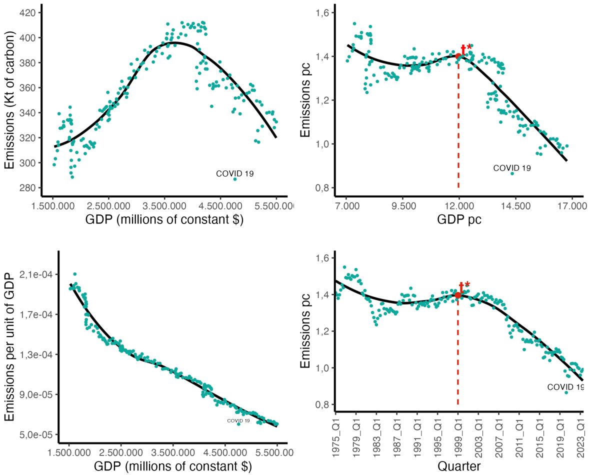
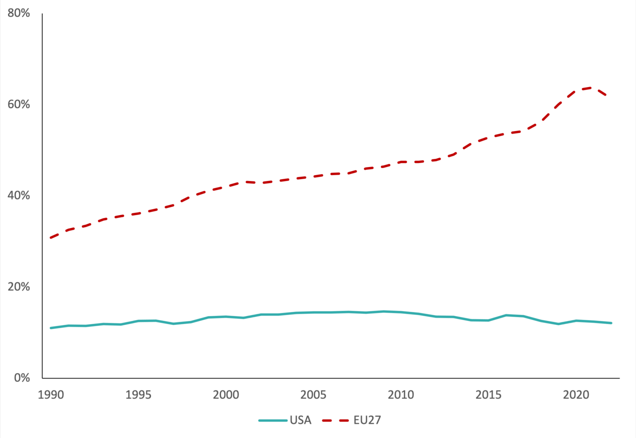


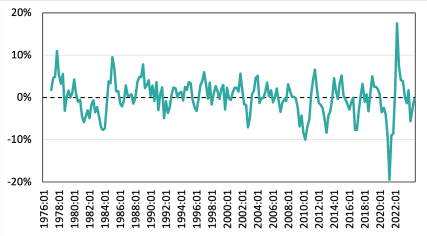
Environmental Kuznets curve



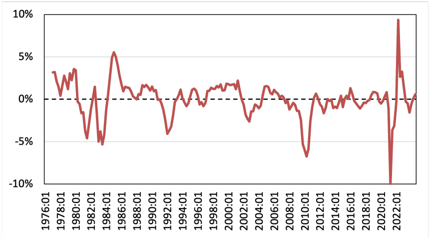
Share of green energy production (excluding biofuels): USA vs EU-27

Emissions cycles

(a) CO2 Emissions



(b) GDP



- *Kaya* identity.

$$emis_t = \left(\frac{emis}{en\_br}\right)_t \times \left(\frac{en\_br}{en\_tot}\right)_t \times \left(\frac{en\_tot}{GDP}\right)_t \times GDP_t \qquad (1)$$

- *Kaya* identity in terms of the cyclical components:

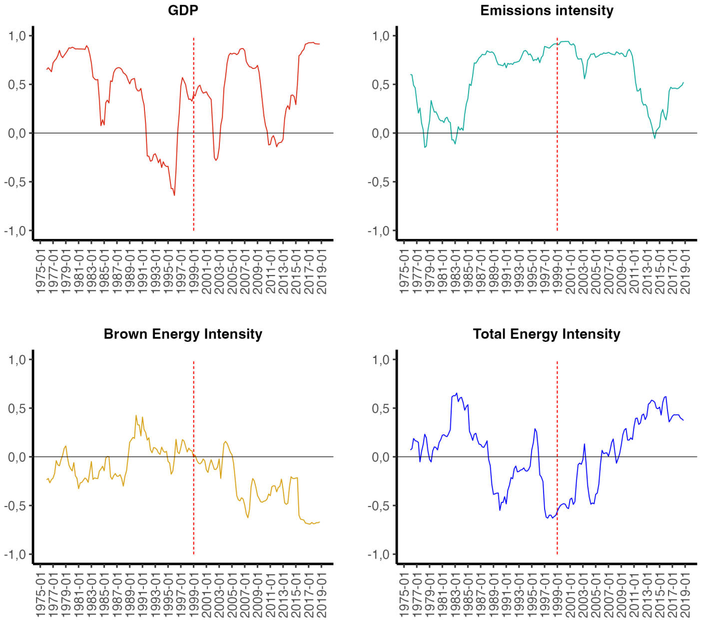
$$\widehat{emis_t} = (\widehat{Iemis_t}) + (\widehat{Ienbr_t}) + (\widehat{Ientot_t}) + (\widehat{GDP_t}) \qquad (2)$$

- Cyclical component :

$$\hat{x}_t = (\ln x_t - \ln x_{t-4}) - \frac{\sum_{j=0}^{T-1} (\ln x_{t+j} - \ln x_{t+j-4})}{T} \qquad (3)$$

- 1975Q1 $\Longrightarrow$ 2023Q3. All series are divided by population.

Cyclical Correlations



Cyclical Correlations

Table: Cross-correlations by subperiods

Correlations	1975:1-2023:3	1975:1-1999:1	1999:1-2023:3
$\widehat{emis}$, $\widehat{GDP}$	0.694***	0.627***	0.735***
$\widehat{emis}$, $\widehat{Iemis_t}$	0.542***	0.468***	0.556***
$\widehat{emis}$, $\widehat{Ienbr_t}$	-0.210***	-0.086	-0.321***
$\widehat{emis}$, $\widehat{Ientot_t}$	0.105	0.066	0.146

Cyclical correlations

- The positive correlation between emissions and GDP cycles has intensified over time
- The correlation between emissions and energy produced per unit of GDP (total energy intensity) does not differ from zero
- The correlation between emissions and the brown energy share in total energy (brown energy intensity), shifts to a significantly negative value since the end of the last century

Probably a key event related to brown energy occurred in the last twenty years, causing brown energy and carbon emissions to diverge. It appears that the United States has managed to decouple emissions from dirty energy production

Economic model: description

- Closed economy produces goods and services using labor, capital, and energy
- Brown energy is produced from capital and fossil fuels
- Green energy is produced using capital
- Brown energy producers have the option to reduce their emission per unit of energy production incurring an economic cost (abatement cost)
- Energy distributors purchase green and brown energy and package them into an "energy mix."
- They sell the mix in the market (total energy)
- Sector specific investment
- Prices stickiness

Economic model: shocks

- Shock on consumption preferences (a pure aggregate demand shock):

$$\mathbb{E}_0 \sum_{t=0}^{\infty} \beta^t \left(\varsigma_t^c \frac{c_t^{1-\sigma}}{1-\sigma} - \kappa_L \frac{h_t^{1+\varphi}}{1+\varphi} \right) \tag{4}$$

where

$$\ln \varsigma_t^c = \rho_c \ln \varsigma_{t-1}^c + \epsilon_t^c \qquad \epsilon_t^c \sim N(0, \sigma_c) \tag{5}$$

- Shock on TFP (a pure aggregate supply shock):

$$y_t(i) = A_t^y (k_{t-1}^y)^{\alpha^y} (h_t)^{\beta^y} (v_t^y)^{1-\alpha^y-\beta^y} \tag{6}$$

$$A_t^y = [1 - d_0 d_1^{x_t}] \varsigma_t^a \widetilde{A}^y \tag{7}$$

where

$$\ln \varsigma_t^a = \rho_a \ln \varsigma_{t-1}^a + \epsilon_t^a \quad \epsilon_t^a \sim N(0, \sigma_a) \tag{8}$$

- Shocks on efficiency in green and brown energy production:

$$v_t^g = \varsigma_t^g A^g \left(k_{t-1}^g\right)^{\alpha^g} \tag{9}$$

$$v_t^b = \varsigma_t^b A^b \left(k_{t-1}^b\right)^{\alpha^b} \left(m_t^b\right)^{(1-\alpha^b)} \tag{10}$$

where

$$\ln \varsigma_t^g = \rho_g \ln \varsigma_{t-1}^g + \epsilon_t^g \qquad \epsilon_t^g \sim N(0, \sigma_g) \tag{11}$$

$$\ln \varsigma_t^b = \rho_b \ln \varsigma_{t-1}^b + \epsilon_t^b \qquad \epsilon_t^b \sim N(0, \sigma_b) \tag{12}$$

- Shock on emissions efficiency:

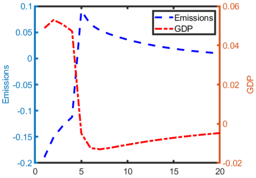
$$e_t^b = \left(1 - \mu_t^b\right) \varsigma_t^e \gamma_1^b \left(v_t^b\right)^{1-\gamma_2^b} \tag{13}$$

where

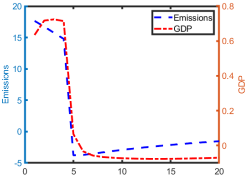
$$\ln \varsigma_t^e = \rho_e \ln \varsigma_{t-1}^e + \epsilon_t^e \quad \epsilon_t^e \sim N(0, \sigma_e) \tag{14}$$

A *negative* value of ϵ_t^e indicates that carbon emissions per unit of brown energy decreases

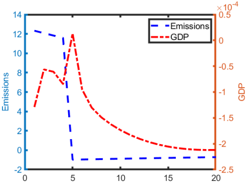
Impulse-response functions



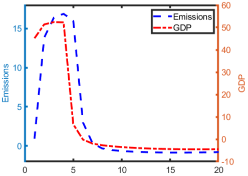
(a) *Green technology shock*



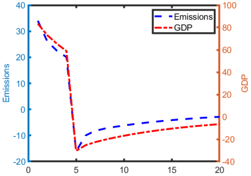
(b) *Brown technology shock*



(c) *Emissions shock*



(d) *TFP shock*



(e) *Consumption shock*

Impulse-Response functions (in percentage points relative to the steady state) to a 100% Variation in Shock Size

Forecast error variance decomposition

Emissions					
Time Horizon	ς_t^g	ς_t^b	ς_t^e	ς_t^a	ς_t^c
Unconditional	0.01	50.12	34.86	9.50	5.50
Conditional p=1	0.02	55.10	37.37	0.03	7.48
Conditional p=4	0.01	50.08	37.62	7.55	4.74
Conditional p=20	0.01	50.36	34.82	9.35	5.46
Conditional p=40	0.01	50.43	34.80	9.28	5.49

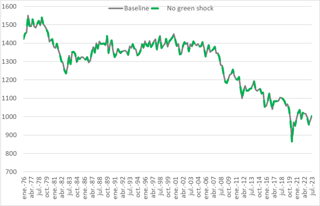
GDP					
Time Horizon	ς_t^g	ς_t^b	ς_t^e	ς_t^a	ς_t^c
Unconditional	0.00	0.07	0.00	71.97	27.96
Conditional p=1	0.00	0.06	0.00	63.14	36.80
Conditional p=4	0.00	0.07	0.00	74.75	25.18
Conditional p=20	0.00	0.07	0.00	71.44	28.49
Conditional p=40	0.00	0.07	0.00	71.79	28.14

Historical shock decomposition

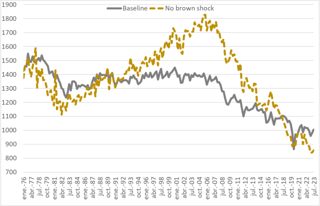
Smoothed shocks						
Period	ϵ_t^g	ϵ_t^b	ϵ_t^e	ϵ_t^a	ϵ_t^c	Emissions
1976-2023	0.00	0.00	0.00	0.00	0.00	0.00
1976-1999	0.25	0.12	0.21	0.11	-0.52	0.72
2000-2023	-0.24	-0.12	-0.22	-0.12	0.53	-0.73
2000-2007	-0.62	-1.21	0.86	0.12	1.32	0.45
2008-2023	-0.05	0.44	-0.77	-0.24	0.13	-1.33
Contributions						
Period	ς_t^g	ς_t^b	ς_t^e	ς_t^a	ς_t^c	Emissions
1976-2023	0.00	0.25	-0.32	-0.26	-0.04	0.00
1976-1999	0.00	**-0.67**	**1.03**	-0.16	0.03	0.72
2000-2023	0.01	1.17	-1.68	-0.35	-0.12	-0.73
2000-2007	0.01	**-1.39**	**1.56**	-0.18	-0.01	0.45
2008-2023	0.00	**2.48**	**-3.32**	-0.44	-0.17	-1.33

Mean of the innovations and their contributions to emissions growth (pp)

Counterfactual evolution of emissions

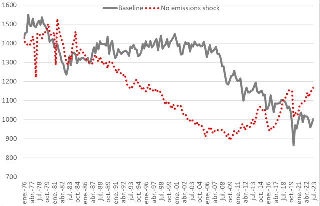


(a) *No green technology shock*

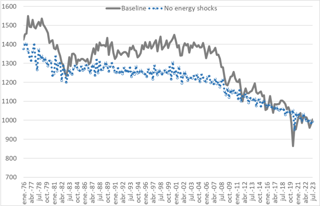


(b) *No brown technology shock*

Counterfactual evolution of emissions

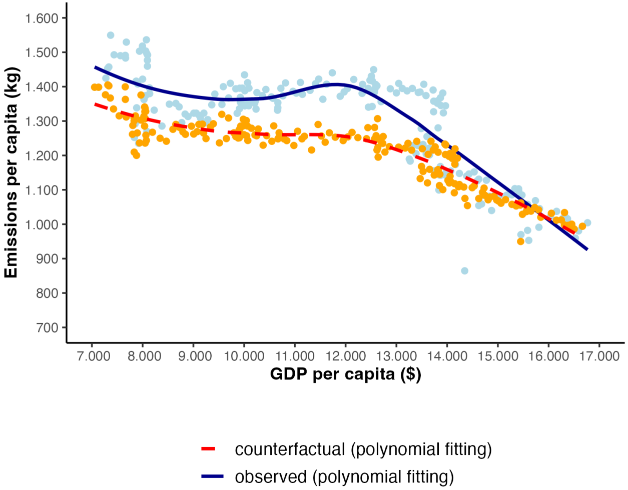


(c) *No emissions technology shock*



(d) *No energy shocks*

Counterfactual evolution of emissions

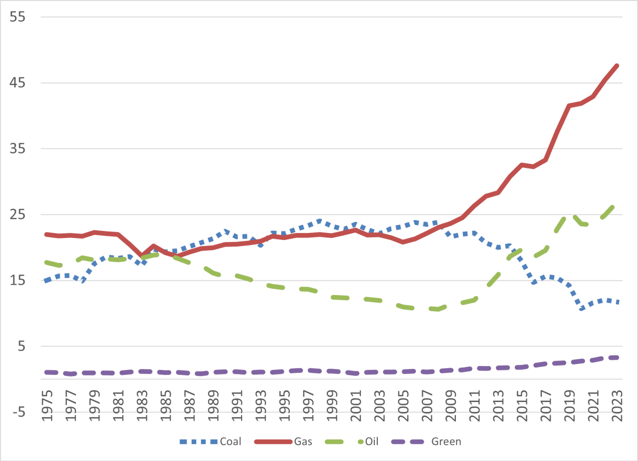


Kuznets curve: observed and counterfactual

Cheaper and less pollutant fossil fuels

- We hypothesize that both shocks are related to U.S. shale oil and gas production:
  - From 2007 to 2019, innovations in shale production led to an eight-fold increase in extraction productivity for natural gas and a nineteen-fold increase for oil.
  - These shale production innovations reduced the price of oil and gas, restraining the substitution of brown energies for green energies.
  - Our model identifies this process through a sequence of ϵ_t^b shocks that contribute to a relative increase in emissions compared to the scenario without such shocks.
  - As the price of gas and oil decreased, coal extraction became noncompetitive and many coal mines closed.
  - The mix of brown energy changed to one with a higher share of gas, and a lower share of coal, which our model identifies as a sequence of shocks ϵ_t^e that reduced the emission per unit of dirty energy produced.

Cheaper and less pollutant fossil fuels



Primary Energy Production by Source (Quadrillion Btu)

Greening through Browning?

- The optimistic interpretation is that the U.S. has significantly reduced carbon emissions in favor of cheaper and less polluting but still brown energies, allowing economic activity in the U.S. not to increase emissions per capita (may help to close the gap with its 2050 targets).
- Unfortunately, relying on greening brown energy has its limitations. No matter how useful the improvement of the brown energy mix to reduce emissions could be, it will deliver the zero gap neither by 2050 nor in the foreseeable future.

Questions?

Thank you!

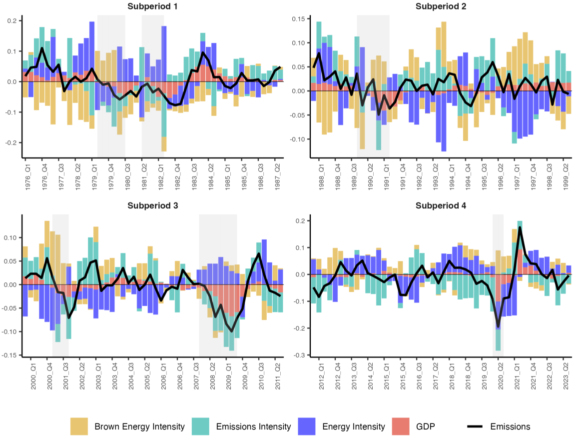


Figure: Cyclical decomposition of emissions using the Kaya Identity

back

- Except for specific events (Great Recession, COVID-19) the cyclical component of GDP explains a relatively small part of the emissions cycle compared to other components of the Kaya Identity.

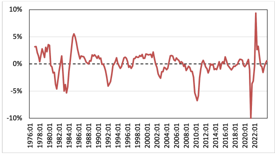
- Significant contribution of the cyclical component of brown energy intensity. Its contribution has decreased since the early 21st century and has been predominantly positive since then.

- Emissions intensity per unit of brown energy has gained importance in determining the carbon emissions cycle, and since 2006, it has had a clearly negative cumulative contribution.

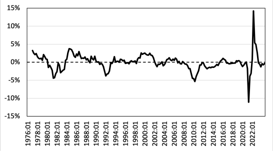
- Factors behind the decomposition are themselves highly endogenous $\Longrightarrow$ a more structural analysis is required to identify the nature and size of the shocks that are ultimately driving the emissions series.

back

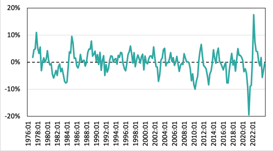
(a) GDP



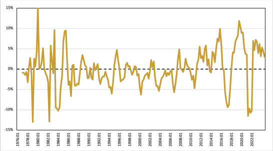
(b) Consumption



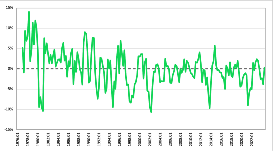
(c) CO2 Emissions



(d) Brown Energy Production



(e) Green Energy Production



Smoothed observables

back

- We establish new empirical facts about the behavior of emission cycles
- We conduct a structural analysis estimating an environmental dynamic stochastic general equilibrium (E-DSGE) model
- We conduct a series of counterfactual exercises to assess the dynamics of emissions with and without some of the estimated shocks

- From 2007 to 2019, innovations in brown energy production reduced the price of oil and gas, limiting the substitution of brown energy sources with green energy → These shocks increased the average YoY emissions growth rate by 2.5 percentage points.
- Simultaneously, a sequence of shocks reduced emissions per unit of dirty energy produced → These shocks decreased the average YoY emissions growth rate by 3.3 percentage points.

- Heutel (2012): **(1)** emissions are procyclical; **(2)** emissions are inelastic with respect to GDP.

- Khan *et al.* (2019) SVAR to identify NT and IST shocks: nearly 66% of the emissions cycle is not explained by the structural shocks usually employed to explain the GDP cycle.

- Jo and Karnizova (2021) VAR model with sign restrictions to identify a shock that can generate a negative correlation between GDP and emissions, explaining nearly half of the volatility in emissions: **(1)** models that omit disturbances to energy production efficiency overestimate the costs of environmental policy.

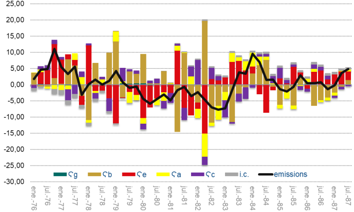
- We calibrate the model for the U.S. at a quarterly frequency, using the average of a series of economic, environmental, and energy ratios for the period 1975:Q1 – 2023:Q3
- Bayesian estimation to obtain the first-order autocorrelation coefficients of the five shocks and the standard deviations of the white noise terms
- Five observables (1975:Q1 to 2023:Q3) closely related to the five shocks: GDP, private consumption, CO2 emissions, green energy production, and brown energy production. All variables divided by population
- Data from the Energy Information Administration (EIA) and from the Economic Data Database of the Federal Reserve Bank of St. Louis (FRED)
- Filtered using YoY log differences and subtracting the mean

SmoothVar

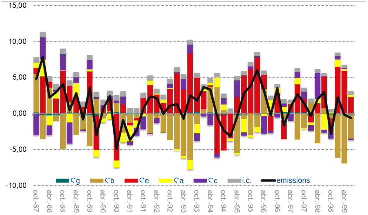
Parameter	**Prior**			**Posterior**	
	Distribution	Mean	Std	Mean	90% HPDI
ρ_c	*Beta*	0.60	0.20	0.9368	[0.9207; 0.9531]
ρ_g	*Beta*	0.50	0.20	0.8812	[0.7400; 0.9954]
ρ_b	*Beta*	0.50	0.20	0.9378	[0.8956; 0.9777]
ρ_e	*Beta*	0.50	0.25	0.9795	[0.9627; 0.9982]
ρ_a	*Beta*	0.80	0.08	0.9498	[0.9397; 0.9600]
σ_c	*Inv-Gamma*	0.05	0.15	0.2166	[0.1969; 0.2365]
σ_g	*Inv-Gamma*	0.05	0.15	0.0249	[0.0225; 0.0273]
σ_b	*Inv-Gamma*	0.05	0.15	0.0414	[0.0378; 0.0450]
σ_e	*Inv-Gamma*	0.05	0.15	0.0351	[0.0321; 0.0380]
σ_a	*Inv-Gamma*	0.05	0.15	0.0896	[0.0813; 0.0976]

Priors and posteriors

Figure: Historical Decomposition of YoY Emissions Growth (pp)

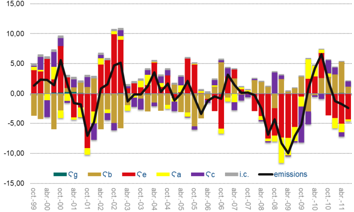


(a) *Period 1976:1 - 1987:3*

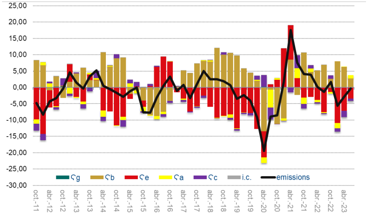


(b) *Period 1987:4 - 1999:3*

Historical Decomposition of YoY Emissions Growth (pp) – Continued



(c) *Period 1999:4 - 2011:3*



(d) *Period 2011:4 - 2023:3*