CO2 Emissions and Energy Technology in Western Europe

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With

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Energy and Climate Change

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Introduction

- Preliminaries: (i) **Energy** is responsible for more than 70% GHG → (ii) leads to **Climate Change** → (iii) harms our **welfare** (**long-run**)

- However, with the current technology, energy is needed to grow (welfare): ***Decoupling GDP from CO2 implies decoupling GDP from energy-intensive-technologies and/or from dirty-energy-technologies.***

- Given this energy-CO2 link, **short-term policy** actions to change the energy model in a country or a región (***path dependence***) could have long-term benefits on CC, and regional agreements (short-term targets) are key!

Introduction

This paper:

- *A follow up of our recent **paper in SERIEs:** Study **within-country E3** (Emissions-Economy-Energy) over the cycle in WE16 countries (*)*

- Updated IEA database (in 2022); additional evidences, stability of estimates

Next:

i) Build and calibrate a DGE model with final goods and energy sector
ii) Estimating the cost in GDP for WE16 of being carbon neutral by 2050;
iii) Policy: the role of regional agreements in a homogenous set of countries

(*) Austria Belgium Denmark Finland France Germany Greece Ireland Italy Netherlands Norway Portugal Spain Sweden Switzerland UK

Looking at data

Kaya identity: a way to relate **Emissions** with **Economic** Activity and **Energy** (use and mix)

$$\underbrace{\frac{CO2}{Population}}_{\textit{(fair) policy target is CO2 per capita.}} = \underbrace{\frac{GDP}{Population}}_{\text{Economic Activity}} \cdot \underbrace{\overbrace{\frac{Energy}{GDP}}^{\text{Energy Intensity (technology)}} \cdot \overbrace{\frac{CO2}{Energy}}^{\text{Carbon intensity (energy)}}}_{\text{Energy-related}}$$

Intensive margin

$$\frac{CO2}{Population} = \frac{GDP}{Population}\phi \rightarrow \frac{\boldsymbol{CO2}}{\boldsymbol{GDP}} = \boldsymbol{\phi}.$$

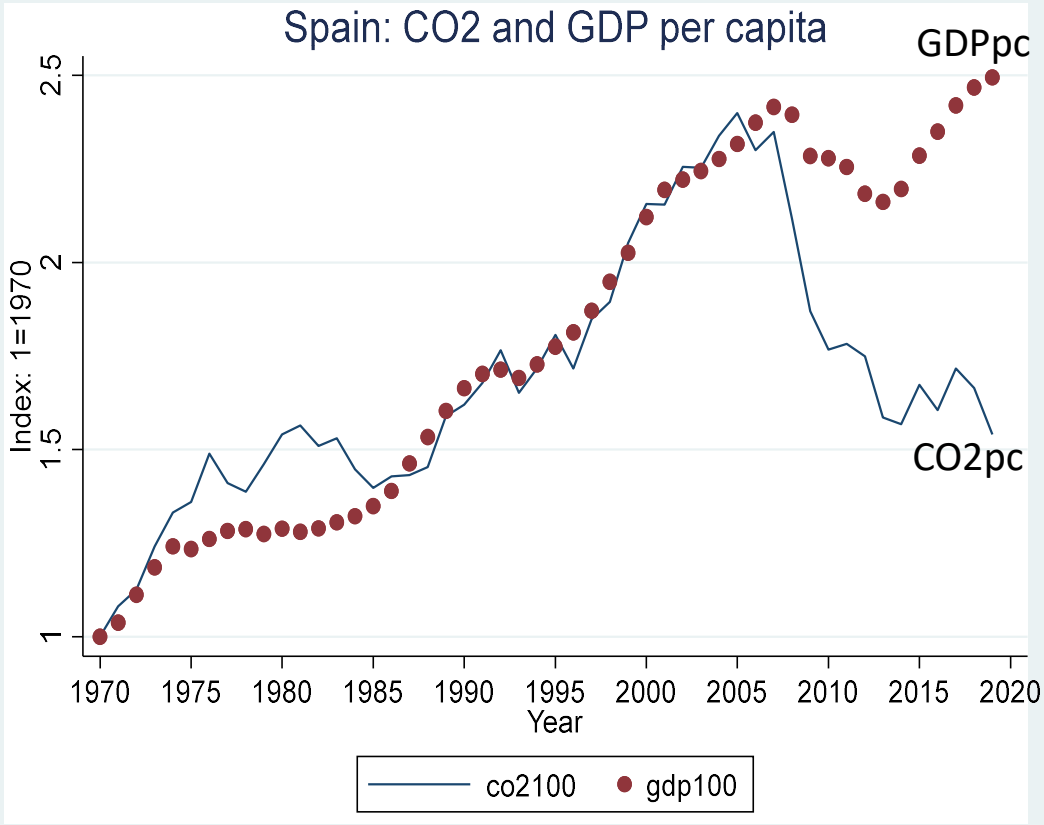
Looking at data …

All data from the IEA Energy Balances & Emissions Database, 2022

- Carbon Emissions: thousands of tones of CO2.
- GDP: billion USD (PPPs)
- Population: millions
- Energy use: million TOEs

- CO2/Population: Kg CO2/person
- CO2/GDP-PPP: Kg CO2/USD-PPP
- **Energy Intensity (TFC/GDP-PPP): TOEs/US million**
- **Energy Mix (primary sources): p.p.**

The CO2-GDP slope … in Spain



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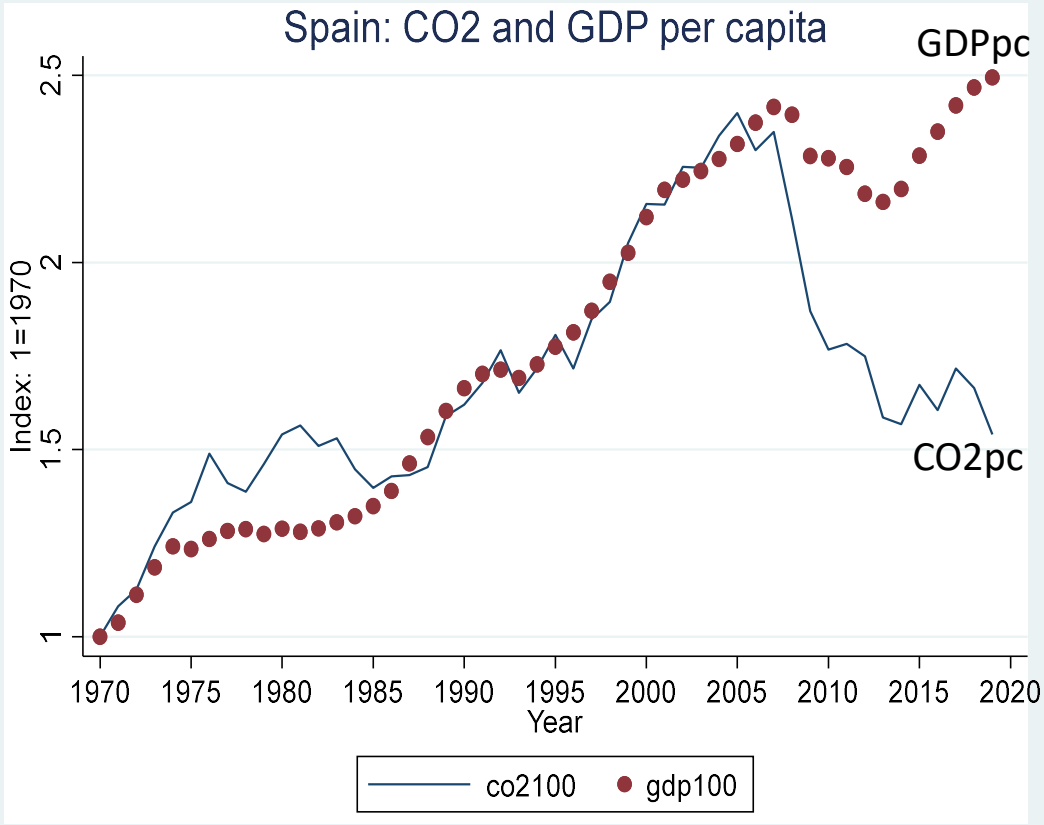
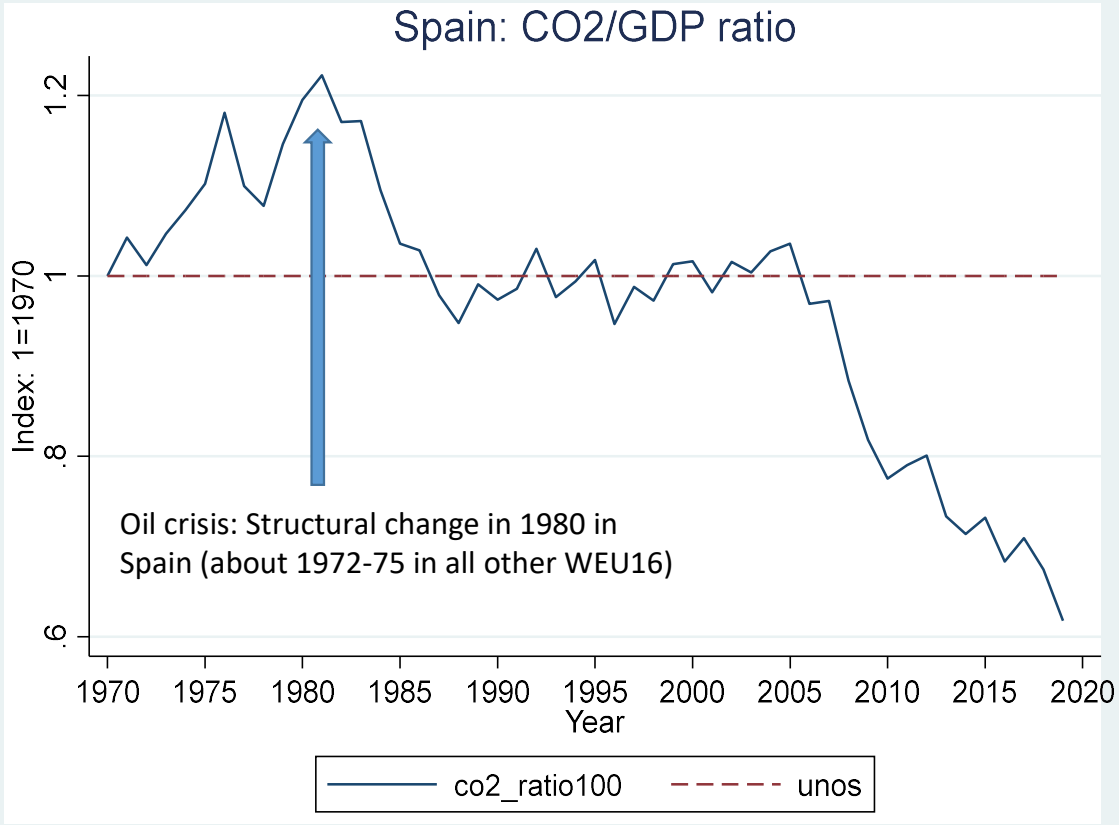
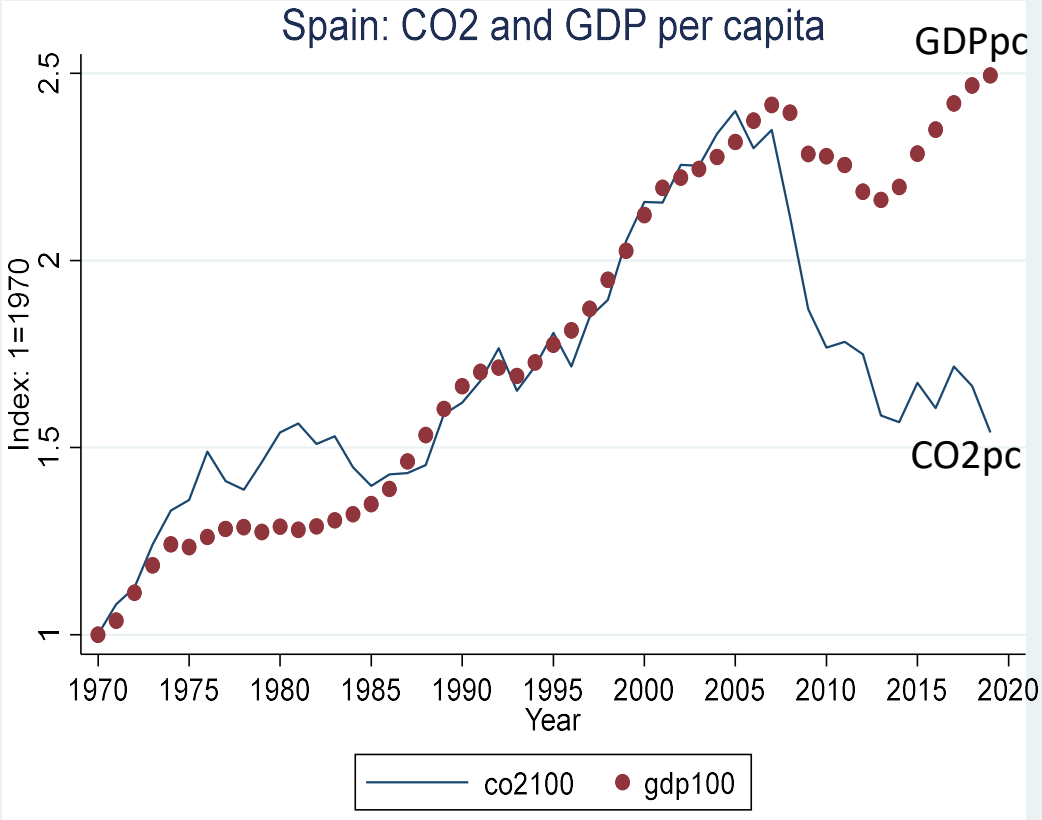
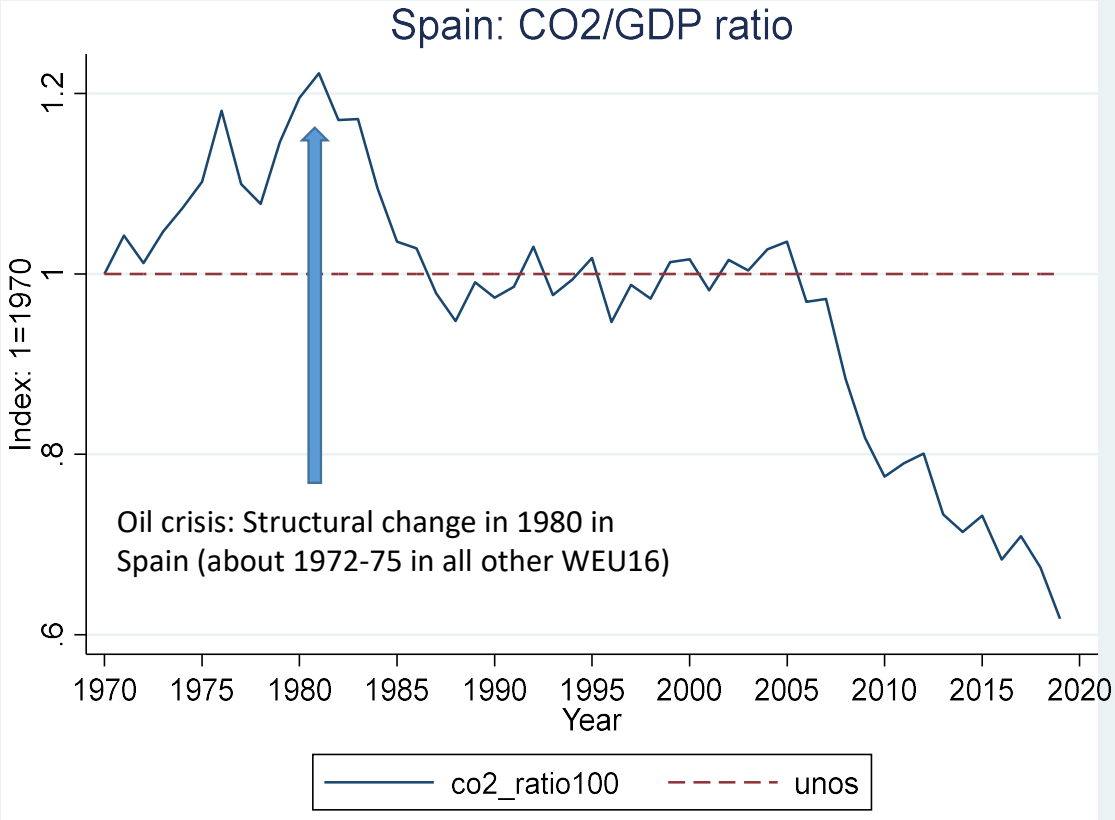




The CO2-GDP slope … in Spain

Can we use energy to (almost) fully explain this pattern? YES





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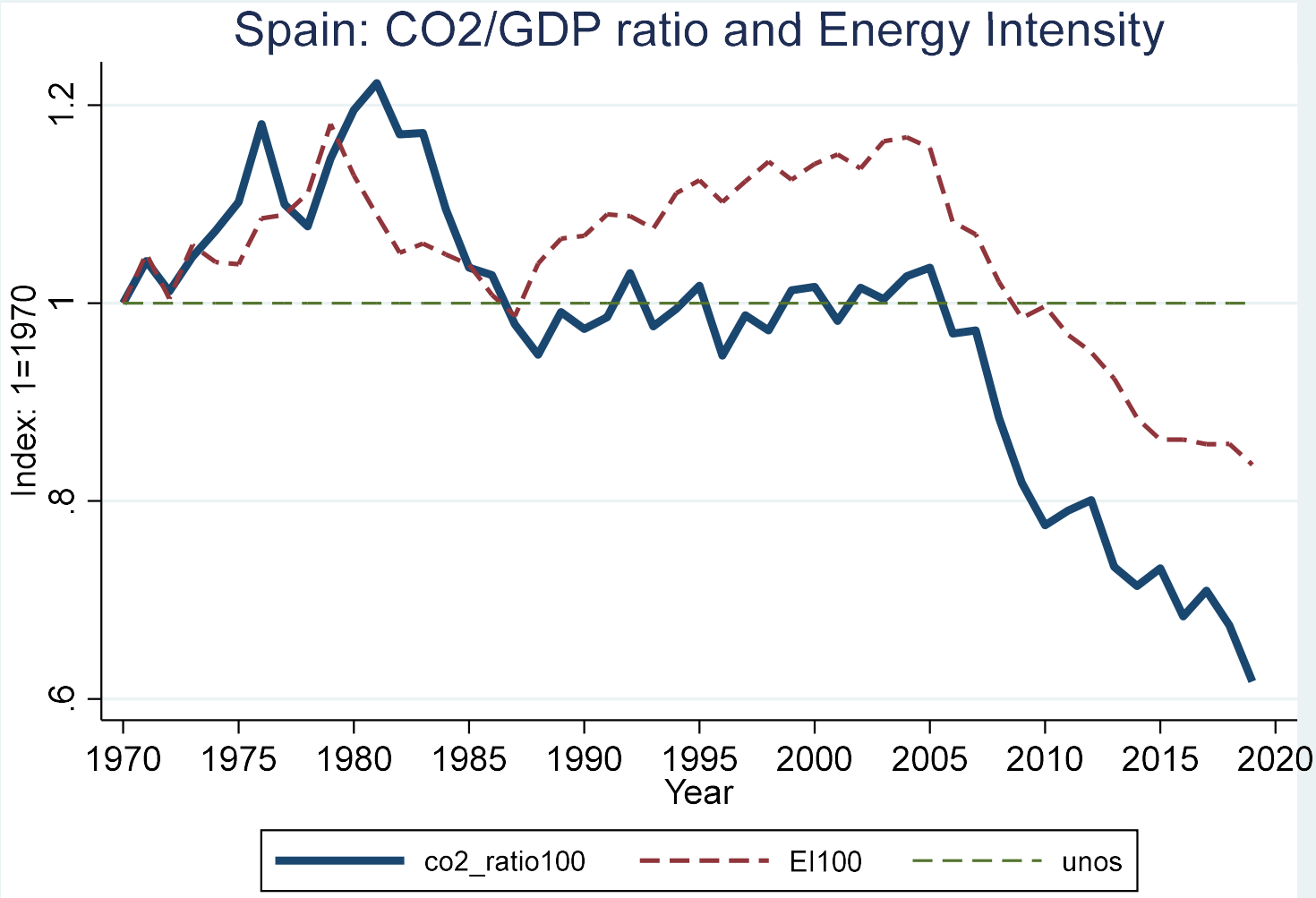
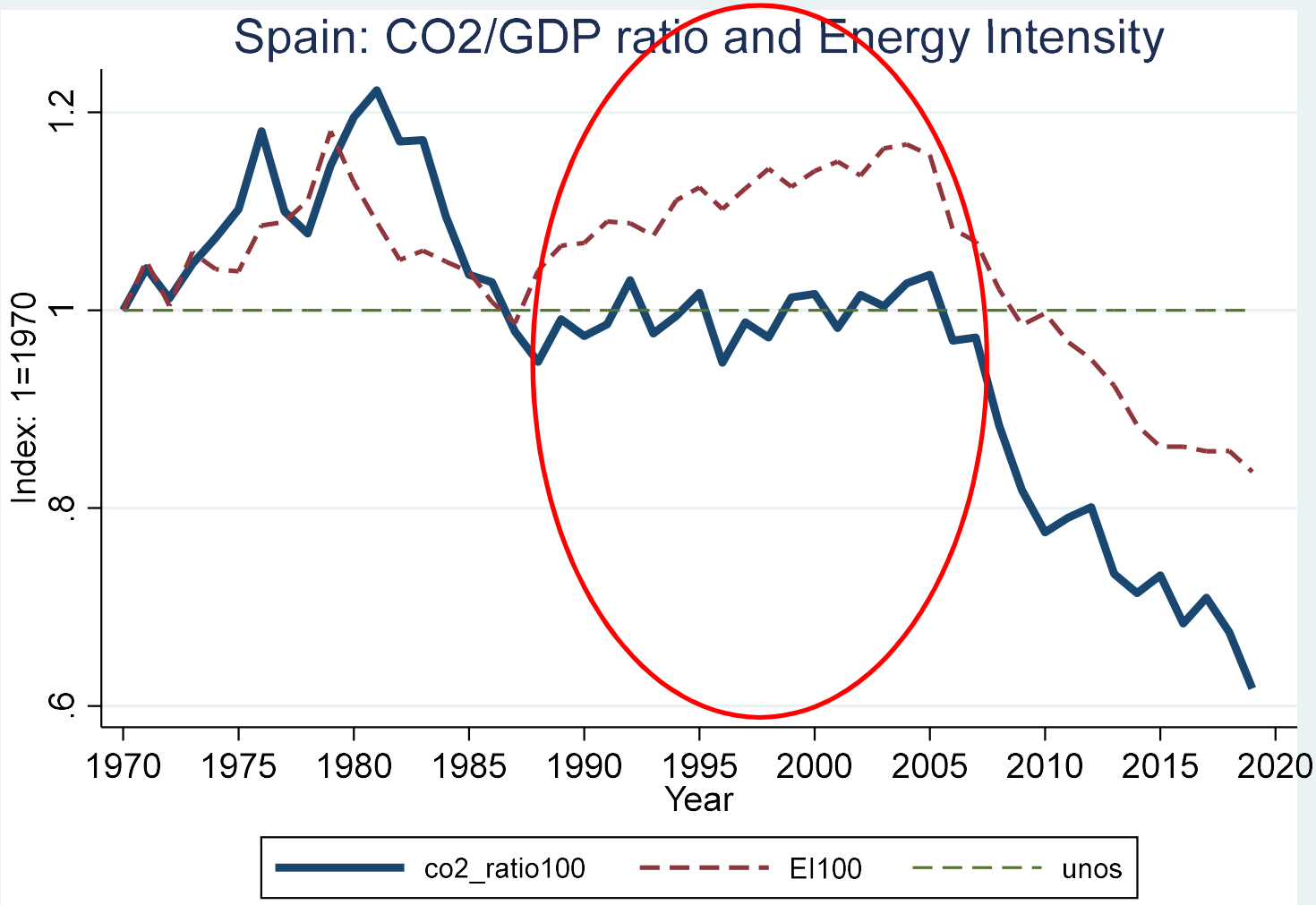


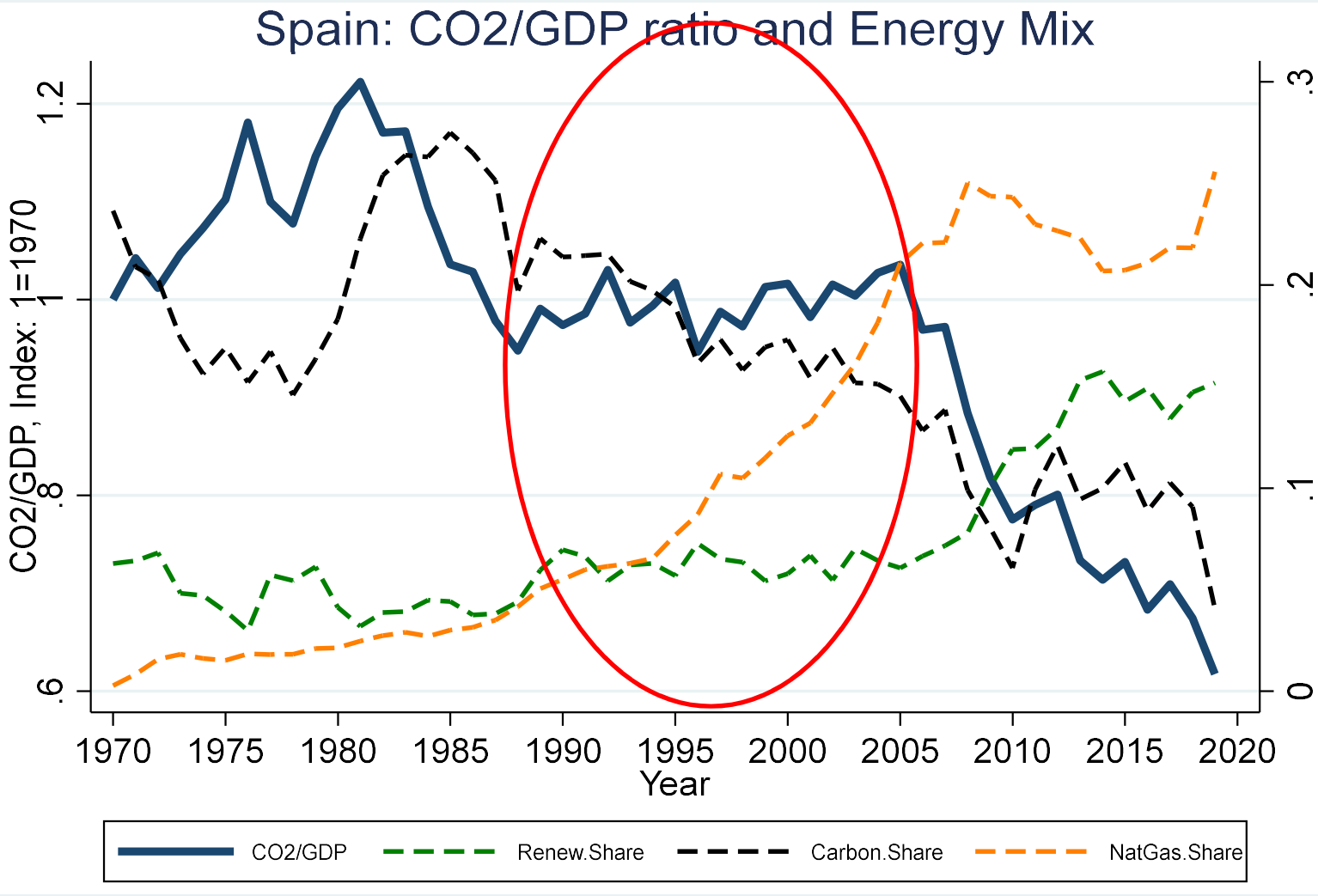
- **EI changes leading turning points**

The CO2-GDP slope … in Spain



- **EI changes leading turning points**
- Increase of EI in the 90's? Construction Boom (also Transport); energy intensive sectors!
- Why better behaviour of CO2/GDP ratio in this period? Improvements in the mix!

The CO2-GDP slope … in Spain



In the 90's …

Steady increase of renewables + Big increase of Gas & decrease Carbon: compensate increase of EI

Stabilization of Oil and minor reduction of nuclear (not shown in the graphic)

Our theory … in a nutshell

Production of final goods

- $Y_t = B_t(u_t K_t)^{\alpha} N_t^{1-\alpha}$
- $E_t = u_t^{\psi} K_t v_t$
- $VA_t = Y_t - p_t E_t$
  - In equilibrium $VA_t = G(K_t, p_t, v_t, u_t)$
- $K_{t+1} = x_t / q_t(v_{t+1}) + \left(1 - \delta(v_{t+1}, v_t)\right) K_t$

ISTC

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The energy mix

- **Supply**

Sources (technologies): $\{e_{1t}, e_{2t}, \dots, e_{nt}\}$:

$e_{jt} = \Phi\left(K_t, v_t, p_{jt}/p_t, \mu_j\right)$,

$\varepsilon_t = \sum_{j\in\Omega_f} e_{jt}, \Omega_f \equiv \{technologies\ from\ fossil\ fuel\}$

$\epsilon_t = \sum_{j\in\Omega_r} e_{jt}, \Omega_r \equiv \{technologies\ from\ non{-}fossil\ fuel\}$,

Our theory … in a nutshell

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The energy mix and emissions

- Supply

Sources (technologies): $\{e_{1t}, e_{2t}, \dots, e_{nt}\}$:

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- **Emissions**

$P_t = \varepsilon_t^{\phi} VA_t^{\varphi} = \boldsymbol{P(K_t, p_t, v_t, Energy\ Mix)}$

(***Base our empirical framework***)

The empirical model

- **Dynamic Panel Data Model with FE** (Marrero, 2010; Díaz, Marrero, Puch & Rodríguez, 2019))
- Target: **CO2 per capita**
- Estimate the **short-run within-country** relationship between **CO2**, **GDP** and **Energy**
- Dynamic term

GDP only model:

$$\Delta ln(CO2_{it}) = \phi_0 \Delta ln(GDP_{it}) + \beta_0 ln(CO2_{it-1}) + \lambda_i + \delta_t + v_{it}$$

Gross elasticity

Extended with Energy model:

$$\Delta ln(CO2_{it}) = \phi_1 \Delta ln(GDP_{it}) + \beta_1 ln(CO2_{it-1}) + \underbrace{\varphi \Delta X_{it}}_{\text{Change in EI \& in E Mix}} + \lambda_i + \delta_t + v_{it}$$

Partial elasticity

The empirical model

We take care about relevant econometric issues:

- endogeneity
- check for robustness
- alternative dynamic specifications, controls, asymmetries
- errors clustered at the country level
- Etc etc etc etc etc etc etc etc

Estimation results

	(1)	(2)	(3)	(4)
lnCO2pc (lag)	-0.0836***	-0.0524***	-0.0397***	-0.0129
	(0.0133)	(0.0126)	(0.00698)	(0.00780)
GDPgr	**0.469*** **	0.808***	0.581***	0.917***
	(0.127)	(0.154)	(0.0992)	(0.133)
EI change		0.0250***		0.0244***
		(0.00483)		(0.00456)
Renew. Share change			-0.0234***	-0.0232***
			(0.00350)	(0.00306)
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			(0.00282)	(0.00259)
Country FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Energy vbles.	No	Yes	Yes	Yes
R2	0.372	0.480	0.673	0.774
Num. Obs.	639	639	639	639

Gross-elasticity (average, short-run, within-country) is the one meassuring whether GDP is decoupled (partially) or not from CO2

Well below 1!

Capturing direct and indirect effects coming throught any relevant correlation with **ommited** – "energy" – variables

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Partial-elasticity: GIVEN EI changes, the CO2-GDP elaticity is 0.808, almost double the gross-elasticity …

The evolution of EI changes in the last 40 years (highly negative in most WEU) is making the difference between 0.809 to 0.469 in the CO2-GDP elasticity!

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What about the direct impact of EI change on (within-country) CO2pc growth?

1 std change (3 TOE/million US$ PPP) associated with 2.5 p.p. of CO2gr (GIVEN growth rate and inertia)

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Smaller effect (although significant) over the CO2-GDP elasticity when including the change in energy mix

The direct effect on emissions of a 1 p.p. change in energy wrt carbon (omitted category) …

Renewable is the clear winner!

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In the full model …. **The CO2-GDP elasticity is almost 1:** a 1% raise of GDP would imply almost a 1% raise in CO2 (being invariant EI and Energy Mix changes)

Changes the E. Mix and especially in the EI have been key to make the gross CO2-GDP elasticity well below 1

The empirical model … Rolling estimates

Evolution of main coefficients between 1980-2019? Stable? Or showing trends?

Based on Kremer et al. (2021); Acemoglu and Molina (2021)

Using **Rolling-panel-FE estimates** (i.e., every 10 years)

GDP only model: $\Delta ln(CO2_{it}) = \boldsymbol{\phi_{0t}} \Delta ln(GDP_{it}) + \beta_{0t} ln(CO2_{it-1}) + \lambda_{it} + \delta_t + v_{it}$

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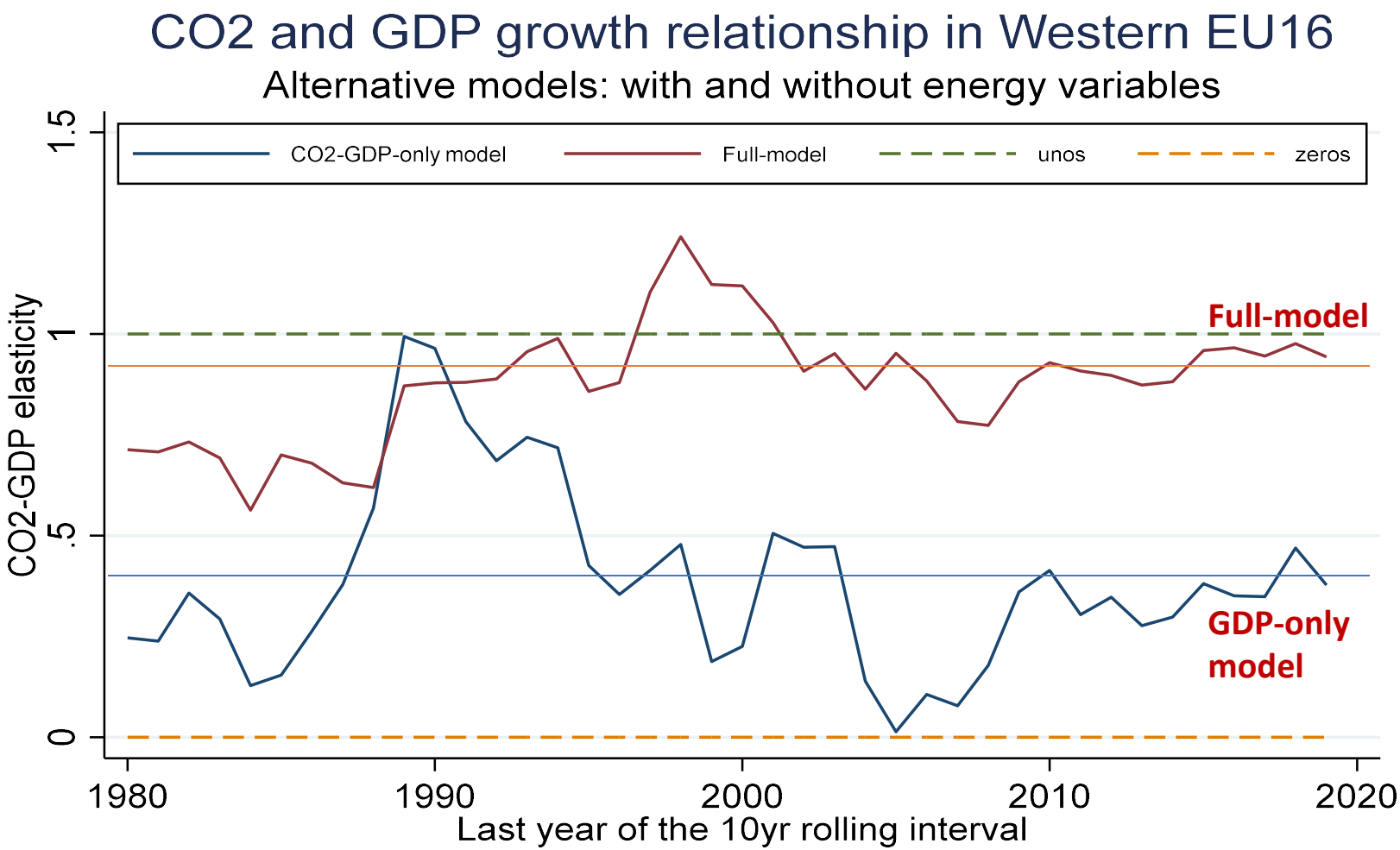
CO2-GDP: Rolling estimates



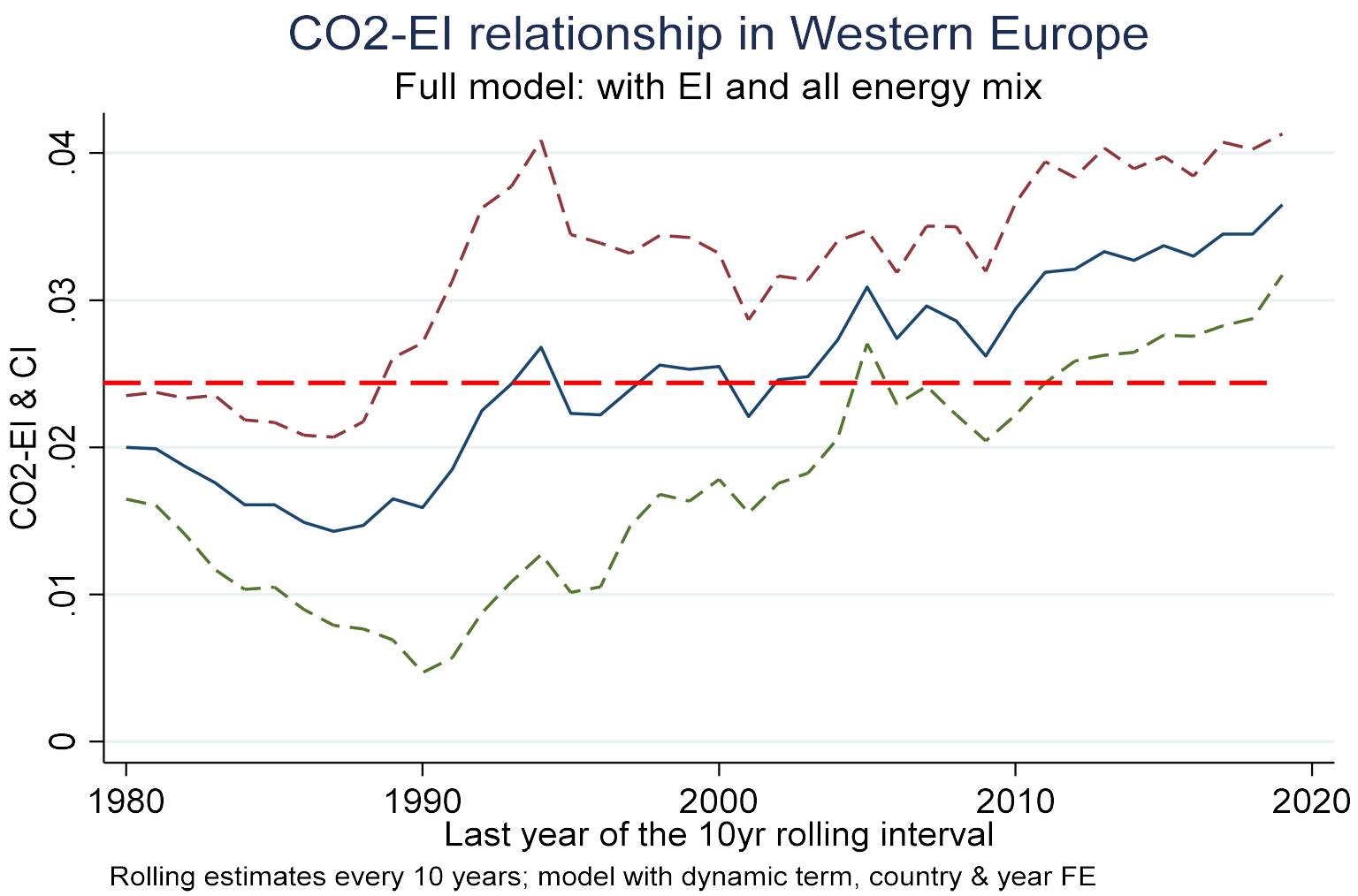
Rolling estimates every 10 years; model with dynamic term, country & year FE

More or less stables after 1995 and both around their point estimates

Amplify the differences after 1990: changes of the energy model in the right direction!

But still not enough! (ϕ_0 stabilizes around 0.45)

CO2-EI: Rolling estimates

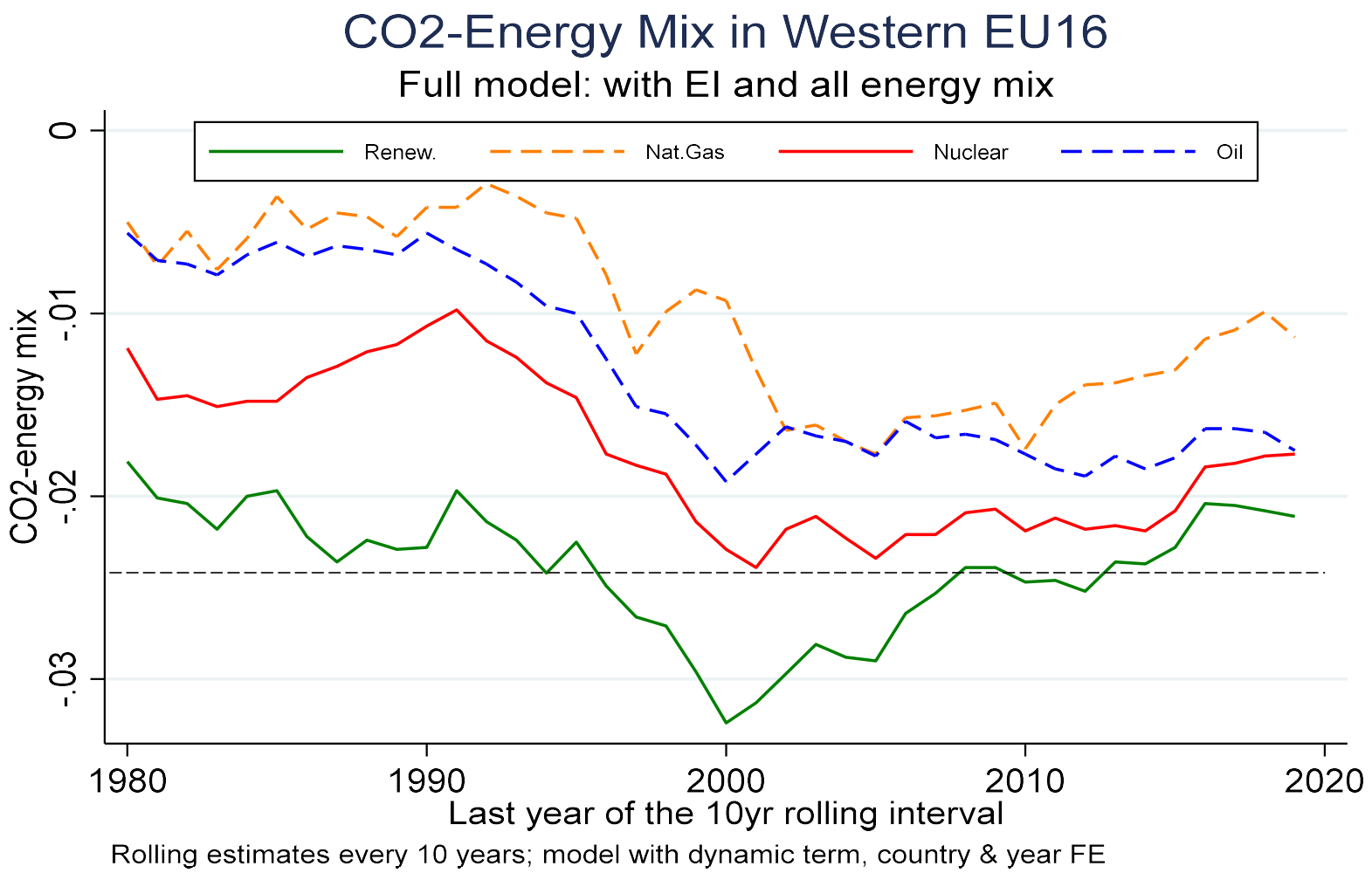


Since 1990, increase in the reaction of CO2 to changes in EI

In 2019: 3.5 p.p. CO2 reaction, while about 2 p.p. in 1990 and less than 3 p.p. in 2010

Caution with EI increases (i.e., Spain in the 2000's) … and very effective when EI decreases!

CO2-Energy mix: Rolling estimates



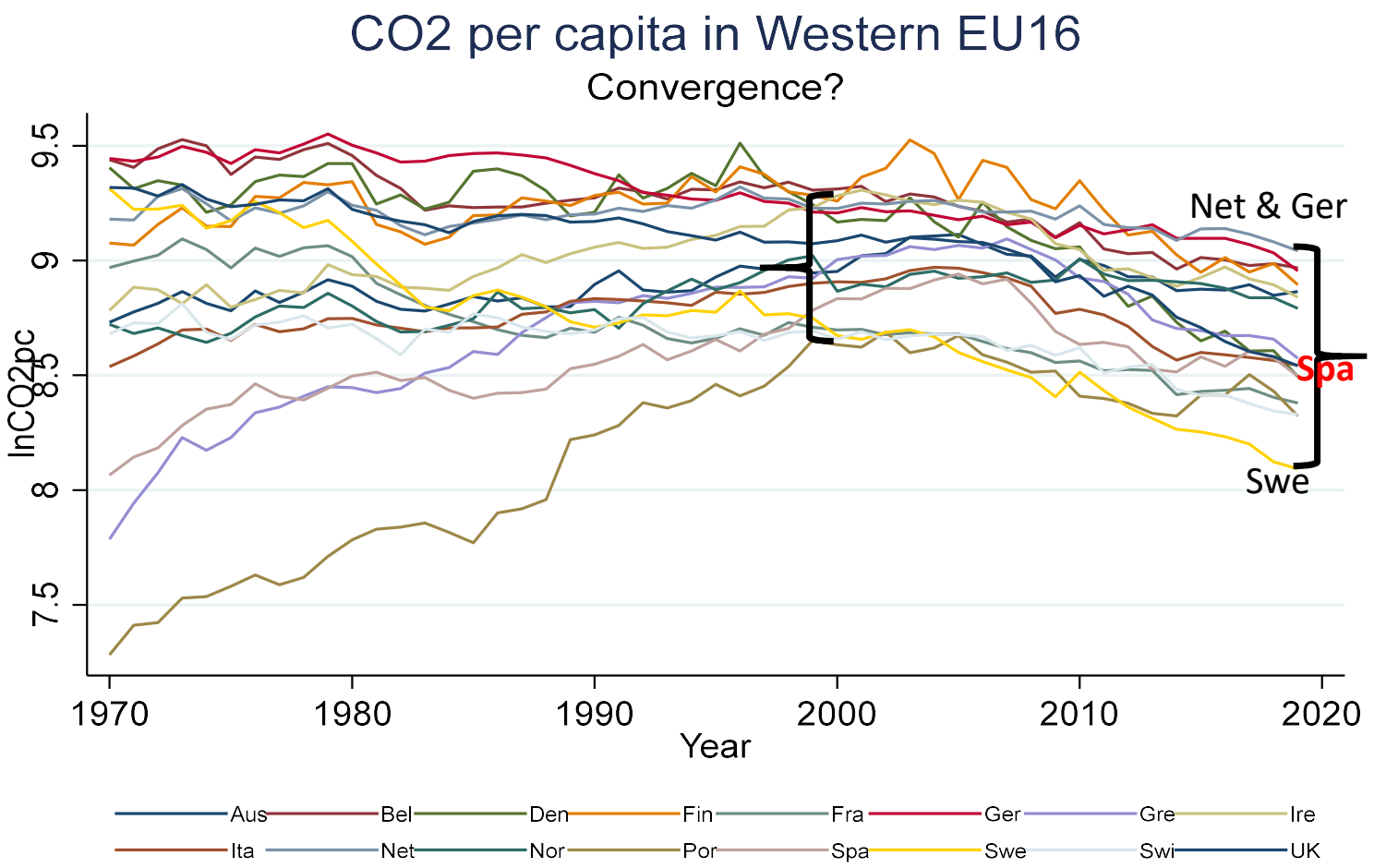
In contrast, the importance of renewables has reduced since 2000; also in other technologies, specially for Natural Gas

The dirtiest Carbon (dirtiest capital/Industry or improvement in carbon "quality") was substituted before 2000 …

2000: coincides with the 1st ECCP (2000-2004)

Convergence

CO2 convergence is a regional target in WEU



Evidence of convergence (conditional more than absolute) until about 2000, even some divergence afterwards

Still important differences in CO2pc (8,000 vs 4,000 KgCO2/person)

The crisis has divided EU in 2 groups (probably cyclical fact)
High: Net, Ger, Fin, Bel, Nor, Aus, Ire
Low: Den, Fra, Gre, Ita, Por, Swi, Swe, UK, Spa

Convergence

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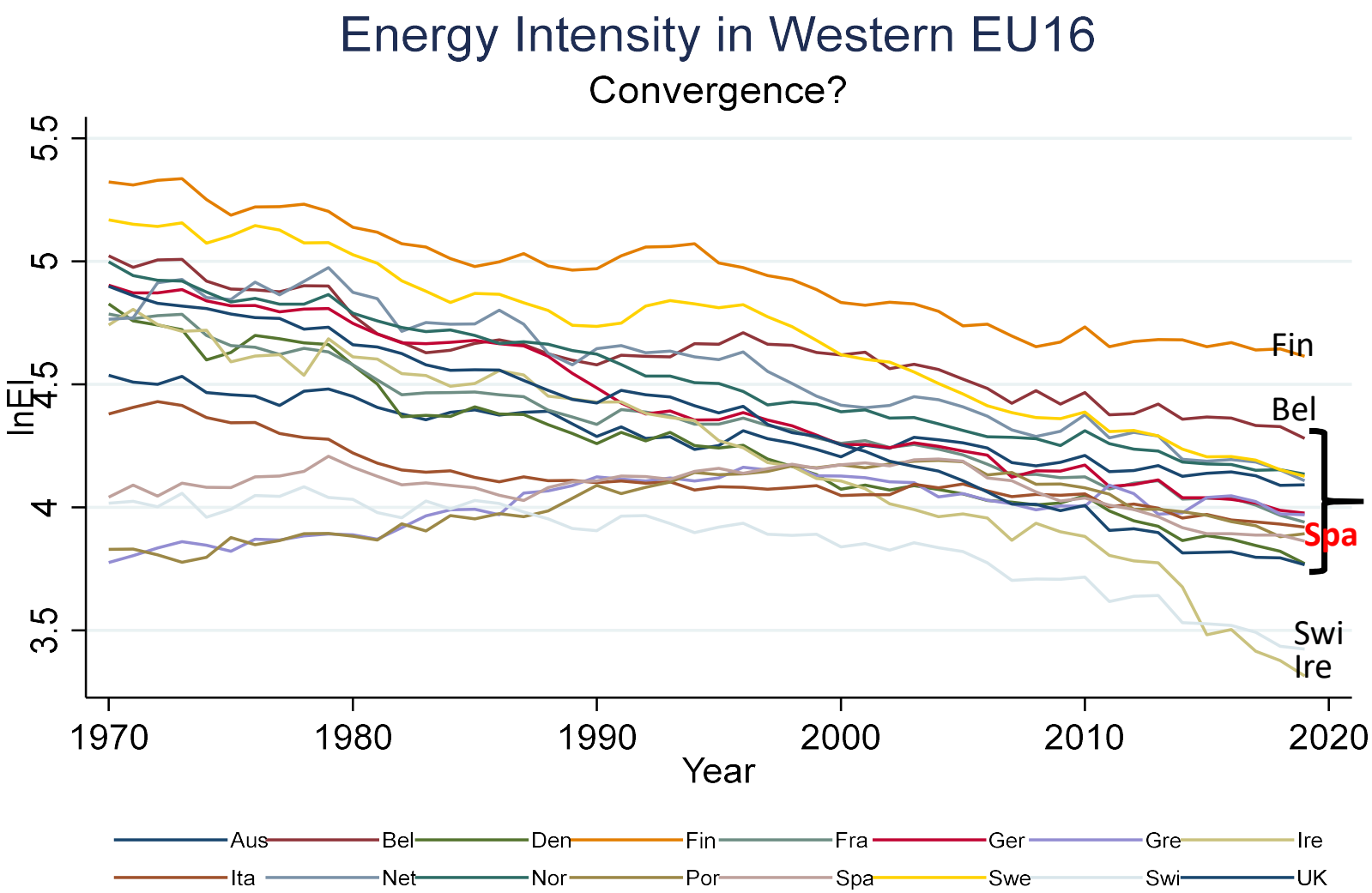
For the "full model", no evidence of convergence!

If energy variables do not change, differences in CO2 emissions remain unchanged and no significant evidence of convergence in CO2 is observed!

Energy model convergence, in the right direction, is the key! …

Is that happening?

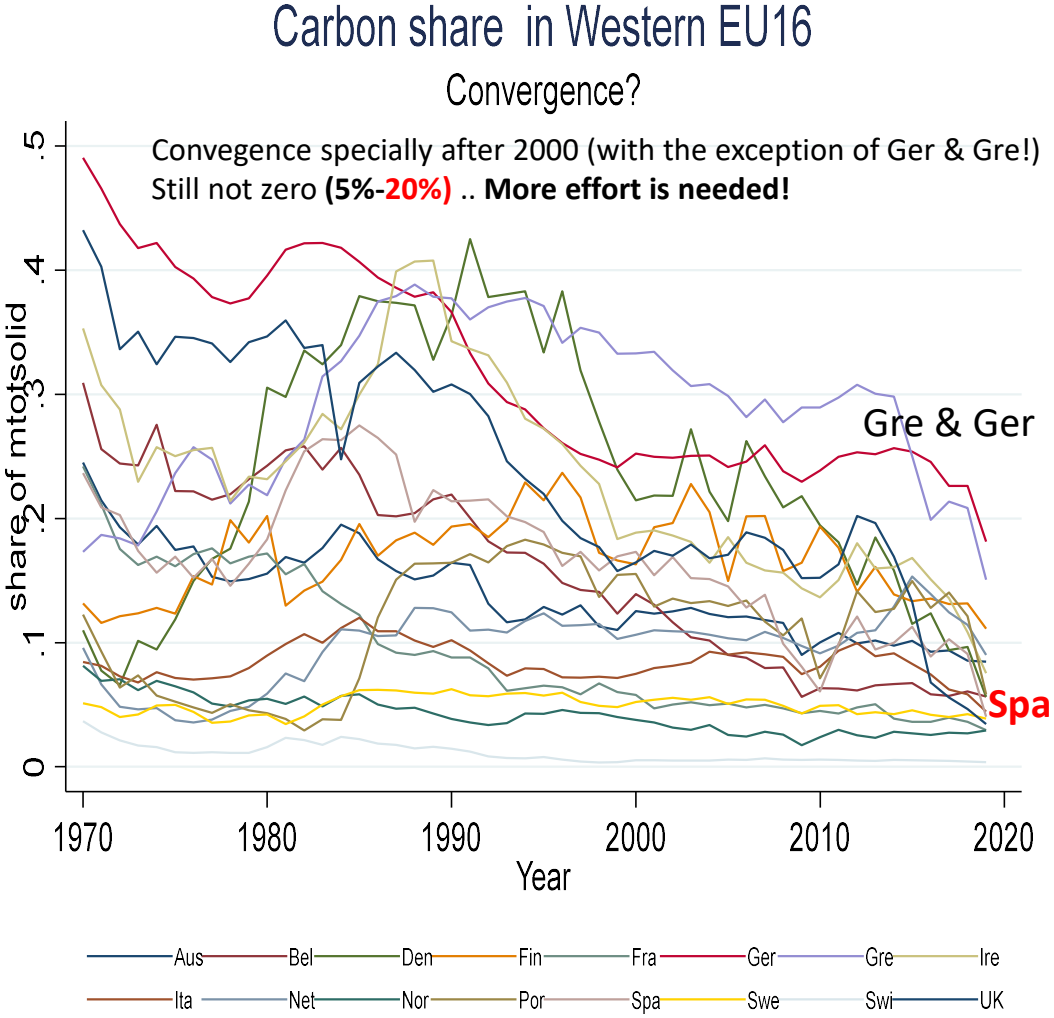
Convergence … in energy intensity?

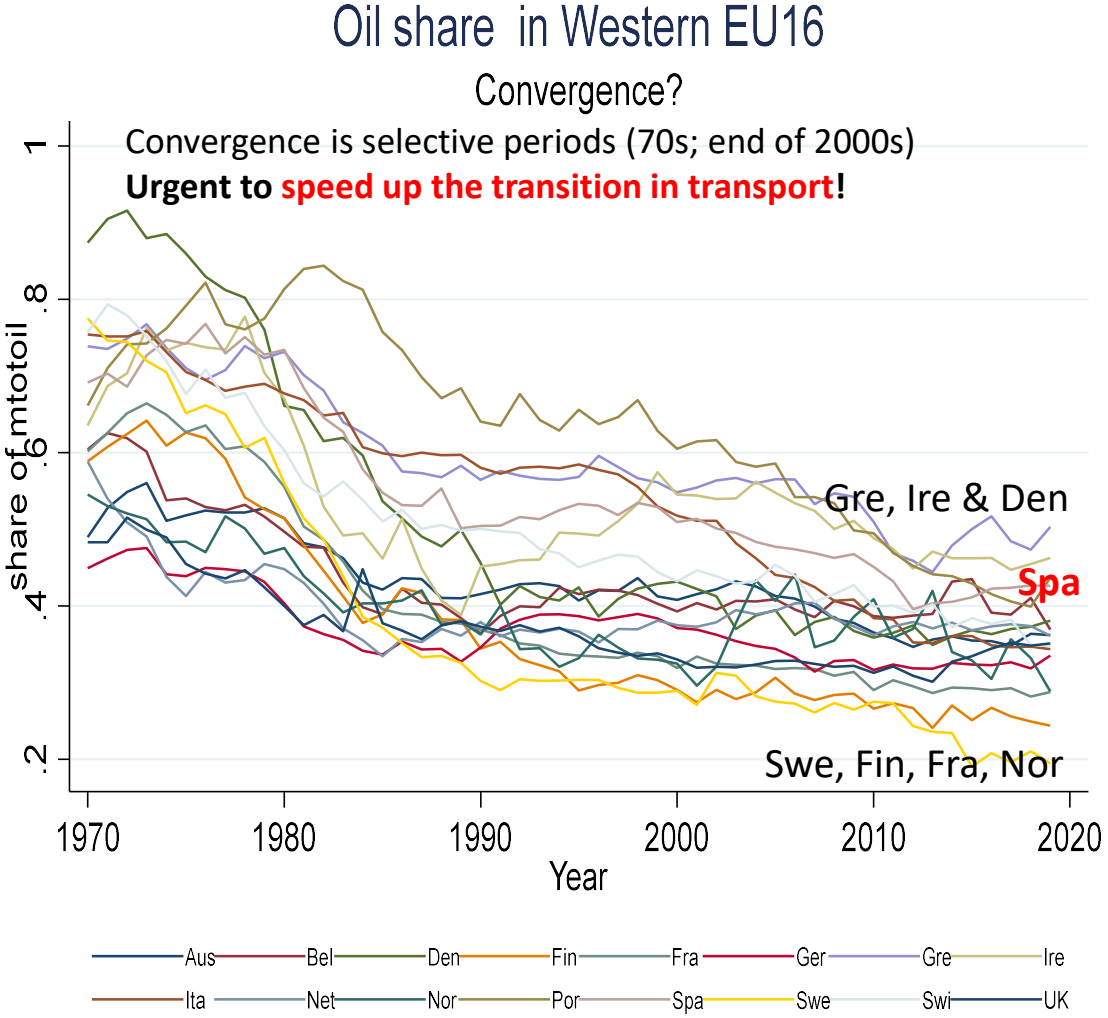


Some evidence of convergence, but also more than 100% differences by 2019 (70-100 TOE/mil.US$ vs. 30-40 TOE/mil.US$)

There is still a lot to do! (**regional policy is needed**!)

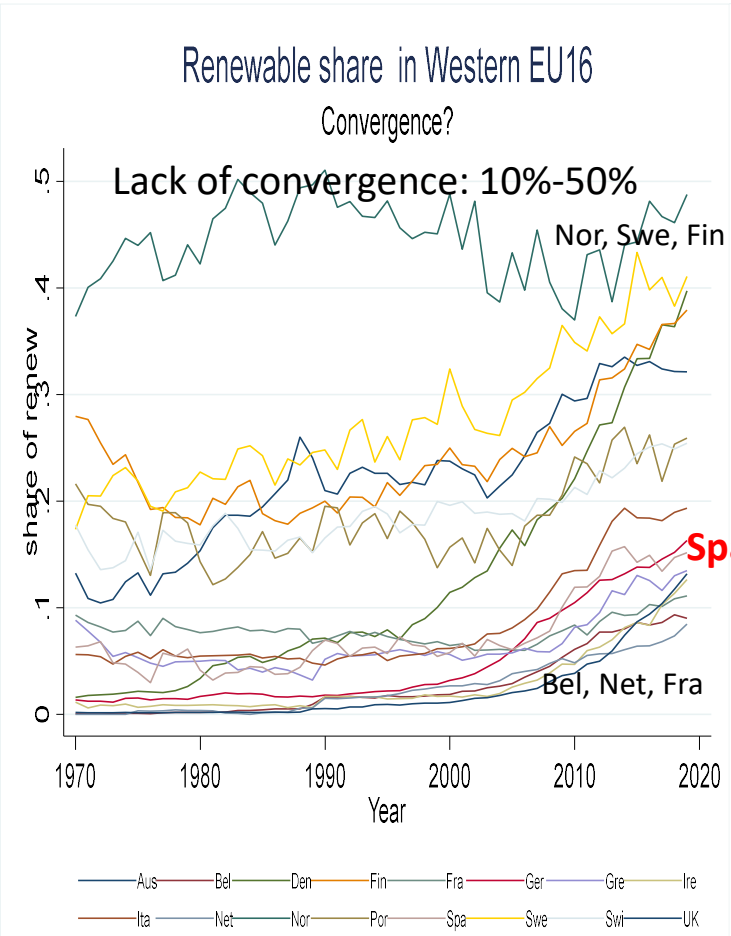
Convergence … in (more polluting) sources?

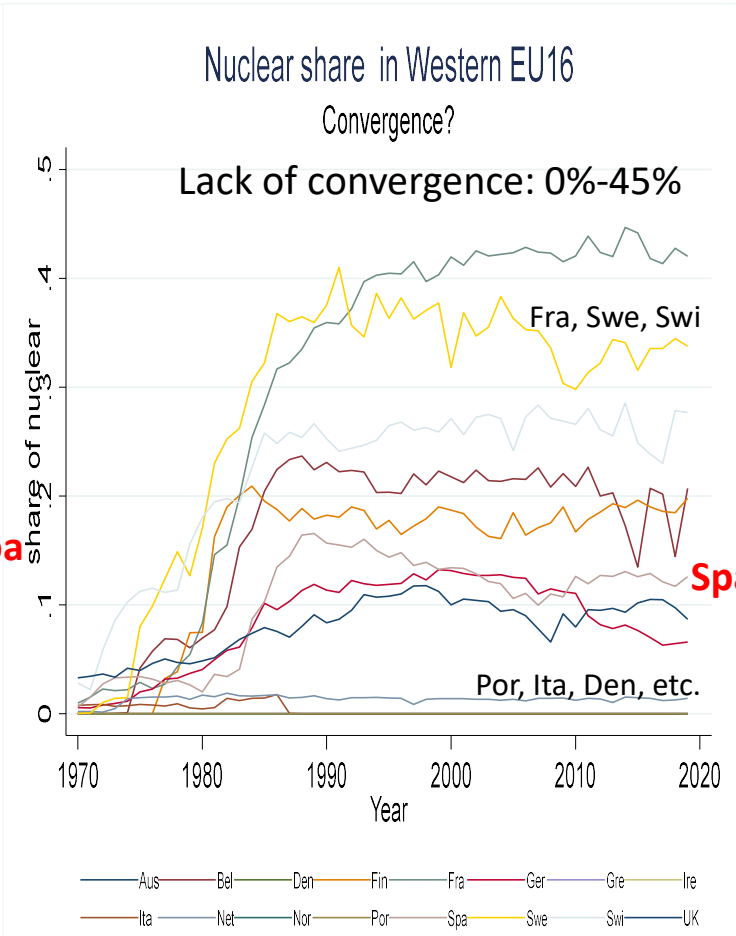


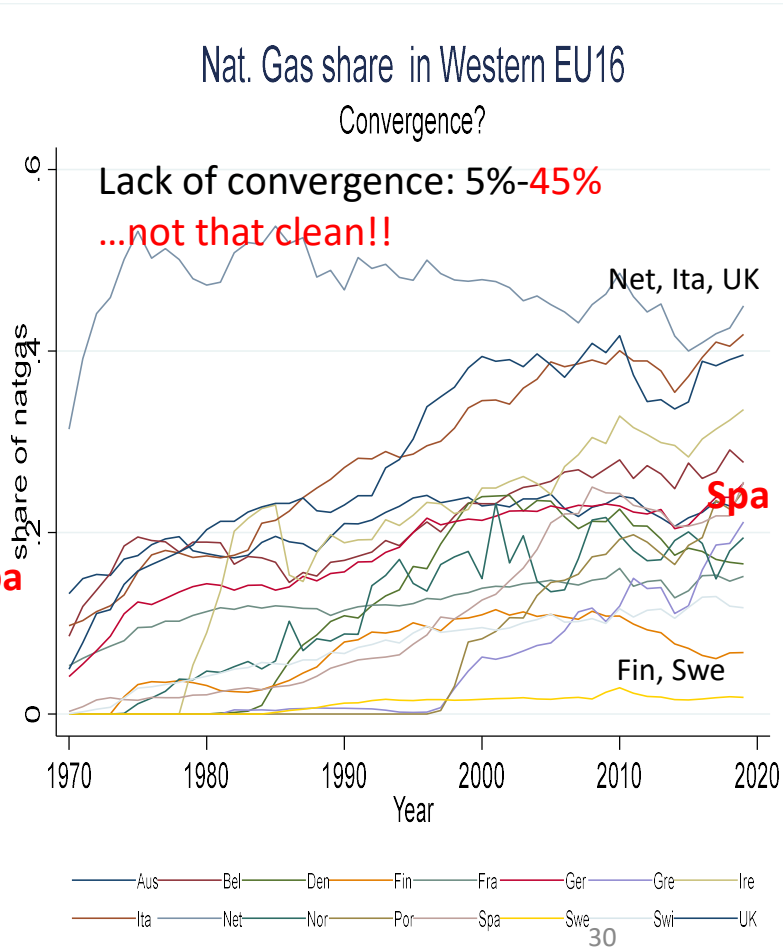


Convergence … in “less” polluting sources?

Convergence in the energy model is far from perfect!
But this needed for CO2 convergence !







To conclude … a summary of more results …

1. In general, the CO2-GDP elasticity is higher in booms than in recesions: Booms are generally associated with: i. increases in EI (or reduction in decreases); ii. increase in transport (OIL) sector

Procyclical Policy: *"Climate/energy actions must be responsive to business cycle fluctuations to content these expansions in booms"*

2. Energy (oil, gas) dependence is associated with higher CO2 emissions … but it is not a direct impact; it is indirectly through worst EI

3. Significant "**amplification**" effects, i.e.:

- Stronger negative impact of renewable on CO2 if EI is shrinking
- Stronger negative impact on emissions of reducing EI if renewables is raising

To conclude … about policies

- Long-run and global environmental policies are subject to moral hazard
- 100% renewable is a (very) long-run solution … in the meantime …
- Short-run and within-country policies (at the regional-level) are key
- Benefits of changing the energy model is beyond pollution: energy dependence, inflation, national security and even political stability!
- Consistent with our theory: procyclical taxes (specially over Energy Intensity→ improve convergence) can generate long-run (permanent) effects in CO2/GDP
    - Externalities and spillovers to all sectors
    - Learning-by-doing effect
    - Change in households / firm's behavior
    - Change in technology, difficult to revert
- The 100% renewable (long-run) situation can only be achieved with low-EI capital (short-term) (need capital transformation)

CO2 Emissions and Energy Technology in Western Europe

Gustavo A. Marrero (ULL)

(Dpto. Of Economics and CEDESOG)

With

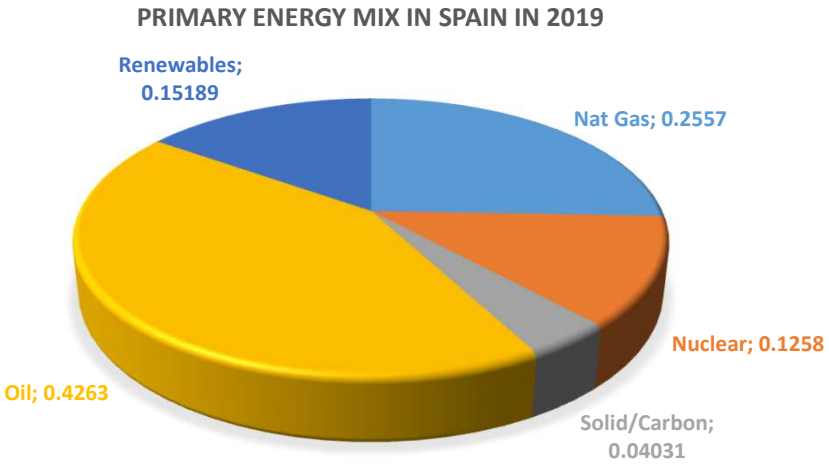
A. Díaz (UC3M); LA Puch (UCM); J Barrera-Santana (ULL)

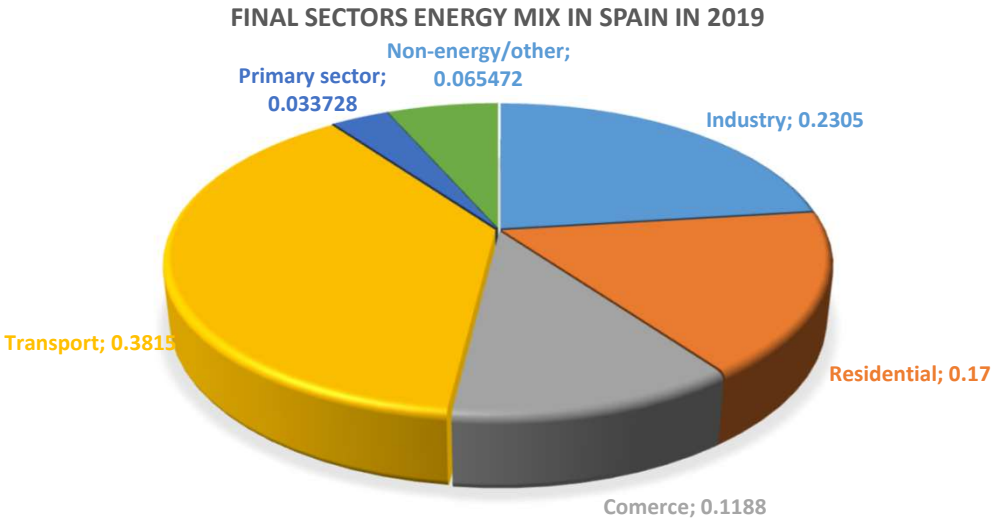
Energy and Climate Change

Bank of Spain, Madrid-Spain

July 8th, 2022

The situation of Spain in 2019

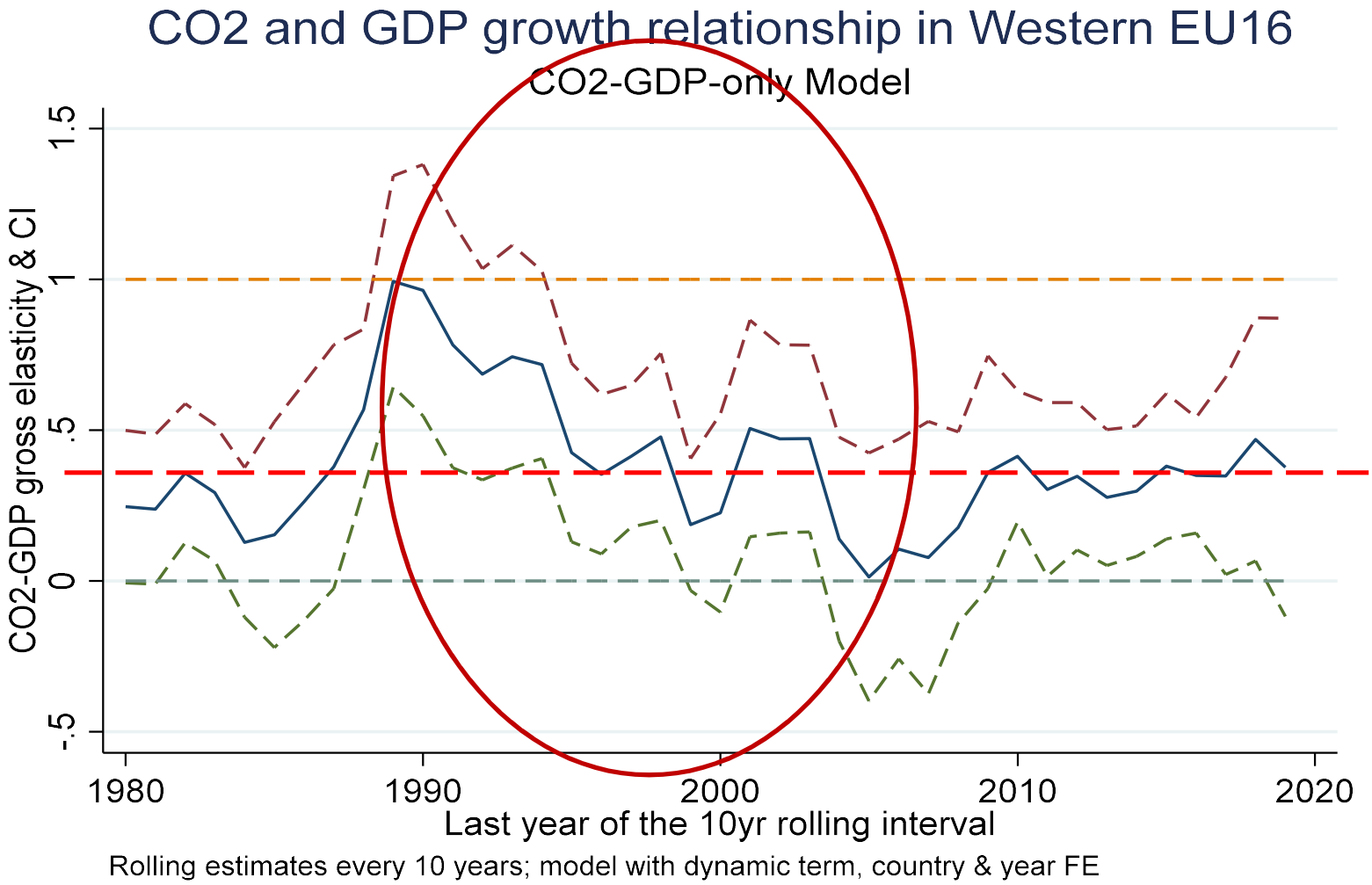




Probably, in terms of energy, 2019 will be the situation after these "two crisis":

- Our primary energy mix (minor movements in 2015-2019): only Oil and Gas have raised in the recovery; Carbon reduced
- Stop renew. share increase and slow down EI reduction!
- Our final energy sectors: Only transport is raising!
- The next steps?: keep improving efficiency; reduce gas and increase renewables in the electric mix; reduce Oil (transport sector)

CO2-GDP over time: Rolling estimates

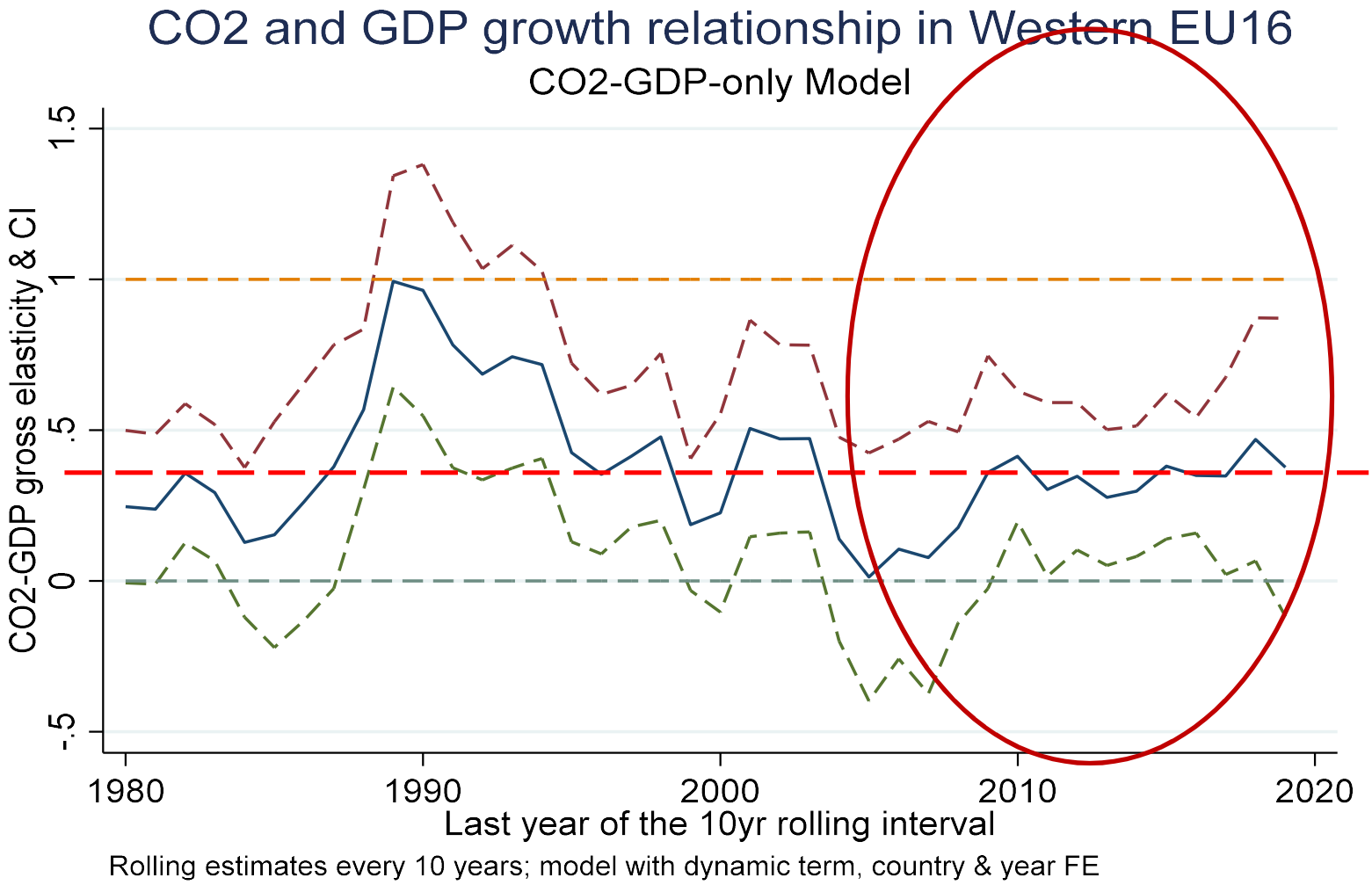


1992-2005-6: Acelerate the reduction of EI and the drop of Carbon (both starting from already low levels!)

Acelerate Gas and to a lesser extend Renewables

Stabilization of Oil at about 30-40% of the mix

CO2-GDP over time: Rolling estimates



2005-6 … : Stabilization of the EI reduction;

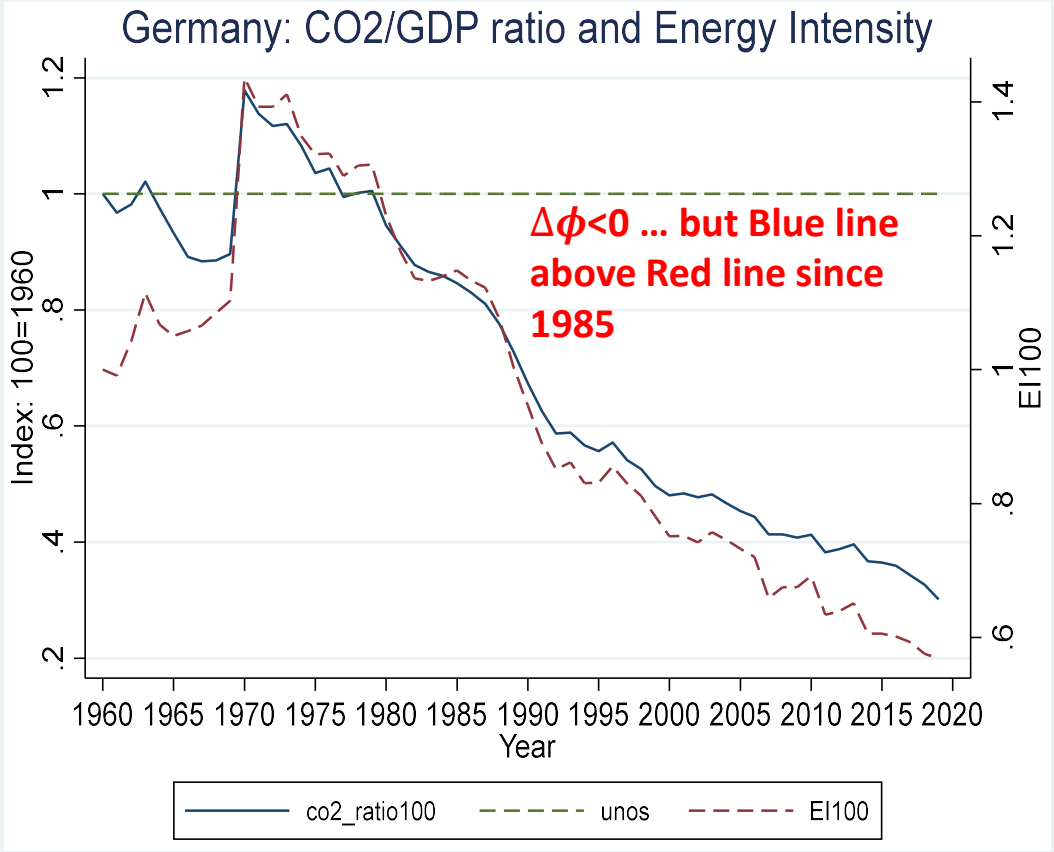
Aceleration of renewables (wind and solar), desaceleration of Gas, but small redcution in Carbon and Oil

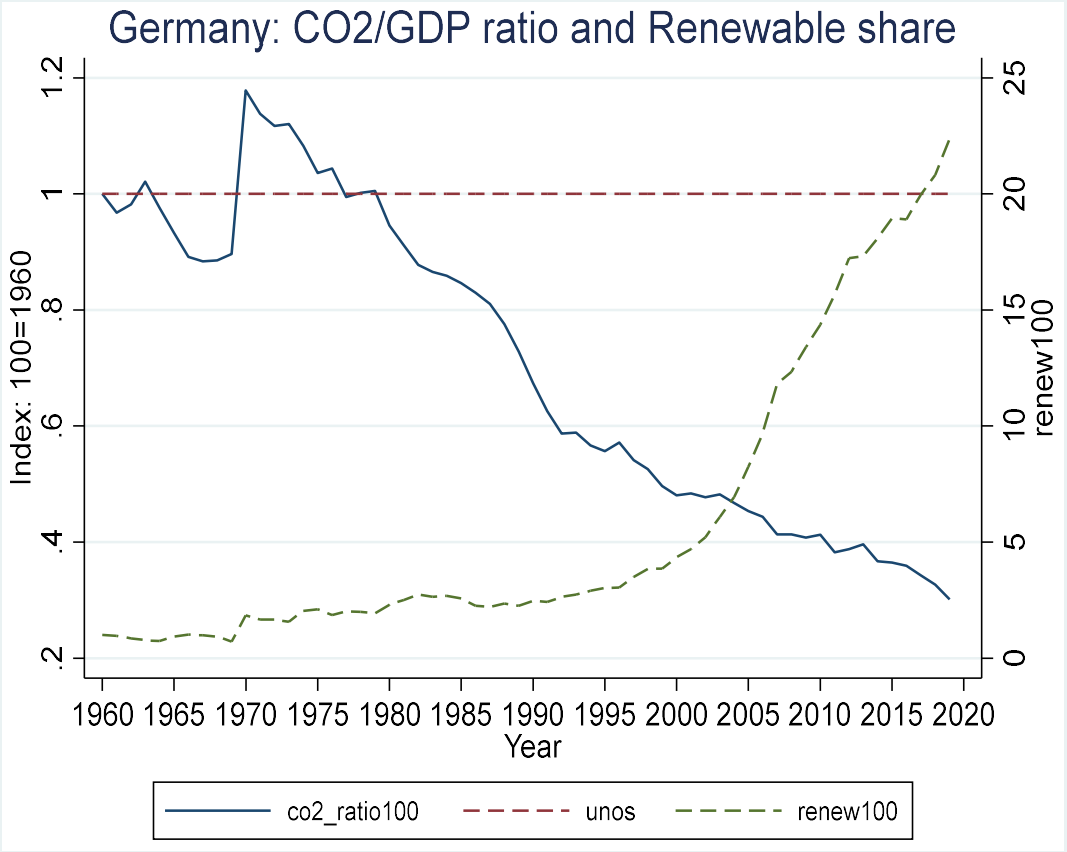
Stabilization of Nuclear

The CO2-GDP slope … in Germany (1970-2019): $\Delta\phi<0$

Big decrease of EI

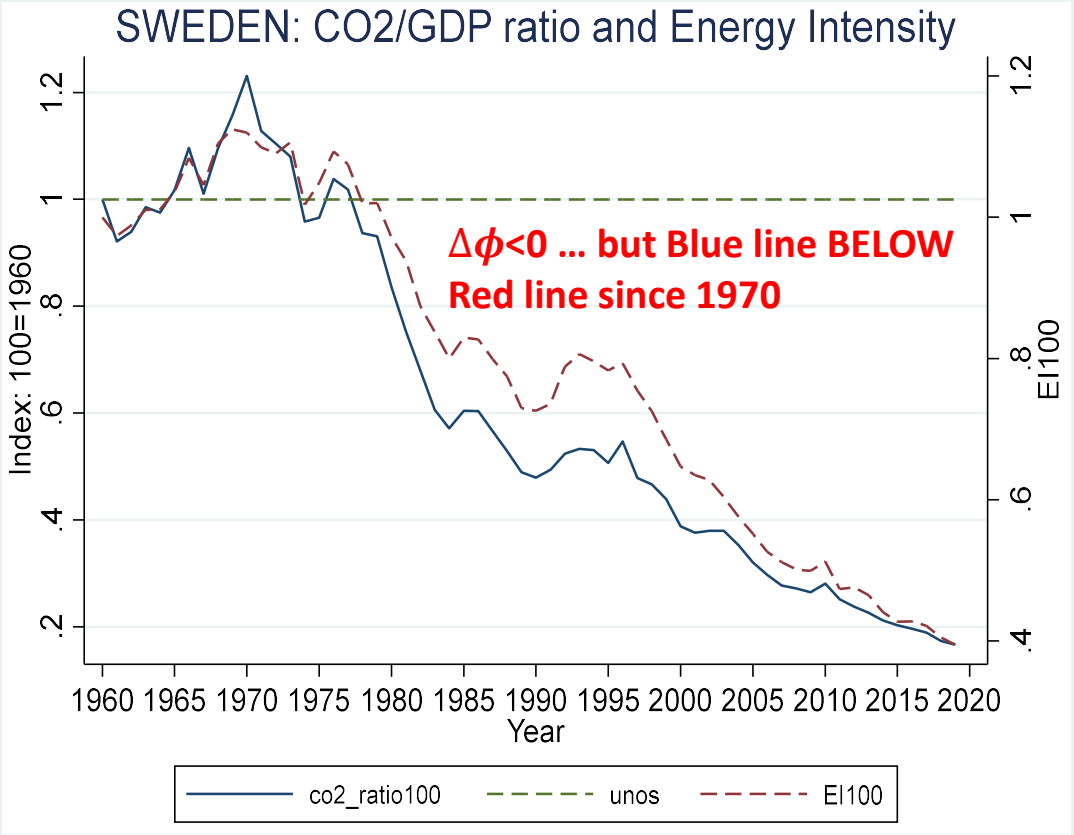
Decrease of nuclear (5%) and lower in carbon (20%), big increase in gas (intensive use - >20%), almost flat in oil (about 35%) … further imporvement after 1995 comes from big increase in renewable share (still below 20%)

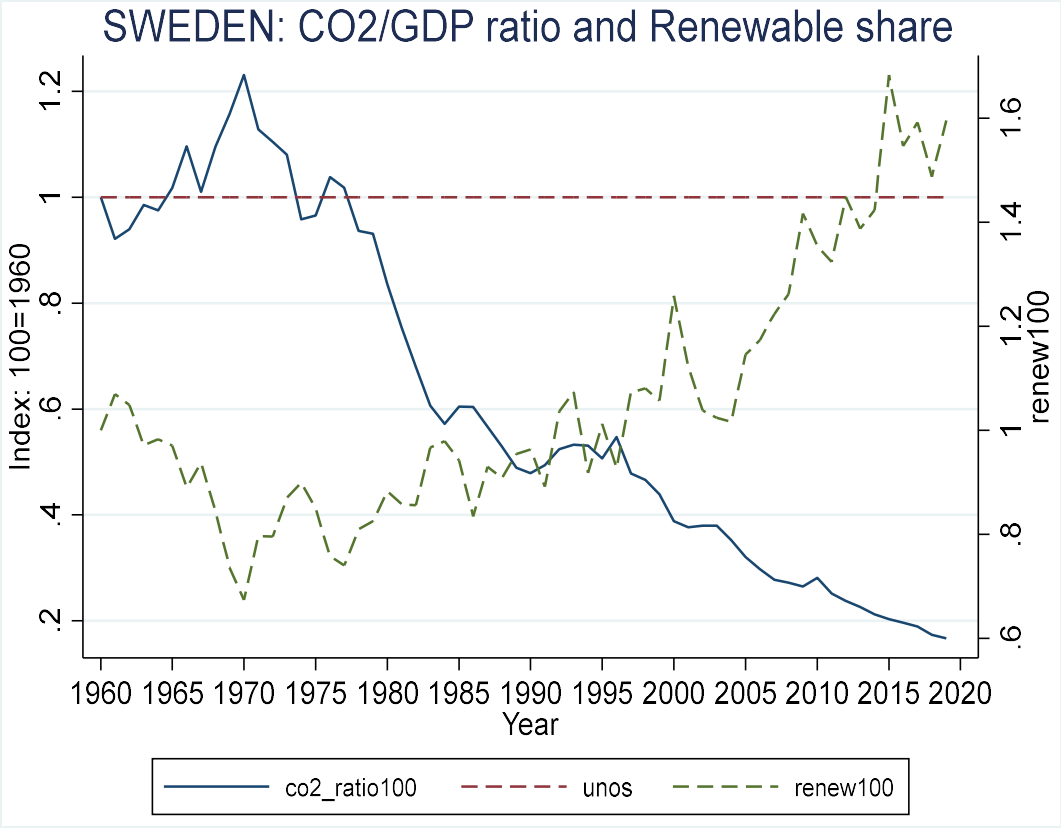




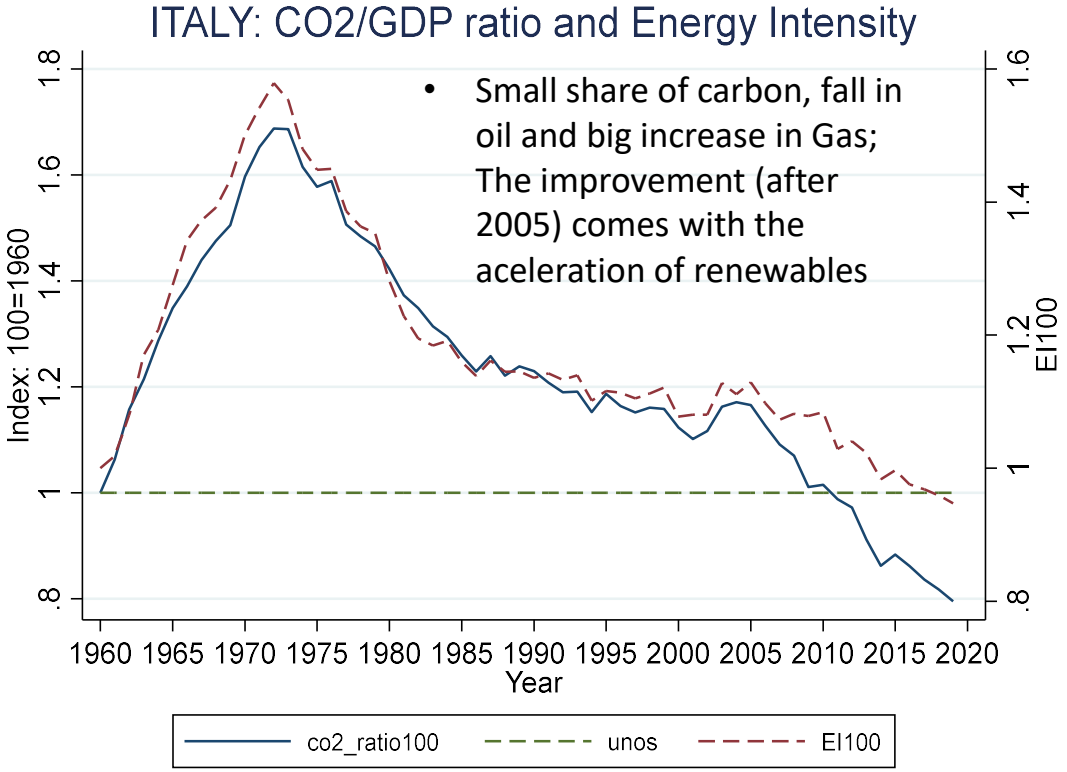
The CO2-GDP slope … in Sweden (1970-2019): $\Delta\phi<0$

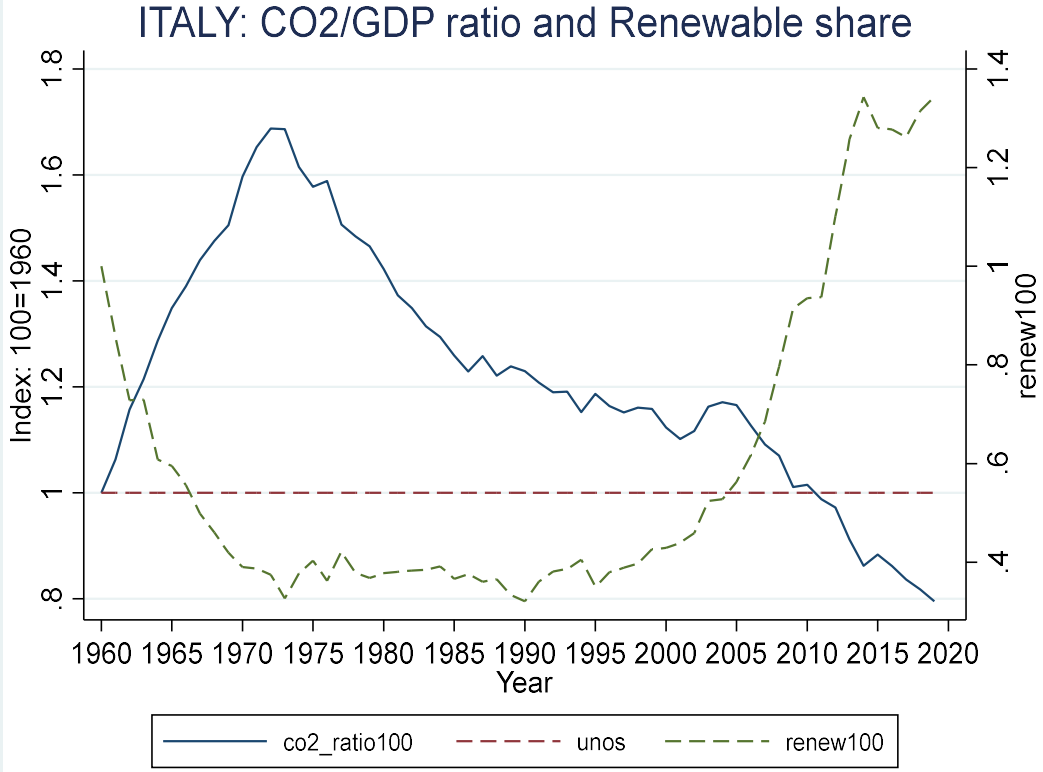
Big drop of EI (similar than in Germany)
Small share of carbon and gas (both below 5%); fall in oil (about 20%) and big increase in nuclear (about 35%) and specially in renewables (about 40%)



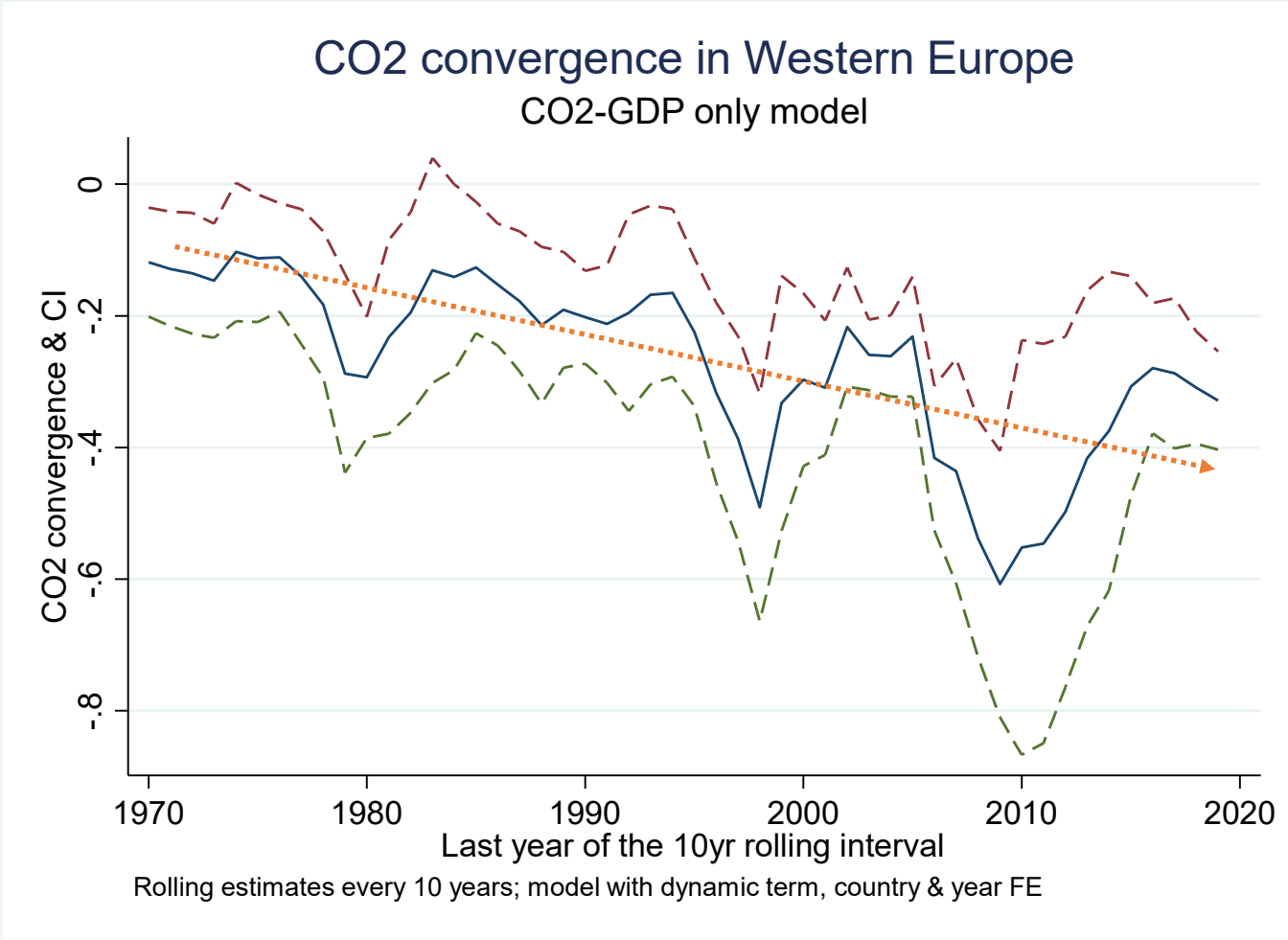


The CO2-GDP slope …



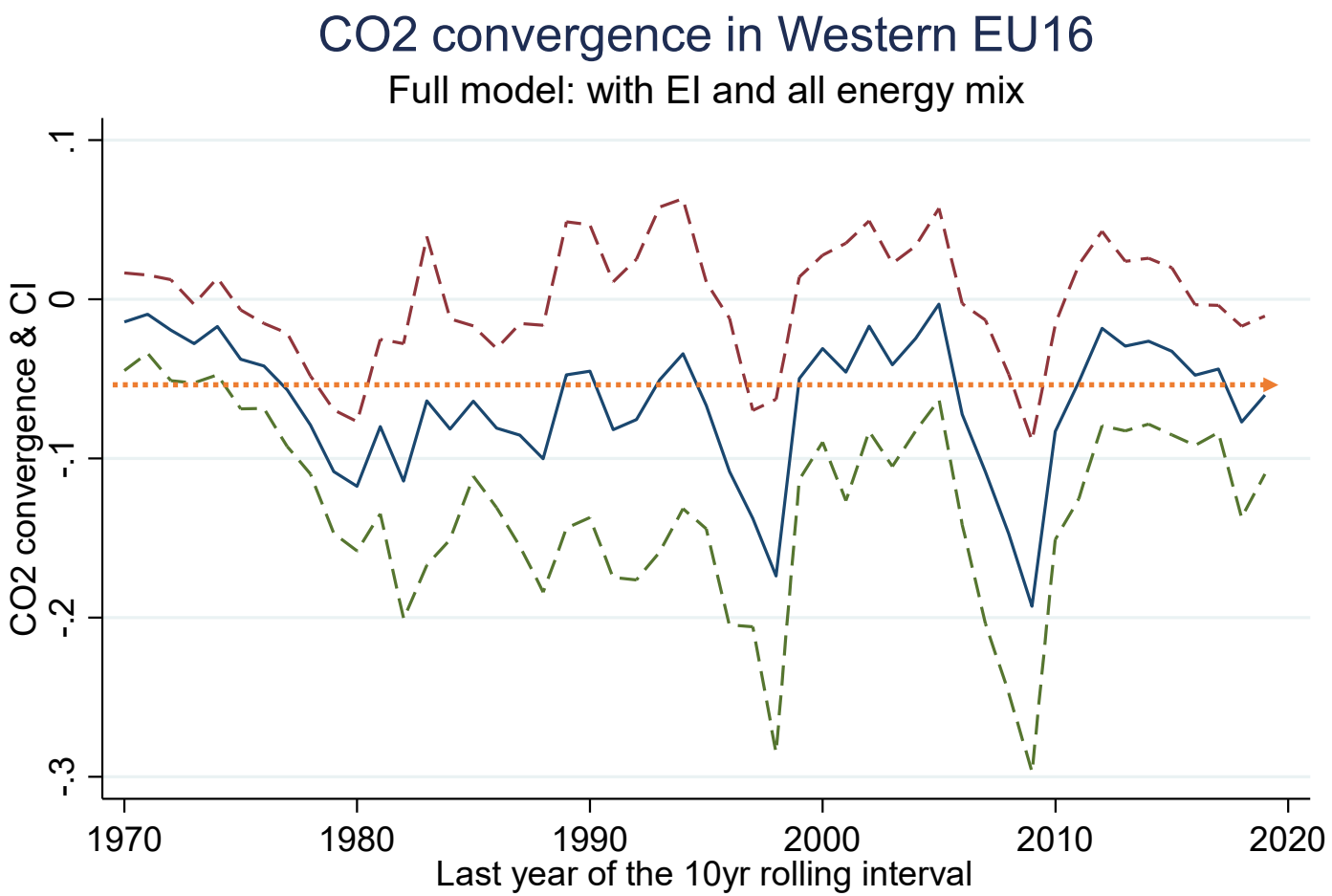


Estimation results: convergence (conditional)



Conditional convergence has increases

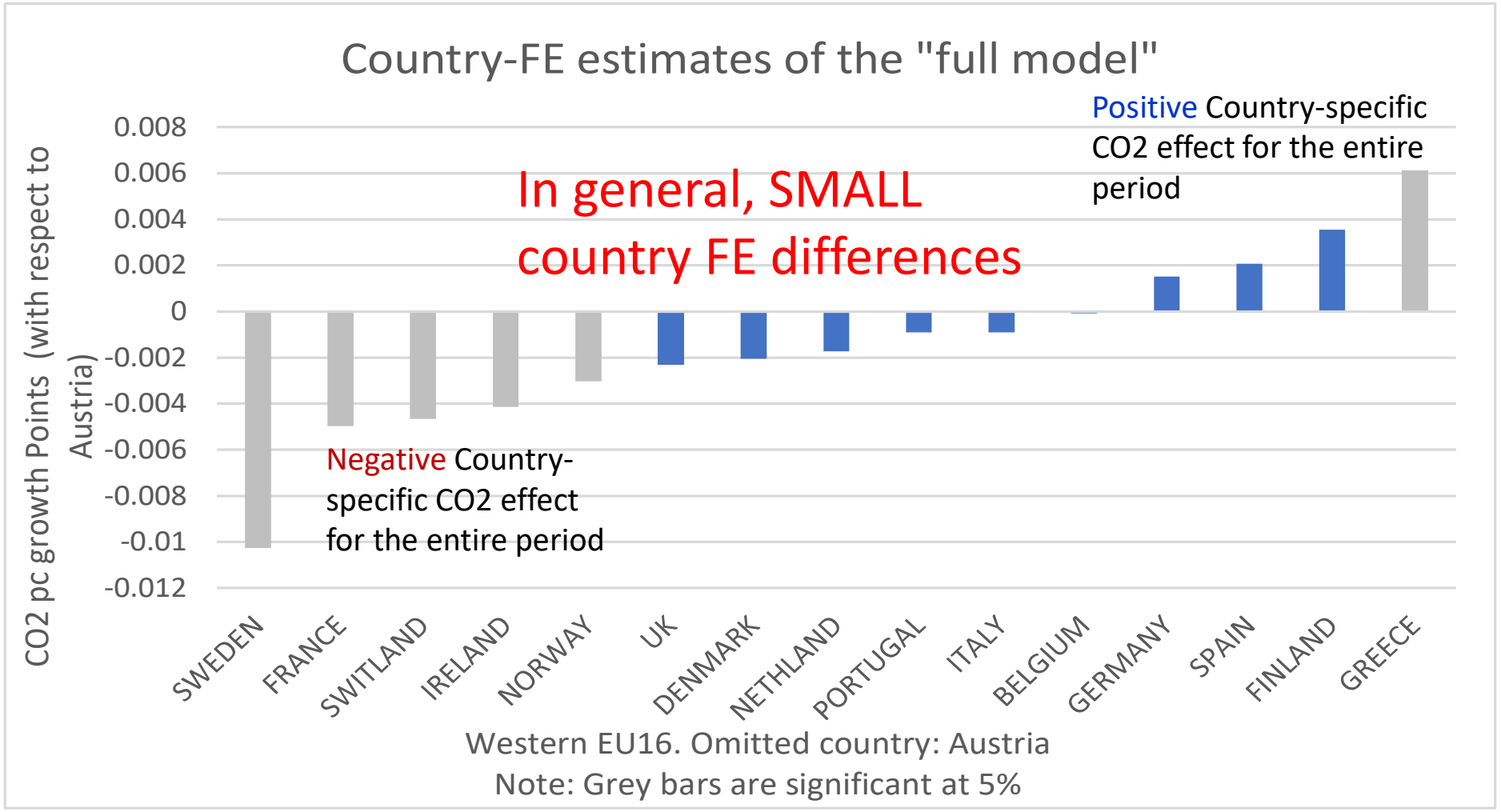
Estimation results: convergence



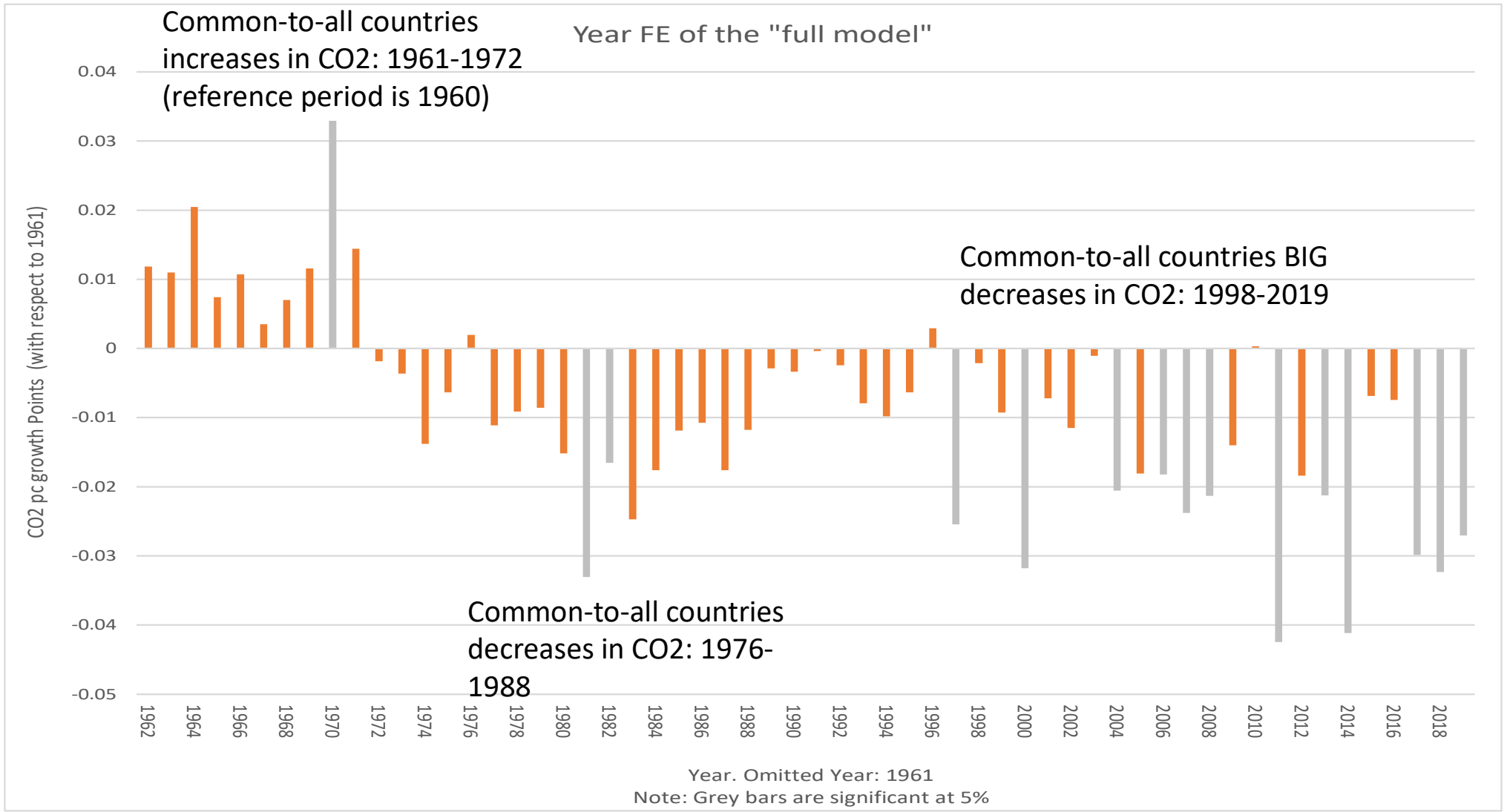
Only when including all energy variables, including the whole energy mix, "conditional" convergence is almost zero!

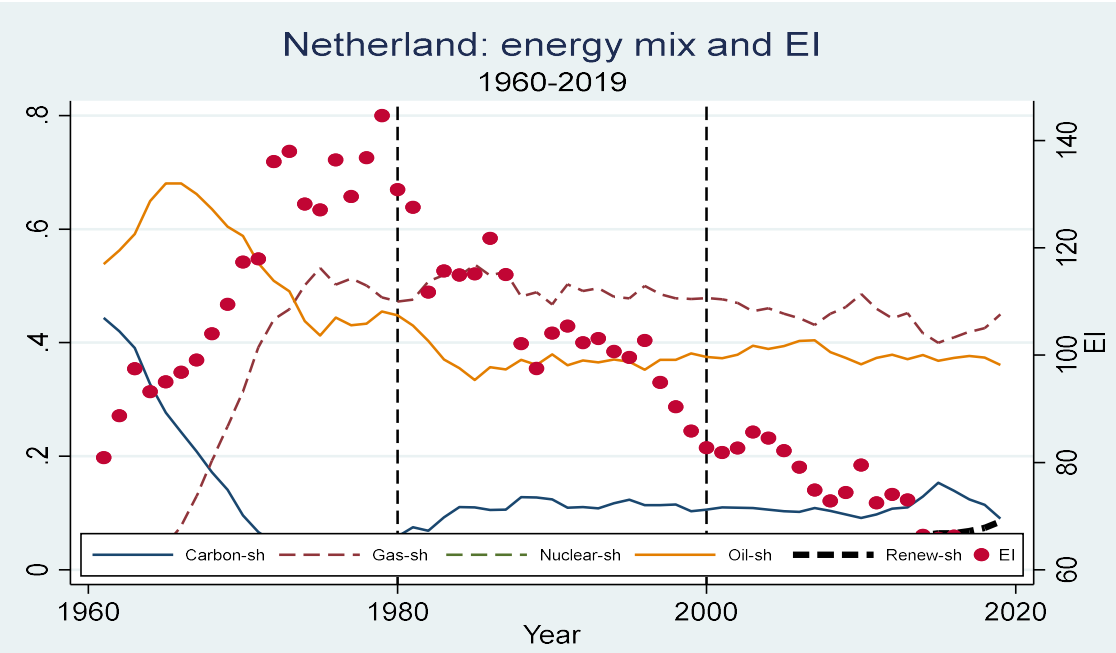
CO2 convergence is also mostly due to energy-related convergence aspects

Estimation results



Estimation results




Netherland: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
Year
1960
1980
2000
2020
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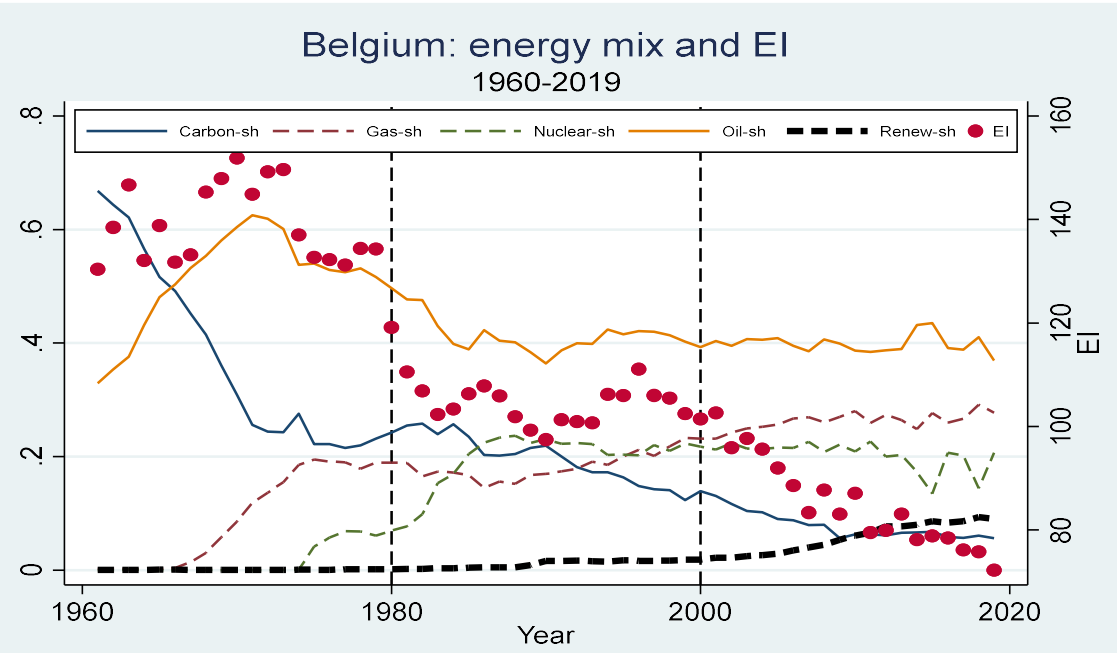
Belgium: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
Year
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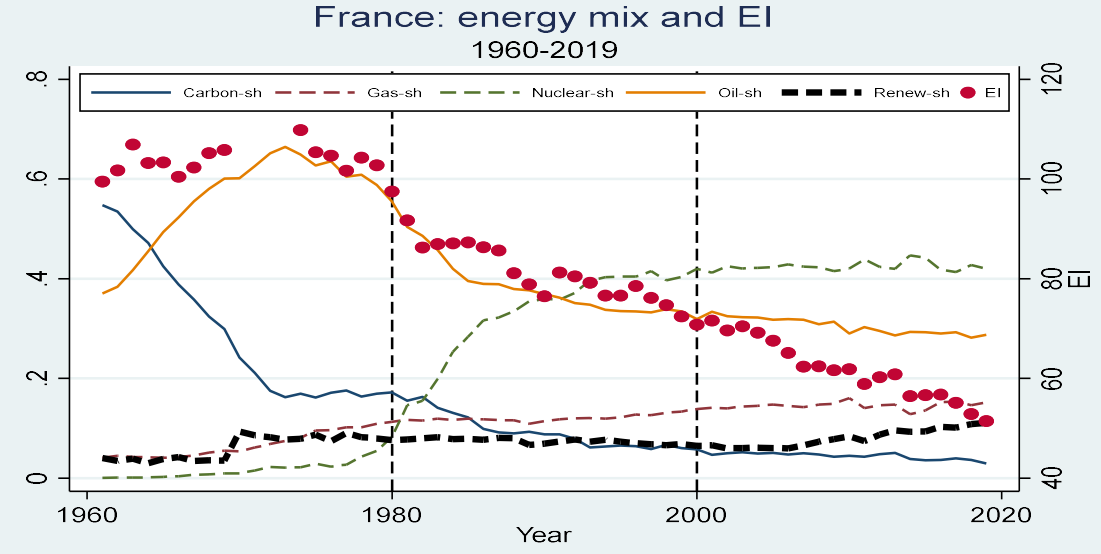
France: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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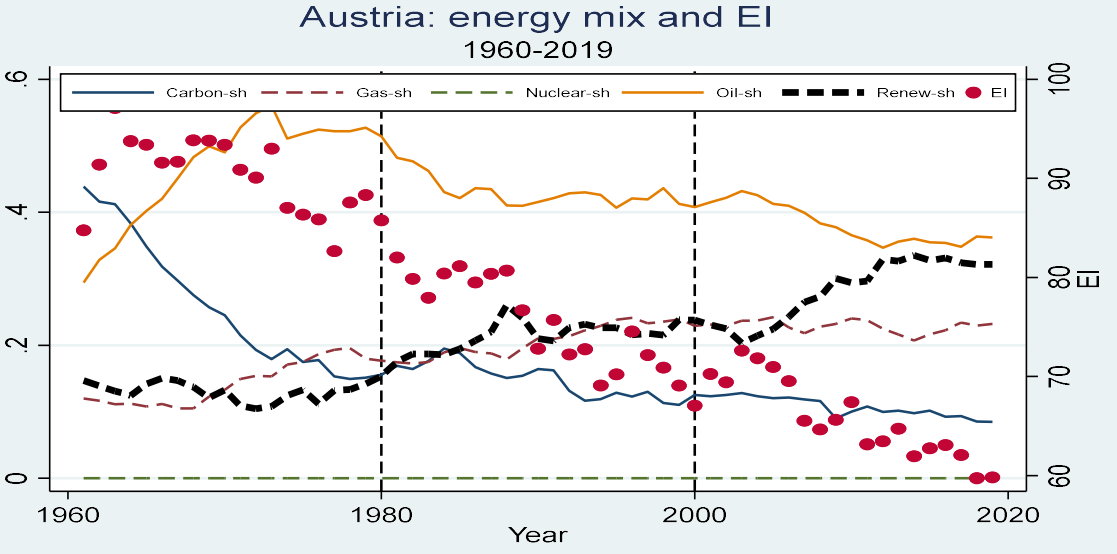
Austria: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
Year
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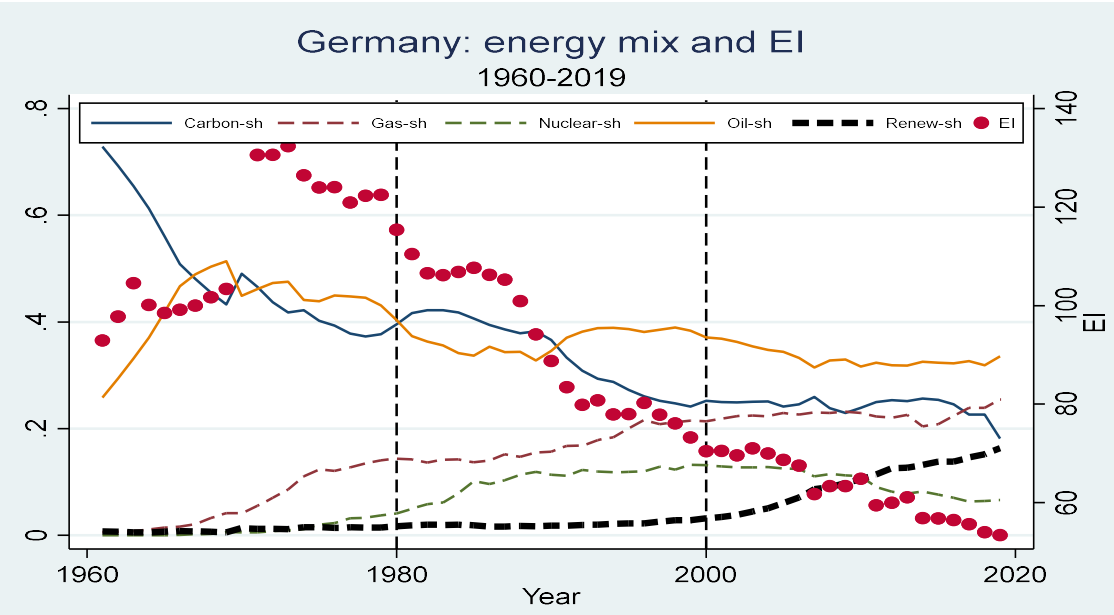
Germany: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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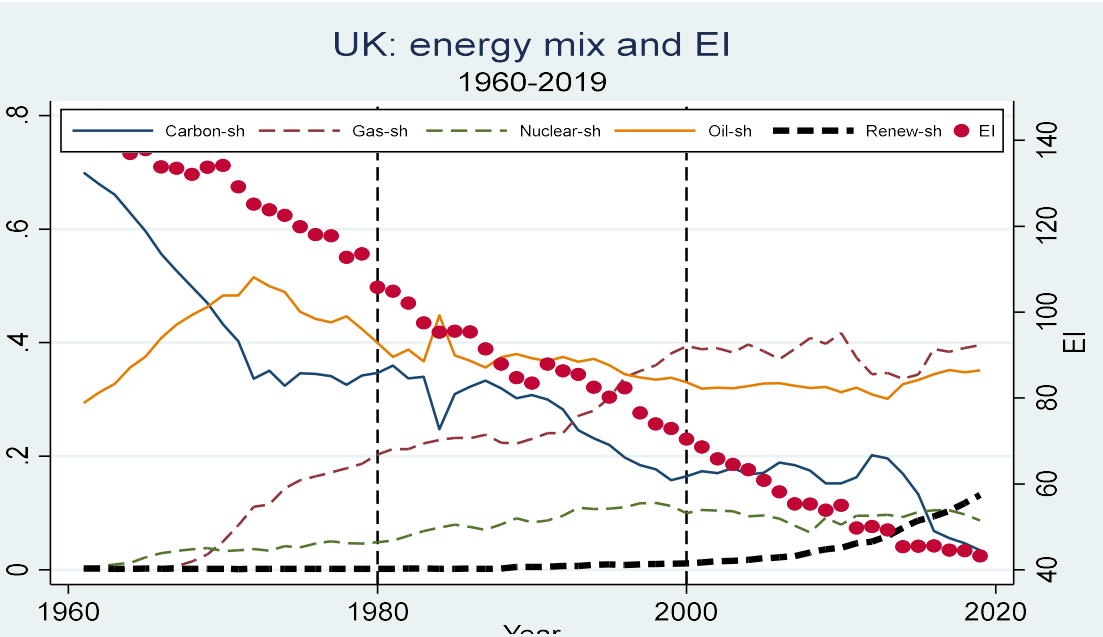
UK: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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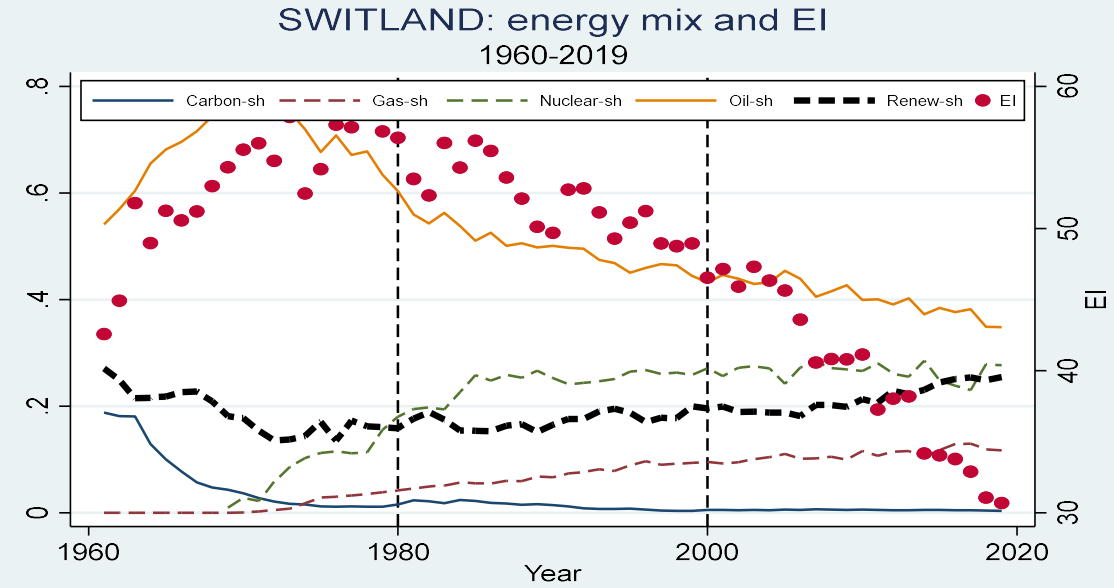
SWITLAND: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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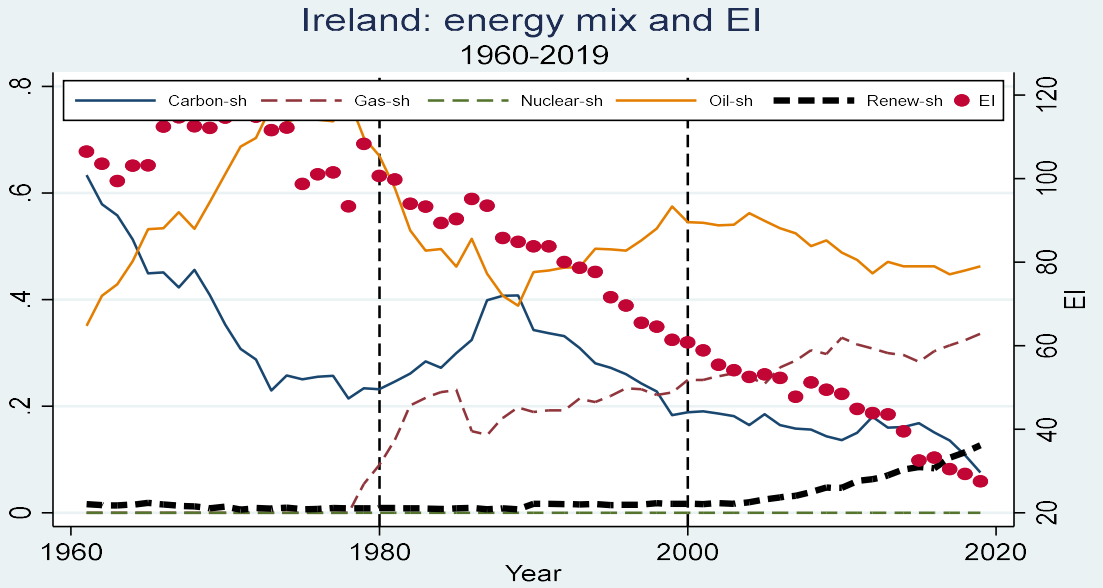
Ireland: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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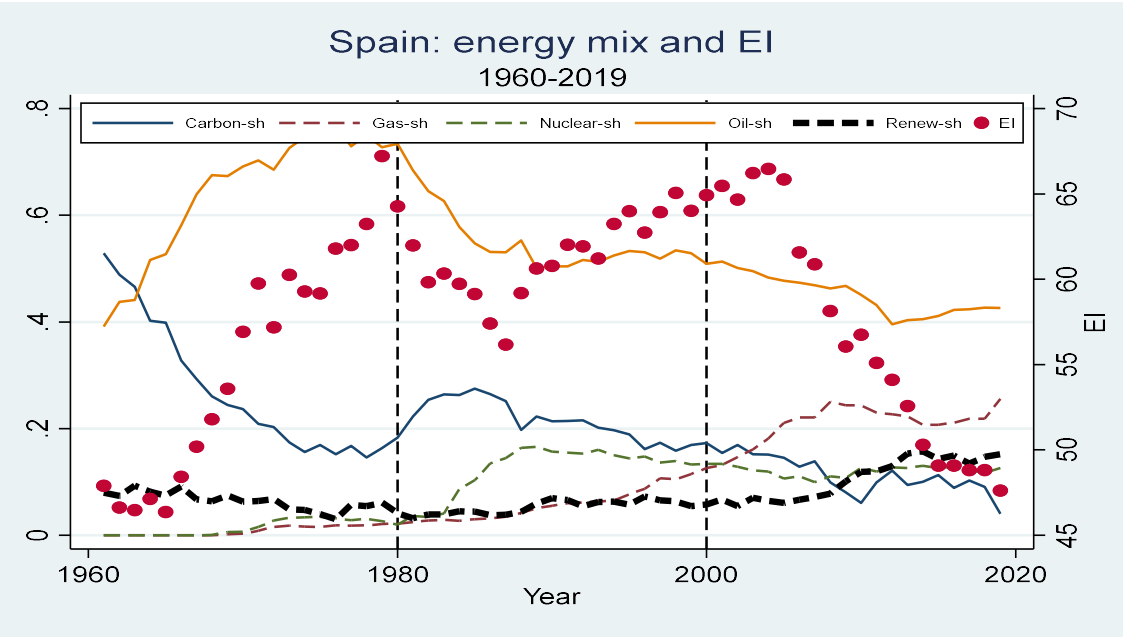
Year


Spain: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
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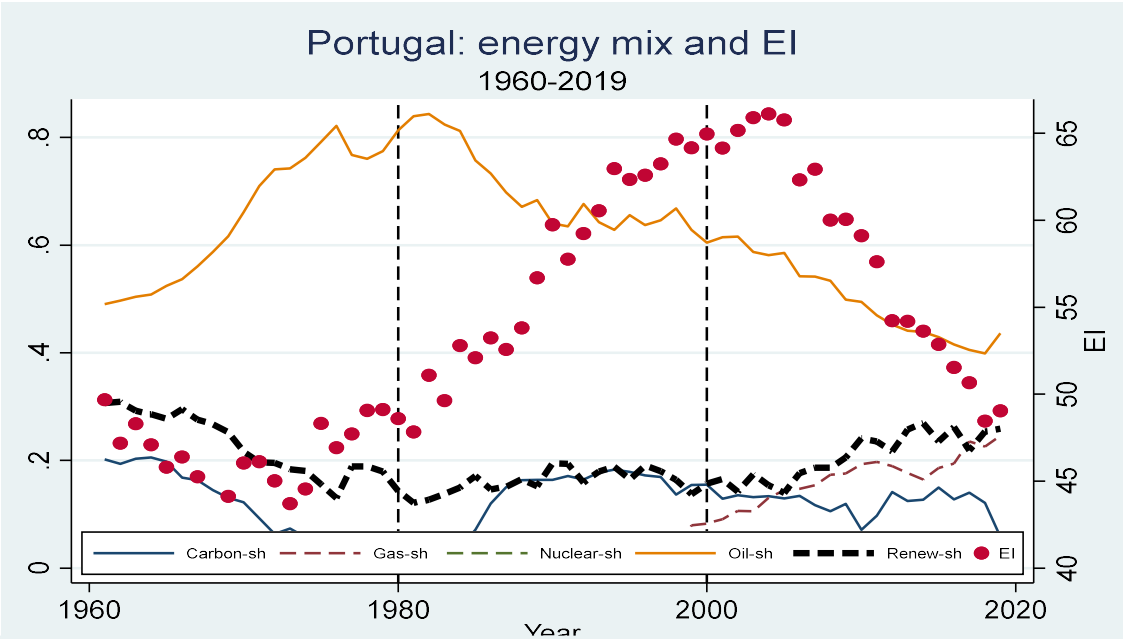
Year


Portugal: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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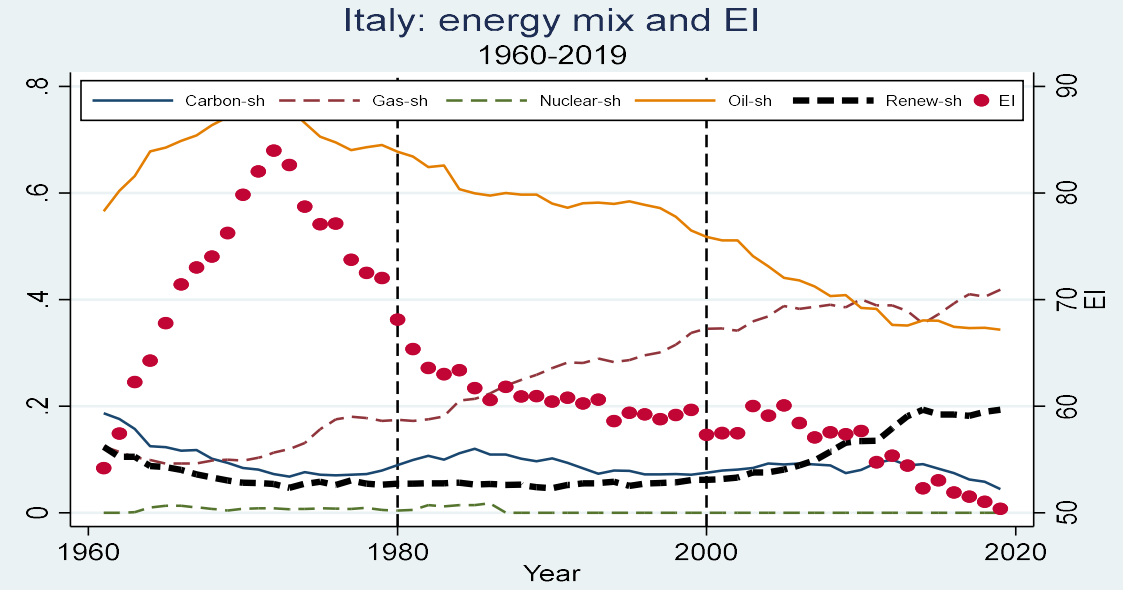
Italy: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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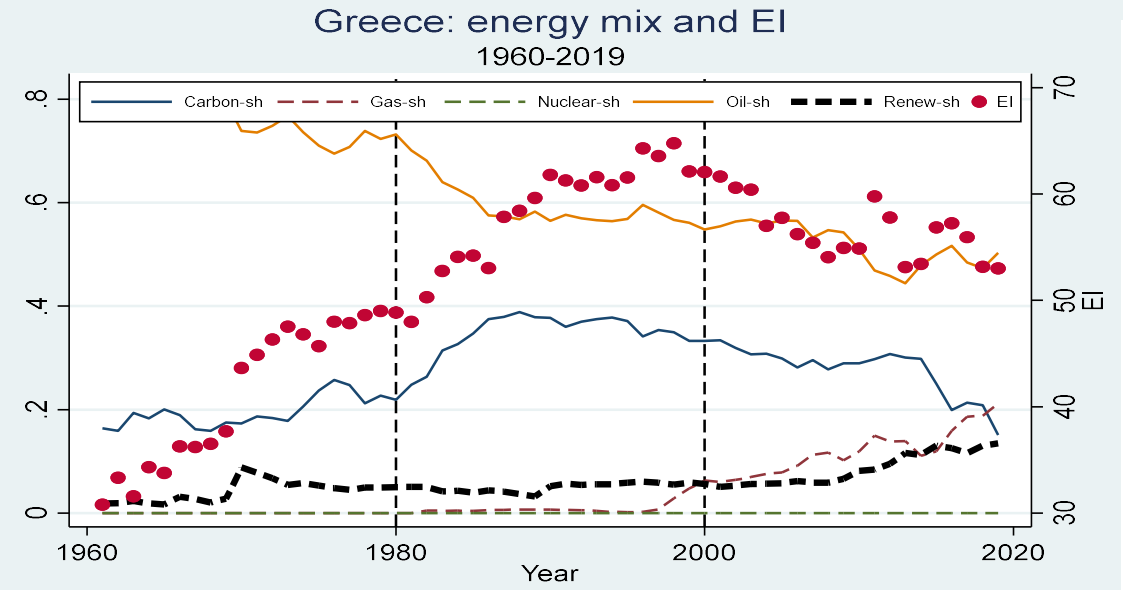
Greece: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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1960
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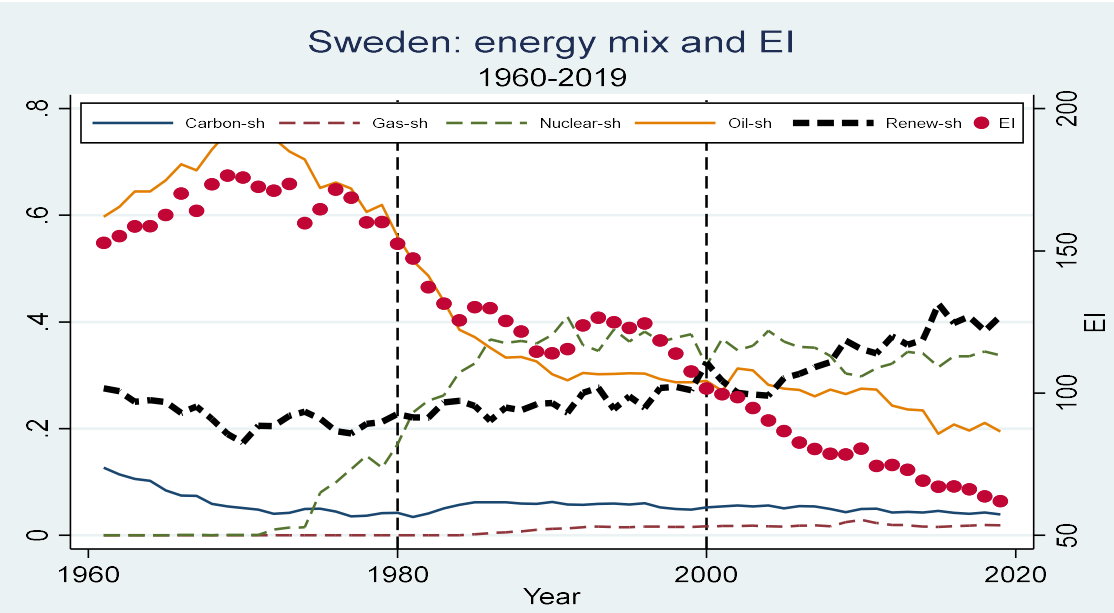
Year


Sweden: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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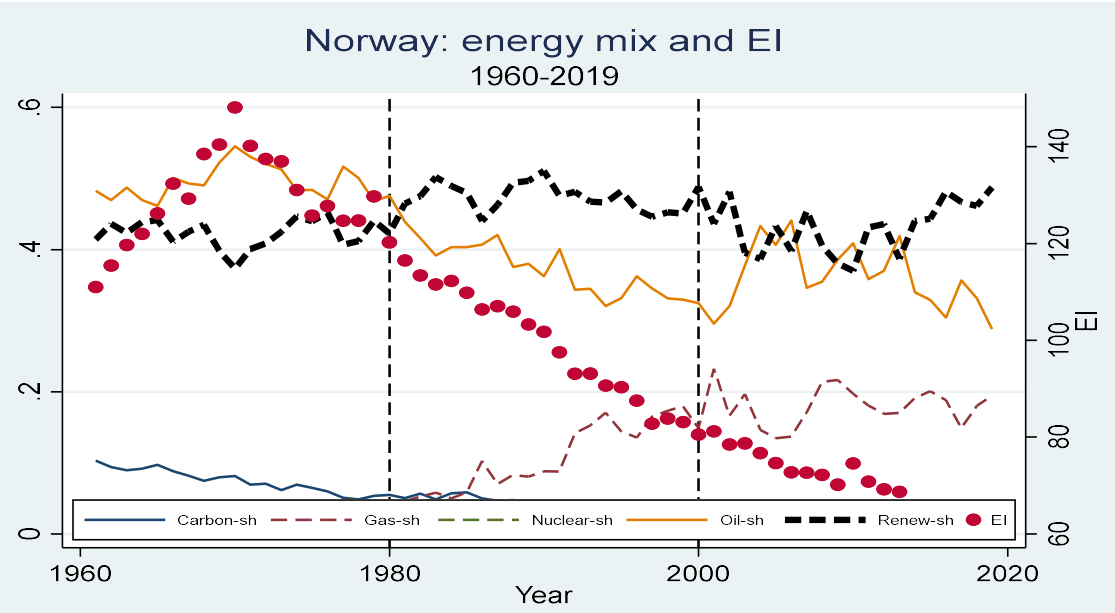
Norway: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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1960
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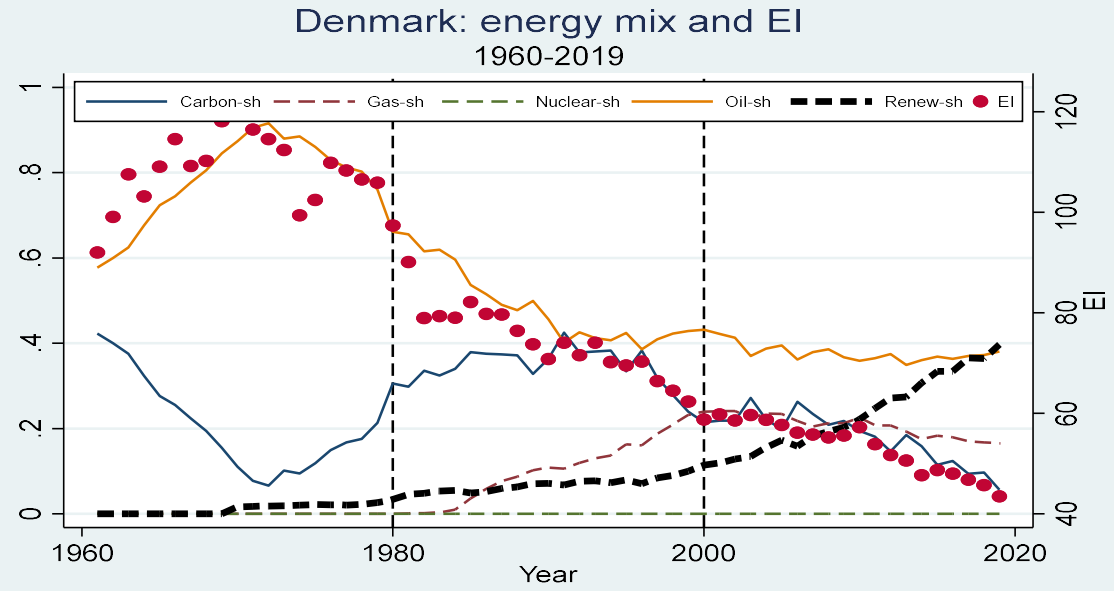
Year


Denmark: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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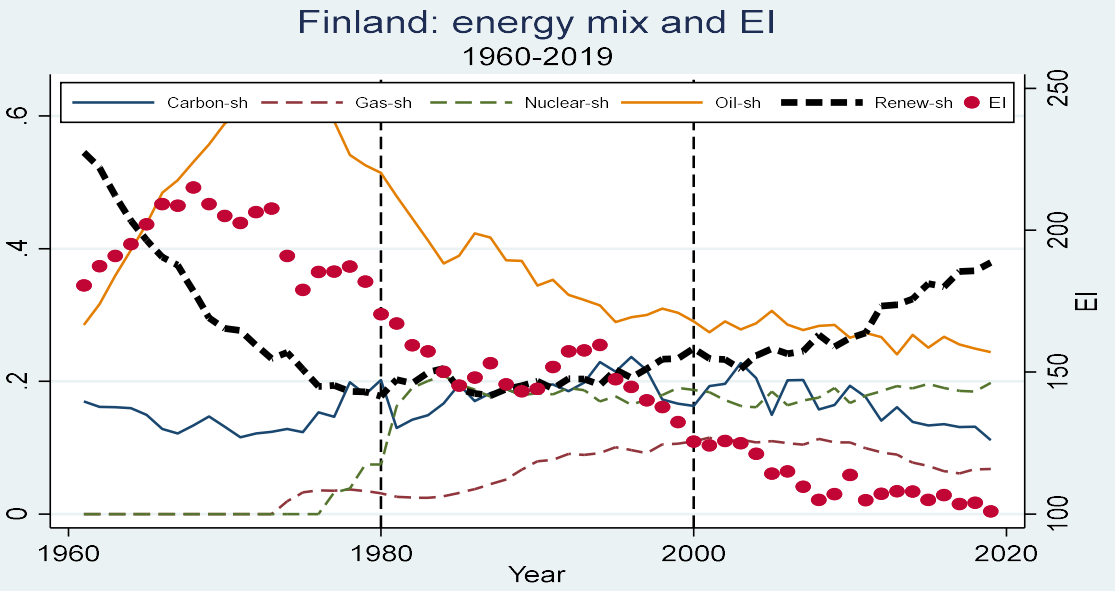
Year


Finland: energy mix and EI
1960-2019
Carbon-sh
Gas-sh
Nuclear-sh
Oil-sh
Renew-sh
EI
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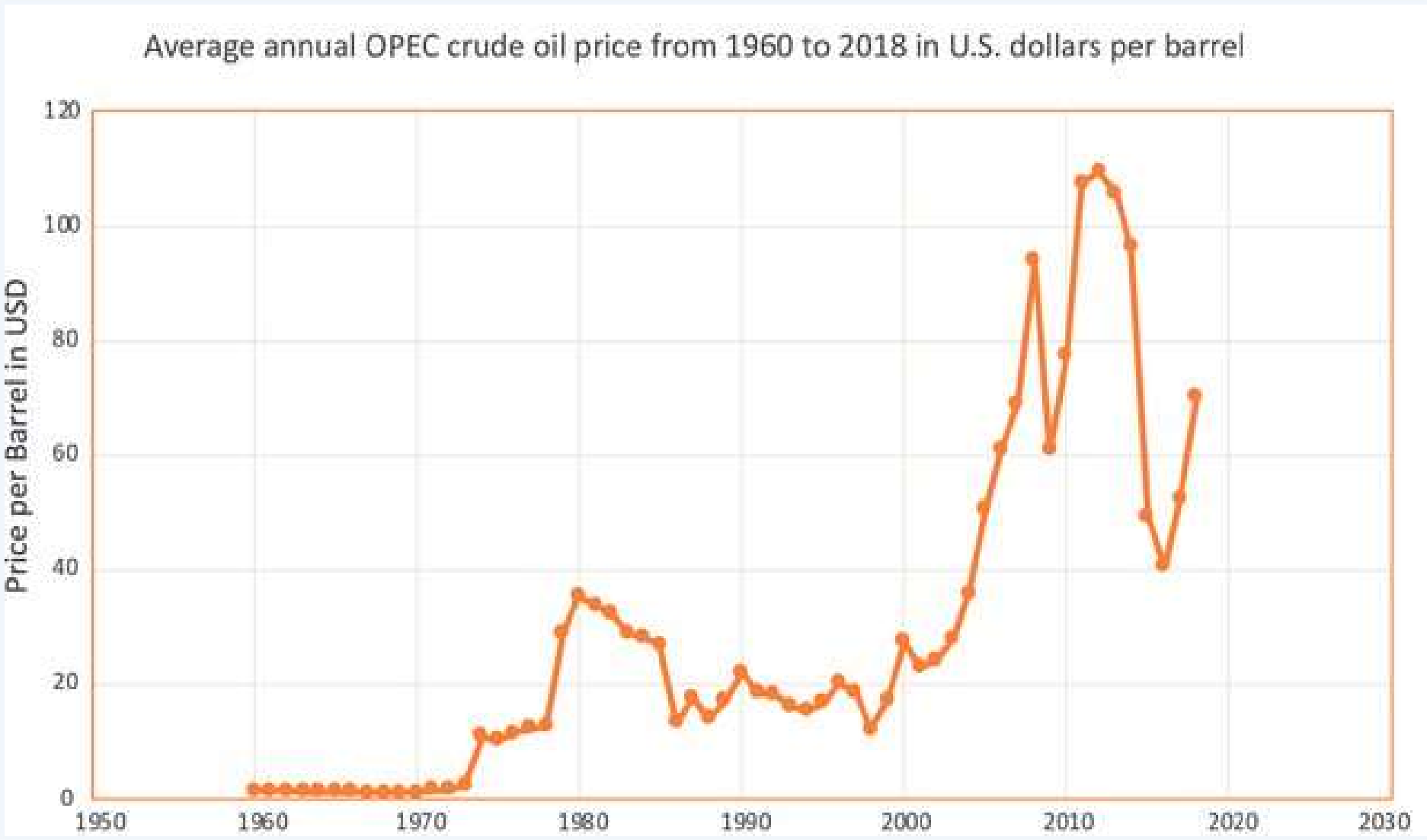
Year


Average annual OPEC crude oil price from 1960 to 2018 in U.S. dollars per barrel
Price per Barrel in USD
120
100
80
60
40
20
0
1950
1960
1970
1980
1990
2000
2010
2020
2030

The empirical model

We take care about relevant econometric issues:

- errors clustered at the country level
- test for endogeneity ("double causality")
- Check for robustness
- Alternative dynamic specifications, controls, asymmetries
- Etc etc etc etc etc etc etc etc

The inclusion of energy variables (together with country and year FE) improves the model specification and the p-values of the tests

"The effect on GDP from climate change damage through productivity (Golosov et al., 2014) is forward looking and of long-run (i.e., through health and human capital) (this mechanism does not operate in the short-run)"

Nevertheless, we check for robustness using alternative approaches (i.e., IV approach, system-GMM), etc.