What are the structural determinants of US carbon dioxide emissions? An econometric approach

Marcio Santetti

Lawrence University

February 2022

Marcio Santetti

Ph.D. Candidate

University of Utah

santetti@gmail.com
marcio.rbind.io
github.com/marciosantetti

Replicate, replicate, replicate...

For *all* code and slide/style templates:

`github.com/marciosantetti/lawrence-university-talk`

Reference

Santetti, M. "What are the structural determinants of US carbon dioxide emissions? An econometric approach," 2021, ***International Journal of Applied Economics***, 18(2): 44–80.

Final chapter of Ph.D. Dissertation

- "*Three essays on growth, distribution, and the environment*"

First chapter:

- "*Growth, cycles, and residential investment* (Job Market Paper).

Second chapter:

- *"The US labor share of income: What shocks matter?"*
    - with Ivan Mendieta-Muñoz, Codrina Rada, and Rudiger von Arnim, 2020, ***Review of Social Economy***, DOI: 10.1080/00346764.2020.1821907.

Outline

Introduction

Introduction

Research Questions:

1. What are the most relevant **structural determinants** of carbon dioxide emissions in the US economy over the post-war period?
2. What is the role of **technological progress** in this setting? Does it lead to emissions mitigation?

Methodology:

1. Theoretically identified Vector Autoregressive (VAR) models, inspired by an extended Kaya identity and the green growth hypothesis;
2. Two different methodologies: one- and two-step VAR procedures

Introduction

Contributions:

1. Empirical methodology based on **theoretical assumptions**;
2. Historically, the US economy's technological progress path **does not** support reductions in emissions.
    - Inconsistent with green growth/absolute decoupling scenario.

In addition, novel econometric methodology

- `Kilian (2009)`;
- `Mendieta-Munoz et al. (2020)`.

Literature review

Literature review

"Backward-looking":

- Using historical data to investigate short- and long-run **dynamic linkages** between environmental and macroeconomic variables.
    - `Copeland and Taylor (2004)`;
    - `Soytas et al. (2007)`;
    - `Hossain (2011)`;
    - `O'Mahony (2013)`;
    - `Shahiduzzaman and Layton (2015)`.

Policy-oriented:

- Only a **big push** with (coordinated) public investments towards renewable energy sources and increased carbon taxes can trigger a shift to mitigate climate change.
    - `Nordhaus (2008, 2014)`;
    - `Heutel (2012)`;
    - `Rezai et al. (2018)`;
    - `Mattauch et al. (2019)`;
    - `Semieniuk et al. (2021)`.

Literature review

The green growth hypothesis:

- **Technological progress** and **resource substitution** are the drivers of a concomitant scenario of economic growth and emissions mitigation (**absolute** decoupling).
    - `OECD (2011)`;
    - `UNEP (2011)`;
    - `World Bank (2012)`;
    - `Jacobs (2013)`;
    - `Hickel and Kallis (2020)`.

Literature review

`OECD (2011)`:

> In June 2009, Ministers from 34 countries signed a Green Growth Declaration, declaring that they will: "Strengthen their efforts to pursue green growth strategies as part of their responses to the crisis and beyond, acknowledging that green and growth can go hand-in-hand." They endorsed a mandate for the OECD to develop a Green Growth Strategy, bringing together economic, environmental, social, technological, and development aspects into a comprehensive framework.

Literature review

World Bank (2012):

Key Messages

- *Greening growth is necessary, efficient, and affordable*. It is critical to achieving sustainable development and mostly amounts to good growth policies.
- *Obstacles to greening growth are political and behavioral inertia and a lack of financing instruments*—not the cost of green policies as commonly thought.
- *Green growth should focus on what needs to be done in the next five to 10 years* to avoid getting locked into unsustainable paths and to generate immediate, local benefits.
- *The way forward requires a blend of economics, political science, and social psychology*—smart solutions to tackle political economy constraints, overcome deeply entrenched behaviors and social norms, and develop the needed financing tools.
- *There is no single green growth model.* Green growth strategies will vary across countries, reflecting local contexts and preferences—but all countries, rich and poor, have opportunities to make their growth greener and more inclusive without slowing it.

Literature review

Relative decoupling

- When the growth rate of the environmentally relevant variable is less than GDP growth for a given period (OECD, 2002).
  - $\dfrac{\text{Emissions/Energy use}}{\text{Output}} < 0$

Absolute decoupling

- Despite GDP growth, when the growth rate of the environmentally damaging variable is zero or negative (OECD, 2002).

Empirical strategy

Empirical strategy

Carbon emissions, Φ_t, are a product of the interactions of:

- the **state of the business cycle**, Y_t;
- **aggregate primary energy demand**
  - including both renewable and non-renewable sources, E_t;
- **population growth**, P_t;
- and the **number of employed workers**, L_t.

An extended **Kaya identity**:

$$\Phi_t \equiv \frac{Y_t}{L_t} \cdot \frac{E_t}{Y_t} \cdot \frac{\Phi_t}{E_t} \cdot \frac{L_t}{P_t} \cdot P_t$$

where

- Y_t/L_t: labor productivity;
- E_t/Y_t: energy intensity of output;
- Φ_t/E_t: emissions intensity of energy use;
- L_t/P_t: employment rate.

Empirical strategy

Technology plays a *key role* for both **relative** and **absolute** decoupling scenarios.

Decomposing energy intensity:

$$\frac{E_t}{Y_t} \equiv \frac{L_t}{Y_t} \cdot \frac{E_t}{L_t}$$

where

- E_t/L_t: energy-labor ratio

In growth rates:

$$\hat{\eta} \equiv \hat{\epsilon} - \hat{\xi}$$

whenever labor productivity growth ($\hat{\xi}$) is *faster* than the growth of the energy-labor ratio ($\hat{\epsilon}$), there is a **relative** decoupling between energy use and output ($\hat{\eta} < 0$).

Empirical strategy

Decomposing emissions intensity of energy use:

$$\frac{\Phi_t}{E_t} \equiv \frac{\Phi_t}{L_t} \cdot \frac{L_t}{E_t}$$

where

- Φ_t / L_t: emissions per worker

In growth rates:

$$\hat{\Phi} \equiv \hat{\mu} + \hat{Y} - \hat{\xi}$$

whenever labor productivity grows *faster* than the sum of the growth rates of emissions per worker ($\hat{\mu}$) and output ($\hat{Y}$), there is an **absolute** decoupling ($\hat{\Phi} < 0$).

Empirical strategy

- The green growth hypothesis claims that *technological progress* is the **main driver** of a possible absolute decoupling;
- Along with the *extended* Kaya identity, this view inspires the **identification** of VAR models;
- Technological progress $\Longrightarrow$ more efficient use of traditional energy sources and/or use of renewable sources $\Longrightarrow$ increasing employment in new industries $\Longrightarrow$ higher output/decreased emissions.

Empirical strategy

VAR identification:

Short-run causal ordering: $X_t \to E_t \to P_t \to Y_t \to \Phi_t$

Endogenous regressors vector: $\nu_t = (X_t, E_t, R_t, P_t, Y_t, \Phi_t)'$

Accounting for non-renewable (E_t) and renewable (R_t) energy use.

- A VAR(p) model:

$$A\nu_t = \alpha + \sum_{i=1}^{p} A_i \nu_{t-i} + u_t$$

- Reduced-form residuals

$$\varepsilon_t = A^{-1} u_t$$

$$\varepsilon_t \equiv \begin{bmatrix} \varepsilon_t^X \\ \varepsilon_t^E \\ \varepsilon_t^R \\ \varepsilon_t^P \\ \varepsilon_t^Y \\ \varepsilon_t^\Phi \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ a_{21} & 1 & 0 & 0 & 0 & 0 \\ a_{31} & a_{32} & 1 & 0 & 0 & 0 \\ a_{41} & a_{42} & a_{43} & 1 & 0 & 0 \\ a_{51} & a_{52} & a_{53} & a_{54} & 1 & 0 \\ a_{61} & a_{62} & a_{63} & a_{64} & a_{65} & 1 \end{bmatrix} \begin{bmatrix} u_t^{\mathrm{X}} \\ u_t^{\mathrm{E}} \\ u_t^{\mathrm{R}} \\ u_t^{\mathrm{P}} \\ u_t^{\mathrm{Y}} \\ u_t^\Phi \end{bmatrix}$$

Empirical strategy

Two recursive VAR estimation methodologies:

- A **single-step** procedure:
  - Directly computing the response of emissions to **all** structural shocks, estimating a 6-variable VAR.
- A **two-step** procedure:
  - Estimating a first-step VAR **without** emissions, retrieving its residuals (shocks);
  - In a *second step*, computing the response of emissions to these structural shocks.
  - Why **two steps**? To avoid potential *endogenous interactions* between emissions and the other variables, possibly affecting the impulse-response analysis.

Data

Data

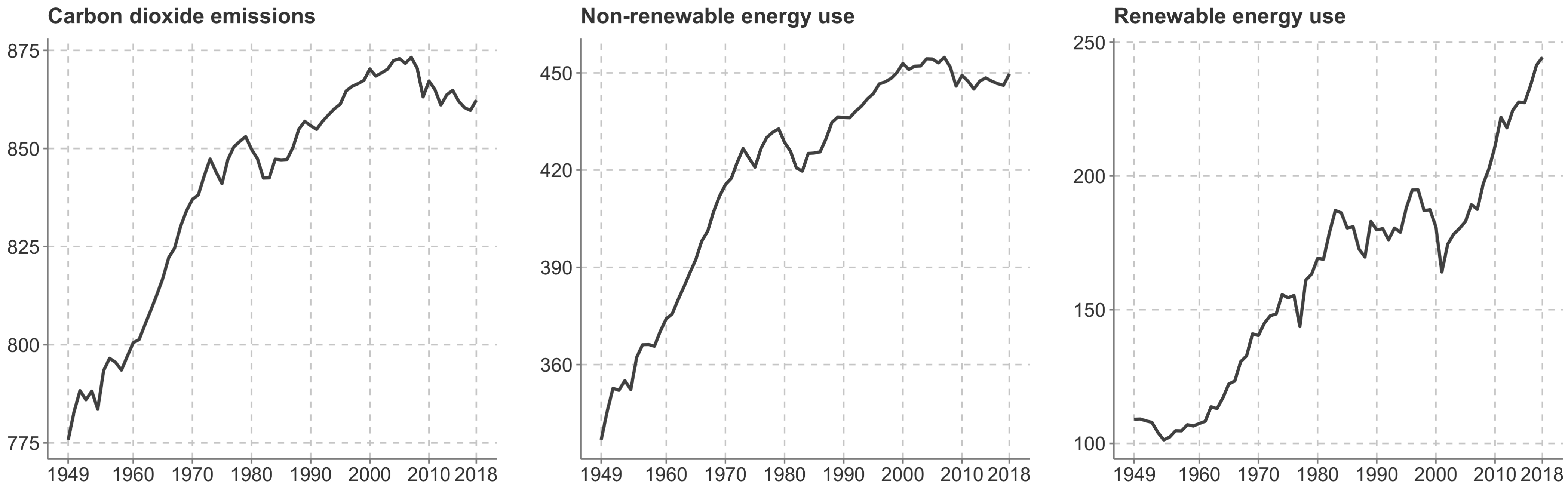
- **Sample period**: 1949—2018

Data

Variables:

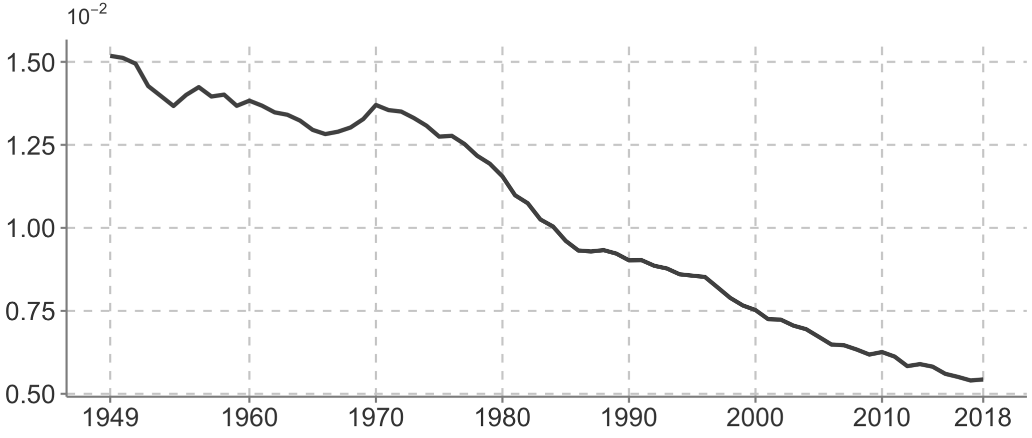
- Aggregate carbon dioxide emissions (US EIA) — million metric tons of carbon dioxide;
- Aggregate primary energy use (quadrillion Btu):
  - Non-renewable energy use (US EIA) - fossil fuels, nuclear energy;
  - Renewable energy use (US EIA) - hydroelectric, geothermal, wind, solar, and biomass.
- Employment-to-population ratio (FRED) — %;
- Real GDP (FRED) — billions of chained 2012 dollars;
- Technology variables:
  - labor productivity (output per hour, business sector, FRED) — baseline;
  - aggregate capital stock (1950—2017, PWT) — millions of 2011 US dollars;
  - total factor productivity (1954—2017, PWT) — 2011=1.

Data

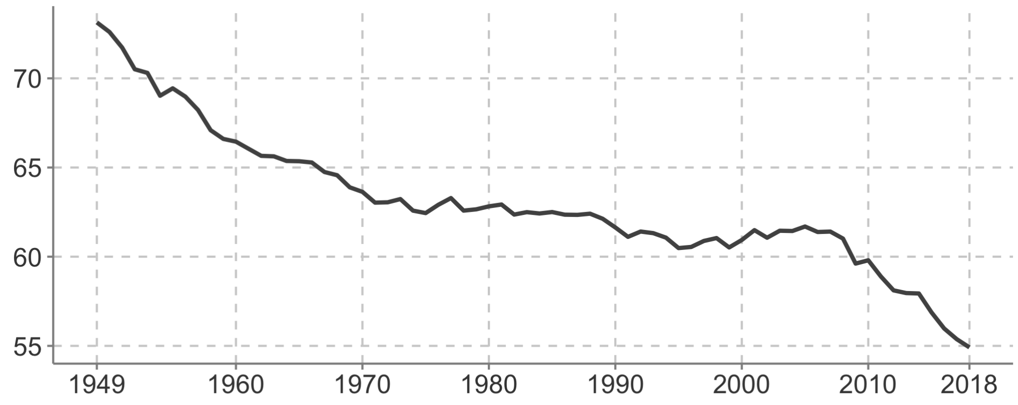

Carbon dioxide emissions
875
850
825
800
775
1949
1960
1970
1980
1990
2000
2010
2018
Non-renewable energy use
450
420
390
360
1949
1960
1970
1980
1990
2000
2010
2018
Renewable energy use
250
200
150
100
1949
1960
1970
1980
1990
2000
2010
2018

Data

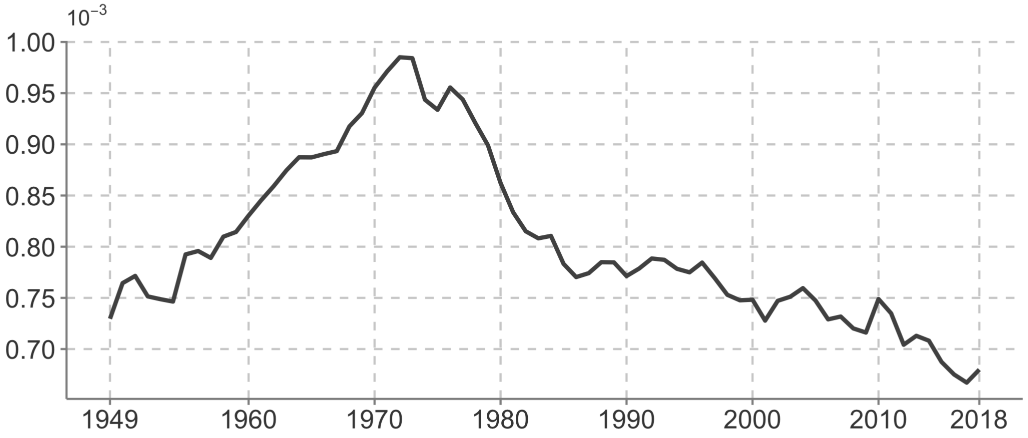
Energy intensity



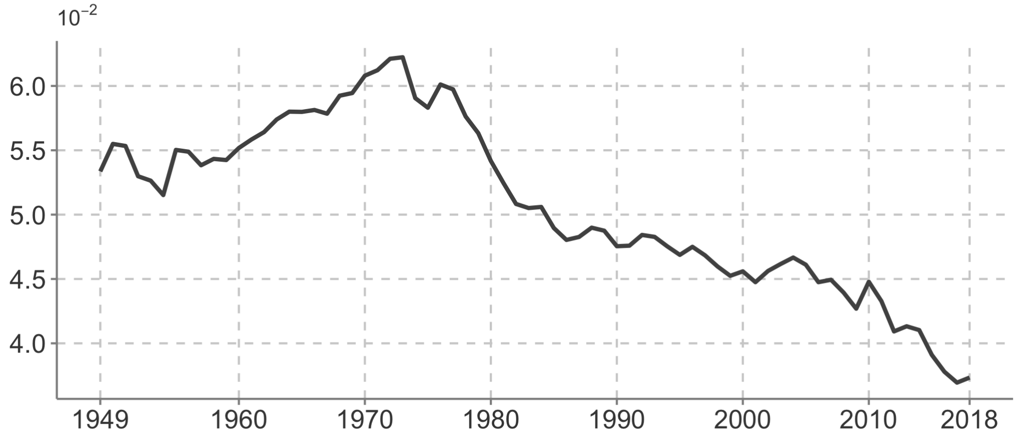
Emissions intensity of energy use



Energy-labor ratio



Emissions per worker



Results

Baseline VAR models:

- Single-step VAR: estimated *in levels*
  - 3 lags
  - no serial correlation nor heteroskedasticity;
- Two-step VAR: estimated *in levels*
  - 4 lags
  - no serial correlation nor heteroskedasticity;
- Labor productivity as the technology variable.

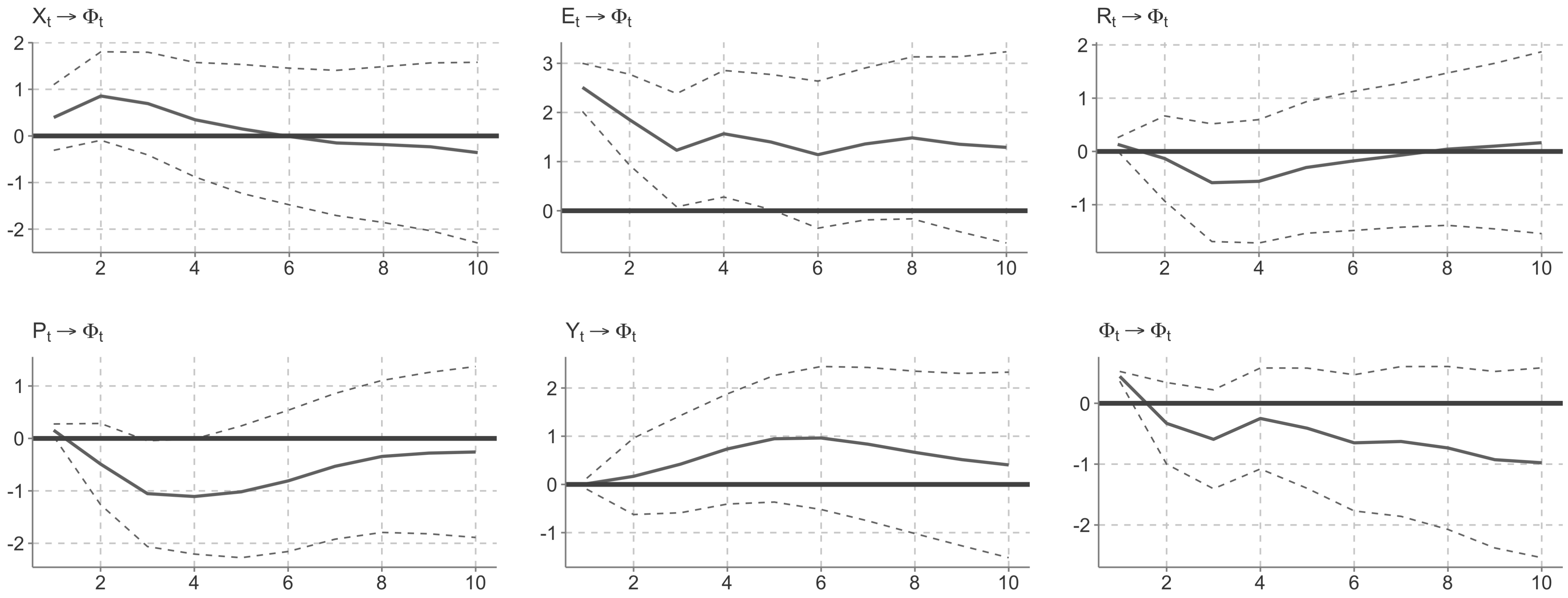
Robustness checks:

- Single and two-step VAR models
  - in *first-differences* and
  - with data *de-trended* with the HP filter;
- Models with two different technology *proxy* variables:
  - aggregate capital stock and
  - total factor productivity (TFP).

Results

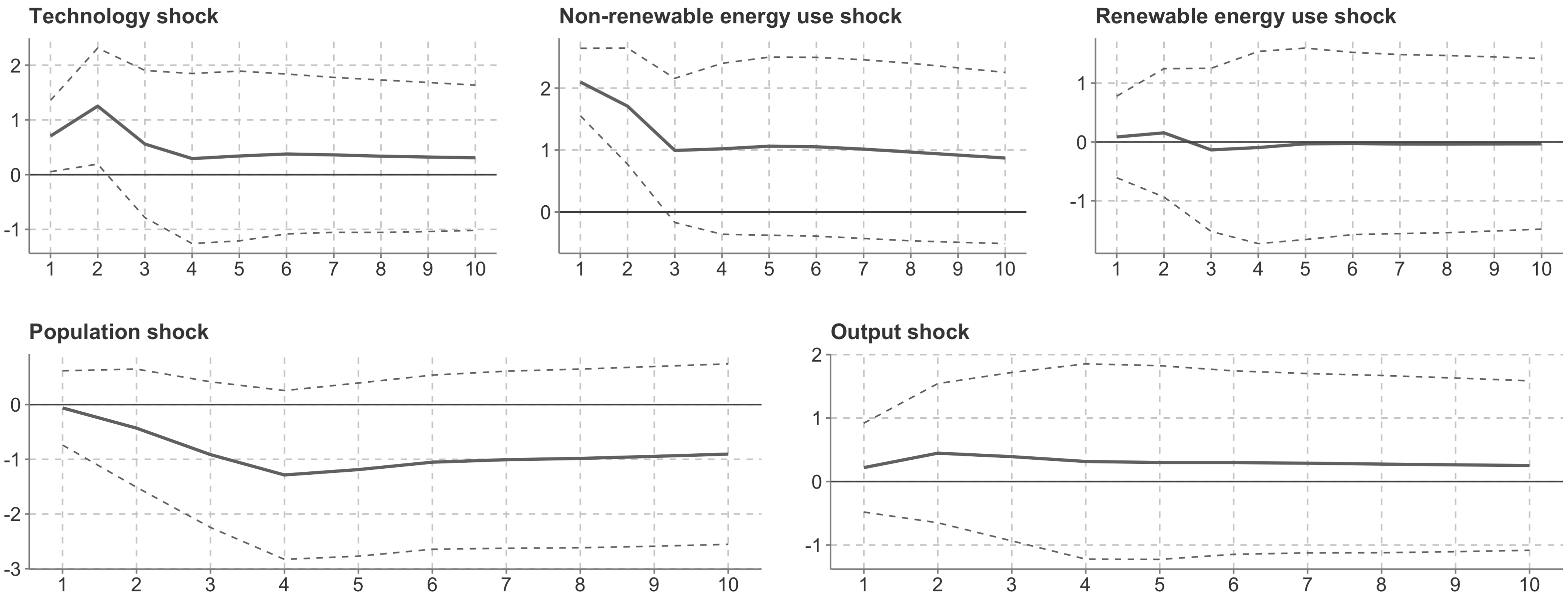
Results

- Single-step VAR (only carbon dioxide responses):



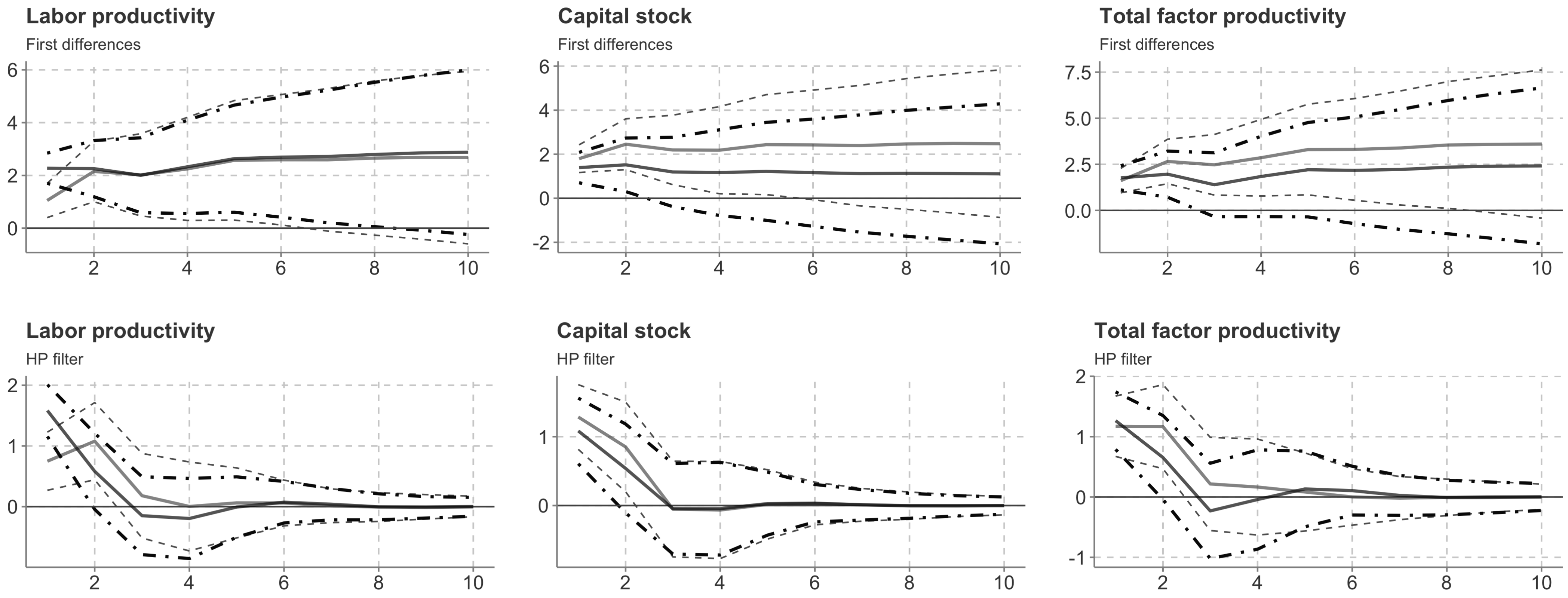
Results

- Two-step VAR (only carbon dioxide responses):



Results

- Robustness checks for two-step VAR (non-renewable energy shock - black; technology shock - gray):



Conclusions

Conclusions

- Most of the estimated models compute both **non-renewable** and **technology** shocks significantly affecting carbon dioxide emissions over the short-run for the US economy;
- While the baseline single-step procedure only predicts a non-renewable energy shock as statistically significant, the two-step baseline model includes the **technology** shock as significant;
- Despite the historical positive growth rates of both labor and energy productivity, the US economy's historical growth path has neither been translated into a **decreased** use of "dirty" energy sources, nor into a significant use of **renewable** energy sources;
- In addition to these results, key **decoupling** variables have shown weak growth paths over the sample period. Energy intensity, output intensity of energy use, emissions per worker, and the energy-labor ratio levels are **far** from those observed by countries experiencing absolute decoupling, such as France, Italy, and the United Kingdom.

Thank you!