Energy intensity and structural changes: does offshoring matter?

Claudia Amadei[1], Cesare Dosi[1], Francesco Jacopo Pintus[2]
[1] Department of Economics and Management, University of Padova and CRIEP
[2] Department of Economics, Ca' Foscari University of Venice and CRIEP
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Outline

- Motivation
- Related Literature
- Empirical Strategy and Results
- Final Remarks

Motivation (I)

Energy intensity as a driver of decarbonization...

The Role of Energy Intensity in Global Decarbonization Efforts: How Fast? Is it Possible?

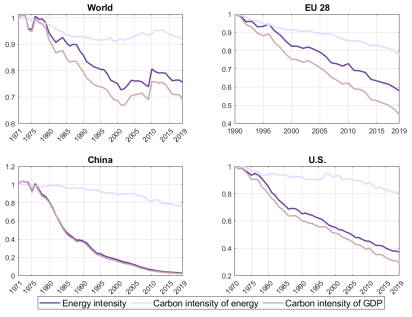
Clean Air Task Force Research Note, March 2, 2015
By Jesse D. Jenkins & Armond M. Cohen

CLEAN AIR TASK FORCE

Motivation (II)

Carbon Intensity of GDP.

$$\frac{C_{it}}{Y_{it}} = \frac{C_{it}}{E_{it}} \cdot \frac{E_{it}}{Y_{it}}$$



Motivation (III)

- Which are the **drivers** of the energy intensity change? (Metcalf, 2008[1])
  - **Structural effects** → changes in the **production structure** of an economy
  - **Sectoral effects** → improvements in **within-sector energy efficiency**
- One could question whether the changes in the production structure have been matched by changes in the consumption patterns of the economy → Exploit the **divergence between CB and PB emissions**

Motivation (IV)

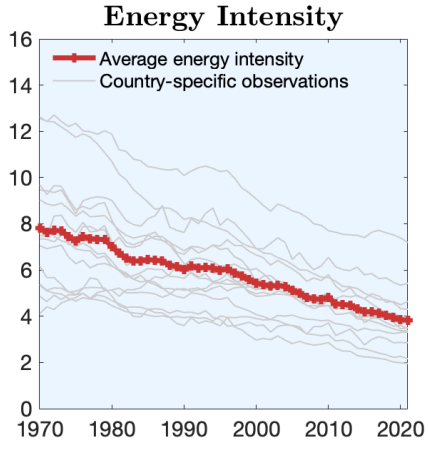
Two ways to look at emissions (OECD, 2016[2]):

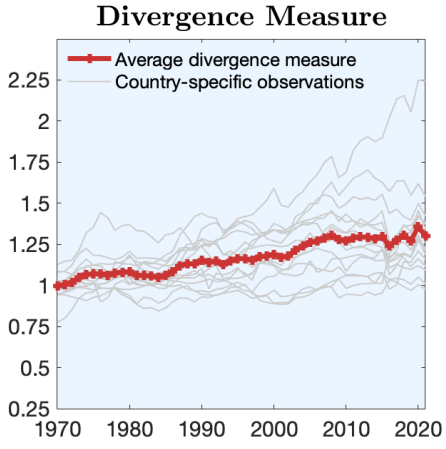
- **Production-based** (PB) emissions → total emissions associated with production
- **Consumption-based** (CB) emissions → total emissions associated with final demand

The two measures coincide at the global level... But can diverge at national level!
If a developed country imports carbon-intensive productions from emerging economies, there might be consequences in terms of:

- Global **emissions**
- Inferences on **emissions decoupling and decarbonization** processes

Energy Intensity and the Dispersion between CB and PB emissions





Research Question and Empirical Strategy

- Can a **change in the structure of production that is not exactly mirrored by demand** lead to an improved nation-wide energy efficiency? → Two-fold empirical strategy:
  - **IDA** of changes in energy intensity, which includes also an offshoring factor
  - Exploit the divergence between CB and PB emissions, net of changes in total final consumption (proxy for *demand-invariant structural changes*), and track its dynamic effect on national energy intensities of developed economies through a **Panel SVAR** analysis
- Do national energy efficiency improvements imply **decarbonization** also at a global level?

Related Literature (I)

Policy implications in line with:

- Quasi-natural experiments to study the relationship between **international trade/negotiations and emissions** (Aichele and Felbermayr, 2015[3], Liu et al., 2016[4], Naegele and Zaklan, 2019[5])
  - Global or partial equilibria models to assess the effects of international trade or climate agreements on emissions embodies in trade
- Use of **CB and PB emissions' accounting methodologies** (Cohen et al. 2018[6], Bhattacharya et al. 2020[7])
  - Effects of considering different approaches to measuring emissions (on decoupling elasticities and carbon intensity convergence clubs)

Our contribution: Feed in the debate on the link between international trade and the inferences on decarbonization contribution of developed economies

Related Literature (II)

Methodologies employed:

- **IDA** of **Energy Intensity of GDP** (Zhang, 2003[8], Fisher-Vanden et al., 2004[9], Alcantara and Duarte, 2004[10], Ma and Stern, 2008[11], Sue Wing, 2008[12], Metcalf, 2008[1], Zhao et al., 2010[13]; Wu, 2012[14], Voigt et al., 2014[15], Hardt et al., 2018[16])
  - *Our contribution*: Adaptation of Hardt et al.'s methodology to a novel setting
- **Dynamic analyses** of emissions and their drivers (Ajmi et al., 2015[17], Mohapatra et al., 2016[18], Fan et al., 2021[19])
  - *Our contribution*: Assess the dynamic relationship between demand-invariant structural changes and energy intensity, using a novel instrument based on emissions divergence

Data and sample selection

- Data for **15 OECD countries**
  - DEU, USA, ITA, GBR, NZL, ESP, BEL, CAN, FIN, FRA, NOR, JPN, NLD, SWE, DNK
- **Time window**
  - 1970-2021
- Total Energy Supply (national and global level, sectoral disaggregation)
  - **IEA** World Energy Balances 2021
- CB and PB emission accounts
  - **World MRIO** Carbon Footprint of Nations 2021
- GDP and final consumption (National and global, and sectoral disaggregation)
  - **UN Stats** 2024 (GDP and total value added by sectors)
  - **OECD** (final consumption)
  - **OECD World I-O** database 2024

IDA - Two tiers of decomposition

Energy Intensity of GDP - baseline decomposition.

$$e_t = \frac{E_t}{Y_t} = \sum_i \frac{E_{it}}{Y_{it}} \cdot \frac{Y_{it}}{Y_t}$$

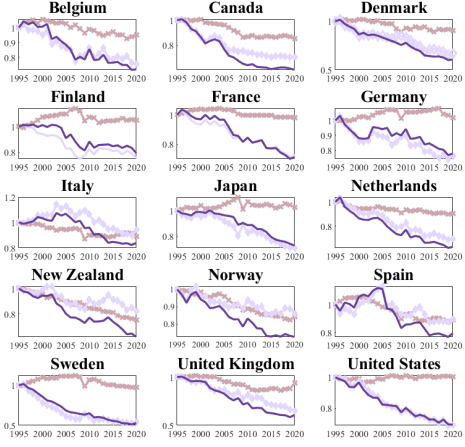
- **Fisher Ideal Index** decomposition: sample countries (1995-2020)

Structural effect - offshoring.

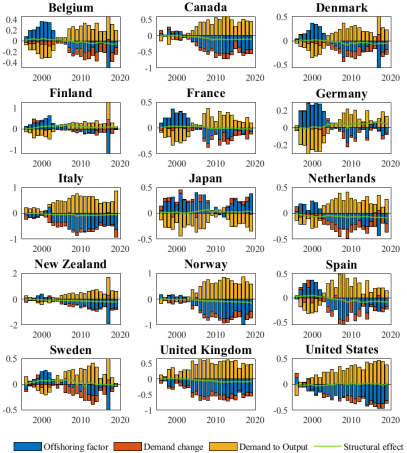
$$\frac{Y_{it}}{Y_t} = \sum_i \left(\frac{Y_{it}}{XG_{it}}\right)\left(\frac{XG_{it}}{X_t}\right)\left(\frac{X_t}{Y_t}\right)$$

- **Fisher Ideal Index** decomposition: sample countries (1996-2019)

IDA - Baseline Results



IDA - Offshoring factor results



The role of structural changes for the reduction of energy intensity: does offshoring matter?

Bayesian Panel SVAR: objective and specification

- **Objective**: Investigate the effect on the energy intensity evolution of structural shocks that are not mirrored by the demand in 15 OECD countries
- We estimate an annual Bayesian panel structural VAR whose reduced form reads as:

$$\boldsymbol{Y}_{i,t} = \boldsymbol{\alpha}_i + \boldsymbol{\theta_t} + \sum_{l=1}^{L} \boldsymbol{A}_{i,l} \boldsymbol{Y}_{i,t-l} + \boldsymbol{\epsilon}_{i,t}, \tag{1}$$

  where α_i are country fixed effects capturing heterogeneity (e.g., institutional features) and $\boldsymbol{\theta_t}$ are time-fixed effects. Reduced form disturbances are stationary $\boldsymbol{\epsilon}_{i,t}(0, \Sigma_i)$

- The structural change in the economy is proxied with a shock in the divergence (γ_t) between consumption-based (C_t^c) and production-based (C_t^p) emissions:

$$\gamma_t = \frac{C_t^c}{C_t^p} \tag{2}$$

Bayesian Panel SVAR: estimation

- $\boldsymbol{Y}_{it} = [d_{i,t}, \gamma_{i,t}, se_{i,t}, ind_{i,t}, ser_{i,t}, ei_{i,t}]'$
- The idea is to include the factors explaining the **structural effect** on energy intensity (VA of industry and service sector) and **sectoral effect** (energy intensity of the industry)
- The model is **estimated** using Bayesian techniques (Inverse Wishart prior as in Banbùra et al., 2010[20]) and assuming:
  - *Cross-sectional dynamic homogeneity* ($\boldsymbol{A_{i,l}} = A_l \ \forall \ i$) $\Rightarrow$ due to data availability we relax it doing sub-sample estimations
  - $\epsilon_{i,t}$ are serially and cross-sectionally uncorrelated $\Rightarrow$ the second is too strong since spillovers are not negligible. In the spirit of the GVAR (Pesaran et al., 2004[21]) we add a global exogenous regressor to account for spillovers (World Industrial Production)

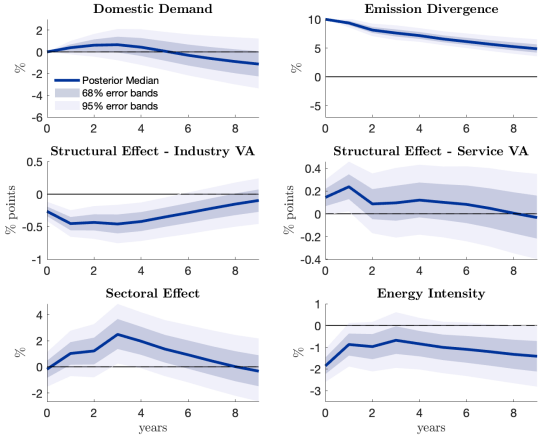
Panel SVAR - Structural Shock Identification

- **Main idea**: shocks in the dispersion measure simulate structural shocks in the economy
- However, we want to capture only those structural shocks which are not mirrored by similar variations in the demand
- We identify the structural shocks $\varepsilon_{i,t}$ imposing a block-triangular Cholesky factorization of the variance-covariance matrix Ω of the reduced form residuals, such that:

$$\boldsymbol{\varepsilon_t} = \boldsymbol{\Omega \epsilon_t} \quad \text{where} \quad \boldsymbol{\Sigma} = \boldsymbol{\Omega \Omega'}, \tag{3}$$

- To ensure the demand-invariant nature of the shock, the domestic demand is order first in the recursive specification, allowing the latter to be predicted only by the lags of the rest of the variables in the VAR
- On impact, the shock in the dispersion measure is therefore *demand-invariant* by construction

Structural IRFs to a 10 % shock in the emission dispersion measure



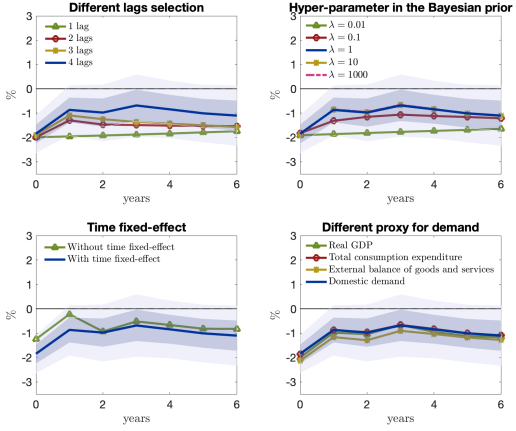
Results: Structural IRFs from the Bayesian Panel VAR

1. The shock in the emission dispersion measure efficiently produces a **structural change** in the economy: an increase in $\gamma_{i,t}$ induces a significant reduction in the VA of the industry sector in favor of an increase in the service VA
2. The shock is **demand invariant**, on impact the response of the demand is 0 but also over a business cycle horizon no significant changes in the demand are shown
3. The **sectoral component** displays an increase in the energy intensity of the industry sector, mainly imputable to the decrease in the denominator (Industry VA)
4. The produced shock is find to **significantly decrease the total energy intensity** by almost 2% on impact and the observed reduction is persistent over time

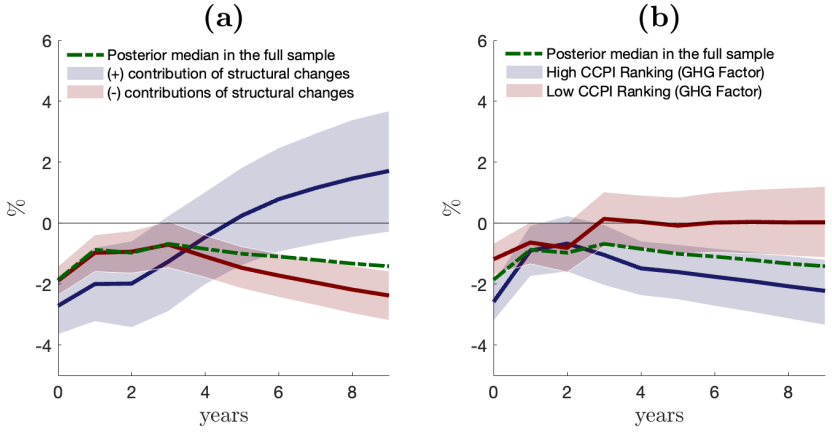
Results: Policy Implications

- Energy intensity reductions may be associated with (and induced by) structural changes which are not mirrored by the domestic demand
- What is the impact of these changes to global decarbonization? Uncertain! Indeed, $\gamma_{i,t}$ may increase if:
  1. CB emissions increase and PB emissions are fixed (negative impact, higher global emissions)
  2. CB and PB emissions both increase but CB emissions increase more (negative impact, higher global emissions)
  3. CB emissions increase and PB emission decrease (it depends on the net effect)
  4. both CB and PB emissions decrease with the former decreasing less than the latter (positive impact, lower global emissions)

Robustness checks



Subsample estimation - does offshoring matter?



Final Remarks and Discussion

- **Results**
  - **IDA → negative contribution of offshoring** to energy intensity dynamics in the majority of the sample OECD economies, while aggregated structural effects did not play much of a role
  - **Panel SVAR → negative and persistent role of structural changes that are not mirrored by changes in demand** in explaining energy intensity dynamics of the sample economies

- Observed **reductions in the national energy intensities** of developed economies **may not imply a contribution to global decarbonization**

- Need to **complement CB and PB emissions** accounting systems and account for potential role of **offshoring** when designing climate policies and targets

- *For future research*: disentangle carbon-related effects from *pure* demand VS output effects in the divergence measure

Thank you for the attention!

Claudia Amadei: claudia.amadei@unipd.it

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