Air Pollution and the Macroeconomy across European Countries

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  – Jorgenson and Wilcoxen (*REE*, 1993)

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- Report facts on the evolution of air pollution conditioning on its initial level

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  – Growth rate of emissions should be viewed jointly with the initial emissions levels (Finland vs. France, ...)

	Real GDP pc			NO_2 pc			CO_2 pc			SO_2 pc		
	1990	2000	γ	1990	2000	γ	1990	2000	γ	1990	2000	γ
De	21.81	26.61	2.2	5.51	3.90	-2.9	11.06	10.83	-0.2	3.44	0.54	-8.4
Sw	20.79	23.64	1.4	3.78	2.82	-2.5	6.36	6.21	-0.2	1.24	0.62	**-5.0**
Fi	20.27	23.79	1.7	6.02	4.56	-2.4	10.73	9.90	-0.8	5.21	1.43	-7.3
Fr	20.02	22.36	**1.2**	3.27	2.37	-2.8	6.45	6.80	0.6	2.29	1.04	-5.5
Be	19.88	23.78	2.0	3.35	3.21	-0.4	12.47	14.08	1.3	3.63	1.61	-5.6
Au	19.81	23.68	2.0	2.75	2.34	-1.5	7.22	8.04	1.1	1.04	0.43	-5.8
Ge	19.56	22.86	1.7	3.58	1.99	**-4.4**	12.54	10.26	-1.8	6.71	0.77	**-8.8**
Ne	19.48	24.31	**2.5**	3.87	2.66	-3.1	14.14	15.66	1.1	1.28	0.48	-6.2
It	19.31	21.78	1.3	3.38	2.36	-3.0	7.32	7.78	0.6	3.08	1.30	-5.8
UK	18.32	22.19	2.1	4.81	2.88	-4.0	10.43	9.29	-1.1	6.46	1.99	-6.9
m_{EU10}	19.92	23.50	1.8	4.03	2.91	-2.7	9.87	9.88	0.1	3.44	1.02	-6.5
σ_{EU10}	0.92	1.37	0.43	1.06	0.79	1.15	2.83	3.04	1.05	2.10	0.54	1.30
Sp	14.48	18.05	2.5	3.10	3.34	0.8	5.83	7.95	3.6	5.40	3.73	-3.1
Ir	14.16	26.38	8.6	3.37	3.30	-0.2	7.38	10.68	4.5	5.31	3.46	-3.5
Po	12.31	15.92	2.9	2.24	2.48	1.1	4.48	6.42	4.3	2.31	2.20	-0.5
Gr	11.97	14.61	2.2	2.85	3.04	0.7	8.02	9.60	2.0	4.85	4.57	-0.6
m_{EU14}	18.01	22.14	2.4	3.71	2.95	-1.8	8.89	9.54	1.1	3.73	1.73	-5.2
σ_{EU14}	3.29	3.57	1.85	1.06	0.69	1.83	2.95	2.75	1.96	1.95	1.33	2.54
Cze	13.59	13.67	0.1	5.25	3.12	-4.0	12.16	10.49	-1.4	18.15	2.57	-8.6
Sle	13.05	15.74	2.1	3.15	2.92	-0.7	6.76	8.01	1.9	9.81	4.98	-4.9
Sla	11.98	11.41	-0.5	4.09	1.98	-5.2	8.14	6.93	-1.5	10.26	2.30	-7.8
Hun	9.60	10.44	0.9	2.30	1.85	-2.0	6.51	5.48	-1.6	9.74	4.85	-5.0
Pol	6.60	9.22	4.0	3.36	2.17	-3.5	8.59	7.48	-1.3	8.42	3.91	-5.4
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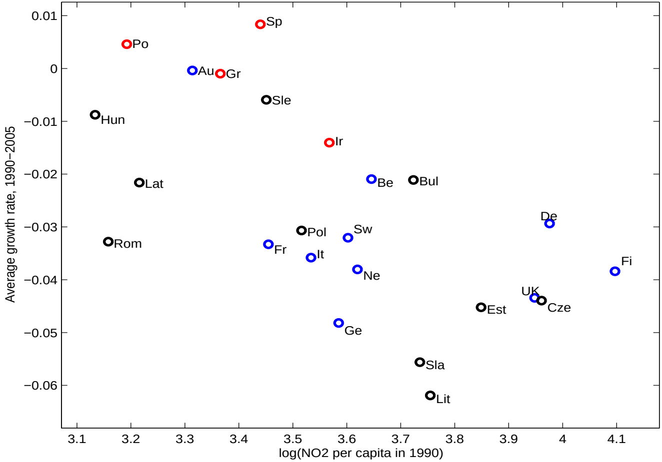
- (Evaluate the evolution of emissions in terms of the targets signed in 2000 for 2010)

Evidence EU



NO_2 emissions per capita in Europe. EU27:1990-2005

EU27 - Lux, Mal, Cyp; **Data:** IEA & EUROSTAT

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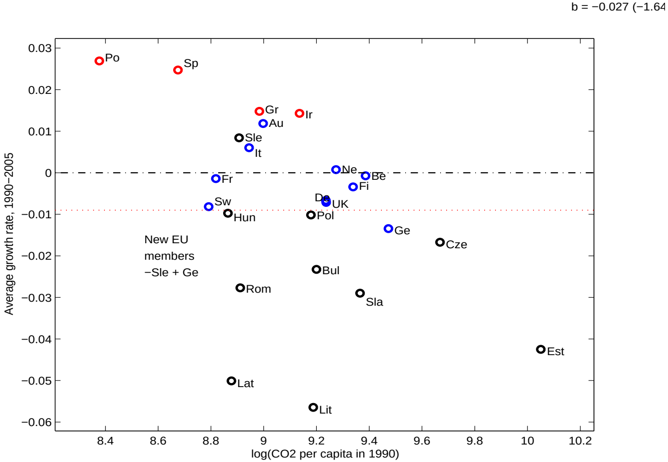

CO_2 emissions per capita in Europe. EU19: 1990-2005

EU27 - Lux, Mal, Cyp; **Data:** IEA & EUROSTAT

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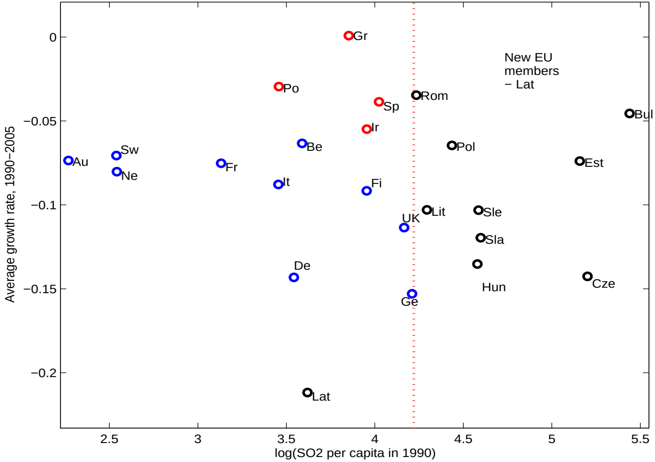

SO_2 emissions per capita in Europe. EU19: 1990-2005

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- Some countries exhibit larger reductions in air pollution intensity than other starting in a more favorable situation
- The macroeconomy can contribute to explaining the observed heterogeneity across countries and pollutants

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  Extra carbon in atmosphere has an output cost rather than a productivity cost (again, two countries, same productive capital, different emissions vs $\tilde{\eta}(\eta)$;
  and a bit of measurement). More below

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  [cf. Díaz & Puch (*RED*, 04), Boucekkine, Díaz & Puch (stand by, 08)]
- $p(t)$ may still fall as a consequence of technology improvements in emission process, $\tilde{B}(t) = \tilde{B}_0 e^{-x_b t}$, $x_b > 0$

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- Represented by an instantaneous CRRA utility function

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- Separable case: identification of structural parameters from the coeff. characterizing the local dynamics

OG with pollution
Baseline Model

The **competitive equilibrium** for an optimal growth economy with pollution can be derived from the solution to the following **problem**

$$\max_{\{C(t)\}_{t=0}^{\infty}} \int_0^{\infty} \mathrm{e}^{-\rho t} U\left[C(t), h\left(\bar{Z}(t)\right)\right] N(t)\ \mathrm{d}t$$

subject to

$$\dot{K}(t) = \varsigma Y(t) - (\delta + n) K(t) - C(t) \quad \varsigma \simeq \tilde{\eta}(\eta)$$

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given $K(0) = K_0$, $\bar{Z}(0) = \bar{Z}_0$ and with discount factor $\rho \geq n$

Optimality Conditions

If we restrict to $F[k] = A_0 k^{\alpha}$ and $G[z,k] = Bz^{\phi}k^{\theta}$, with $\theta = \alpha(1-\phi)$, and

$$U(C,\bar{Z}) = \frac{\left(C^{\nu}h(\bar{Z})^{1-\nu}\right)^{1-\sigma} - 1}{1-\sigma}, \ \sigma > 0, \ \nu \in [0,1]$$

$$\begin{aligned}
\frac{\dot{c}}{c} &= \frac{1}{\tilde{\sigma}}\left(\varsigma \alpha A_0 k^{\alpha-1} - [\rho + \delta + x\tilde{\sigma}] - (1-\sigma)(1-\nu)\varepsilon\left(x + n + \frac{\dot{z}}{z}\right)\right) \\
\frac{\dot{k}}{k} &= \varsigma A_0 k^{\alpha-1} - \frac{c}{k} - [\delta + n + x], \\
\frac{\dot{z}}{z} &= \eta B z^{\phi-1} k^{\alpha(1-\phi)} - (\delta_z + x + n),
\end{aligned}$$

with $\tilde{\sigma} = 1 - \nu(1-\sigma)$ and $B = \tilde{B}_0 e^{-x_b t} A_0^{(1-\phi)}$

Balanced Growth Path

A steady state is defined by $\dot{c}(t) = \dot{k}(t) = 0$, so that k_s and c_s are given by

$$k_s = \left(\frac{\varsigma \alpha A_0}{[\rho + \delta + x\tilde{\sigma}] + (1-\sigma)(1-\nu)\varepsilon\left(x + n - x_b/(1-\phi)\right)} \right)^{1/1-\alpha},$$

$$c_s = \varsigma A_0 k_s^{\alpha} - (\delta + n + x)\, k_s.$$

Assuming decreasing $\tilde{B}$, then $\tilde{z}(t) = z(t)\ \mathrm{e}^{(x_b/(1-\phi))}$ is constant along the BGP

$$\tilde{z}_s = \left(\frac{B_0 \eta}{\delta_z + x + n - x_b/(1-\phi)} \right)^{1/(1-\phi)} k_s^{\alpha},$$

(BGP cont.) so that the per capita pollution-output ratio decreases at $x_b/(1-\phi)$ and is given by

$$P(t)/Y(t) = B_1 B_0^{1/(1-\phi)} e^{-(x_b/(1-\phi))t},$$

where $B_1 = \left(\frac{\eta}{\delta_z + x + n - x^b/(1-\phi)}\right)^{\phi/(1-\phi)}$
Further, the degree of dirtiness along the bgp of the pollution technology is given by,

$$\left(\frac{z_s}{y_s}\right)^{\phi} = A^{-\phi}\left(\frac{B\eta}{\delta_z + x + n}\right)^{\phi/(1-\phi)} (k_s)^{\frac{\phi(\theta-\alpha(1-\phi))}{(1-\phi)}}.$$

The pollution/output ratio along the bgp is constant and equal to:

$$p_s/y_s = BA^{(\theta-\alpha(1-\phi)-\phi)}\left(\frac{B\eta}{\delta_z + x + n)}\right)^{\phi/(1-\phi)} (k_s)^{\frac{(\theta-\alpha(1-\phi))}{(1-\phi)}},$$

Empirical Implications
local to steady state

The empirical model is derived from log-linear approximation around the steady state. For the separable case:

$$\begin{pmatrix} \log k(t) - \log k_s \\ \log \tilde{z}(t) - \log \tilde{z}_s \end{pmatrix} = \begin{pmatrix} e^{-\beta t} & 0 \\ \frac{\beta_{zk}}{\beta - \beta_{zz}} \left(e^{-\beta_{zz} t} - e^{-\beta t} \right) & e^{-\beta_{zz} t} \end{pmatrix} \begin{pmatrix} \log k(0) - \log k_s \\ \log \tilde{z}(0) - \log \tilde{z}_s \end{pmatrix}$$

together with the definition of the technologies, imply

$$\begin{aligned} \log y(t) - \log y_s &= (\log y(0) - \log y_s)\ \mathrm{e}^{-\beta t} \quad \text{and} \\ \log \tilde{p}(t) - \log \tilde{p}_s &= (\log \tilde{p}(0) - \log \tilde{p}_s)\, e^{-\beta_{zz} t} + \lambda (\log y(0) - \log y_s) \left(e^{-\beta t} - e^{-\beta_{zz} t} \right), \end{aligned}$$

Consequently,

$$\log \tilde{p}(t) - \log \tilde{p}(0) = \left(\log \tilde{p}(0) - \log \tilde{p}_s - \lambda\left(\log y(0) - \log y_s\right)\right)\left(e^{-\beta_{zz}t} - 1\right) + \lambda\left(\log y(t) - \log y(0)\right)$$

where λ is a nightmare, but jointly with β_{zz} may allow for identification of ϕ and δ_z

The emissions growth equation (in discrete time, the unit of time is a year):

$$\begin{aligned} GP_{i,t} &= x(1-\lambda) - x_b/(1-\phi) + \left[\left(1 - e^{-\beta_{zz}T}\right)/T\right](\tilde{p}_s - \lambda y_s) \\ &- \left[\left(1 - e^{-\beta_{zz}T}\right)/T\right]\log P_{i,t-T} + \lambda\left[\left(1 - e^{-\beta_{zz}T}\right)/T\right]\log Y_{i,t-T} + \lambda GY_{i,t}, \end{aligned}$$

where $GP_{i,t} = \frac{1}{T}\log(P_{i,t}/P_{i,t-T})$ and $GY_{i,t} = \frac{1}{T}\log(Y_{i,t}/Y_{i,t-T})$

- Where
$$\lambda = \left((1-\phi) + \frac{\beta_{zk}}{\beta_{zz}-\beta}\frac{\phi}{\alpha}\right).$$
- The model imposes restrictions between the coefficients of the regressors

Empirical Model

The **competitive equilibrium** of the model economy can be rewritten as

$$GP_{i,t} = \alpha - \beta \log P_{i,t-T} + \delta \log Y_{i,t-T} + \varphi GY_{i,t-T} + \varepsilon_{i,t}$$

where $\delta = \beta\varphi$

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- Cross section regression: T is sample length
  - Controlling for P_0 and Y_0, as well as average macroeconomic performance
  - Then, **analysis of residuals**: growing *clean* or *dirty*

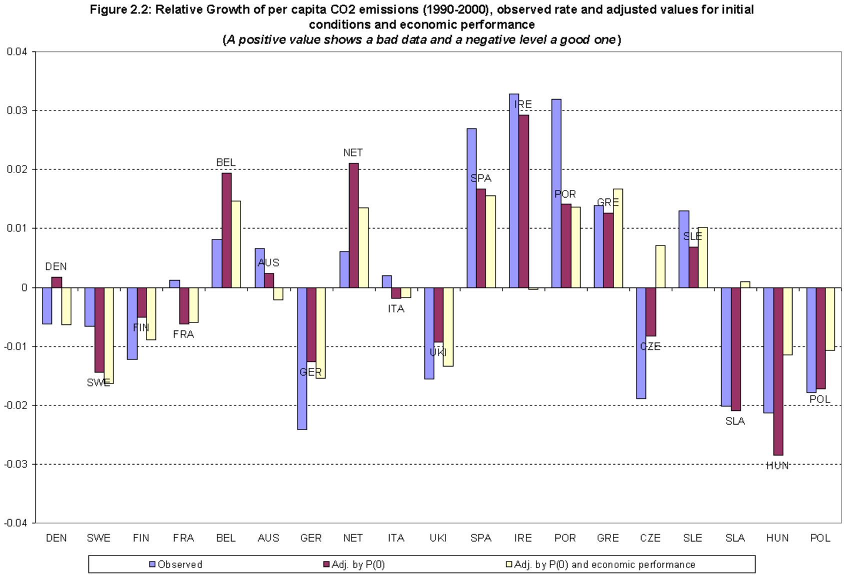
Figure 2.2: Relative Growth of per capita CO2 emissions (1990-2000), observed rate and adjusted values for initial conditions and economic performance
(A positive value shows a bad data and a negative level a good one)
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
DEN
SWE
FIN
FRA
BEL
AUS
GER
NET
ITA
UKI
SPA
IRE
POR
GRE
CZE
SLE
SLA
HUN
POL
Observed
Adj. by P(0)
Adj. by P(0) and economic performance

Dynamic Panel Data

- The following DPD model is implied:

$$\log P_{i,t} = \alpha_i + \eta_t + \lambda \log P_{i,t-1} + \delta \log Y_{i,t-1} + \varphi GY_{i,t} + \varepsilon_{i,t}$$

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  moment conditions under GMM estimates robustly supported

DPD estimations
Unrestricted, with fixed effects

- mild conditional convergence in CO_2

	OLS-POOL		WG-Fixed Effects		GMM-SYS	
	coef	p-val	coef	p-val	coef	p-val
CO2 – EU24						
Lag of emissions	**0.972**	0.000	**0.822**	0.000	**0.904**	0.000
Associated β	**0.028**		**0.178**		**0.096**	
GDP growth	**0.756**	0.000	**0.501**	0.000	**0.609**	0.000
Lag of GDP	**0.036**	0.000	**0.071**	0.040	**0.050**	0.006
Check $\delta = \beta \times \varphi$	0.021		0.089		0.058	
Haussman-test	–		33.39	0.000	–	
m1-test	–		–		-3.814	0.000
m2-test	–		–		-0.085	0.932

$p_{i,t} = \alpha_i + \eta_t + \lambda p_{i,t-1} + \delta y_{i,t-1} + \varphi g y_{i,t} + v_{i,t}$
Robust Standard Errors

DPD estimations

Unrestricted, with fixed effects

- mild conditional convergence in CO2
- GDP growth positively affect the level of emissions, GDP level does not (EKC rejected; convergence interacts with activity)

	OLS-POOL		WG-Fixed Effects		GMM-SYS	
	coef	p-val	coef	p-val	coef	p-val
CO2 – EU24						
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Robust Standard Errors

DPD estimations
Unrestricted, with fixed effects

- SO2 shows no evidence of convergence << NO2 < CO2

	SO2		NO2		CO2	
	coef	p-val	coef	p-val	coef	p-val
GMM – SYS						
Lag of emissions	**0.999**	0.000	**0.910**	0.000	**0.904**	0.000
Associated β	**0.001**		**0.090**		**0.096**	
GDP growth	0.222	0.426	**0.816**	0.000	**0.609**	0.000
Lag of GDP	0.002	0.898	0.024	0.277	**0.050**	0.006
Check $\delta = \beta \times \varphi$	0.000		0.074		0.058	
m1-test	-3.833	0.000	-3.502	0.000	-3.814	0.000
m2-test	0.554	0.569	-1.799	0.072	-0.085	0.932

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- GDP growth counts more for NO2

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Robust Standard Errors

DPD estimations

Unrestricted, with fixed effects

- SO2 shows no evidence of convergence << NO2 < CO2
- GDP growth counts more for NO2
- GDP level is not significant

	SO2		NO2		CO2	
	coef	p-val	coef	p-val	coef	p-val
GMM – SYS						
Lag of emissions	**0.999**	0.000	**0.910**	0.000	**0.904**	0.000
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Robust Standard Errors

DPD estimations
Energy variables

	SO2		NO2		CO2	
	coef	p-val	coef	p-val	coef	p-val
GMM – SYS						
Lag of emissions	**1.001**	0.000	**0.935**	0.000	**0.986**	0.000
Associated β	**-0.001**		**0.065**		**0.014**	
GDP growth	-0.286	0.132	**0.147**	0.075	0.022	0.677
Lag of GDP	**-0.058**	0.050	0.005	0.687	0.004	0.528
Check $\delta = \beta \times \varphi$	0.000		0.010		0.000	
Energy growth	**1.207**	0.000	**0.757**	0.000	**0.956**	0.000
Lag of Energy	0.076	0.160	-0.007	0.761	0.002	0.869
Change mix oil	-0.851	0.321	0.399	0.202	**-0.379**	0.038
Change mix gas	**-3.093**	0.010	-0.092	0.750	**-0.366**	0.052
Change mix nuclear	**-2.220**	0.008	**-0.780**	0.001	**-1.150**	0.000
Change mix renewable	**-2.556**	0.008	-0.150	0.615	**-1.218**	0.000

$p_{i,t} = \alpha_i + \eta_t + \lambda p_{i,t-1} + \delta y_{i,t-1} + \varphi g y_{i,t} + \theta_1 e_{i,t-1} + \theta_2 g e_{i,t} + \sum_{j=1}^{J} \mu_j m_{ji,t} + \nu_{i,t}$
White Heteroskedasticity-Consistent Standard Errors and Covariance

DPD estimations
Energy variables, different regions

	CO2 – EU10		CO2 – EU15		CO2 – EU24	
	coef	p-val	coef	p-val	coef	p-val
GMM – SYS						
Lag of emissions	**1.007**	0.000	**0.997**	0.000	**0.986**	0.000
Associated β	**-0.007**		**0.003**		**0.014**	
GDP growth	**0.207**	0.002	**0.127**	0.018	0.022	0.677
Lag of GDP	0.005	0.294	**0.008**	0.056	0.004	0.528
Check $\delta = \beta \times \varphi$	-0.001		0.000		0.000	
Energy growth	**0.836**	0.000	**0.842**	0.000	**0.956**	0.000
Lag of Energy	-0.010	0.172	-0.007	0.379	0.002	0.869
Change mix oil	**-1.745**	0.000	**0.899**	0.015	**-0.379**	0.038
Change mix gas	**-0.859**	0.000	**-0.450**	0.038	**-0.366**	0.052
Change mix nuclear	**-1.914**	0.000	**-1.638**	0.000	**-1.150**	0.000
Change mix renewable	**-1.769**	0.000	**-1.696**	0.000	**-1.218**	0.000

$p_{i,t} = \alpha_i + \eta_t + \lambda p_{i,t-1} + \delta y_{i,t-1} + \varphi g y_{i,t} + \theta_1 e_{i,t-1} + \theta_2 g e_{i,t} + \sum_{j=1}^{J} \mu_j m_{ji,t} + \nu_{i,t}$
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Concluding Remarks

- The evolution of emissions in the short-run is determined by initial levels (as a proxy for the state of the *pollution technology*)
  – once energy patterns: *i)* in NO2 remains, *ii)* in CO2 comes from Eastern

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- Under vigorous economic growth a slowdown in the reduction of emissions can be expected only in NO2
  – it is energy, not GDP
- Emissions of some pollutants corrected by macroeconomic performance shows mild compatibility with (descending branch of) EKC
- There is evidence of region-specific (descending branches of) EKCs (to be interpreted as adoption of abatement technologies and its diffusion) and the role of regulation (SO2)

Air Pollution and the Macroeconomy across European Countries

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