Patterns of cyclical fluctuations and decoupling: towards a common EU-28 environmental performance

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Highlights ?

- The fluctuation of CO_2 emissions in the EU-28 was examined during 1950-2012.
- The Dynamic factor model and recursive method were used in the analysis.
- We proposed a CO_2 emissions-GDP linkage matrix to identify patterns of environmental performance across Member States.
- We differentiated between eco-leader and eco-follower countries in the EU-28.
- Member States spread into different dissociation degrees of emissions from GDP.

Abstract:

The EU-28 is one of the largest emitters of CO_2 in the world that is more committed to reduce emissions. However, the national environmental strategies of the Member States still are diverse. This study aims to evaluate the environmental performance of the European economies by analysing the fluctuations of CO_2 emissions and their links with economic activity over the period 1950-2012. The modelling framework is based on the dynamic factor analysis to estimate in parametric form an index for the EU fluctuation of CO_2 emissions. This index can be used to monitor the progress towards a common behaviour across Member States with a time-varying recursive method. Following this approach, we also track the efforts made to decouple their CO_2 emissions from GDP. Based on these analyses we develop a CO_2 emissions-GDP linkage matrix to attain useful information on the environmental performance of EU Member.

Keywords: CO_2 emissions; Dynamic Factor model, Recursive, Cyclical environmental performance.

JEL codes: C38, E32, Q51

1. Introduction

As a world leader in taking action on climate change, the EU has made significant progress in the mitigation of CO_2 emissions attracting a great deal of attention. The EU commitment with climate change has been recently strengthened with the signing of the Paris Agreement (Council Decision 2016), which provides a binding target of at least a 40 % domestic reduction in greenhouse gas emissions by 2030, compared to the 1990 levels. Considering its important role in global CO_2 emissions, the EU has become a key target for the analysis of its progression.

Along its history, the EU has been increasing demands for environment regulations, which became a reality with the approval of the first Environmental Action Programme (EAP) in 1973. The EU´s Environmental Action Programs have set an incremental CO_2 common target, as shown in Table 1.

Table 1: EU Environment Action Programmes (EAP) on Climate Change

EAP Period covered	*Date approved*	*GHG Reductions Target*
1st EAP 1973 – 1976	22/11/1973	No Target
2nd EAP 1977 – 1981	17/05/1977	No Target
3th EAP 1982 – 1986	07/02/1983	No Target
4th EAP 1987 – 1992	19/10/1987	No Target
5th EAP 1993 – 2000	01/02/1993	The EC´s decision to stabilise CO_2 emissions at the 1990 levels by 2000.
6th EAP 2002 – 2012	22/07/2002	The EU-15 target is for an 8% reduction in emissions, compared to the 1990 levels.
7th EAP 2013 – 2020	20/11/2013	The EU-28 target is for a 20% reduction in emissions, compared to the 1990 levels.

Source: Adapted and updated from Pallemaerts 2009

These regulations have contributed to the progress in the EU´s environmental achievements. Accordingly, the report of European Environmental Agency (EEA, 2015) shows that Europe´s efforts to cut greenhouse gas emission and invest in energy efficiency and renewable energy has resulted in cutting GHG emissions by 23% between 1990 and 2014. This has been attained at the same time as the European economy grew by 46% over the same period.

Despite the interest aroused by the evaluation of the experience accumulated in the EU over time from environmental and energy policies, there are still not sufficient academic papers on the issue. Table 2 provides a summary of the recent published articles on the EU that can be framed in two of the key challenging area of research: (1) understanding the driving forces behind the changes in CO_2 emissions and decoupling and (2) assessment of environmental efficiency and convergence in terms of $CO_{2.}$

Another emerging area of research concentrates on the study of the business cycles effects on energy variables. A better understanding of carbon emission cyclical performance is needed to monitor environmental trends, to evaluate progress and to set up environmental targets. Table 3 provides a summary of the recent literature on this area, but it does not have yet applied works on the EU. The present research seeks to cover this gap and to expand the knowledge about the environmental behaviour of the EU. Thus, this study focuses on the evaluation of national and European cyclical performance by monitoring the fluctuations of CO_2 emissions and their links with economic activity over the period 1950-2012. With this aim, we use the dynamic factor model framework to estimate, in parametric form, the EU-28 co-fluctuation pattern in the per capita CO_2 emission. This model considers the dynamics of the common factor that can be used as an index for the EU-cyclical performance, contributing to the development of EU environmental indicators. From this index, we propose the use of a time-varying recursive method to assess the progress of each Member State towards the common pattern. Finally, we employ the same approach to track the efforts made to decouple their CO_2 emissions from GDP. This is the first study we are aware of that combines these issues.

Based on the previous analyses we develop a CO_2 emissions-GDP linkage matrix that combines information on possible outcomes from environmental strategies at EU and national levels. The EU and the Member States have launched environmental policies to mitigate CO_2 emissions and promote environmental efficiency. Although the member states have similar objectives, they differ considerably with regard to the scope of the policy that they advocate for and by the means they propose to execute them. Current EU policy up to 2020 (The European Parliament Council, 2013) fixes the dual responsibility of the EU institutions and national governments in the environment. Following these guidelines, in this paper we offer an innovative empirical approach that can be a useful tool to evaluate the features of CO_2 emissions performance across member states. These kind of results leads to environmental recommendations about which countries should make further adjustment to integrate their environmental national objectives with the European common targets and to increase efforts to decouple their emissions growth from economic cycle.

Table 2. Overview of recent empirical papers examining environmental performance in EU

Key area	Reference	Methodology	Period	Scope	Key findings
Driving forces (1)	*Bhattacharyya and Matsumura, 2010.*	*Log-mean Divisia index(LMDI) method*	*1990-2007*	*EU-15*	*Changes in the energy mix, in energy intensity and in the emissions intensity explain success in the EU-15. A scenario analysis is used to show the emission reduction possibilities through cross-learning.*
	Fernández et al., 2014.	*Log Mean Divisia Index (LMDI) method*	*2001-2008*	*EU-27*	*The EU-27 has adapted to more efficient techniques and technical change offsetting the joint pressures of economic and population growth.*
	Morales-Lage et al., 2016.	*The stochastic formulation of the IPAT model (STIRPAT)*	*1971-2012*	*EU-28*	*Differences in the influence of population, industry and energy use are found depending on the group of countries considered.*
	Moutinho et al., 2016.	*The Kaya Identify and LMDI (2) and VAR system,*	*1995-2000* *2001-2004* *2005-2007* *2008-2010*	*EU-15*	*The EU-15 has reduced emissions by adopting more efficient techniques, through innovation changes and higher quality energies, particularly observed during the first phase of the Kyoto protocol.*
	Diakoulaki and Madaraka, 2007.	*Refined Laspeyres Model and decoupling index.*	*1990–2003*	*EU-14*	*The decrease in industrial energy intensity and the shift towards cleaner energy forms in electricity generation are found to have the greatest beneficial impact on the decoupling process.*
Environmental efficiency and convergence (2)	*Robaina-Alves et al., 2015.*	*Sstochastic frontier approach using maximum entropy indicators*	*2000-2004* *2005-2011*	*UE-26*	*Evaluate eco-efficiency problem and identifies changes in the positioning of the Member States in the two periods studied.*
	Picazo-Tadeo et al., 2014.	*Data Envelopment Analysis (DEA), directional distance functions and Luenberger productivity indicators.*	*1990–2011*	*UE-28*	*Environmental performance has been boosted by environmental technical change rather than by increases in eco-efficiency.*
	Camarero et al., 2014.	*DEA techniques, directional distance functions and Phillips and Sull approach.*	*1990-2009*	*UE-27*	*Existence of different convergence clubs depending on the specific pollutant considered.*
	Jobert el al., 2010.	*The Bayesian shrinkage estimation method.*	*1971-2006*	*EU-22*	*Member States differ considerably in both their speed of convergence and volatility in emissions which makes possible to identify different groups of countries.*
	Herrerias, 2012.	*The distribution dynamics approach.*	*1920-2007*	*EU-25*	*Convergence is much faster when population and economic activity are introduced in the model.*

Source: Own elaboration

Table 3. Overview of recent empirical papers on business cycles and energy variables.

Reference	Methodology	Period	Scope	Key findings
Doda, 2014.	*The Hodrick-Prescott filter and correlation analysis.*	*1950-2011*	*122 countries*	*Emissions are procyclical and positively correlated with GDP pc*
York, 2012.	*Panel Data models with the Prais–Winsten correction for first-order autocorrelation*	*1960-2008*	*160 countries*	*Changes in GDP have effects on emissions: emissions grow faster during expansions than the rate at which they decline during expansions.*
Heutel, 2012.	*Dynamic stochastic general equilibrium real business cycle model*	*1981-2003*	*EE.UU.*	*The optimal emissions tax rate and the optimal emissions quota are both procyclical.*
Shahiduzzaman and Layton, 2015.	*IPAT identify framework*	*1949–2013*	*EE.UU*	*CO_2 emissions reduce much faster in contractions than they increase in expansions.*
Burke et al., 2015.	*Panel Data model*	*1961–2010*	*189 countries*	*No strong evidence that the emissions-income elasticity is larger during individual years of economic expansion as compared to recession.*
Sheldon 2017.	*Linear time series model Forecasting Models*	*1950-2010*	*EE.UU.*	*Emissions fall more sharply when GDP declines than they rise when GDP increases.*
Igwenagu, 2011.	*Correlation and Principal Component Analysis.*	*2006*	*50 countries*	*Strong correlation between CO_2 emissions and GDP.*
McKitrick and Wood, 2013.	*Correlation and Principal Component Analysis*	*1950-2000*	*132 countries*	*CO_2 emissions are linked between countries and energy markets act as an offsetting mechanism.*

Source: Own elaboration

2. Data and methodological approach

The analysis in this paper uses annual per capita emissions data over the interval 1950-2012 for the EU-28 member states. National data on CO_2 emissions (in million metric tonnes of carbon dioxide-equivalent) come from the CAIT Climate Data Explorer 2016, available online at http://cait.wri.org and reflect the anthropogenic emissions from electricity-heat, manufacturing-construction, transportation, other fuel combustion and fugitive emissions. The GDP and population data are drawn from *The Conference Board* 2016, Total Economy Database, which provides data from 1950 onwards and it is available at http://www.conference-board.org/data/economydatabase. GDP is in 1990 US$ which are converted using Geary-Khamis PPPs. Both series of per capita CO_2 emissions and GDP have been transformed by applying neperian logarithm and the first differencing filter to obtain its cyclical component following Bowen *et al.,* 2009. In the literature of CO_2 emissions, the Hodrick-Prescott filter is more frequently used to identify cyclical components of emissions (Heutel, 2011; Doda, 2014). However, papers comparing the results obtained with alternative filters conclude that they are not so sensitive to the particular filter employed in decomposing or detrending the series (Lucas *et al.*, 2009 and Doda, 2014).

Our methodological approach begins by applying dynamic factor analysis to estimate the common fluctuation pattern of the CO_2 emissions in the EU-28. In economics, dynamic factor analysis has been widely used in many fields: forecasting macroeconomics variables (Stock and Watson, 2002), examining business cycles (Del Negro and Otrok, 2008) and detecting countries sharing a common business cycle (Lucas *et al.*, 2011). The presentation of the dynamic factor model follows Stock and Watson 2010.

The dynamic factor model is based on the assumption that a small number of unobserved latent factors, f_t, generate the observed time series through a stochastically perturbed linear structure. Formally, in the model is assumed that the pattern of observed co-movements of a high-dimensional vector of time-series countries, $X_t = \nabla \ln GDP_{i.t}$, can be represented by few unobserved latent common dynamic factors. The latent factors follow time series process, which are commonly taken to be a vector autoregression (VAR). In equations the dynamic factor model is

$$X_t = \Lambda f_t + e_t; \tag{1}$$

$$f_t = \psi(L) f_{t-1} + \eta_t \tag{2}$$

where there are N countries, so X_t and e_t are $N\times 1$, there are m dynamic factors so f_t and η_t are $m\times 1$, $\Lambda = (\lambda_1, \lambda_2, \ldots, \lambda_m)$ is $N\times m$, L is the lag operator, and the lag polynomial matrix $\psi(L)$ is $m\times m$. The *i-th* λ_i are called factor loadings for the *i-th* countries, X_{it}. The idiosyncratic disturbances, $e_t = (e_{1,t}, e_{2,t}, \ldots, e_{N,t})'$, are the specific elements of each series contained in a vector; they are serially correlated and slightly cross-sectionally correlated with other variables in the model and are mutually uncorrelated at all leads and lags, that is, $Ee_{it}e_{js} = 0$ for all s if $i \neq s$. They are assumed to be uncorrelated with the factor innovations at all leads and lags, that is, $Ee_t\eta'_{t-k} = 0$ for all k. The pth order autoregressive polynomial, $\psi_i(L)$, is assumed to have stationary roots. As we do here, it is frequent to reduce the number of parameters by estimating the signal to noise ratios $q_{i,m} = \frac{\sigma^2_{\eta,i}}{\sigma^2_{e,i}}$ (see Harvey and Trimbur, 2008, for its importance for spectral analysis). The standard estimation method is provided by maximizing the likelihood of the corresponding model and estimation accuracy via the Kalman filter, after a suitable reparameterization of the model in state-space form. Assuming that all the processes in (1)-(2) are stationary and not cointegrated, we use the GROCER's Econometric Toolbox written by Dubois and Michaux 2016.

In our analysis, we have confirmed the existence of only one common factor, $\hat{f}_{1,t}$ employing the statistical criterion proposed by Bay and Ng 2002. This single common factor represents the co-fluctuation of per capita emissions in the EU and it is referred as the common factor or *index of EU-cyclical environmental performance*. Further, for an appropriate interpretation of results, we have standardized the factor loadings: $\lambda_i \frac{\sigma_{\hat{f}_1}}{\sigma_{x_i}} = \frac{\text{cov}(x_i, \hat{f}_1)}{\sigma^2_{\hat{f}_1}} \frac{\sigma_{\hat{f}}}{\sigma_{x_i}} = \frac{\text{cov}(x_i, \hat{f}_1)}{\sigma_{x_i}\sigma_{\hat{f}_1}} = \rho_i$, such that it provides an estimation of the correlation or linkages between each Member State´s emissions with the common factor. The values obtained parametrically, ρ_i, are the proportion of total variation explained by the common factor which offers a measure of the degree to which the country is co-moving following the fluctuation pattern of per capita emissions in the EU over the time period. Additionally, in this analysis we employed the test proposed in Cendejas 2011 to confirm the stability of parameters.

In order to analyse the possible results obtained by ρ_i, we differentiate three types of results according to the percentage of variation explained by the common factor:

- $\rho_i \geq 0.5$ - Denoting emissions strongly linked. We interpret that this result is obtained by countries that we considers as eco-leaders in emissions fluctuations in the EU.
- $0 < \rho_i < 0.5$ - Denoting emissions with weak linkages. In this case, countries are regarded as eco-followers in emissions fluctuation in the EU.
- $\rho_i = 0$ - Denoting independent emissions fluctuation pattern. This type of result implies that these countries are non-followers or independent from the common emissions fluctuations in the EU.

We can obtain additional information on the evolution of these linkages by monitoring the time-varying correlation of their CO_2 emissions with the index of EU-cyclical environmental performance. This procedure consists of estimating recursively for every economy as:

$$x_{i,t} = \beta_i(\tau)\hat{f}_{1,t} + v_{i,t}(\tau) \tag{3}$$

where the moving index $\tau = \tau_0, \tau_0 + 1, \ldots, T$, excludes some portions (trimming) of the sample at the beginning, where $\tau_0 = \pi T$ (the integer part), and π, the proposed trimming, is a minimum sample percentage excluded at the beginning of the sample. Therefore, the parameter stability is assessed in a main segment of the sample. So, the recursive coefficients $\beta_i(\tau)$ are estimated from an increasing segment of the sample (note that

$\beta_i \approx \rho_i$ *if the full sample is used in the estimation*) and $v_{i,t}(\tau)$ is the error term or idiosyncratic component uncorrelated with the index of EU-cyclical environmental performance, $\hat{f}_{1,t}$, for consistent OLS estimation of (3) which is robust to heteroskedasticity and autocorrelation by employing the Newey-West 1987 estimator. This procedure provides a continuum of results for every Member State that are useful to graphically keep track of their progress towards the common environmental behaviour.

Starting from the considered stable parameters ρ_i estimated in model (1)-(2), we can complete the initial classification shown above by including the information about the evolution of the resulting values in model (3) for $\beta_i(\tau)$. From these results, we can offer a wider classification of the EU State Member:

1. In the case of countries with ($\rho_i \geq 0.5$), we can distinguish 2 groups:
   1.1 When $\beta_i(\tau) \geq 0.5$ at the full sample period: in this case, we regard the countries as eco-leaders.
   1.2 Initially $0 < \beta_i(\tau) < 0.5$ and increasing linkages during the rest of the period obtaining $\beta_i(\tau) \geq 0.5$ by certain date: we define these countries as new eco-leaders.
2. In the case of countries with ($0 < \rho_i < 0.5$), we can also distinguish 2 groups:
   2.1. When $\beta_i(\tau) \geq 0.5$ at the full sample or initially $0 < \beta_i(\tau) < 0.5$ and increasing linkages in the period obtaining $\beta_i(\tau) \geq 0.5$ during the period: we consider these countries as eco-followers.
   2.2. When $\beta_i(\tau) < 0.5$ at the full sample: in this case, we define the countries as fragile Eco-followers.
3. Finally, in the case of $\rho_i = \beta_i(\tau) = 0$, we referred these countries as non-followers denoting an independent fluctuation pattern.

Once we have examined the linkages in the CO_2 emissions fluctuation in the EU, we propose to complete this analysis by evaluating also the progress in dissociating CO_2 emissions from economic activity in the State Members. These results contribute to identify patterns of decoupling across the State Members that can be compared with the patterns of cyclical fluctuation analysed previously. For this purpose, we apply the same recursive procedure, described above in (3), for the model:

$$x_{i,t} = \alpha_i(\tau)\nabla \ln GDP_{i,t} + \xi_{i,t}(\tau) \qquad (4)$$

This is an alternative to the definitions of decoupling in Tapio 2005 and Diakoulaki and Mandaraka, 2007 and in line with the correlation analysis proposed by Doda 2014, who evaluates the relationship of the cycles of the CO_2 emissions and GDP across countries through contemporaneous cross-country correlation.

From the continuum of results obtained for the recursive coefficients $\alpha_i(\tau)$ of model (4), it is possible to analyse the efforts that countries made to decouple their CO_2 emissions from their GDP along the period. In order to better interpret the results, the time-varying correlation values were divided into five groups according to its degree (we consider that the correlation is high if it takes values $\alpha_i(\tau) > 0.5$) and evolution (the reductions in the relationship denotes progress in the dissociation of emissions with GDP):

a. Decoupled**:** decoupled occurs when there is no linear dependency between CO_2 emissions and GDP: the recursive coefficients $\alpha_i(\tau)$ are not significant in the whole period.
b. Smooth decoupling: smooth decoupling occurs when correlation fluctuates around a low level $\alpha_i(\tau) < 0.5$ in the period analysed, diminishing in some years. This is the case of countries that already show a low dependency between CO_2 emissions and GDP.
c. Intensive decoupling: intensive efforts in decoupling occurs when the initial correlation is high $\alpha_i(\tau) > 0.5$ and countries are able to reduce the correlation to a low value $\alpha_i(\tau) < 0.5$ at a certain date.
d. Moderate decoupling: moderate efforts in decoupling occurs when the initial correlation is high $\alpha_i(\tau) > 0.5$ and countries reduce correlation along the period but they are not able to reduce the correlation to a value $\alpha_i(\tau) < 0.5$.

e. Difficulties in decoupling: in this case, countries show difficulties to reduce the correlation along the period in spite of in some cases the value is low $\alpha_i(\tau)$<0.5.

Based on the previous analysis, we combine the possible results that a country can reach in a CO_2 emission-GDP linkages matrix. This is a useful tool to classify countries according to the features of their environmental behaviour, ranging from countries that share the common fluctuations and their emissions are decoupled from economic activity (1) to countries with independent fluctuations and difficulties to reduce correlation between emissions and economic activity (25). Table 4 addresses the 25 possible combinations of results.

Table 4. CO_2 Emissions-GDP linkages matrix

CO_2 linkages / ***GDP linkages***	$\rho_i \geq 0.5$		$0 < \rho_i < 0.5$		$\rho_i = 0$
	$\beta_i(\tau) \geq 0.5$	Initial: $0 < \beta_i(\tau) < 0.5$ Final: $\beta_i(\tau) \geq 0.5$		$\beta_i(\tau) < 0.5$	$\beta_i(\tau) = 0$
$\alpha_i(\tau) = 0$	Eco-leaders Decoupled (1)	New eco-leaders decoupled	Eco-followers decoupled	Fragile Eco-followers decoupled	Non followers decoupled
$\alpha_i^I(\tau): low \approx \alpha_i^F(\tau): low$	Eco-leaders with smooth decoupling	New Eco-leaders with smooth decoupling	Eco-Followers with smooth decoupling	Fragile Eco-Followers with smooth decoupling	Non-followers with smooth decoupling
$\alpha_i^I(\tau): high > \alpha_i^F(\tau): low$	Eco-leaders with intensive decoupling	New Eco-leaders with intensive decoupling	Eco-Followers with intensive decoupling	Fragile Eco-Followers with intensive decoupling	Non-followers with intensive decoupling
$\alpha_i^I(\tau): high > \alpha_i^F(\tau): high$	Eco-leaders with moderate decoupling	New Eco-leaders with moderate decoupling	Eco-Followers with moderate decoupling	Fragile Eco-Followers with moderate decoupling	Non followers with moderate decoupling
Other situations	Eco-leaders with difficulties in decoupling	New Eco-leaders with difficulties in decoupling	Eco-Followers with difficulties in decoupling	Fragile Eco-Followers with difficulties in decoupling	Non followers with difficulties in decoupling (25)

3. Results and discussion

3.1. The index of EU- cyclical environmental performance.

The first step in our analysis is to estimate the co-fluctuation pattern for per capita CO_2 emissions in the EU-28 over the period 1950-2012: the index of the EU-cyclical environmental performance which contributes to the development of EU environmental indicators.

The results of the estimation according to the dynamic factor model in (1)-(2) are shown in table 5. The AR idiosyncratic parameter and noise ratio confirm the suitability and dynamic of the model. The significance of the factor loadings indicates which country´ emissions are co-moving and which are not. Results confirm that all factor loadings are significant and statistically similar, with the exceptions of Spain, Portugal and Malta. These countries are then excluded from the estimation of the model, this is why they do not appear in table 5. Spain, Portugal and Malta follow an independent emissions fluctuation pattern and, then, they are considered as countries non-followers or independent from the EU common fluctuation pattern.

Additionally, the proportion of total variation explained by the factor loading is a measure of the degree of the linkages among CO_2 emissions. Following the criteria stablished in the methodology section, we can identify countries that strongly share the EU common fluctuation pattern ($\rho_i \geq 0.5$), which we denominate as countries eco-leaders. This is the case of most of the members of the EU-15 and Poland (one of the countries that made more remarkable environmental progress, meeting most of environmental targets of European Directives, OECD, 2017).

In our analysis we also find that countries which emissions show weak linkages ($0 < \rho_i < 0.5$). This is the case of Greece, Ireland, and the rest of Central and Eastern European members, they are regarded as eco-followers. The enlargements to include new Member States in Central and Eastern Europe have given a greater dimension to the EU, but these new Member States did not have strong energy efficiency policy or governance structures when they joined the EU so their progress to a common environmental performance is in less advanced stages. This explains in part the results obtained for these countries.

Table 5. Estimation results from model (1)-(2). Sample period: 1951-2012

The index of EU cyclical environmental performance

$$f_t = \underset{(5.28)}{1.01}^{***} f_{t-1} + \eta_t + \underset{(-6.44)}{0.85}^{***} \eta_{t-1}$$

Countries	Standarized factor loadings ρ_i	AR idiosyncratic parameter ψ_i	Noise ratios q_i
EU 15			
Austria	0.75 (7.81)***	0.02 (0.14)	0.33 (4.94)***
Belgium	0.69 (6.94)***	0.01 (0.1)	0.43 (5.17)***
Denmark	0.52 (5.28)***	-0.19 (-1.44)	0.65 (5.41)***
Finland	0.68 (7.54)***	-0.35 (-2.72)***	0.4 (5.08)***
France	0.69 (6.93)***	0.06 (0.47)	0.42 (5.16)***
Germany	0.76 (7.73)***	0.29 (2.14)***	0.31 (4.84)***
Greece	0.45 (4.12)***	0 (-0.01)	0.75 (5.47)***
Ireland	0.34 (3.58)***	-0.31 (-2.53)***	0.79 (5.51)***
Italy	0.53 (6.35)***	0.52 (4.53)***	0.31 (5.14)***
Luxembourg	0.50 (4.61)***	0.16 (1.2)	0.67 (5.43)***
Netherlands	0.60 (7.12)***	-0.45 (-3.73)***	0.43 (5.19)***
Sweden	0.65 (6.78)***	-0.16 (-1.22)	0.48 (5.23)***
United Kingdom	0.56 (6.57)***	-0.39 (-3.22)***	0.47 (5.28)***
Central and Eastern Europe			
Bulgaria	0.26 (2.37)***	0.27 (2.18)***	0.77 (5.53)***
Croatia	0.28 (2.46)***	0.07 (0.51)	0.88 (5.54)***
Czech Republic	0.39 (3.60)***	0.17 (1.34)	0.72 (5.49)***
Cyprus	0.35 (3.15)***	0.07 (0.56)	0.82 (5.51)***
Estonia	0.44 (3.94)***	0.11 (0.84)	0.75 (5.48)***
Hungary	0.44 (4.15)***	0.23 (1.85)*	0.68 (5.45)***
Latvia	0.41 (4.36)***	0.54 (4.95)***	0.51 (5.41)***
Lithuania	0.36 (3.21)***	0.29 (2.36)***	0.75 (5.5)***
Poland	0.51 (4.72)***	0.23 (1.81)*	0.62 (5.41)***
Romania	0.27 (3.04)***	0.58 (5.57)***	0.5 (5.5)***
Slovakia	0.48 (4.48)***	0.03 (0.22)	0.71 (5.45)***
Slovenia	0.39 (3.73)***	-0.1 (-0.78)	0.80 (5.5)***

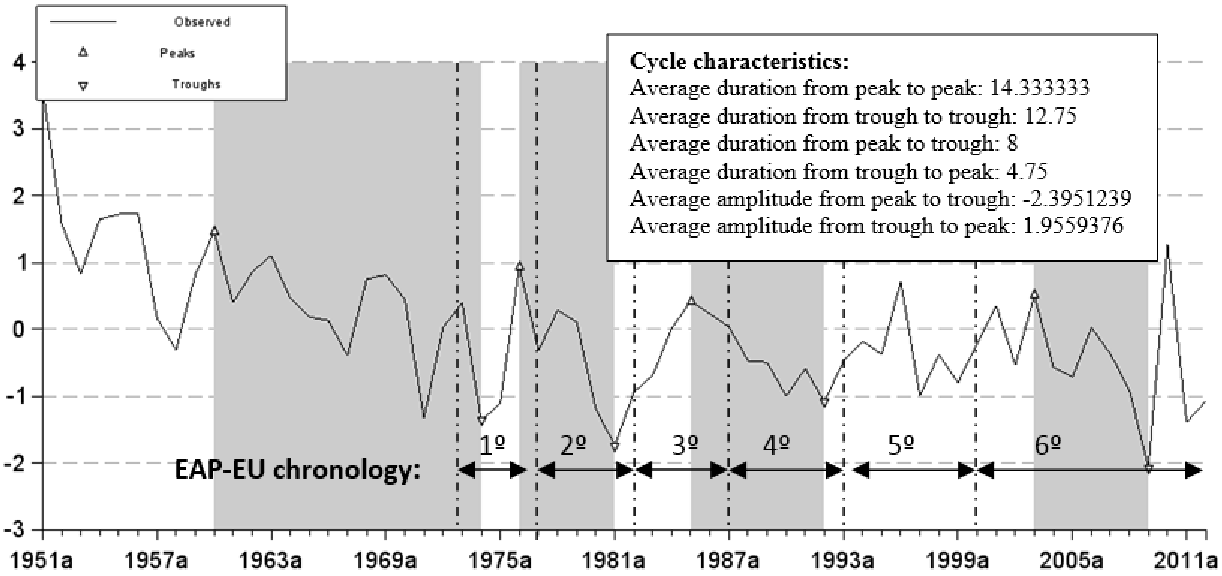
Note: Using the test proposed in Cendejas et al. 2011, we have not detected dates of structural breaks, confirming the stability of parameters' model (1)-(2).

Once the estimation of the index for the EU-cyclical environmental performance is made, we can provide an analysis of the properties of common fluctuations following dating methodology for Centre for Economic Policy Research (CEPR) available at http://cepr.org/content/euro-area-business-cycle-dating-committee. This is a more specific and formal analysis about the behaviour of fluctuations than the results based only in the standard deviation or volatility measure executed by others authors, this is the case of Doda 2014.

The Fig. 1 shows the evolution of the index of the EU-cyclical environmental performance over the phases of the business cycle throughout the time period beginning in 1951 and ending in 2012. The characteristics of the changes in this index over business cycle recessions and expansions show a clear asymmetry in their behaviour, with the average duration of the recession being almost double of that of the expansions. In addition, the recessions are on average steeper or more intense than the expansions when the amplitude is analysed. We highlight the significant effects of the recent economic crisis, with a starting time in year 2008, on the development of the index by reducing its growth severely, although a great recovery occurs later.

Furthermore, we can observe that fluctuations of emissions are longer and steeper in the period 1951-1990 (pre-Kyoto) than in the second period 1991-2012 (post-Kyoto) in which the differences of expansion and recessions are smaller. Significant regulation to mitigate CO_2 emissions has being implemented in these countries after the adoption of the Kyoto protocol which has influenced the results. The graph also includes information about the Environmental Action Programmes (EAPs). Since the 90´s, the EAPs have set tangible targets to reduce GHG in comparison with the emissions levels of 1990 (see table 1) which has also contributed positively to moderate the CO_2 emissions growth.

Fig. 1: Dating the EU cyclical environmental performance index



Source: Own elaboration by Harding and Pagan method 2002 available at Grocer.
Note: Shaded areas correspond to recession phases according to the definition of CEPR chronology.

3.2. *Monitoring the* CO_2 *interdependences across the EU-28 Member States.*

The existence of a common fluctuation pattern in the EU facilitates the trace of the environmental trends and the possibilities of fulfil the emissions mitigation targets. In the analysis of this common behavior it is also important to provide measures to monitor the CO_2 interdependences across the Member States. The recursive procedure proposed in the methodology section allows to explore whether the correlation of CO_2 emissions′ of the members states with the EU-cyclical common factor vary over time. The continuum of results obtained in the estimation and their t-statistics are shown graphically in Fig. 2 and 3. We can identify different patterns according the degree and evolution of the linkages in CO_2 emissions for the sub-set of EU-15 countries (Fig. 2) and for the 13 countries belonging to the Central and Eastern Europe (Fig. 3).

Firstly, in the analysis of the EU-15, we identify mostly countries eco-leaders: with $\rho_i \geq 0.5$ that obtained $\beta_i(\tau) \geq 0.5$ at the full sample period, which means that they share largely the common fluctuation pattern. In this group, we can differentiate economies that have an increasing high correlation with the EU-cyclical factor along the period (starting around 50% reaching higher levels at the end of the sample: Austria, Belgium Finland, France, Sweden and UK) from countries which correlation with the EU-cyclical factor and fluctuates relatively stable around high levels during all the period (above 70%: Germany and Italy). In the EU-15 we find also new eco-leaders: countries with $\rho_i \geq 0.5$ that obtained initially $\beta_i(\tau) < 0.5$, but reach $\beta_i(\tau) \geq 0.5$ at a certain date. This is the case of Luxembourg, Netherlands (since the 70s) and Denmark (since the 90s). These results show that core European high-income countries and Scandinavian economies (Austria, Belgium, France, Germany, Finland and Sweden) are the main eco-leaders countries pushing to a common fluctuation pattern in the EU-28. Although there are no papers that made similar analysis to ours, in the environmental evaluation of the EU it is frequently highlighted that this the group of countries that reaches the best eco-efficiency scores, this is the case of Camarero et al., 2014

Inside the EU-15, there are also countries with $\rho_i < 0.5$ that also maintained $\beta_i(\tau) < 0.5$ along the period. In this group, we find Greece and Ireland, who are considered fragile eco-followers. Finally, results for Spain and Portugal, confirm that these countries are non-followers of independent countries.

Next, we analyse the Central and Eastern Europe Member States that are incorporated in the EU since 2000. In this group we identify only one country that obtained $\rho_i \geq 0.5$, initially it shows $\beta_i(\tau) < 0.5$, but reach $\beta_i(\tau) \geq 0.5$ from the 80´s. This is the case of Poland that is considered as a new eco-leader. The rest of Central and Eastern European countries have $\rho_i < 0.5$, they are regarded as countries eco-followers. In this group we can differentiate, according to the values of $\beta_i(\tau)$: countries that obtained initially $\beta_i(\tau) < 0.5$, but reach $\beta_i(\tau) \geq 0.5$ at a certain date (this is the case of Czech Republic, Latvia and Slovakia) and countries that reach $\beta_i(\tau) \geq 0.5$ at the full sample period: Hungary and Romania. Finally, we find countries that obtained $\beta_i(\tau) < 0.5$ at the full sample period: this is the case of Slovenia, Lithuania, Croatia, Bulgaria, Cyprus and Estonia. They are considered as fragile eco-followers. Another frequent result in environmental literature is that peripheral countries (Spain, Ireland, Portugal and Greece) together with Central and Eastern countries are countries with more difficulties to increase their eco-efficiency scores.

Fig. 2: Estimation of recursively parameters respect to common factor of CO2 in EU-28 (at 5% of significance and 20% of initial trimming)

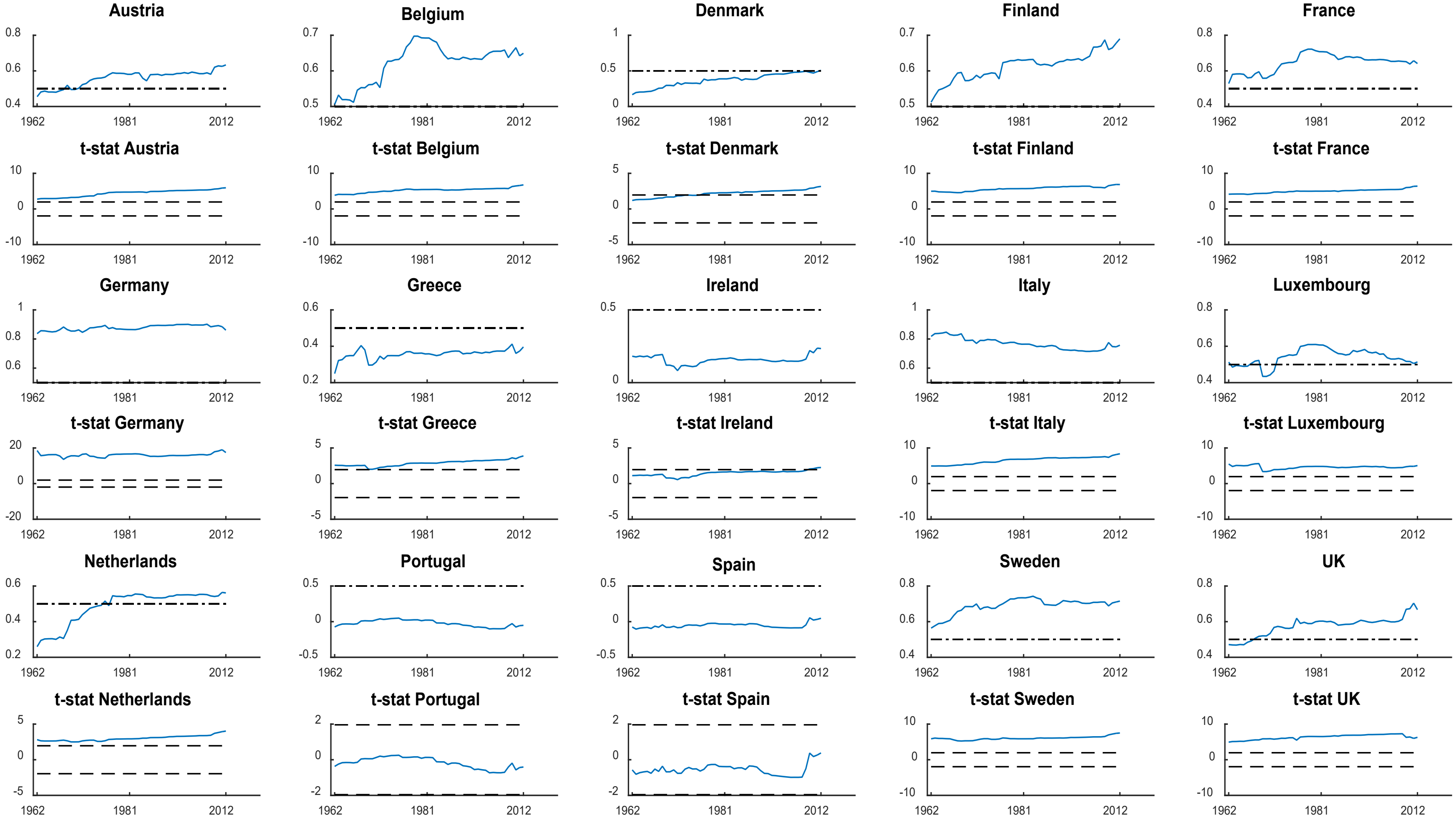
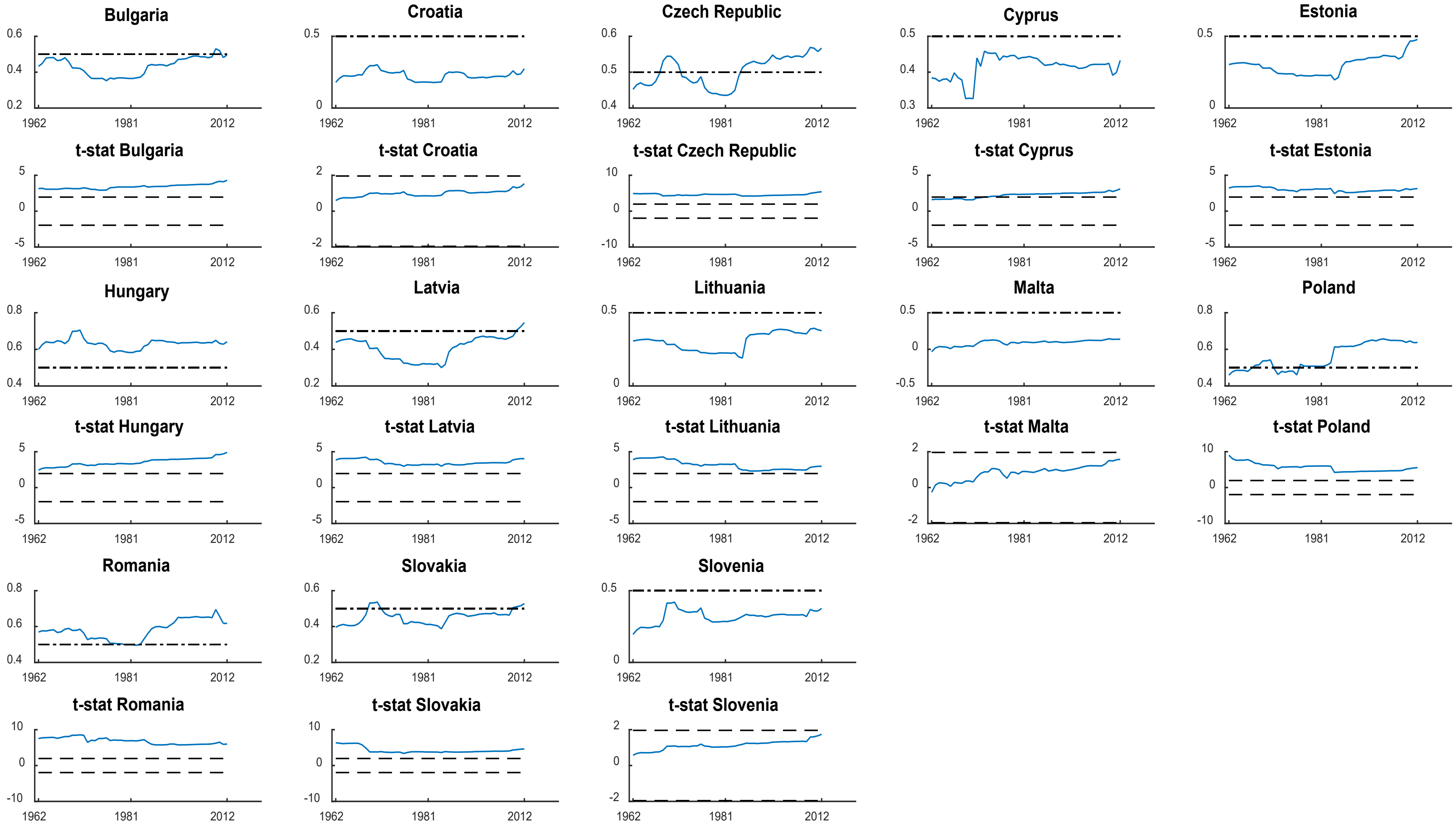


Fig. 3: Estimation of recursively parameters respect to common factor of CO_2 in the rest of EU-28 (at 5% of significance and 20% initial trimming)



3.3. Monitoring decoupling CO_2 emissions growth from business cycle.

As one of the largest emitters in the world, the EU has been trying to mitigate its CO_2 emissions. To achieve this challenge each Member State has been promoting decoupling strategies, which differ according to the efforts made and the results obtained. In order to evaluate the progress in dissociating economic growth from economic activity, we propose the use of an alternative decoupling measure using a time-varying correlation method. This estimation offers a continuum of results and their t-statistics that are shown graphically in Fig. 4 and 5. Fig. 4 shows the time-varying correlation results in the EU-15 while Fig. 5 shows the same for the Central and Eastern countries. Following the criteria proposed in the methodology section, we differentiate five groups according to the degree and evolution showed by the results. We identify countries with emissions decoupled from GDP, countries with smooth, moderate, and intensive efforts in decoupling, and countries that show difficulties in decoupling.

Examining the relationship between the cycles of CO_2 emissions and economic activity in the EU-15, we see that among the most efficient countries, we find that a decoupled situation has occurred in Luxembourg, as we do not find linear dependency between CO_2 emissions and GDP. The small size of this country and its productive structure make its results considered cautious. We can also identify two additional countries, Netherland and Denmark, where correlations are low during the whole period. They are generally regarded as the most environmentally focussed member states, acting as the motors of EU environmental policy change. Our analysis confirms their environmental position (with a correlation under 0.5 during all period); although they experience two separates sub-periods. In the first period (decades of the 60s and 70s), they increase their correlation and from then on they show a downward evolution (The Netherlands) or a quite stable correlation with a low value (Denmark).

Our results also show that most of the EU-15 countries reveal decoupling efforts to dissociate emissions from the economic cycle although there are different patterns across the Member States. Firstly, we can see countries that show intensive efforts in decoupling that resulted in a continued reduction in correlation since the beginning of the sample period and eventually reached a value under 0.5 on a certain date. This is the case for Finland, Sweden (with values under 0.5 since the 90s), and Ireland (since the 70s). We can also identify countries that reduced their correlation from the 1980s, but in this case the countries do not reach values lower than 0.5 at the end of the sample period. We consider that in this case the countries only made moderate efforts in decoupling. Austria, Belgium, France, Germany, Italy and UK are part of this group.

Finally, Greece, Spain and Portugal show different patterns, but share some worrying aspects that place them in the same group. In the case of Greece, it shows an increase in correlation during the first years studied and then it is stabilized in a correlation value higher than 0.5. The difficulties to reduce its correlation value show the strong relationship of their emissions with their economic activity. Spain is a country that maintains a correlation below 0.5 during the greater part of the analysed years, but its correlation keeps an increasing evolution surpassing the 0.5 correlation value at the end of the period. This result reveals an important impact of the crisis in this economy. Portugal started in the 70s a continuous upward trajectory until the end of the period.

In the analysis of the Central and Eastern European Member States, we also find countries classified in the group of decoupled countries: Slovenia and Malta. There are also two countries that have a correlation value below 0.5 in the whole period (with the exception of a few years in which it reaches the value of 0.5) and shows a generally positive evolution. These are the cases of Bulgary and Poland. Among the countries that show a moderate decoupling effort are Czech Republic (although the crisis has a negative effect in this country), Hungary (that maintains a correlation value of 0.5 since the 80s), Lithuania, and Croatia, which has experienced an intense reduction in their correlation since the 90s.

In the group of Central and Eastern countries, we also find a sub-group of member states that are comprised of Romania, Latvia, Slovakia, Cyprus, and Estonia which show difficulties in implementing efficient national environmental policies. They had trouble reducing their correlation results, although their values fluctuate around 0.5.

Fig. 4: Estimation of recursively parameters respect to growth of GDPpc of every country in EU-15 (at 5% of significance and 20% initial trimming)

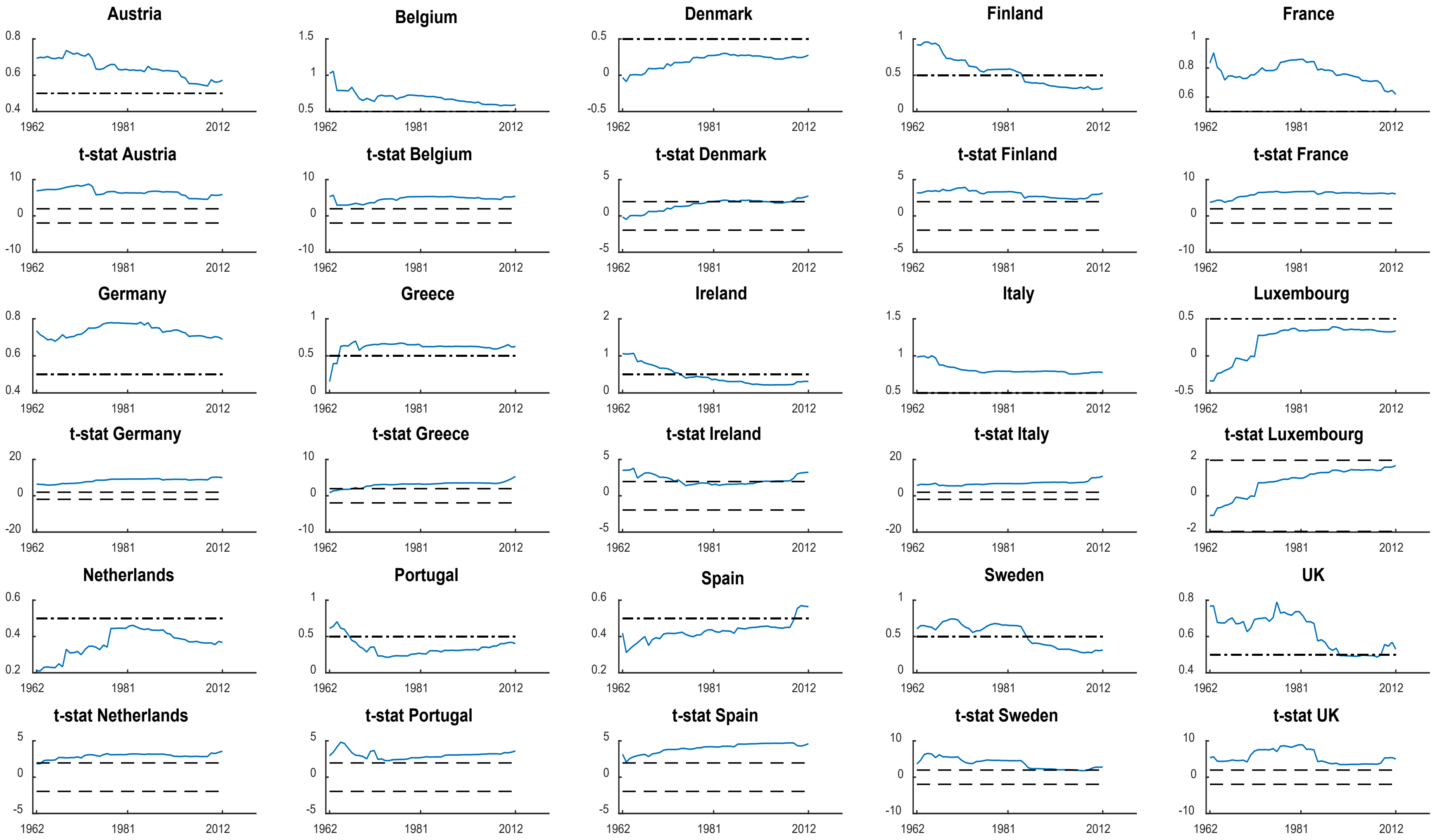
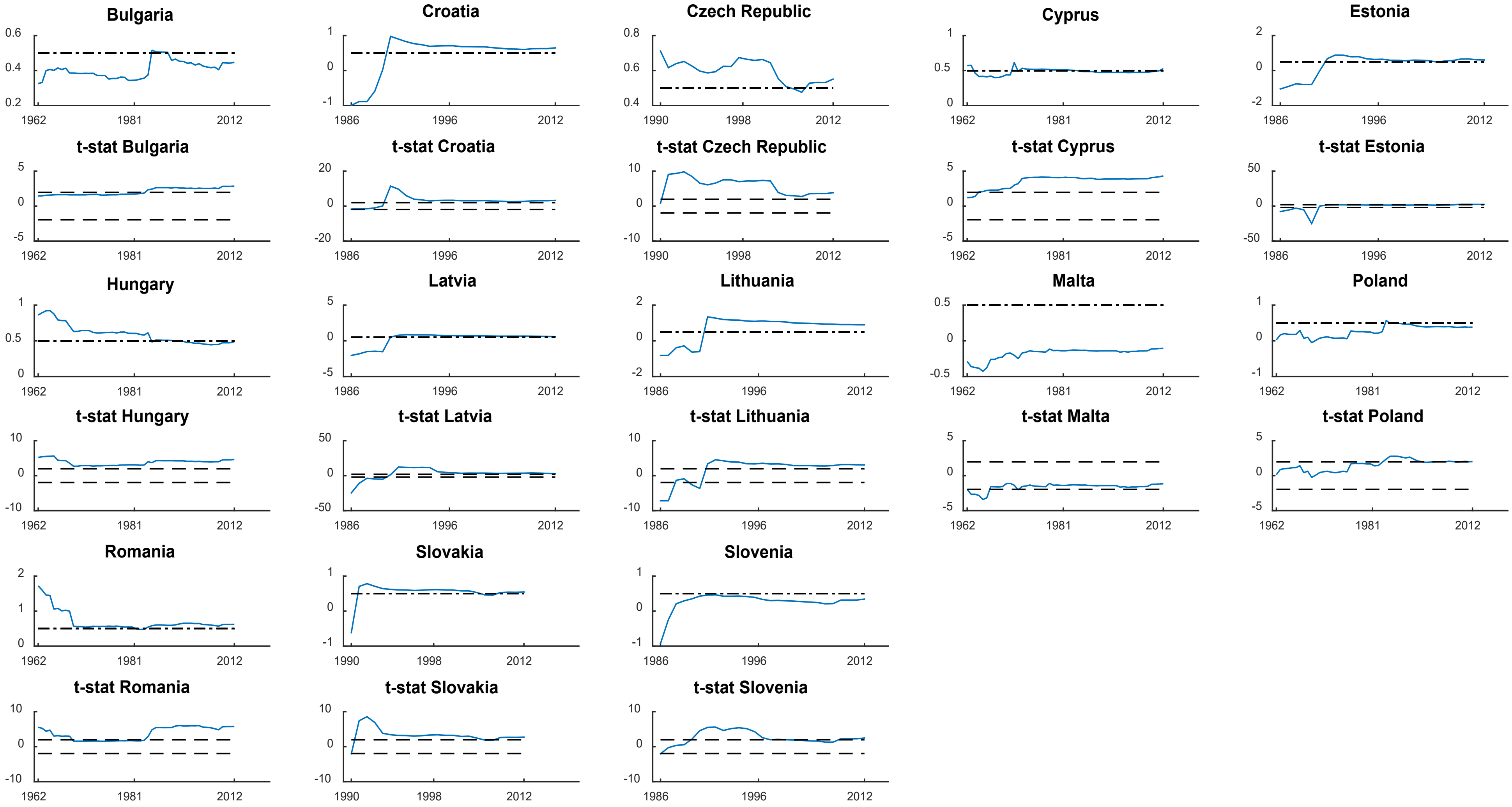


Fig. 5: Estimation of recursively parameters respect to growth of GDPpc of every country in the rest of EU-28 (at 5% of significance and 20% initial trimming)



* The period studied in this analysis depends on the data availability offered by the Conference Board for GDP in Central and Eastern European members

**Dates of structural breaks are identified with test proposed in Cendejas et al. 2011: Croatia in 1992, Estonia in 1990, Latvia in 1990, Lithuania in 1991 and Poland in 1980

3.4. ***CO_2 Emission-GDP linkages matrix.***

In the analysis of this paper we consider that increasing participation in the index of EU cyclical performance by the Member States is an indicator of progress towards a common environmental behaviour. This common strategy can be implemented along with national decoupling or efficiency efforts. Differences between European commitments and national objectives can be an obstacle in the achievement of a solid path to sustainability in the EU-28.

With the aim to evaluate these strategies, we range the possible results according to the intensity of the interdependences with the common fluctuation pattern and with economic activity. Table 6 summarizes these results in an emissions-GDP linkage matrix that combine the outcomes from environmental strategies at EU (toward a common fluctuation) and national level (decoupling efforts). We can identify countries sharing largely the common emission fluctuations (eco-leaders and new eco-leaders) which show progress in decoupling emissions from GDP (in a smooth, intense or moderate way). In general, the members of the EU-15 are in this group, with the exception of Ireland, Greece, Spain and Portugal (the peripheral countries). These last four countries need special guidance to improve their environmental results.

In the analysis of the Central and Eastern European Member States we show that most of these countries are eco-followers or fragile eco-followers, with the only exception being Poland. This country has made considerable efforts to fulfill the EU commitments and show a smooth decoupling trajectory that has supported the positive result obtained. The rest of member states need to enforce environmental measures to guarantee the mitigation of emissions and reach progress towards the common environmental path.

Table 6. CO_2 Emission-GDP linkages matrix for the EU-28

CO_2 linkages	$\rho_i \geq 0.5$		$0 < \rho_i < 0.5$		$\rho_i = 0$
GDP linkages	$\beta_i(\tau) \geq 0.5$	Initial: $0 < \beta_i(\tau) < 0.5$ Final: $\beta_i(\tau) \geq 0.5$		$\beta_i(\tau) < 0.5$	$\beta_i(\tau) = 0$
$\alpha_i(\tau) = 0$		Luxembourg		Slovenia	Malta
$\alpha_i^I(\tau): low \approx \alpha_i^F(\tau): low$		Denmark Netherlands Poland*		Bulgary	
$\alpha_i^I(\tau): high > \alpha_i^F(\tau): low$	Finland Sweden			Ireland	
$\alpha_i^I(\tau): high > \alpha_i^F(\tau): high$	Austria Belgium France UK Germany Italy		C. Republic Hungary	Lithuania* Croatia*	
Other situations: difficulties in decoupling			Latvia* Romania Slovakia	Greece Cyprus Estonia*	Portugal Spain

*Dates of structural breaks identified with test proposed in Cendejas et al. 2011: Croatia in 1992, Estonia in 1990, Latvia in 1990, Lithuania in 1991 and Poland in 1980.

4. Conclusions

The results reached in this paper can be summarized in the following main aspects. The first concerns the estimation of the index for the EU-cyclical environmental performance over the period 1950-2012 by applying the dynamic factor model. This index contributes to the development of environmental indicators and can be used to monitor the response of the EU to the Community´s environmental policy. The results obtained evidences that the introduction of more stringent emission targets since the 5th EAP has contributed to the restraint in the CO_2 emissions growth in the EU.

The second contribution of the study concerns the evaluation of the progress of the 28 Member State towards the EU common fluctuation pattern. Based on the information contained in the index, we propose the use of a time-varying recursive method to track the changes in the CO_2 emissions interdependences over the period studied. With this proposal, we contribute to ensure accessible information on the assessment of common targets. In this analysis, we identify countries leading the common fluctuations that increase their CO_2 linkages boosting the common response to the EU´s EAPs (these are the case of Austria, Belgium and France) and countries that require introduce additional incentives or policy measures to foster the implementation of European regulations (Ireland and Bulgary).

Thirdly, we contribute to track the efforts made by the Member States to decouple their CO_2 emissions from GDP using the same recursive method. In this analysis, we find countries with emissions decoupled or close to be decoupled from GDP (these are the cases of Luxembourg, Netherland and Denmark) in contrast with countries that show difficulties in decoupling (Greece and Romania, among others). In the last cases, their national environmental strategies seems not be focused enough in decoupling and these countries should make further adjustments to integrate their environmental objectives with the common targets.

To continue with further analysis, we combine the results obtained in the recursive analysis in an emissions-GDP linkage matrix that helps to position every Member State according to the characteristics of their emissions performance. Results show a contrasting picture with Finland and Sweden on one hand and Spain and Portugal on the other. These results evidence that countries are following differentiated cyclical emissions trajectories. Given the diversity in the performance within the EU-28, there is ample room for improving the integration of Member States in the common fluctuation pattern.

The methodology proposed in this article is a starting point for future work related to the assessment of the common and national environmental policy in the EU. Its application will allow policies to be modulated for each member state, with the objective of increasing linkages among CO_2 emissions and decoupling them from economic activity. Further research on how to contribute to the understanding of these linkages is needed.

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List of acronyms and abbreviations

AEP	Environmental Action Programme
AR	Autoregressive process
CAIT	Climate Analysis Indicator Tool
CEPR	Centre for Economic Policy Research
CO_2	Carbon Dioxide
EEA	European Environmental Agency
DEA	Data Envelopment Analysis
EU	European Union
GDP	Gross Domestic Product
GDP_{pc}	Gross Domestic Product per capita
GHG	Green House Gas
HP filter	Hodrick–Prescott filter
IPAT	???????
LMDI	Log-Mean Divisia Index
OCDE	Organization for Economic Co-operation and Development
OLS estimation	Ordinary Least Squares estimation
PCA	Principal Component Analysis
PPPs	Purchasing Power Parity
STIRPAT	????????
VAR	Vector Autoregressive

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