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An Analysis of Progress Toward EU Macroeconomic and Environmental Indicator Convergence

T. Daniel Coggin

Florence, SC, USA
dcoggin1948@gmail.com

ABSTRACT

The purpose of this paper is to examine and update the progress toward meeting the macroeconomic and environmental "convergence criteria" outlined in original Maastricht Treaty of 1991, and the Kyoto Protocol of 1997 and its successor climate agreements. Using recently developed econometric models of convergence, this study presents an inventory of the convergence properties of 12 macroeconomic and environmental indicators for a sample of 15 EU member countries with data for the period 1990-2020. While not exhaustive, it is representative of widely accepted macroeconomic and environmental indicators used to gauge progress toward achieving the stated EU convergence criteria, including some that to our knowledge have not yet been formally studied for convergence. We also give an example of how using an inappropriate convergence model can lead to incorrect and misleading results, and suggest a testing strategy to obtain more reliable results. Using the appropriate convergence model, we found evidence for weak σ-convergence in 5 of the 12 indicators (4 macroeconomic and 1 environmental). Thus progress toward EU economic and environmental convergence remains mixed.

Keywords: EU convergence, relative convergence, weak σ-convergence, environmental indicators, macroeconomic indicators

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1. Introduction and Background

The European Union and its current status as a political unit is the subject of ongoing analysis, discussion and debate. As noted and detailed in Wilde (2019), "The European Union (EU) was founded as a result of the Maastricht Treaty which took effect on November 1, 1993. It is a political and economic union between European countries that sets policies concerning the members' economies, societies, laws, and, to some extent, security." As stated by the The European Commission (2021), "In order to adopt the euro, EU countries have to bring their national legislation in line with relevant EU law and meet specific conditions designed to ensure economic convergence. These requirements, agreed by the EU Member States in Maastricht in 1991, are known as the **convergence criteria** [emphasis added]."

In 1997, another area for EU convergence was added called the Kyoto Protocol. As explained in Tardi (2021), the Kyoto Protocol was an international agreement that aimed to reduce carbon dioxide (CO_2) emissions and the presence of greenhouse gases (GHG) in the atmosphere. The essential tenet of the Kyoto Protocol was that industrialized nations needed to lessen the amount of their CO_2 emissions. The history of EU involvement, agreement and commitment to combatting global warming is quite extensive. Under the Kyoto Protocol, the EU committed itself to reducing its greenhouse gases emissions by 8% during the first commitment period from 2008 to 2012. In the Paris Agreement of 2015, the international community agreed to limit global warming to 2 degrees Celsius or less by 2050. In December 2019, the EU heads of state and government committed to reaching the goal of climate neutrality by 2050. The purpose of this study is to examine and update the progress toward meeting the macroeconomic and climate "convergence criteria" stated and outlined in original Maastricht Treaty of 1991, and the 1997 Kyoto Protocol and its successor climate agreements.

The issue of economic and climate "convergence "in general and with regard to in the Euro Area states in particular has been extensively studied. The EU itself issues a bi-annual *Convergence Report* [see European Commission (2020)] to assess the progress toward economic and social convergence goals. See del Hoyo, *et al*. (2017) and Mascherini (2020) for more discussion. Academic studies of environmental and economic convergence in the Euro Area are varied and quite numerous. The early study by Baimbridge, *et al*. (1999) evaluated the proposed alternative convergence criteria to determine the suitability for membership of the European single currency and found "only sporadic conformity." However, the majority of studies focus on *single issues*, such as CO_2 emissions [see, *e.g*., Morales-Lage, *et al.* (2019)] or income [see, *e.g*., Yin, *et al*. (2003), Próchniak and Witkowski (2013), and Cavallaro and Villani (2021)]. Representative studies that present comprehensive summaries and lists of the large Euro Area convergence literature include Glawe and Wagner (2021) and Eckey and Türck (2007). Excellent recent studies include Pérez-Moreno, *et al*. (2020), and Kollias and Messis (2021).

Using recently developed econometric models, this study presents an inventory of the quantitative convergence properties of 12 macroeconomic and environmental indicators for a sample of 15 EU member countries for the period 1990-2020. While our study is not exhaustive, it is representative of widely accepted indicators commonly used to gauge EU convergence. Our study has the added value of combining all these indicators into one comprehensive and detailed quantitative analysis including indicators that to our knowledge have not yet been analyzed for convergence.

2. Data and Basic Statistics

2.1. Sample countries

Our sample of countries includes 15 EU member countries that also have been members long enough to allow a meaningful EU convergence analysis, beginning with data from 1990 and continuing through 2020, or whenever data are available for this period. This time period covers the formation of the EU until the present. Table 1 presents our sample of 15 countries ranked by population and GDP in 2020. The (rank) correlation between these ranks is 0.864. We include the UK because their formal exit from the EU was not finalized until December 31, 2020.

Table 1.		
Rank in 2020		
	Population	GDP
Germany (GER)	1	1
France (FR)	2	3
UK (UK)	3	2
Italy (ITA)	4	4
Spain (SP)	5	5
Netherlands (NETH)	6	6
Belgium (BEL)	7	8
Denmark (DEN)	8	11
Greece (GRE)	9	14
Sweden (SWE)	10	7
Portugal (POR)	11	13
Austria (AUS)	12	9
Finland (FIN)	13	12
Ireland (IRE)	14	10
Luxembourg (LUX)	15	15
Rank Correlation ($r_{Population,\ GDP}$) = 0.864		

Source: World Bank Data Bank. Population=Total Population; GDP=Current $US. Country abbreviatrion in ( ).

2.2. Indicator variables

Our list of convergence indicator variables includes 12 variables: 3 environmental and 9 macroeconomic. To enhance comparability, the variables are measured as "*per capita*" or as "% of GDP" where possible. The **Appendix** provides a complete list of these variables, their definitions and sources.

2.2.1. Environmental variables

Our 3 environmental indicator variables include: *CO_2* Emissions (in tons per capita), Ecological *Footprint* (in number of earths) [see *e.g.,* Lu (2020); Neagu (2020), Calgar, *et al.*, (2021) and studies listed therein]; and *Fossil Fuels* (% of primary energy use). These 3 variables are widely accepted as primary indicators of environmental/ecological quality.

2.2.2. Macroeconomic variables

Many of our economic variables are also included in the *EU Convergence Criteria* (European Commission, 2021). Our 9 macroeconomic indicator variables include: *Complexity* [see, *e.g.* Neagu (2020)], *Deficit* (% of GDP); *Gini Coefficient* [see e.g., OECD (2017)]; *GDP* (*per capita* in constant 2010 $US); *Inflation* (% annual rate); *Long-term Interest Rates* (% annual rate on 10-yr government bonds); *Military Expenditures* (% of GDP) [see, *e.g*., Eurostat (2021)]; *Trade Balance* (external balance as % GDP); and *Unemployment* (% of labor force). We also include *Voter Turnout* (% of all registered voters casting a vote by year). Voter turnout is widely considered to be a fundamental indicator of a healthy democracy [see Aldrich (1993)].

Table 2 presents descriptive statistics (means, standard deviations and sample periods) for our sample of indicator variables. We tried to obtain data from 1990-2020 to cover the period of the formation of the EU up to the present. As indicated in Table 2, some indicators did not have data available from 1990. *Voter Turnout* data availability was further constrained by the number of national elections held in each country per year. For this reason we extended the sample of data for this indicator back to 1970 in order to get more data points. An inspection of Table 2 suggests that our sample of 15 EU countries is not completely uniform in these average (mean) statistics. For example, CO_2 Emissions (tons *per capita*) ranges from 21.818 for Luxembourg to 5.161 for Portugal; *Fossil Fuels* (% of primary energy) ranges from 97.744 for Luxembourg to 36.969 for Sweden; and *Unemployment* (% labor force) ranges from 16.14 for Spain to 4.42 for Luxembourg. In addition, The indicator means presented in Table 2 also show that 4 of the NATO members in our sample meet the 2006 requirement to spend at least 2 percent of their GDP on defense (France, Greece, Portugal and UK).

Table 2.
Descriptive statistics

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Voter Turnout(%)															
1970-2020 Mean	82.88	91.83	86.38	72.32	78.81	81.38	75.22	67.64	85.00	89.34	80.53	67.77	73.42	86.90	69.80
SD	9.77	2.12	1.68	5.81	5.96	6.94	8.19	8.21	6.36	1.70	4.30	12.55	3.98	3.71	5.61
N (Elections)	23	15	17	22	13	13	14	15	13	10	15	22	14	15	13
Panel One: Environment															
CO_2(Tons)*															
1990-2018 Mean	8.014	10.199	9.487	10.693	5.653	10.009	7.856	9.477	6.992	21.818	10.012	5.161	6.340	5.488	8.243
SD	0.634	1.294	2.228	1.584	0.589	0.853	1.042	1.334	0.899	4.433	0.588	0.628	0.913	1.060	1.346
Footprint															
1990-2017 Mean	3.299	4.018	4.428	3.585	2.939	3.043	2.856	3.233	2.891	8.080	3.417	2.412	2.704	3.525	3.063
SD	0.439	0.328	0.223	0.466	0.162	0.104	0.418	0.247	0.257	0.903	0.361	0.206	0.381	0.426	0.280
Fossil Fuels(%)															
1990-2019 Mean	69.910	81.700	88.025	64.342	55.080	84.179	94.277	94.675	90.493	97.744	96.909	83.044	78.942	36.969	88.091
SD	2.738	1.366	9.544	4.513	2.725	3.027	3.879	4.639	4.256	1.960	1.714	6.356	3.838	3.324	3.735
Panel Two: Macroeconomy															
Complexity															
1995-2018 Mean	1.649	NA	1.216	1.675	1.470	1.985	0.188	1.340	1.339	NA	1.118	0.483	0.950	1.834	1.722
SD	0.058	NA	0.061	0.144	0.088	0.083	0.093	0.090	0.037	NA	0.053	0.194	0.057	0.120	0.130
Deficit(%)															
1995-2020 Mean	-2.616	-2.298	0.338	0.139	-3.798	-1.758	-6.652	-2.887	-3.487	1.685	-1.768	-4.769	-4.045	-0.106	-3.990
SD	2.045	2.229	2.592	3.414	1.807	2.549	4.183	7.568	1.828	2.079	2.496	2.538	4.061	2.183	3.312
Gini Coefficient															
1995-2018 Mean	26.93	27.02	24.09	24.74	28.24	28.33	33.49	30.78	33.21	27.95	25.70	34.56	33.26	24.45	33.74
SD	1.01	1.20	2.03	1.75	0.69	1.21	1.14	1.35	0.73	1.74	1.26	1.64	1.37	1.91	0.75
GDP($)*															
1990-2020 Mean	43407.4	40940.5	56135.8	41825.7	38772.7	39959.6	23381.5	47955.7	34887.6	95011.0	47022.2	21060.8	28574.7	47982.6	37175.7
SD	5294.2	4777.2	6036.5	6728.6	3619.3	4620.7	3226.1	16078.8	2139.4	14898.7	6192.5	2162.6	3433.1	7644.8	5010.0
Inflation(%)															
1990-2020 Mean	2.06	1.99	1.77	1.78	1.54	1.78	4.78	1.94	2.45	2.01	2.04	3.21	2.71	1.92	2.49
SD	0.91	0.99	0.82	1.21	0.84	1.12	5.84	2.08	1.78	0.97	0.84	3.32	1.90	2.44	1.65
LT Rates(%)															
1993-2020 Mean	4.91	3.59	3.43	3.55	3.43	3.13	NA	4.19	4.68	NA	3.28	5.05	4.36	3.68	3.96
SD	2.06	2.23	2.45	2.52	2.12	2.21	NA	2.56	2.72	NA	2.15	3.06	2.62	2.68	2.16
Military Expend(%)															
1990-2020 Mean	0.904	1.285	1.469	1.472	2.146	1.376	2.982	0.670	1.562	0.630	1.508	2.010	1.553	1.578	2.607
SD	0.144	0.381	0.242	0.180	0.311	0.298	0.442	0.298	0.174	0.141	0.338	0.202	0.312	0.509	0.580
Trade Balance(%)															
1990-2020 Mean	2.207	4.187	4.568	1.708	-3.633	3.706	3.469	7.940	14.211	17.340	1.137	-3.169	1.785	1.551	1.190
SD	2.026	1.687	1.268	3.872	1.476	2.811	3.598	6.427	1.778	7.432	1.916	3.997	2.986	1.716	0.873
Unemployment(%)															
1995-2020 Mean	5.16	7.81	5.64	9.15	9.63	7.16	NA	8.32	9.72	4.42	5.20	9.19	16.14	7.40	5.96
SD	0.74	1.14	1.23	2.17	1.38	2.44	NA	3.85	1.85	1.46	1.46	3.44	5.29	1.13	1.43

Note: *Measured *per capita* .

3. Results

3.1. Results for basic time series statistics

The primary focus of this study is *convergence* of EU panel indicators *over time*. Means and standard deviations are interesting and useful, but they tell us little about the time series properties of our data. As more fully discussed in Phillips (2001) and Clark and Coggin (2011), if time series data are not (covariance) *stationary* the sample mean has *no* asymptotic limit.

Thus, technically speaking, there is *no* “mean value” for a nonstationary time series. For this reason, we also include an analysis of *stationarity* and *trends* in our data. With only a maximum of 31 data points (years) for our indicator variables (1990-2020), we did not attempt an analysis of our data including a *structural break*. This is also consistent with our goal of specifically examining the time period since the formation of the EU up until the present. We now proceed with tests for stationarity.

As discussed below, stationarity of the *primary* panel data is *not* required for convergence to exist, but it is still of interest to know. It is important to note here that the concept of convergence can apply to individual *pairs* of variables [see *e.g*. Pesaran (2007)] or a whole *panel* of variables [see *e.g*. Phillips and Sul (2007a, 2007b, 2009)]. Table 3 presents the results of the Elliott, Rothenburg and Stock (1996) ADF-GLS unit root test applied to the 12 individual indicators across 15 EU countries. In Table 3, we see that a majority of countries in our sample do *not* reject the unit root (nonstationarity) null hypothesis for all or a majority of their indicator variables. In order for convergence to exist, the indicator variables (pairs or panels) should converge to a steady state level. We will explore this in more detail later in our presentation.

Table 3.

Elliott, Rothenburg and Stock (1996) DF-GLS unit root test

	Number reject H(0) at 0.05 level
CO_2(15)	None
Footprint(15)	1
Fossil Fuels(15)	None
Complexity(13)	2*
Deficit(15)	5*
Gini Coefficient(15)	None*
lnGDP(15)	None
Inflation(15)	None
LT Rates(13)	None**
Military Expend(15)	None
TradeBalance(15)	3
Unemployment(15)	5*

Note: Number of countries in ( ). *Data begin 1995. **Data begin in 1993.
The specification of the DF-GLS test includes a constant term.

Trends are also of interest in analyzing convergence. As will be discussed below, trends are central to the definition and measurement of convergence [see Sul (2019a, Chapter 7) for a full discussion]. For this reason, we apply the time series regression test of Perron and Yabu (2009) on the slopes of time trends that is valid whether the time is series is trend-stationary or has an autoregressive unit root. The test is the (standard normal) t-test on the trend in a time series regression of the individual indicator variable onto a constant term and a deterministic time trend. The complete details of the test are presented in Perron and Yabu (2009). In Table 4 we see the results of the t-tests on the slopes of the deterministic time trends for our two panels of macroeconomic and environmental indicators. The null hypothesis for these t-tests is that the slope of the time trend estimate (β in their notation) is zero.

Table 4.
Perron-Yabu (2009) deterministic trend (β) t-stat

	Austria	Belgium	Denmark	Finland	France	Germany	Greece	Ireland	Italy	Luxembourg	Netherlands	Portugal	Spain	Sweden	UK
Voter Turnout(%)															
1970-2020	-6.478*	-0.569	-1.315	-3.748*	-0.369	-5.102*	-2.165*	-5.051*	-3.290*	-0.133	-1.016	-5.674*	-0.866	-0.134	-0.318
Panel One: Environment															
CO_2(Tons)															
1990-2018	-0.237	-2.295*	-2.435*	-1.010	-1.801	-3.533*	-0.540	-0.563	-1.348	-1.794	-1.331	0.459	-0.006	-1.864	-2.917*
Footprint															
1990-2017	1.503	1.016	0.065	0.122	0.390	-1.241	0.274	0.077	0.408	0.804	0.279	1.192	0.430	1.561	-0.360
Fossil Fuels(%)															
1990-2019	-2.130*	-1.276	-5.227*	-2.085*	-5.498*	-14.047*	-2.782*	-3.328*	-1.849	-3.350*	-3.640*	-1.020	-0.440	-1.638	-2.569*
Panel Two: Macroeconomy															
Complexity															
1995-2018	-1.580	NA	-3.312*	-0.820	-3.097*	-0.558	0.941	0.031	-0.607	NA	-5.921*	1.946	-3.636*	-0.925	-1.000
Deficit(%)															
1995-2020	0.512	-0.475	0.231	0.043	-0.508	0.532	0.510	-0.100	0.374	-1.539	0.395	0.087	-0.313	0.467	-0.578
Gini Coefficient															
1995-2018	1.852	-4.488*	2.317*	1.581	-0.161	13.869*	-1.377	-1.124	0.377	4.224*	0.462	-1.149	-0.648	4.655*	-1.262
lnGDP															
1990-2020	2.823*	2.806*	3.415*	1.971*	1.886	20.781*	0.196	4.466*	0.462	3.003*	2.011*	2.141*	0.646	2.907*	2.068*
Inflation(%)															
1990-2020	-0.771	-1.752	-2.160*	-1.340	-2.724*	-1.152	-2.600*	-2.015*	-5.154*	-1.990*	-2.036*	-1.986*	-5.055*	-0.988	-1.401
LT Rates(%)															
1993-2020	-4.252*	-6.203*	-15.309*	-10.675*	-9.416*	-10.072*	NA	-1.023	-3.532*	NA	-8.276*	-2.276*	-1.396	-10.822*	-13.149*
Military Expend(%)															
1990-2020	-1.607	-1.841	-1.348	-0.049	-1.631	-1.757	-3.607*	-4.234*	-0.656	-0.351	-0.762	-0.633	-2.189*	-3.197*	-1.015
Trade Balance(%)															
1990-2020	1.042	-0.298	0.525	0.274	-0.447	1.390	0.309	2.668*	0.685	10.691*	11.760*	0.606	0.882	1.029	0.536
Unemployment(%)															
1995-2020	2.520*	-1.268	-0.277	-1.952	-1.271	-1.272	NA	-0.328	-0.237	1.492	-0.916	-0.004	-0.206	-0.123	-1.326

Note: H(0): β=0, two-sided test, standard normal. * Significant at 0.05 level or less.

We now list some highlights of the results in Table 4. One would desire voter turnout to increase, or at least stay the same. However, the slopes of *Voter Turnout* are negative and significantly negative in 7 of the 15 countries and statistically zero in 8. We suggest that this is a finding that is in need of further investigation in future research. For the Environmental variables, the most desirable outcome would be for all the slopes to be negative. All slopes of *CO_2* Emissions (per capita) are negative but only significant for 4 countries (Belgium, Denmark, Germany and UK). Ecological *Footprint* is a measure of the impact of human activity on nature; i.e., how much of nature's resources are needed to sustain human activity in a geographical location. None of the *Footprint* slopes are significantly different from zero. All slopes of *Fossil Fuels (%)* are negative with ten significantly so. Thus the time trend slope tests in Table 4 suggest that more progress is being made on reducing fossil fuels usage than on reducing CO_2 emissions in the EU. No doubt this will be a topic of ongoing research by academics and EU policy makers.

For the Macroeconomic variables, a more mixed picture emerges. Economic *Complexity* is rather complicated, but basically a measure of how well a country organizes its productive capabilities. A basic discussion is given in Hidalgo and Hausmann (2009). One would generally want *Complexity* to be positive and increasing. While Table 2 indicates that *Complexity* is (mean) positive for every country with complete data, the slopes in Table 4 are mixed with 4 significantly negative and the rest statistically zero. The slopes of *Deficit (%)* are all statistically zero. *Gini Coefficient* is a number between 0 and 1 that measures the degree of income inequality in a country or region, with 1 denoting perfect inequality. The SWID index that we use here is a standardized index that seeks to maximize the comparability of Gini income inequality estimates across countries and years. A more full discussion is given in Solt (2016) and Camacho and Palmieri (2019). One would generally want Gini slopes to be decreasing (i.e., trending toward 0 ➔ more equality of income). The results in Table 4 are decidedly mixed, with only 1 significantly negative and 4 significantly positive. The *lnGDP* (log per capita) slopes are all positive, with 11 significantly so. *Inflation (%)* slopes are all negative, with 9 significantly so. *Long-term Rates* slopes are all negative for every country with complete data, with 11 significantly so. *Military Expenditures (%)* slopes are all negative, with 4 significantly so. *Trade Balance(%)* is the external balance on goods and services as % of GDP. One would generally like this number to be positive indicating a surplus. Table 2 indicates that the means are all positive except France and Portugal. Table 4 indicates the slopes are all positive with 2 significantly so (Ireland and Netherlands). *Unemployment* (% of Labor Force) slopes are not significantly different from zero, except for Austria which is significantly positive. Having now presented the results for our basic time series statistics we now move to our main focus, a discussion of the *convergence* properties of our sample of indicators.

3.2. Econometric convergence tests and results

As discussed by Sul (2019a) and elsewhere, the notion of "convergence" has a prominent place in the social science literature, and is also a focus of the founding of the EU. A recent comprehensive discussion and summary of the convergence literature is presented in Johnson and Papageorgiou (2020). While relatively easy to discuss qualitatively, it presents a challenge to define statistically. Fortunately the econometric literature provides a number of quantitative tests for convergence. In this section we will present and briefly define two of the most recent tests.

3.2.1. Phillips and Sul log t regression panel convergence tests

In series of papers, Phillips and Sul (2007a, 2007b, 2009; hereafter PS) present what they describe as a nonlinear time-varying factor model of panel convergence that has become very popular and widely used in applied econometric analysis. They call their model *relative convergence*. As noted by PS and discussed in Desli and Gkoulgkoutsika (2020), the relative convergence model of PS allows *both* deterministic *and* stochastic trends, does not assume linearity and allows "asymptotic cointegration." The relative convergence model of PS also addresses some of the pitfalls in the well-known *β-convergence* model described in Barro and Sala-i-Martin (1991, 1992). Young, *et al*. (2008) discuss problems that can arise when testing for both beta and sigma convergence together. In addition, Desli and Gkoulgkoutsika (2020) argued that tests of *stochastic convergence* which rely on unit root testing [as in Pesaran (2007)] may not be as informative as full panel tests that allow both stochastic and deterministic trends [as in the model of PS] and may even *understate* evidence for convergence.

The full details of the relative convergence model and its development are beyond the scope of this paper [see Sul (2019a, Chapter 7)]. However, it can be briefly described as follows. Relative convergence holds if the variance of the *ratio* of the *individual* country time trend slopes to the cross-sectional *average panel* time trend slope converges to zero over time. They note that relative convergence is particularly useful if the variables show trending behavior. To formally test relative convergence, PS further developed the log *t* panel regression test. The full details are presented in PS. Using their notation, the log *t* panel regression model is:

$$\log H(1)/H(t) - 2*\log(\log t) = a + b*\log t + u(t) ,$$

where H(1)/H(*t*) denotes a cross-sectional variance ratio, *t* denotes time, a and b are OLS time series regression estimates and u(*t*) is a zero-mean random error term. This regression equation is called a *log t* regression by PS because of the log *t* regressor. The presence of the log–log *t* term on the left side of the equation arises because it is helpful in assuring good power properties of the test. The null hypothesis of the panel log *t* regression is:

H(0) : Convergence for *all i* vs. H(A) : No convergence for *some i* ,

where *i* denotes panel member *i*. The log *t* relative convergence test is the heteroscedasticity and autocorrelation consistent *t*-statistic on the estimated b-coefficient for (null hypothesis) b>=0. Thus the test is considered one-sided standard normal and is significant (reject convergence) at the 0.05 level if t< -1.65.

Establishing panel *convergence and convergence clubs* is a multi-step process described in full in detail in PS. The process first applies the log *t* test to the entire panel. If this test is satisfied, the entire panel is deemed a convergence club. If not, smaller convergence clubs are formed (if possible) which pass the log *t* test until all panel members are in a sub-group or no more sub-groups pass the test. It is therefore possible that *all* panel members will form a convergence club (panel convergence), *some* will form convergence clubs, or *none* will.

Table 5 presents the results of the Phillips-Sul log *t* panel regression test applied to our environmental and macroeconomic panels. We see in Table 5 that in every case except *Deficit* the null hypothesis of panel convergence is *rejected* at the 0.05 level or less. However those results have a problem which we will address below.

Table 5.
Phillips and Sul log t regression relative convergence test
H(0): Convergence [Reject for t-alpha < -1.65, 0.05 level]

Panel One: Environment	Panel Two: Macroeconomy		
CO_2	Complexity	lnGDP	Military Expend
1990-2018 (N=15)	1995-2018 (N=13)	1990-2020 (N=15)	1990-2020 (N=15)
t = -6.548*	t = -7.528*	t = -31.459*	t = -25.152*
Footprint	Deficit	Inflation	TradeBalance
1990-2017 (N=15)	1995-2020 (N=15)	1990-2020 (N=15)	1990-2020 (N=15)
t = -14.021*	t = -0.273	t = -1.912*	t = -2.169*
Fossil Fuels	Gini Coefficient	LT Rates	Unemployment
1990-2019 (N=15)	1995-2018 (N=15)	1993-2020 (N=13)	1995-2020 (N=14)
t = -28.100*	t = -2.458*	t= -3.087*	t = -11.135*

Note: *Reject H(0) at 0.05 level or less.

3.2.2. Problems with the β-convergence and PS relative convergence models

Sul (2019a, Chapter 7, 2019b) discusses some general problems and pitfalls in tests of convergence. As explained in Sul (2019a, 2019b) the β-convergence model of Barro and Sala-i-Martin (1991, 1992) can result in a "statistical illusion." That is, even in cases where the cross-sectional variance of y_{it} *increases*, β-convergence still holds. Furthermore, the relative convergence tests of PS become problematic when the panel data of interest have sign changes or do *not* display deterministic or stochastic *trends*. Specifically, when panel data include distinct stochastic trends, the nonstationarity in the data assists in identifying club membership. *Otherwise applying the relative convergence model and testing for "convergence clubs" does not work*. As shown in Table 4, our indicator variables display a *mix* of positive, negative and zero trends. Thus we do not present tests for convergence clubs here because, as explained above, they are not appropriate for our data. The PS relative convergence regression *only* works when y_{it} has a (non)stochastic trend. These results, detailed in Kong, Phillips and Sul (2019, 2020) and Sul (2019a, 2019b), are relatively new to the econometric literature on convergence.

3.2.3. Kong, Phillips and Sul weak σ-convergence test

In response to the problems associated with the relative convergence model of PS, Kong, Phillips and Sul (2019, 2020. hereafter KPS), develop the *weak σ-convergence* model in which *cross-section variation* in panel data *decreases* over time. The complete details are available in their papers, but we give a brief outline here.

KPS note that weak σ-convergence is related to the definition of convergence suggested by Milton Friedman (1992) who quoted Harold Hotelling, "*The real test of a tendency to converge would be in showing a consistent diminution of variance.*" Assume we want to test convergence of a cross-sectional panel variable y_{it} (country i at time t). KPS discuss and propose a simple t-test of the parameter estimate, φ , in the linear trend regression:

$$K^{y}_{nt} = a + \varphi t + u_t ,$$

where K^{y}_{nt} is the sample cross-section variance of y_i , a is the regression intercept, t is a linear time-trend and u_t is a zero-mean random error term. As a test of weak σ-convergence, they use the Newey-West (Bartlett kernel) corrected t-statistic on φ, t_φ . They propose the following decision rule for the null hypothesis of No weak σ-convergence:

$$t_\varphi < -1.65 \Rightarrow \textit{accept weak } \sigma\textit{-convergence}$$

$$-1.65 < t_\varphi < 1.65 \Rightarrow \textit{fluctuating } y_i$$

$$1.65 < t_\varphi \Rightarrow \sigma\textit{-divergence}$$

Thus weak σ-convergence is consistent with the original concept and meaning of convergence. That is, if cross-sectional variance is overall *decreasing* over time, weak σ convergence holds.

As described and presented in the results for Table 4 above, the estimated statistical trends of our macroeconomic and environmental indicators are a mix of positive, negative and zero. As discussed above, this presents a serious problem for estimating the relative convergence model of PS, and suggests that weak σ-convergence model of KPS is the appropriate model for our data. As noted in Sul (2019b), many empirical researchers have traditionally used the notion of weak σ convergence, but they didn't define it as such and know how to test it properly. Our study is among the first to correctly apply the weak σ convergence model. The results are presented in Table 6.

Table 6.

Kong, Phillips and Sul (2019) weak σ-convergence test

H(0): No weak σ-convergence

Panel One: Environment	Panel Two: Macroeconomy		
CO_2	Complexity	lnGDP	Military Expend
1990-2018 (N=15)	1995-2018 (N=13)	1990-2020 (N=15)	1990-2020 (N=15)
t = -5.270*	t = -6.546*	t = 5.135***	t = -8.175*
Footprint	Deficit	Inflation	TradeBalance
1990-2017 (N=15)	1995-2020 (N=15)	1990-2020 (N=15)	1990-2020 (N=15)
t = 5.149***	t = 0.138**	t = -3.759*	t = 6.832***
Fossil Fuels	Gini Coefficient	LT Rates	Unemployment
1990-2019 (N=15)	1995-2018 (N=15)	1993-2020 (N=13)	1995-2020 (N=14)
t = 4.511***	t = -8.814*	t= 0.355**	t = 0.545**

Note:

$t_\varphi < -1.65$ ==> accept weak σ-convergence, 0.05 level*

$-1.65 < t_\varphi < 1.65$ ==> fluctuating y_i**

$1.65 < t_\varphi$ ==> σ-divergence***

The results in Table 6 for weak σ convergence are in rather stark contrast to those presented in Table 5 for the PS convergence model. All but one indicator *rejects* convergence using the PS model in Table 5, whereas weak σ-convergence is *accepted* for 5 indicators in Table 6 (CO_2, Complexity, Gini Coefficient, Inflation and Military Expenditures). *Weak σ-divergence* is indicated for 4 indicators (Footprint, Fossil Fuels, lnGDP and Trade Balance). We now present a summary of this comparison in Table 7.

Perhaps the key result in Table 7 is that *the convergence model analysts use to define and measure convergence matters*. As explained above, convergence models are heavily dependent on trends in the data. Our data contain a mixture of positive, negative and zero trends. The existence of zero trends and both positive and negative trends render currently popular convergence models generally inappropriate and highly misleading. If we were to rely on our results for the PS relative convergence model alone to evaluate EU convergence, we would conclude that is it nearly nonexistent in our indicator data. Also as noted above, when the data contain no trends or contain conflicting trends, the weak σ-convergence is more appropriate. This strongly suggests a strategy of *pretesting data* for the existence of trends before selecting a convergence model. If trends are present and there are no sign changes, one can proceed with the relative convergence model of PS and test for the existence of convergence clubs. Otherwise the weak σ-convergence model of KPS is the appropriate model. Based on the weak σ-convergence model, we see evidence for convergence in 5 of the 12 indicators (4 macroeconomic and 1 environmental). Weak σ-divergence was found in 4 of the 12 indicators convergence (2 macroeconomic and 2 environmental). Desli and Gkoulgkoutsika (2020) argued that tests that allow both stochastic and deterministic trends [as in the model of PS] are preferred to tests of *stochastic convergence* [as in Pesaran (2007)]. We go a step further and suggest that the relatively new weak σ-convergence model of KPS is generally to be preferred to the popular relative convergence model of PS, especially in cases where the two models disagree.

Table 7.
Comparison of relative and weak σ-convergence test results

	Relative Convergence	Weak σ-convergence	Decision*
CO_2	No convergence	Weak σ-convergence	Weak σ-convergence
Footprint	No convergence	σ-divergence	σ-divergence
Fossil Fuels	No convergence	σ-divergence	σ-divergence
Complexity	No convergence	Weak σ-convergence	Weak σ-convergence
Deficit	Convergence	Fluctuating	Fluctuating
Gini Coefficient	No convergence	Weak σ-convergence	Weak σ-convergence
lnGDP	No convergence	σ-divergence	σ-divergence
Inflation	No convergence	Weak σ-convergence	Weak σ-convergence
LT Rates	No convergence	Fluctuating	Fluctuating
Military Expend	No convergence	Weak σ-convergence	Weak σ-convergence
TradeBalance	No convergence	σ-divergence	σ-divergence
Unemployment	No convergence	Fluctuating	Fluctuating

*Note: Decision ==> Choose weak σ-convergence result when results differ.

4. Summary and Conclusion

If we measure from the formal signing of the Maastricht Treaty in 1992 and its entry into force in 1993, the EU entered its 27^{th} year in 2020. As noted in the Introduction, the EU has a stated goal of achieving "economic convergence." Membership in the 1997 Kyoto Protocol and subsequent agreements also suggests a level of "environmental convergence" in limiting the emission of greenhouse gases. This paper presents a detailed analysis and quantitative summary of progress toward EU macroeconomic and environmental indicator convergence over the period 1990-2020 using a sample of 15 EU member countries and 12 macroeconomic and environmental indicators.

Our study makes two contributions: one substantive and one methodological. One, it presents a summary of progress toward the stated goals of macroeconomic and environmental indicator convergence as of 2020. Two, it discusses and gives an example of how using an inappropriate convergence model can lead to incorrect and misleading results, and suggests a testing strategy to obtain more reliable results. Using the appropriate convergence model, we found evidence for weak σ-convergence in 5 of the 12 indicators (4 macroeconomic and 1 environmental). Thus progress toward EU economic and environmental convergence remains mixed. Our study ends with data for 2020 (as the available data permitted). The question for academic and governmental policy analysts now is how will macroeconomic and environmental convergence progress evolve *after* the massive disruption caused by the worldwide COVID-19 pandemic and the departure of the UK which took place in late 2020? This point is also emphasized in the Eurofound study by Mascherini (2020). New members to the EU are also being added. These issues will undoubtedly be the subject of numerous future research projects.

Appendix

Data Sources
Voter Turnout (v2eltrnout) (V-Dem Dataset -Version 11.1, % of all registered voters who cast a vote in the national election according to official results): https://www.v-dem.net/en/data/data/v-dem-dataset-v111/

Environmental Data
CO_2 (Emissions, Metric Tons Per Capita): https://data.worldbank.org/indicator/EN.ATM.CO2E.PC

Footprint (Ecological Footprint, Number of Earths): https://data.footprintnetwork.org/?_ga=2.234103193.682788949.1633103678-1586343266.1633103678#/countryTrends?

Fossil Fuels (% Share of Primary Energy from Fossil Fuels): https://ourworldindata.org/fossil-fuels#per-capita-where-do-people-consume-the-most-energy-from-fossil-fuels

Macroeconomic Data
Complexity (Economic Complexity Index): https://oec.world/en/rankings/eci/hs4/hs92

Deficit (General Government Deficit as % of GDP): https://data.oecd.org/gga/general-government-deficit.htm

GDP (Real GDP Per Capita, Constant 2010 $US): https://data.worldbank.org/indicator/NY.GDP.PCAP.KD

Gini Coefficient (SWID 9.1 Database): https://github.com/fsolt/swiid.git

Inflation (Consumer Price Index, % Annual Rate): https://data.worldbank.org/indicator/FP.CPI.TOTL.ZG

Long-term Interest Rates (% rate at year end on government bonds maturing in ten years): https://data.oecd.org/interest/long-term-interest-rates.htm

Military Expenditure (% of GDP) https://data.worldbank.org/indicator/MS.MIL.XPND.GD.ZS

Trade Balance (External balance on goods and services as % of GDP): https://data.worldbank.org/indicator/NE.RSB.GNFS.ZS

Unemployment (Total, % of Labor Force): https://data.oecd.org/unemp/unemployment-rate.htm

References

Aldrich, J. (1993). "Rational Choice and Turnout." *American Journal of Political Science* 37:246-278. https://doi.org/10.2307/2111531

Baimbridge, M., B. Burkitt, and P. Whyman. (1999). "Convergence Criteria and EMU Membership: Theory and Evidence." *Journal of European Integration* 21:281-305. https://doi.org/10.1080/07036339908429071

Barro, R.J. and X. Sala-i-Martin. (1991). "Convergence Across States and Regions." *Brookings Papers on Economic Activity* 1:107.158. https://doi.org/10.2307/2534639

Barro, R.J. and X. Sala-i-Martin. (1992). "Convergence." *Journal of Political Economy* 100:223-251. https://doi.org/10.1086/261816

Caglar, A.E., D. Balsalobre-Lorente, and C.S. Akin. (2021). "Analysing the Ecological Footprint in EU-5 Countries Under a Scenario of Carbon Neutrality." *Journal of Environmental Management* 293:113155. https://doi.org/10.1016/j.jenvman.2021.113155

Clark, S.P., and T.D. Coggin. (2011). "Are U.S. Stock Prices Mean Reverting? Some New Tests Using Fractional Integration Models with Overlapping Data and Structural Breaks." *Empirical Economics* 40:373–391. https://doi.org/10.1007/s00181-010-0338-y

Camacho, M., and G. Palmieri. (2019). "Do Economic Recessions Cause Inequality to Rise?" *Journal of Applied Economics* 22:304-320. https://doi.org/10.1080/15140326.2019.1620982

Cavallaro, E., and I. Villani. (2021). "Real income convergence and the patterns of financial integration in the EU." *The North American Journal of Economics and Finance* 56:101337. https://doi.org/10.1016/j.najef.2020.101337

Desli, E., and A. Gkoulgkoutsika. (2020). "World Economic Convergence: Does the Estimation Methodology Matter?" *Economic Modelling* 91:138-147. https://doi.org/10.1016/j.econmod.2020.05.027

del Hoyo, J.L.D., E, Dorrucci, F.F. Heinz, and S. Muzikarova. (2017). "Real Convergence in the Euro Area: A Long-term Perspective." Occasional Paper Series No. 203, European Central Bank, Luxembourg.

Dickey D.A., and W.A. Fuller. (1979). "Distribution of the estimators for autoregressive time series with a unit root." *Journal of the American Statistical Association* 74:427–431. https://doi.org/10.1080/01621459.1979.10482531

Elliott, G., T.J. Rothenburg, and J.H. Stock. 1996. "Efficient Tests for an Autoregressive Unit Root." *Econometrica* 64:813-836. https://doi.org/10.2307/2171846

European Commission. (2020). *Convergence Report*, Institutional Paper 129, June 2020. https://ec.europa.eu/info/publications/convergence-report-2020_en.

European Commission. (2021). *Convergence criteria for joining*. https://ec.europa.eu/nfo/business-economy-euro/euro-area/enlargement-euro-area/convergence-criteria-joining_en.

Eurostat. 2021. *Government Expenditure on Defence*. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Government_expenditure_on_defence.

Eckey, H-F., and M. Türck. (2007). "Convergence of EU-Regions. A Literature Report," *Investigaciones Regionales* 10:5-32.

Friedman, M. (1992). "Do Old Fallacies Ever Die?" *Journal of Economic Literature* 30:2129-2132.

Glawe, G. and H. Wagner. (2021). "Divergence Tendencies in the European Integration Process: A Danger for the Sustainability of the E(M)U?" *Journal of Risk and Financial Management* 14:104. https://doi.org/10.3390/jrfm14030104

Hidalgo, C.A., and R. Hausmann. (2009). "The Building Blocks of Economic Complexity," *PNAS* 106:10570–10575. https://doi.org/10.1073/pnas.0900943106

Johnson, P. and C. Papageorgiou. (2020). "What Remains of Cross-Country Convergence?" *Journal of Economic Literature* 58:129–175. https://doi.org/10.1257/jel.20181207

Kollias, C., and P. Messis. (2021). Institutional Quality Convergence in the Euro Area Countries: A Note and Further Evidence." *Journal of Contemporary European Studies.* Online May 2021. https://doi.org/10.1080/14782804.2021.1924642

Kong, J., P.C.P. Phillips, and D. Sul. (2019). "Weak σ-convergence: Theory and applications." *Journal of Econometrics* 209:185-207. https://doi.org/10.1016/j.jeconom.2018.12.022

Kong, J., P.C.B Phillips, and D. Sul. (2020). "Testing Convergence Using HAR Inference", in Li, T., Pesaran, M.H. and Terrell, D. (Eds.) *Essays in Honor of Cheng Hsiao* (*Advances in Econometrics, Vol. 41*), Emerald Publishing Limited, 25:72. https://doi.org/10.1108/S0731-905320200000041002

Lu, W-C. (2020). "The Interplay Among Ecological Footprint, Real Income, Energy Consumption, and Trade Openness in 13 Asian Countries." *Environmental Science and Pollution Research* 27:45148–45160. https://doi.org/10.1007/s11356-020-10399-7

Mascherini, M. (2020). *Upward Convergence in the EU: Definition, Measurement and Trends*. Publications Office of the European Union, Luxembourg.

Morales-Lage, R., A. Bengochea-Morancho, M. Camarero, and I. Martínez-Zarzoso. (2019). "Club convergence of sectoral CO_2 emissions in the European Union." *Energy Policy* 135: 111019. https://doi.org/10.1016/j.enpol.2019.111019

Neagu, O. (2020). "Economic Complexity and Ecological Footprint: Evidence from the Most Complex Economies in the World." Sustainability 12:9031. https://doi.org/10.3390/su12219031

OECD, (2017). *Understanding the Socio-Economic Divide in Europe*. OECD Center for Opportunity in Europe.

Pérez-Moreno, S., E. Bárcena-Martín, and J. Ritzen. (2020). "Institutional Quality in the Euro area Countries: Any Evidence of Convergence?" *Journal of Contemporary European Studies* 28:387-402. https://doi.org/10.1080/14782804.2020.1779044

Perron, P., and T. Yabu. (2009). "Estimating Deterministic Trends with an Integrated or Stationary Noise Component." *Journal of Econometrics* 151:56-69. https://doi.org/10.1016/j.jeconom.2009.03.011

Pesaran, M.H. (2007). "A Pair-wise Approach to Testing for Output and Growth Convergence." *Journal of Econometrics* 138:312-355. https://doi.org/10.1016/j.jeconom.2006.05.024

Phillips, P.C.B, (2001). "Descriptive Econometrics for Non-stationary Time Series with Empirical Illustrations." *Journal of Applied Economics* 16:389–413. https://doi.org/10.1002/jae.600

Phillips, P.C.B., and D. Sul. (2007a). "Transition Modeling and Econometric Convergence Tests." *Econometrica* 75:1771-1855. https://doi.org/10.1111/j.1468-0262.2007.00811.x

Phillips, P.C.B., and D. Sul. (2007b). "Some Empirics on Economic Growth under Heterogeneous Technology." *Journal of Macroeconomics* 29:455-469. https://doi.org/10.1016/j.jmacro.2007.03.002

Phillips, P.C.B., and D. Sul. (2009). "Economic Transition and Growth." *Journal of Applied Econometrics* 24:1153-1185. https://doi.org/10.1002/jae.1080

Próchniak, M., and B. Witkowski. (2013). "Time Stability of the Beta Convergence Among EU Countries." *Economic Modelling* 30:322-333. https://doi.org/10.1016/j.econmod.2012.08.031

Said S.E., and D.A. Dickey. (1984). "Testing for unit roots in autoregressive moving average models of unknown order." *Biometrika* 71:599–607. https://doi.org/10.1093/biomet/71.3.599

Solt, F. (2016). "The Standardized World Income Inequality Database." *Social Science Quarterly* 97:1267-1281. https://doi.org/10.1111/ssqu.12295

Sul, D., (2019a). *Panel Data Econometrics*. Routledge. https://doi.org/10.4324/9780429423765

Sul, D., (2019b). "Econometrics Of Convergence & Cross-sectional Dependence." *Power Point* presentation available at https://personal.utdallas.edu/~dxs093000/book/panel.htm .

Tardi, C. (2021). "The Kyoto Protocol." https://www.investopedia.com/terms/k/kyoto.asp.

Wilde, R. (2019). "The History of the European Union." https://www.thoughtco.com/the-history-of-the-european-union-1221595.

Yin, L., G.K. Zestos, and L. Michelis. (2003). "Economic Convergence in the European Union." *Journal of Economic Integration* 18:188-213. https://doi.org/10.11130/jei.2003.18.1.188

Young, A.T., M.J. Higgins, and D. Levy. (2008). "Sigma Convergence versus Beta Convergence: Evidence from U.S. County-Level Data." *Journal of Money, Credit and Banking* 40:1083-1093. https://doi.org/10.1111/j.1538-4616.2008.00148.x