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REAL CONVERGENCE IN PER CAPITA OUTPUT AND GROWTH IN EUROZONE: A TIME-SERIES APPROACH

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Abstract

Real convergence in per capita output and growth in Eurozone: a time-series approach

The real convergence hypothesis has spurred a myriad of empirical tests and approaches in the economic literature. This Work Project intends to test for real output and growth convergence in all N(N-1)/2 possible pairs of output and output growth gaps of 14 Eurozone countries. This paper follows a time-series approach, as it tests for the presence of unit roots and persistence changes in the above mentioned pairs of output gaps, as well as for the existence of growth convergence with autoregressive models. Overall, significantly greater evidence has been found to support growth convergence rather than output convergence in our sample.

JEL classification: C32, E01, E23, O4, O11

Keywords: convergence, economic growth, stationarity, persistence change

I. Introduction

With the inception of the European Economic Community (EEC) with the Treaty of Rome in 1957, we witnessed in the second half of the 20th century a significant deepening of commercial, social and institutional relations between European countries. In the aftermath of World War II, many European regions were still deprived of resources and communities struggled to make ends meet. In such a context and alongside the European project, the European Social Fund (ESF) was created in 1958, subsequently followed by the European Regional Development Fund (ERDF) in 1975. Both these funds had at their cornerstone the idea of providing funds to regions in difficulty in order to equip them with the means to converge with the richer regions in Europe. Such funds started gaining a great deal of momentum with the accession of Greece, Spain and Portugal to ensure that their level of output would increase and be more on par with the remaining members of the EEC. Since then, every entrant in the now European Union has had the chance to benefit from such structural funds, a powerful tool for convergence across Europe.

But has it really been a powerful tool or not? In the literature, the convergence hypothesis has found empirical mixed results and, when it comes to Europe, the same mixed results are found. The aims of this Work Project (WP) are twofold: firstly, we aim at testing real per capita output convergence in 14 countries of the Eurozone using a pair-wise time-series approach following Pesaran (2004) that also enables us to detect eventual persistence breaks and, additionally, we test for per capita output growth convergence with the usage of autoregressive models. When testing per capita output convergence we begin with a typical Augmented Dickey-Fuller (ADF) test complemented by a persistence change test, followed by the subsequent detection of a deterministic trend. As for real per capita output growth convergence we resorted to autoregressive models and their short and long-run intercepts to infer regarding the equalisation of such rates across the Eurozone. The main conclusions of this

WP is the strong evidence we found against long-run convergence in our sample and, in contrast, the significant evidence favouring the existence of real per capita output growth convergence. The rest of the paper is structured as follows: section II presents the literature review; section III develops the existing notions of output convergence; section IV contains the data and its description; section V presents our methodology and the empirical results whereas section VI concludes.

II. Literature Review

The Solow-Swan model (1956) predicts that similar economies, in terms of production technology and economic agents' preferences but with different rates of capital intensity, will converge to the same steady-state, thus shrinking over time their output differences. However, researchers came across incongruences between this model and empirical evidence and, also, this model does not predict secular per capita output growth, unless it is set via exogenous technological progress. Thus, it has spurred the development of other models that could explain long-term growth in economies using an endogenous growth approach, by including the source of growth in its intrinsic dynamics. Notable work under this approach was done primarily by Lucas (1988) and Romer (1986).

On the one hand, the Lucas model (1988) has, at its basis, the role of human capital in the production function of the economy. It extends the Solow-Swan model with a variable that captures the contribution of human capital to production and by modelling an equation that explains human capital formation endogenously. Long-term per capita output growth is explained by the model as human capital accumulation does not present diminishing returns. Moreover, by introducing a variable that captures human capital accumulation externalities, Lucas provides us with a model with increasing returns to scale, which predicts richer economies will grow faster than poorer ones. On the other hand, the Romer (1986) model considered in his paper presents a framework of analysis with the inclusion of non-diminishing returns to capital in the aggregate economy due to positive knowledge externalities between economic agents. Unlike the Arrow (1962) version of this model, Romer's version has explosive growth associated to it, as the aggregate production function exhibits increasing returns to scale. Economies with more capital intensity will produce higher growth rates than economies with less capital intensity and, therefore, this model does not present any theoretical grounds for the notion of convergence between countries.

Following Durlauf, Johnson and Temple (2004), we have as main empirical approaches to the convergence phenomenon the cross-country approach and the time-series approach. On the one hand, the cross-country approach sets out to determine if a country is undertaking β-convergence or not, and relies on the neoclassical model of growth with or without extensions. Thus, it is tested if β<0 in the following regression as presented by Durlauf (2003):

$$g_i = y_{i,0}\beta + X_i\delta + Z_i\gamma + \varepsilon_i \tag{1}$$

where g_i is the real per capita output of a given country i on a time interval, $y_{i,0}$ is the per capita output on the outset of the series, X_i refers to a set of additional regressors implied by the neoclassical model, Z_i represents a group of regressors which are proxy for variables deemed relevant in new economic growth theories and ε_i is the error term.

Particular authors, who worked under this approach and yielded interesting results favouring convergence, were, among others, Baumol (1986), Dowrick and Nguyen (1989), Barro (1991), Barro and Sala-i-Martin (1992, 1991, 1990) and Mankiw, Romer and Weil (1990). Generally speaking, this approach has relevant critiques to it, as noted by Durlauf, Johnson and Temple (2004). Namely, these relate to the choice of control variables (Z) which may or not be relevant for the regression at stake, biasing the results; multicollinearity between the regressors and endogeneity and, lastly, variable measurement errors and the lack of power of such tests against non-convergent alternatives based on new growth theories or multiple equilibria models, like the Azariadis-Drazen (1990) model.

On the other hand, the time-series approach relies on testing for persistence of per capita output time series between economic units. As such, the effort is directed towards checking if a country pair's output gap series follows a time-invariant Wold representation, i.e., an infinite moving average. Nonetheless, it has the critique that it is not supported by any particular growth theory, as noted by Durlauf et al. (2009). Under this approach, research has been focused in detecting deterministic and unit root components present in such series. Should either of these components be present in the series, that will suggest that the series will not converge to zero in the long-run. This occurs because a time trend suggests that output differentials between the two countries have a time-varying mean and will increase/decrease at a steady linear rate. On the other hand, a unit root will make the series follow a random walk like behaviour implying that, at one given point, with probability 1, the series may become arbitrarily large. Conversely, a non-trending stationary output gap series indicates that both countries converge at an exponential rate in a similar fashion to a standard stationary autoregressive (AR) process. As such, the methodology associated with this approach is typically based on the usage of unit root tests and significance testing of time trends in the series. However, there are some critiques to this approach and its respective methodology. Firstly, Bernard and Durlauf (1996) claim time series tests applied to countries far from their invariant distributions but converging towards them will produce erroneous results as the sample mean will not provide valid inference for the asymptotic mean. Secondly, we have the issue of unit root testing not being valid in the presence of structural breaks in the series as pointed out by Perron (1989), i.e., not allowing for the existence of structural breaks when carrying out unit root tests may lead to spurious results. Thirdly and lastly, Michellacci and Zaffaroni (2000) refer that unit root testing may not be the correct tool to properly assess the existence of convergence when the series exhibit long memory, that is, when the shocks in the series fade away at a hyperbolic and not a typical geometric rate. As for notable results in the literature under this approach we have Bernard and Durlauf (1995) who turns to 15 advanced economies using Maddison data on GDP between 1900 and 1989, finding little evidence for convergence and Hobijn and Franses (2000), who also do not find significant evidence of convergence across 112 countries taken from the Penn World Table for the period 1960-1989 using a clustering algorithm for club convergence identification.

Finally, let us now focus on literature concerning the European case. Constantini and Lupi (2005) offer an approach to convergence in Europe based on independent and dependent panel unit root tests for 15 European countries using two subsamples with Germany as the benchmark country: the first between 1950 and 1976 and the second between 1977 and 2003. The results present significant evidence for convergence in the first period but not in the second. Moreover, we have a cluster analysis done by Monfort et al. (2013) using econometric techniques based on factor analysis which provide evidence on divergence in EU-14 countries globally speaking but, at the same time, detected the existence of 2 convergence clubs. Additionally, according to Gligorić (2014) and using a pair-wise panel unit root approach for a crisis and a non-crisis subsample with quarterly data spanning from 1995 until 2013, catching-up processes are prevalent in Europe while long-run convergence is restricted to 3 convergence clubs. Reza and Zahra (2008) study real convergence in the ten 2004 European Union entrants with the usage of different unit root tests finding evidence of absolute convergence and catching-up processes with the EU-25 average and the EU-15 per capita output. Finally, statistical evidence of β-convergence is found in the work done by Cuaresma et al. (2013) who regard human capital investments as a driver for output convergence within Europe.

III. Definition of Convergence

In the first place, let us compare the notion of β-convergence with σ-convergence. As defined by Durlauf, Johnson and Temple (2004), β-convergence is the first measure of convergence used in modern literature and is associated to cross-country approaches for testing the convergence hypothesis. It corresponds to the catching-up effect, on which a less capital-intensive country benefits from the technology diffusion made by the countries in the technological frontier and further benefits from having higher marginal products of capital. These two factors induce higher growth regimes in such countries. On the other hand, *σ-convergence* refers to the cross-country dispersion of output across countries. If this dispersion reduces, this means countries are experiencing convergence as it implies that cross-country output discrepancies are transitory. In the Appendix, Figures A.1 and A.2 shed some light on both these two measures in our sample. Regarding the β-convergence case, we have graphics on output growth vs initial per capita output on 3 periods, namely 1950-1980, 1980-2000 and 2000-2015. From these graphs, we have evidence that supports the hypothesis of the 14 countries in our sample converging as we verify that there is a negative relation between output growth and initial per capita output values as suggested by the downward trend in such graphs. However, such convergence is not verified in the 2000-2015 period and already undergoes some weakening in the 1980-2000 period. This appears to coincide with the oil crises and the dollar-gold standard associated to the ending of the Golden Age of growth during the 1970s. As for the 2000-2015 period, it seems to be coincidental with the adoption of the Euro as a single currency in 1999 (Greece only adopted it in 2002), but it should also be noted that the data is heavily influenced by the Great Recession of 2008. On the other hand, concerning σ-convergence, we verify that there is a steady rate of reduction in the dispersion of per capita outputs throughout our sample until the Great Recession, implying an overall catching-up process of the sample poorer economies.

Yet, let us now focus on the statistical definitions. According to Durlauf (2003), convergence can be defined as the $\lim_{k\to+\infty} \mu(g_{i,t+k} \,|S_{i,t}, \theta, \rho)$ not depending on $S_{i,t}$, being μ(.) a probabilistic measure, $S_{i,t}$ the human and physical capital endowments and θ and ρ the technology and preferences of the economy, respectively. This definition is furthered with two additional definitions by Bernard and Durlauf (1996). Their Definition 1 is stated as follows:

$$E\left(y_{i,t+T} - y_{j,t+T} \middle| \Im_t\right) < \; y_{i,t} - y_{j,t} \tag{2}$$

where $y_{i,t}$ and $y_{j,t}$ are the logs of per capita output of country i and j, respectively and $\Im_t$ represents all the information at time t. This means that output growth is not influenced by the initial endowments of human and physical capital of an economy, leading us to infer that the long-term reduction of output level discrepancies between economies is expected.

On the other hand, these authors also define convergence as the long-term equalisation of log per capita output for both countries at time t, as it is stated by the following equation:

$$\lim_{k\to+\infty} E(y_{i,t+k} - y_{j,t+k} |\, \Im_t) = 0 \tag{3}$$

Still, for our main analysis, we are going to use the definition of long-run convergence of Pesaran (2004). His definition of pair-wise convergence is a probabilistic one, and less restrictive than the one postulated by Bernard and Durlauf (1996), presented here as follows:

$$\lim_{s\to\infty} Pr\{\left|y_{i,t+s} - y_{j,t+s}\right| < C|\Im_t\} > 0 \tag{4}$$

where C corresponds to a tolerable constant value. This definition does not force long-run forecasts of output gaps between country pairs to converge to zero, allowing for converging economies to have different microeconomic fundamentals such as endowments, saving rates and population growth rates. An output differential series having a zero sample mean is not a necessary condition for the existence of convergence according to this definition.

IV. Data

The data retrieved for our analysis corresponds to annual observations of real per capita Gross Domestic Product (GDP) in Geary-Khamis dollars (international 1990 US dollars) of 14 Eurozone countries spanning from 1950 to 2015. The data was later logarithmised and used to calculate the N(N-1)/2 combinations of output differentials between the 14 countries, i.e., a total of 91 output differentials. This data was retrieved from The Conference Board Total Economy Database™ as of May 2015.

V. Methodology and empirical analysis

Following the definition of convergence proposed by Pesaran (2004) described earlier, we are going to represent the output gap series having as basis the model suggested by Lee, Pesaran and Smith (1996):

$$y_{it} - y_{jt} = (c_i - c_j) + (g_i - g_j)t + (u_{it} - u_{jt}) + \varepsilon_{ijt} \tag{5}$$

where $(c_i - c_j)$ is a fixed effect dependent on the country pairs respective initial conditions, $(g_i - g_j)t$ is a deterministic time trend related to the countries technological growth rates, $(u_{it} - u_{jt})$ is an idiosyncratic stochastic component of technology that follows an autoregressive process and $\varepsilon_{ijt} \sim iid(0, \sigma^2)$.

Consequently, we take the 91 log-linearized output differentials and we set out testing on its stationary properties using ADF regressions, using the lags determined by the Bayesian information criterion (BIC) and a significance level of 5%. In Table A.1, in the Appendix, we can find the results of such testing on our data. With these tests, alongside trend significance tests covered ahead, we come to the conclusion that long-run convergence is not happening in Eurozone as a whole, but we detect 7 long-run convergence cases which roughly represent 8% of all series. They are, namely, Belgium – Austria, Finland – Austria, Spain – Belgium, Germany – France, Italy – France, Netherlands – Germany and, lastly, Spain – Portugal. These were the only cases where the ADF tests revealed stationarity and we could not detect a deterministic component in the respective series.

For robustness and to complement these findings, we turn to the work developed by Harvey et al. (2006) on persistence change testing and their modified versions of ratio-based statistics developed by Kim (2000, 2002) and Busetti and Taylor (2004) as presented in the Appendix, model B.1. We apply to these series the Vogelsang-based approach variant of the modified mean, exponential and maximum score statistics to test for I(0) to I(1) persistence changes and their reciprocals for I(1) to I(0) persistence changes, i.e. $MS_{m\ min}$, $ME_{m\ min}$, $MX_{m\ min}$ and $MS_m{}^R{}_{min}$, $ME_m{}^R{}_{min}$, $MX_m{}^R{}_{min}$, respectively. According to the authors, these are the test-statistics which produce less size distortion and, at the same time, possess the most size-adjusted power. It should be noted that these tests dismiss 15% of the observations: the former in the beginning and their reciprocals in the end of the series and that we will only consider one persistence change due to our relatively small sample. Finally, these test statistics are compared to the critical values presented in the above mentioned paper correspondent for a sample size of T=100 and a nominal significance level of 5% (α=5%).

Finally, in order to detect if a deterministic trend is present in the series, we test for the series we found to be stationary the significance of a time trend with an OLS heteroskedasticity and autocorrelation consistent (HAC) Newey-West estimator in a model with a time trend and an AR component with lags also determined by the BIC:

$$y_{i,t} - y_{j,t} = \alpha_{ij} + \beta_{ij}t + \sum_{i=1}^{p} \gamma_{ij}\left(y_{i,t-i} - y_{j,t-i}\right) + \varepsilon_t \quad (6)$$

The summary of our results can be found in Table A.2, in the Appendix. For instance, in the first line of our table, Austria is our benchmark country and we found persistence changes for all countries with the exception of Ireland, Netherlands, Portugal and Spain. The persistence changes under this benchmark were mostly in the direction of I(1) to I(0), whereas Cyprus, Greece, Italy and Malta experienced an I(0) to I(1) persistence change. According to our results, a persistence change was detected in roughly 92% of all series, suggesting potential cases of convergence as the null hypothesis of nonstationarity is rejected in detriment of I(1) to I(0) scenarios in 39.56% of all country pair series and potential cases of divergence in the remaining 52.75%. Persistence changes were not detected in 7 series, from which only Netherlands – Germany presented constant stationarity. By jointly interpreting the results of the time trend significance tests and persistence change testing, we come to the conclusion that long-run output convergence happens in only 14 pairs (in bold in Table A.2), i.e., roughly 15% of all possible country pairs in our sample. The respective pairs are Belgium – Austria, Finland – Austria, Italy – Belgium, Spain – Finland, Germany – France, Italy – France, Netherlands – France, Netherlands – Germany, Luxembourg – Italy, Netherlands – Italy, Portugal – Luxembourg, Spain – Luxembourg, Netherlands – Spain and, finally, Portugal – Spain. These were the only cases where we did not detect a deterministic trend in a stationary process or in processes that underwent a shift from nonstationarity to stationarity. As an example of two long-run converging countries, we can find, in the graph below, the evolution of the logs of the Spanish and Portuguese GDP:

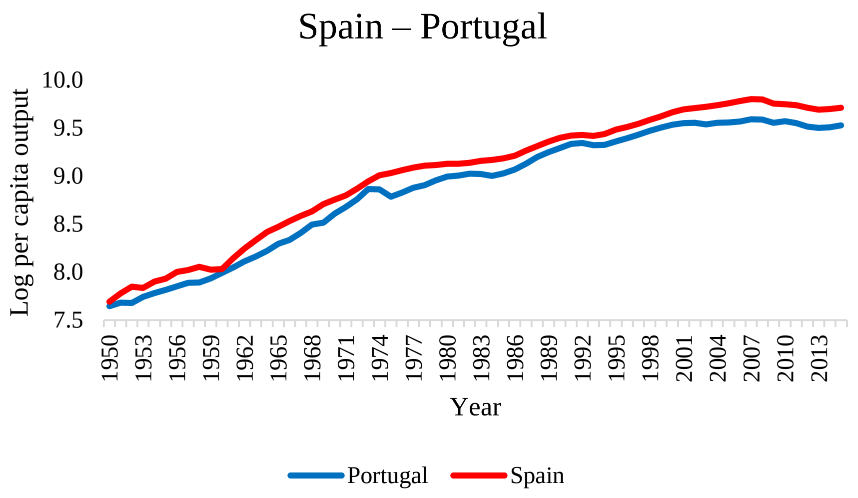

Figure 1: Log of per capita output in Spain and Portugal

To be noted that the number of long-run convergence cases is heterogeneous amongst the countries in our sample. Whereas Italy and the Netherlands display 4 cases of long-run convergence each, Cyprus, Greece, Ireland and Malta, peripheral countries of the EMU, do not present one single case of long-run convergence case. As a final note, most persistence change break dates can be found in the time period between 1956 and 1966, a period of time coincidental with the outset of the deepening of market integration of Western European Countries within the EEC and also within the European Free Trade Association (EFTA).

Nevertheless, we should take into account that, in our data, not rejecting the null hypothesis of nonstationarity does not necessarily mean that a pair of countries is on a divergence path. In fact, due to the catching-up effects of a country in relation to the benchmark, the output differential series might display nonstationarity and we can still infer favourably to the convergence hypothesis between these two countries, though without the statistical backing we find for the stationary cases.

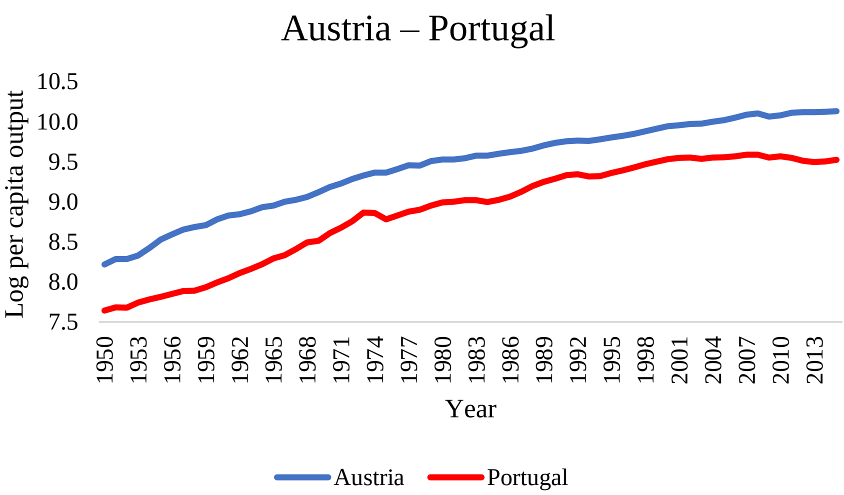

Figure 2: Log of per capita output of Austria and Portugal

Take, for instance, the case of Austria and Portugal. The output gap between these two countries is nonstationary. Thus, in the light of our empirical analysis we would argue that these two nations are not converging when it is not the case. Actually, the nonstationarity detected in the series has more to do with the catching-up dynamics followed by Portugal (interrupted in 2009 with the Great Recession and subsequent Sovereign Debt Crisis) than with output divergence.

Lastly, we follow once again Pesaran (2004) and test for convergence in our sample in terms of output growth rates. Hence, considering g as a country's growth rate, we test: $H_{gc}: g_{ij} = g_i - g_j = 0$ for all i and j. According to the above mentioned author, we can test such hypothesis by testing the statistical significance of the short and long-run intercept in the following regression:

$$g_{it} - g_{jt} = g_{ij} + \sum_{s=1}^{p_{ij}} \varphi_{ij}\left(g_{i,t-s} - g_{j,t-s}\right) + v_{ijt} \tag{7}$$

which is an $AR(p_{ij})$ model where p_{ij} is determined using the BIC. For the long-run intercept, HAC Newey-West estimation was used with the lags being automatically selected based on the

BIC. The short-run intercept is g_{ij} whereas the long-run intercept corresponds to the derived long run equilibrium of the AR model:

$$g_{ij}^* = \frac{g_{ij}}{1-\sum_{s=1}^{\rho_{ij}} \varphi_{ij}} \,. \tag{8}$$

The summary of the results can be found in the Appendix, in Table A.3. For illustration, in the first line of table A.3, Austria is our benchmark country and we detect short and long-run output growth convergence for all other countries in our sample with the exception of France and Netherlands for α=5% and Malta for α=10% We happen to find more evidence of growth convergence in our sample than for output convergence, being Malta the only nation in which growth convergence does not appear to be prevalent, showing somewhat mixed results. In reality, we came across 82 cases of short-run convergence and 81 cases of long-run growth convergence for α=5% (roughly 90% and 89% of all series, respectively), capturing most cases of countries which, according to our previous tests, were not converging in terms of output. In fact, when taking a look at the dispersion, measured by the standard deviation of the output growth rates of the 14 Eurozone countries of our sample (see Appendix Figure A.6), we can see a significant reduction as of 1978-1979, stabilising within a small window of values. However, one can detect a slight increase in such dispersion between 2008 and 2012, the period of time corresponding to the Great Recession and subsequent Sovereign Debt Crisis which had a significant impact in the Greek, Portuguese, Irish and Cypriot economies. This overall dispersion reduction seems to be coincidental with the introduction of the European Exchange Rate Mechanism (ERM), which produced exchange rate stabilisation of member-state currencies with the European Currency Unit (ECU) and, therefore, progressive harmonisation of member-state monetary policies in preparation for the implementation of the single currency – the Euro.

VI. Conclusions

The focus in this WP was aimed at studying the persistence and trending components of Eurozone output differentials. In such endeavour, we found little evidence of long-run output convergence in the 14 Eurozone countries analysed. Only roughly 15% of output differentials that were analysed presented a stationary and non-trending behaviour, yielding strong evidence in favour of long-run convergence between these countries. Nevertheless, roughly 40% of all series presented stationarity and a deterministic component, which might also indicate potential cases of output convergence. It should be highlighted that all countries that did not present any long-run convergence behaviour with any Eurozone country pair belong to the periphery of the EMU. Conversely, we discovered significant evidence of growth convergence in our data as the majority of all growth differentials revealed short and long-run convergence. To be noted that Cyprus, Ireland and Greece revealed the most prevalent paths of output divergence against their Eurozone peers whereas Malta showed more cases of growth divergence than convergence. In the light of these results, one would argue against the convergence hypothesis within the Eurozone, but we have to take into account that most of the countries we analysed may still be in catching-up processes, thus a scenario marked by predominant real long-run output convergence in the Eurozone may still be possible in the future. As limitations in this study, we have the fact that we did not find adequate data for our time period for the remaining countries of the Eurozone not covered in this WP, namely Estonia, Latvia, Lithuania, Slovakia and Slovenia and, finally, for future research, one can develop about the specific determinants of the output differentials within the Eurozone and thus shed light on the causes regarding the lack of real long-run output convergence cases we happen to find within our sample.

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VIII. Appendix

Figure A.1: Output growth vs initial values of GDP per capita

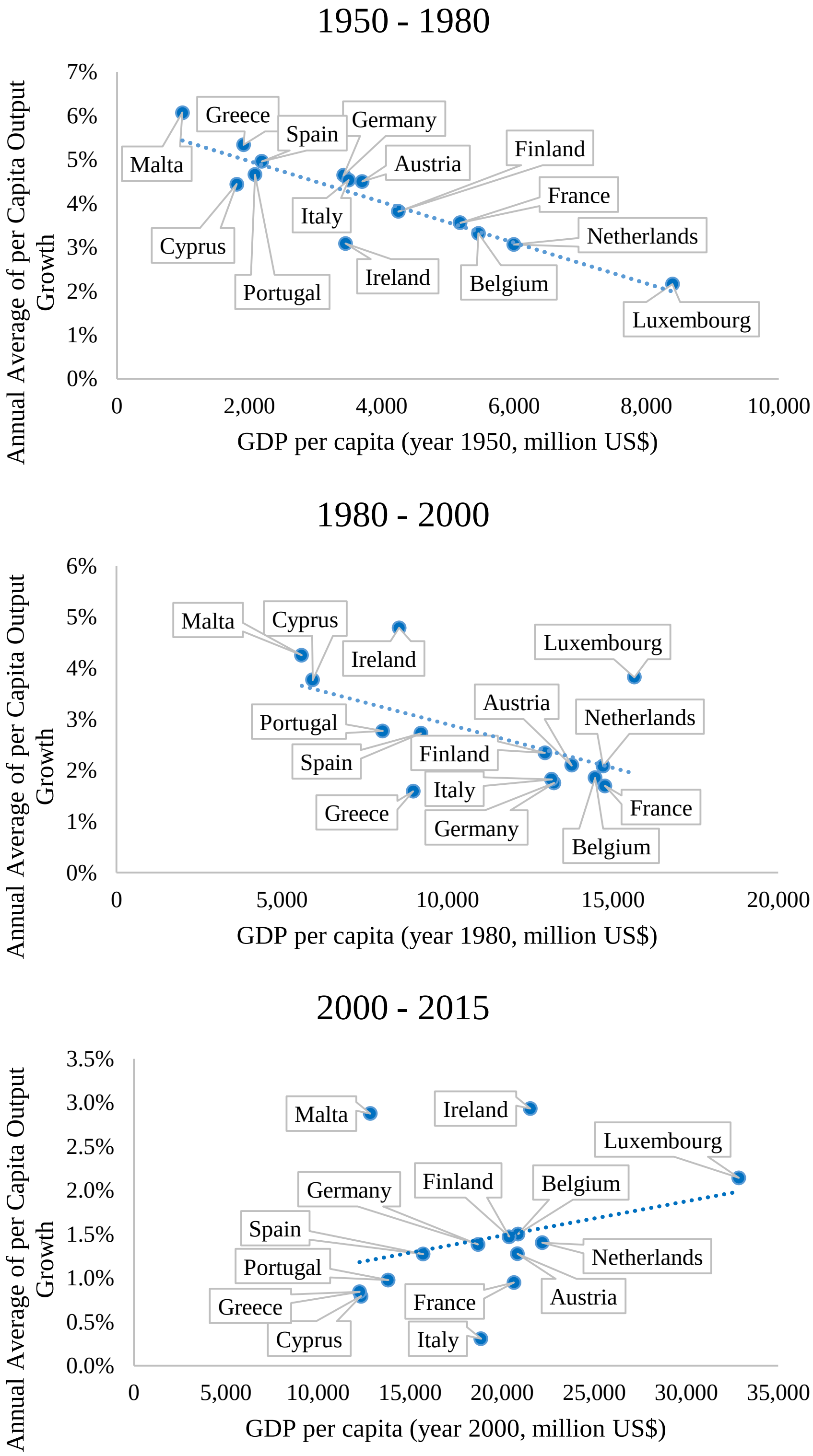


Figure A.2: σ-convergence

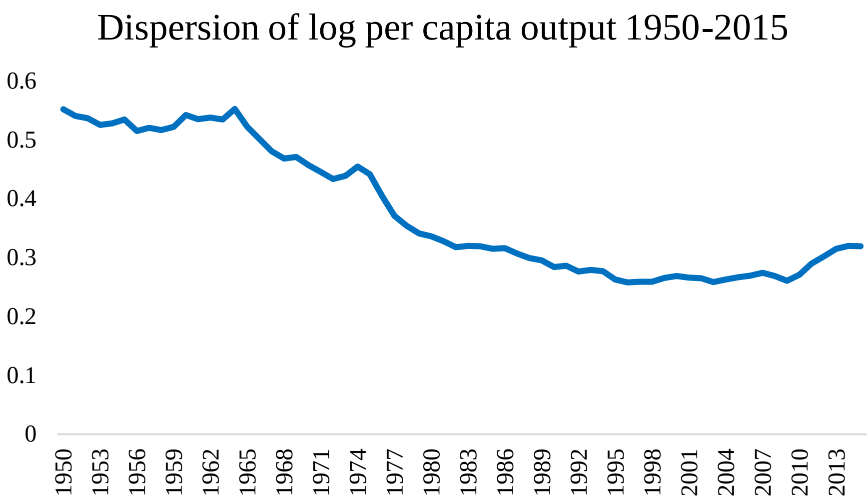


Table A.3: ADF test results and time trend significance test results

Country Pair	MacKinnon p-value	Country Pair	MacKinnon p-value	Country Pair	MacKinnon p-value
Belgium – Austria	0.0001	Ireland – Belgium	0.3005	France – Finland	0.0921
Cyprus – Austria	0.5492	Italy – Belgium	0.2017	Germany – Finland	0.0060
Finland – Austria	0.0040	Luxembourg – Belgium	0.6095	Greece – Finland	0.2055
France – Austria	0.0011	Malta – Belgium	0.4371	Ireland – Finland	0.6864
Germany – Austria	0.0020	Netherlands – Belgium	0.5251	Italy – Finland	0.4825
Greece – Austria	0.5178	Portugal – Belgium	0.1396	Luxembourg – Finland	0.4450
Ireland – Austria	0.4210	Spain – Belgium	0.0180	Malta – Finland	0.4846
Italy – Austria	0.9528	Finland – Cyprus	0.4338	Netherlands – Finland	0.1292
Luxembourg – Austria	0.0942	France – Cyprus	0.6067	Portugal – Finland	0.3244
Malta – Austria	0.5526	Germany – Cyprus	0.3426	Spain – Finland	0.2269
Netherlands – Austria	0.2488	Greece – Cyprus	0.4694	Germany – France	0.0004
Portugal – Austria	0.4914	Ireland – Cyprus	0.4744	Greece – France	0.1630
Spain – Austria	0.4774	Italy – Cyprus	0.1533	Ireland – France	0.6331
Cyprus – Belgium	0.5465	Luxembourg – Cyprus	0.2492	Italy – France	0.0469
Finland – Belgium	0.1393	Malta – Cyprus	0.4593	Luxembourg – France	0.3491
France – Belgium	0.3295	Netherlands – Cyprus	0.7946	Malta – France	0.3151
Germany – Belgium	0.0144	Portugal – Cyprus	0.3463	Netherlands – France	0.5029
Greece – Belgium	0.0771	Spain – Cyprus	0.2399	Portugal – France	0.5613

Country Pair	MacKinnon p-value
Spain – France	0.5157
Greece – Germany	0.4874
Ireland – Germany	0.1656
Italy – Germany	0.6539
Luxembourg – Germany	0.0001
Malta – Germany	0.3568
Netherlands – Germany	0.0287
Portugal – Germany	0.4063
Spain – Germany	0.3546
Ireland – Greece	0.8479
Italy – Greece	0.5005
Luxembourg – Greece	0.5526
Malta – Greece	0.4834

Country Pair	MacKinnon p-value
Netherlands – Greece	0.0501
Portugal – Greece	0.2646
Spain – Greece	0.3332
Italy – Ireland	0.1671
Luxembourg – Ireland	0.6365
Malta – Ireland	0.5413
Netherlands – Ireland	0.1343
Portugal – Ireland	0.5983
Spain – Ireland	0.7264
Luxembourg – Italy	0.9176
Malta – Italy	0.2550
Netherlands – Italy	0.3222
Portugal – Italy	0.0120

Country Pair	MacKinnon p-value
Spain – Italy	0.0937
Malta – Luxembourg	0.9070
Netherlands – Luxembourg	0.2621
Portugal – Luxembourg	0.1068
Spain – Luxembourg	0.3492
Netherlands – Malta	0.5319
Portugal – Malta	0.3179
Spain – Malta	0.4031
Portugal – Netherlands	0.5148
Spain – Netherlands	0.1364
Spain – Portugal	0.0123

Table A.4: Modified tests for persistence change results summary

Benchmark Country	I(0)	I(1) to I(0)	I(0) to I(1)	I(1)
Austria	–	**Belgium** (1975), **Finland** (1958), France (1994), Germany (1959), Luxembourg (1959)	Cyprus (1962), Greece (1962), Italy (1963), Malta (1963)	Ireland, Netherlands, Portugal, Spain
Belgium	–	**Austria** (1975), France (1963), Germany (1960), **Italy** (1959), Luxembourg (1958), Malta (1958), Netherlands (1957)	Cyprus (1962), Finland (1962), Greece (1962), Ireland (1962), Portugal (1964), Spain (1961)	–
Cyprus	–	Italy (1975)	Austria (1962), Belgium (1962), Finland (1962), France (1962), Germany (1962), Greece (1962), Ireland (1962), Luxembourg (1961), Malta (1962), Netherlands (1962), Portugal (1961), Spain (1962)	–
Finland	–	**Austria** (1958), France (1957), Germany (1957), Italy (1957), Luxembourg (1958), Netherlands (1960), **Spain** (1972)	Belgium (1962), Cyprus (1962), Greece (1961), Ireland (1964), Malta (1962), Portugal (1962)	–
France	–	Austria (1994), Belgium (1963), Finland (1957), **Germany** (1960), **Italy** (1958), Luxembourg (1957), Malta (1958), **Netherlands** (1957),	Cyprus (1962), Greece (1962), Ireland (1962), Portugal (1963), Spain (1961)	–
Germany	**Netherlands**	Austria (1959), Belgium (1960), Finland (1957), **France** (1960), Luxembourg (1957), Malta (1964)	Cyprus (1962), Greece (1963), Ireland (1961), Italy (1961), Spain (1961)	Portugal
Greece	–	–	Austria (1962), Belgium (1962), Cyprus (1962), Finland (1961), France (1962), Germany (1963), Ireland (1961), Italy (1964), Luxembourg (1961), Malta (1962), Netherlands (1962), Portugal (1961)	Spain
Ireland	–	–	Belgium (1962), Cyprus (1962), Finland (1964), France (1962), Germany (1961), Greece (1961), Italy (1962), Luxembourg (1988), Malta (1962), Netherlands (1961), Portugal (1962), Spain (1961)	Austria

Benchmark Country	I(0)	I(1) to I(0)	I(0) to I(1)	I(1)
Italy	–	**Belgium** (1959), Cyprus (1975), Finland (1957), **France** (1958), **Luxembourg** (1957), Malta (1958), **Netherlands** (1957), Portugal (1967)	Austria (1963), Germany (1961), Greece (1964), Ireland (1962), Spain (1961)	–
Luxembourg	–	Austria (1959), Belgium (1958), Finland (1958), France (1957), Germany (1957), **Italy** (1957), Malta (1957), Netherlands (1964), **Portugal** (1965), **Spain** (1961)	Cyprus (1961), Greece (1961), Ireland (1988)	–
Malta	–	Belgium (1958), France (1958), Germany (1964), Italy (1958), Luxembourg (1957), Portugal (1977), Spain (1958)	Austria (1963), Cyprus (1962), Finland (1962), Greece (1962), Ireland (1962), Netherlands (1964)	–
Netherlands	**Germany**	Belgium (1957), Finland (1960), **France** (1957), **Italy** (1957), Luxembourg (1964)	Cyprus (1962), Greece (1962), Ireland (1961), Malta (1964), Portugal (1961), Spain (1961)	Austria
Portugal	–	Italy (1967), **Luxembourg** (1965), Malta (1977), **Spain** (1959)	Belgium (1964), Cyprus (1961), Finland (1962), France (1963), Greece (1961), Ireland (1962), Netherlands (1961)	Austria, Germany
Spain	–	**Finland** (1972), **Luxembourg** (1961), Malta (1958), **Portugal** (1959)	Belgium (1961), Cyprus (1962), France (1961), Germany (1961), Ireland (1961), Italy (1961), Netherlands (1961)	Austria, Greece

Persistence break dates in parenthesis

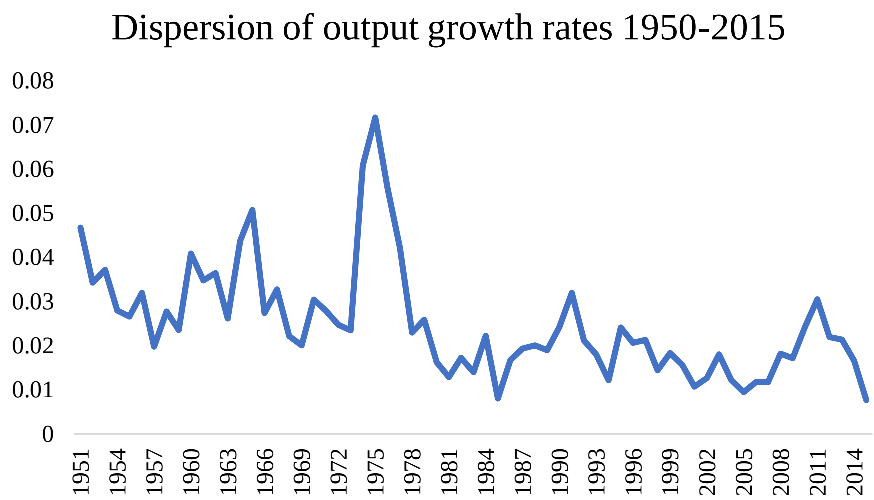
Table A.5: Growth Convergence Summary

Benchmark Country	Growth convergence		Growth divergence	
	Short-run	Long-run	Short-run	Long-run
Austria	Belgium, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain	Belgium, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Portugal, Spain	France (**), Malta (*), Netherlands (**)	France (***), Malta (*), Netherlands(**)
Belgium	Austria, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal	Austria, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal	Malta (***), Spain (*)	Malta (***), Spain (**)
Cyprus	Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain	Austria, Belgium, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain		
Finland	Austria, Belgium, Cyprus, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain	Austria, Belgium, Cyprus, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain	Malta (*)	Malta (*)
France	Belgium, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands	Belgium, Cyprus, Finland, Greece, Ireland, Italy, Luxembourg, Netherlands	Austria (**), Malta (**), Portugal (*), Spain (**)	Austria (***), Germany (*), Malta (**), Portugal (*), Spain (**)
Germany	Austria, Belgium, Cyprus, Finland, France, Greece, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain	Austria, Belgium, Cyprus, Finland, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain	Malta (*)	France (*)
Greece	Austria, Belgium, Cyprus, Finland, France, Germany, Ireland, Italy, Luxembourg, Netherlands, Portugal, Spain	Austria, Belgium, Cyprus, Finland, France, Germany, Ireland, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain	Malta(*)	
Ireland	Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain	Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Italy, Luxembourg, Malta, Netherlands, Portugal, Spain		

Benchmark Country	Growth convergence		Growth divergence	
	Short-run	Long-run	Short-run	Long-run
Italy	Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Luxembourg, Netherlands, Portugal, Spain	Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Luxembourg, Netherlands, Portugal, Spain	Malta (**)	Malta (**)
Luxembourg	Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain	Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Netherlands, Portugal, Spain	Malta (**)	Malta (**)
Malta	Cyprus, Germany, Ireland, Portugal, Spain	Cyprus, Germany, Greece, Ireland, Portugal, Spain	Austria (*), Belgium (***), Finland (*), France (**), Greece (*) Italy (**), Luxembourg (**), Netherlands (**)	Austria (*), Belgium (***), Finland (*), France (**), Italy (**), Luxembourg (**), Netherlands (**)
Netherlands	Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Portugal	Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg	Austria (**), Malta (**), Spain (**)	Austria (**), Malta (**), Portugal (*), Spain (**)
Portugal	Austria, Belgium, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Netherlands, Spain	Austria, Belgium, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Spain	France (*)	France (*), Netherlands (*)
Spain	Austria, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Portugal	Austria, Cyprus, Finland, Germany, Greece, Ireland, Italy, Luxembourg, Malta, Portugal	Belgium (*), France (**), Netherlands (**)	Belgium (**), France (**), Netherlands (**)

*** $p<0.01$, ** $p<0.05$, * $p<0.1$

Figure A.3: Dispersion of output growth rates in our sample



B.1: Tests for persistence of output differentials model

To understand how our used persistence change tests work, first we have to take into account the underlying model assumed for such testing. We follow the model presented by Harvey et al. (2006):

$$y_t = x_t' + v_t$$
$$v_t = \rho_t v_{t-1} + \varepsilon_t, t = 1, \dots, T; x_o = 0 \quad (9)$$

It should be noted that x_t corresponds to a set of deterministic variables, v_t satisfies the mild regularity conditions defined by Phillips and Xiao (1998) and the innovation sequence is assumed to follow a mean zero process that satisfies the familiar α-mixing conditions of Phillips and Perron (1986) with strictly positive and bounded long-run variance $\omega^2 = \lim_{T\to\infty} E(\sum \varepsilon_T)^2$. 4 hypotheses to be tested are presented in the paper:

1. H_1: the series is integrated of order 1 (nonstationary) across the sample period and $\rho_t = 1 - c/t$, c equal or greater than zero in order to allow for unit root and local to unit root behaviour in the series.
2. H_{01}: the series changes from I(0) to I(1) at time $[\tau^* T]$, i.e, $\rho_t = \rho, \rho < 1$ for t equal or smaller than $[\tau^* T]$ and $\rho_t = 1 - c/t$ for $t > [\tau^* T]$. The change point proportion τ^* is assumed to be an unknown point in $\Lambda = [\tau_l, \tau_u]$, an interval in (0,1) symmetric around 0.5;
3. H_{10}: y_t is changing from I(1) to I(0) at time $[\tau^* T]$;
4. H_0: the series is stationary throughout the sample period.

Therefore, Kim (2000), Kim et al. (2002) and Busetti and Taylor (2004) develop tests for the constant I(0) data-generating process against the I(0) – I(1) change (H_{01}) based on the following ratio statistic:

$$K_{[\tau T]} = \frac{(T-[\tau T])^{-2} \sum_{t=[\tau T]+1}^{T} \left(\sum_{i=[\tau T]+1}^{t} \tilde{v}_{i\tau}\right)^2}{[\tau T]^{-2} \sum_{t=1}^{[\tau T]} \left(\sum_{i=1}^{t} \hat{v}_{i\tau}\right)^2} \quad (10)$$

, where $\hat{v}_{i\tau}$ is the residual from the OLS regression of y_t on x_t for observations up to $[\tau T]$ and, on the other hand, $\tilde{v}_{i\tau}$ is the OLS residual from the regression of y_t on x_t for observations equal to $[\tau T] + 1, \dots, T$. Assuming that the true change point τ^* is unknown, Kim (2000), Kim et al.

(2002) and Busetti and Taylor (2004) take into account three statistics based on the sequence of statistics $\{K(\tau), \tau \epsilon \Lambda\}$, where $\Lambda = [\tau_l, \tau_u]$. These are:

$$MS = T^{-1} \sum_{s=[\tau_l]}^{[\tau_u]} K(s/T) \tag{11}$$

$$ME = ln\left\{\{T_*^{-1} \sum_{s=[\tau_l]}^{[\tau_u]} \exp\left[\frac{1}{2} K(s/T)\right]\right\} \tag{12}$$

$$MX = \max_{s \, \epsilon \, \{[\tau_l], \dots, [\tau_u]\}} K(s/T) \tag{13}$$

where $T_* = [\tau_u] - [\tau_l] + 1$. MS, ME and MX correspond to Hansen's (1991) mean score statistic, Andrews and Ploberger's (1994) mean-exponential statistic and Andrews' (1993) maximum statistic. To test H_0 against the H_{10} hypothesis, Busetti and Taylor (2004) propose tests based on the reciprocals of K_t, i.e. MS^R, ME^R and MX^R. To test for an unknown direction of change, they propose MS^M, ME^M, MX^M which are the pairwise maximum statistics.

To modify these statistics, the authors use the Vogelsang (1998) approach:

$$MS_m = \exp\left(-bJ_{1,T}\right) MS \tag{14}$$

$$ME_m = \exp\left(-bJ_{1,T}\right) ME \tag{15}$$

$$MX_m = \exp\left(-bJ_{1,T}\right) MX \tag{16}$$

where b is determined by simulation, assuming $\bar{\alpha} = 0$, for a particular level of significance and $J_{1,T}$ is T^{-1} the Wald statistic for testing the joint hypothesis $\gamma_{k+1} = \dots = \gamma_9$ in the following regression:

$$y_t = x'_t\beta + \sum_{i=k+1}^{9} \gamma_i t^i + error, t = 1, \dots, T \tag{17}$$

The m-min modified tests, which are predominantly used in this WP, are calculated by changing the above mentioned correction factor $J_{1,T}$ to $J_{min} = min_{\tau\epsilon\Lambda} J_{1,[\tau T]}$.