A Reappraisal of Eurozone Countries Output Differentials

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Abstract
In this paper, we use the concept of real convergence (considering the stationarity of per capita cross-country output differences) and present updated evidence on the persistence properties of output differential data, accounting for the potential occurrence of persistence changes. We focus on per capita output differences for 14 Eurozone countries over the period 1950-2015. Results suggest that the gap between the central and northwestern countries has been reduced through persistent convergence paths. However, the convergence path of the southern countries to the central and northern countries seems to have been interrupted. (JEL: C12, C22, O4)

Introduction

E conomic convergence constitutes a central goal of the European authorities as it is a key factor for the success of the single monetary policy and to achieve per capital real income convergence. In 1992, the Maastricht Treaty set the convergence criteria which the member states should accomplish before adopting the single currency. Meanwhile, several policy tools were in place directed to improve the economic integration of the less developed countries. These have been the recipients of structural funds aimed at increasing competitiveness and reducing income disparities within the European Union (EU), achieving thereby economic and social cohesion among the member states. Several countries have also adopted structural policies toward economic integration over the last decades, which include the liberalization of capital and labor markets and the creation of the European Economic and Monetary Union (EMU).

Although the issue of real convergence is central for the success of the European Union, neither economic theory nor empirical evidence available have provided an unambiguous proof for its existence among the European

member states. This divergence of results follows, in general, the lack of consensus that characterize the two main branches in the literature. On the one hand, the neoclassical growth theory (Solow, 1956; Mankiw *et al.*, 1992) predicts conditional convergence between lesser developed and developed countries. According to such models, real per capita output can rise with increases of the stock of capital available to each worker and technological progress. Given identical technologies, and identical structures, countries will converge to identical steady states and the mechanism behind convergence is based on diminishing capital returns: countries far way from their steady states, with lower capital per worker and lower per capita incomes, will exhibit higher growth rates and thereby the catching up process is activated. On the other hand, the New Growth Theories, starting with Romer (1986) and Lucas (1988), state the lack of convergence between lesser developed and developed countries in practice due to inconsistencies that motivate reduction of capital earnings in the former countries.

The absence of consensus on economic convergence has motivated an intense debate on the question of cross-country per capita output convergence, from which a vast theoretical and applied literature has emerged. The huge variety of results is partially explained by differences in data, countries, sample periods and methodologies. Recent references that illustrate such disparity of results include, *inter alia*, Azomahou *et al.* (2011), Beyaert and García-Solanes (2014), Cuaresma *et al.* (2013), Palan and Schmiedeberg (2010), Crespo-Cuaresma and Fernández-Amador (2013), Kutan and Yigit (2009), Monfort *et al.* (2013), Iancu (2009) and Mihuţ and Luţaş (2013). Azomahou *et al.* (2011) suggest that there has been no convergence among developed countries. Beyaert and García-Solanes (2014) and Crespo-Cuaresma and Fernández-Amador (2013) suggest that the convergence process is vulnerable to business cycles. For Cuaresma *et al.* (2013) and Kutan and Yigit (2009), the investment in human capital is a decisive key for convergence. Palan and Schmiedeberg (2010) develop a sectorial study and show evidence of divergence in technology intensive manufacturing industries. Divergence is also found in Monfort *et al.* (2013) in which two convergence clubs in the EU-14 were identified. Iancu (2009) also detects an increase of divergence in Europe over the period from 1995 to 2006, whereas Mihuţ and Luţaş (2013) assess the Sigma (σ)-convergence across the new EU member states. Other references exploring convergence of transition countries to the EU level are, *inter alia*, Kocenda (2001), Kasman *et al.* (2005), Kutan and Yigit (2009) and Matkowski and Prochniak (2007).

All these studies follow the research lines of the early studies on the convergence of countries and regions, which were based on simple cross country regressions (see e.g. Baumol, 1986, DeLong, 1988, Barro, 1991, Levine and Renelt, 1992, Barro and Sala-i-Martin, 1992 and Mankiw *et al.*, 1992). Other reference studies such as Barro and Sala-i-Martin (1991, 1992) evaluate the

concepts of Beta (β)- and σ-convergence (see Appendix A for a set of empirical results using these measures).

Following several criticisms to cross-sectional approaches to evaluate real convergence (see, *inter alia*, Quah, 1993; Evans, 1998; and Bernard and Durlauf, 1995) recent studies make use of time series-based concepts. These include the use of panel unit root tests to evaluate stochastic convergence and to test whether shocks have temporary or permanent effects on income differentials (see Ben-David, 1996; Koeenda and Papell, 1997; Kocenda, 2001; Evans and Karras, 1996; Lee *et al.*, 1997; and Holmes, 2002). Other studies report results based on principal components methods (see Snell, 1996), and on cointegration in a VAR framework as developed by Bernard and Durlauf (1995), which became a reference for many subsequent studies in the field (see e.g. Greasley and Oxley, 1997; and Mills and Holmes, 1999).

In this paper, we evaluate real convergence between 14 European countries based on their per capita output differences, both from a group convergence perspective as well as from an individual country's perspective. We adopt a time series framework to test for per capita output convergence which, as shown by Evans (1998), provides a better approach to test for convergence than cross-section analysis. Following recent literature, we build on the notion of cross-country output convergence initially proposed by Bernard and Durlauf (1995, 1996) and used recently in Pesaran (2007), which shows that for two countries to have converged it is necessary that their output differential is a stationary process, irrespectively of whether the individual country's output series are trend stationary and/or contain a unit root. Moreover, to analyse output convergence across a large number of countries without being subject to the pitfalls that surround the use of output differentials measured relatively to a particular benchmark country, we consider the properties of all possible real per-capita output differentials.

We approach the analysis of convergence based on the analysis of nonstationarity and persistence change of per capita output differentials among countries, which take into consideration possible structural changes in the data. Moreover, we investigate whether the output differentials within the group of EU members have stabilized over the sample period.

The structure of the paper is as follows. Section 2 introduces the notion of convergence. Section 3 presents the data and the empirical analysis of per capita output differentials, and section 4 provides some concluding remarks. An appendix collects the tests for persistence change used in the paper.

Notion of Convergence

Traditionally, convergence analysis has been developed in the literature based on the analysis of cross-section correlation between initial per capita levels and subsequent growth rates for groups of countries. A negative correlation

is taken as evidence of convergence as it implies that, on average, countries with lower per capita incomes are growing faster than countries with higher initial per capita incomes. This cross-sectional approach is often encapsulated in the notion of Beta (β)-convergence, which requires that lesser developed countries grow faster than developed ones. However, several criticisms have been raised against the conclusions reached in many of these studies on the account of "Galton's fallacy"[1].

In contrast, we employ a time series approach which builds on a stochastic definition of convergence where per capita output differentials are expected to be stationary. Moreover, temporary shocks to key structural variables such as saving rates, population growth, and technological progress are characterized by stationary relative outputs thereby indicating that economies are stochastically converging. This means that the convergence definition followed in this paper considers the behavior of output differentials between pairs of economies over the sample period. This procedure is based on a probabilistic definition of convergence and the idea behind this is that the time-series properties of all possible countries' output differentials are examined by means of unit root and persistence change tests. These tests interpret convergence to mean that per capita output differentials are always transitory in the sense that long-run forecasts of the difference between any pair of countries converges to zero (Bernard and Durlauf, 1996) or to a tolerable constant value (allowing for convergent economies to have different endowments, saving rates or population growth rates, as suggested in Pesaran, 2007) as the forecast horizon grows. Convergence, according to this approach has the strong implication that per capita output differences between any two economies cannot contain unit roots or time trends.

To illustrate the approach consider the log-linearised output of country i as (see Lee, Pesaran and Smith, 1997) ,

$$y_{it} = c_i + g_i t + u_{it} + \eta_t \qquad (1)$$

where c_i is a fixed effect, $g_i t$ is a deterministic trend component, $\eta_t \sim iid(0, \sigma_\eta^2)$ is a common shock and $u_{it} = \varphi_i u_{i,t-1} + \varepsilon_{it}$ is an idiosyncratic component that is assumed to be autoregressive (AR).

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1. According to Galton´s fallacy, the regressions to estimate Beta-convergence, which relate growth rates and initial levels of output do not provide complete information about the output distribution among countries because they are regressions towards the mean. In fact, if there is evidence of a negative relationship between initial output levels and growth rates, that relationship occurs on average and does not necessarily mean that there has been a reduction of output dispersion. Because of this, Galton´s fallacy recommends to focus at economic relationships beyond the conditional mean.

Hence, given (1) the output differential of countries i and j at time t is defined as,

$$
\begin{aligned}
x_{ij,t} &= y_{it} - y_{jt} \\
&= (c_i - c_j) + (g_i - g_j)\,t + (u_{it} - u_{jt}) \\
&= \delta_{ij} + \gamma_{ij}t + v_{ij,t}
\end{aligned}
\tag{2}
$$

where $\delta_{ij} = c_i - c_j$ is a fixed effect that depends on the initial conditions in countries i and j, $\gamma_{ij}t = (g_i - g_j)\,t$ is a deterministic time trend component which is equal to zero if the growth rates of technology in countries i and j are equal, $g_i = g_j$, and $v_{ij,t} = u_{it} - u_{jt}$ is a stochastic component.

Equation (2) represents the framework typically used to test for convergence between countries i and j. If the trend is not statistically significant ($H_0 : \gamma_{ij} = 0$) and the output differential $x_{ij,t}$ is integrated of order zero (stationary) then economies i and j converge at an exponential rate, as implied by a standard stationary AR process and remain on similar paths afterwards. Hence, for this concept of convergence to hold we must observe that, $i)$ $v_{ij,t} \sim I(0)$ and $ii)\gamma_{ij} = 0$ (see e.g. Pesaran, 2007).

For illustrative purposes consider the following graphs which represent the log of per capita output of two fictitious countries:

(A) I(0)

(B) I(0)

(C) I(1)

(D) I(1)
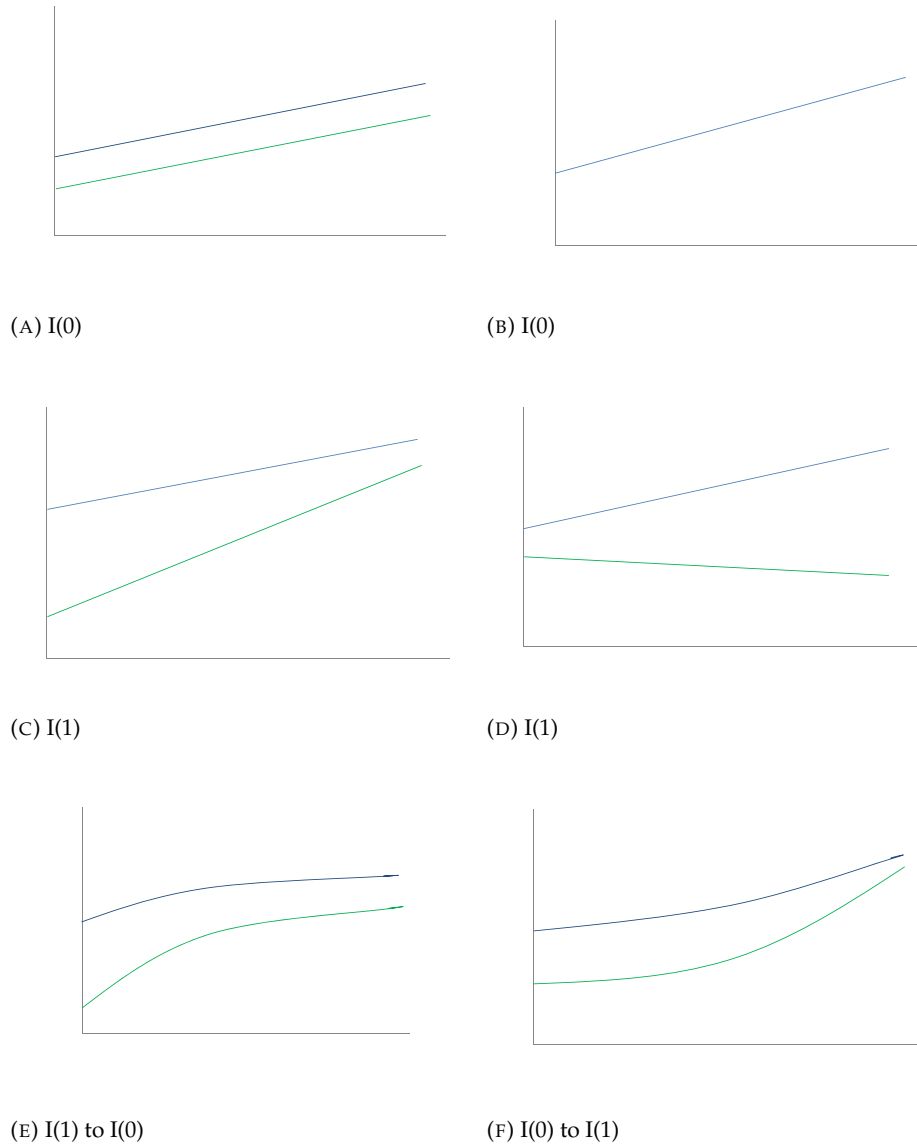
(E) I(1) to I(0)

(F) I(0) to I(1)

FIGURE 1: Illustration of notions of persistence

Hence, the concept of log per capita output convergence allowed by (2), i.e., the null hypothesis considered (that the output differential $x_{ij,t}$ is stationary and that its trend is not statistically significant) corresponds to the behaviour displayed in graphs A) and B), whereas rejection of this null hypothesis by traditional unit root test procedures (or trend stationarity of the series) implies output differential behaviour of the type displayed in graphs C)

and D). One contribution of our analysis is that, through the use of persistence change tests we also allow the behaviour of countries' output differentials to change from stationary to nonstationary or vice versa, as displayed in graphs E) and F). Note that the behaviour patterns displayed in C) and E), and in D) and F) are different in nature since in E) and F) there are periods during which the output differential is stable (in graph E) this would correspond to the first part of the sample, whereas in graph F) it is the second part), which is not observed in C) and D). An interesting property of the procedures used in this paper to test for persistence change is that once the persistence change is detected it allows to discriminate whether the change is from stationarity to nonstationarity (as suggested in graph E) or vice versa (as suggested in graph F)).

In the procedure used in this paper the change in persistence is endogenously considered and therefore the timing of the change (or changes) is determined by the procedure and not exogenously imposed. Moreover, given the small sample sizes considered in the empirical analysis we only allow for at most one change in persistence.

Empirical Analysis

Data description and sources

The data used in our analysis consists of annual observations of per capita output for a total of 14 European countries: Austria, Belgium, Cyprus, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, the Netherlands, Portugal and Spain. The source of this data is The Conference Board Total Economy Database™, May 2015 (http://www.conference-board.org/data/economydatabase).

Figure 1 illustrates the evolution of the log of real per capita output from 1950 to 2015 for the 14 countries under analysis. For the purpose of analysis we consider two groups of countries. Group I is composed by the central and northwestern European countries (Austria, Belgium, Finland, France, Germany, Ireland, Luxembourg, and the Netherlands); and Group II includes southern countries (Cyprus, Greece, Italy, Malta, Portugal and Spain).

Although upward trends are noticeable from Figure 1, reflecting a positive annual average growth, the data also indicates the consequences of the recent financial crisis on per capita output of all countries, but in particular in southern countries, which are reflected in a pronounced slowdown or even an effective reduction by the end of the decade.

The lower growth of per capita output is not independent from the evolution observed in the labor markets. Over the period under analysis all countries experienced reductions of the number of working hours (see Figure 2). Such reductions are particularly pronounced in the first group. Given
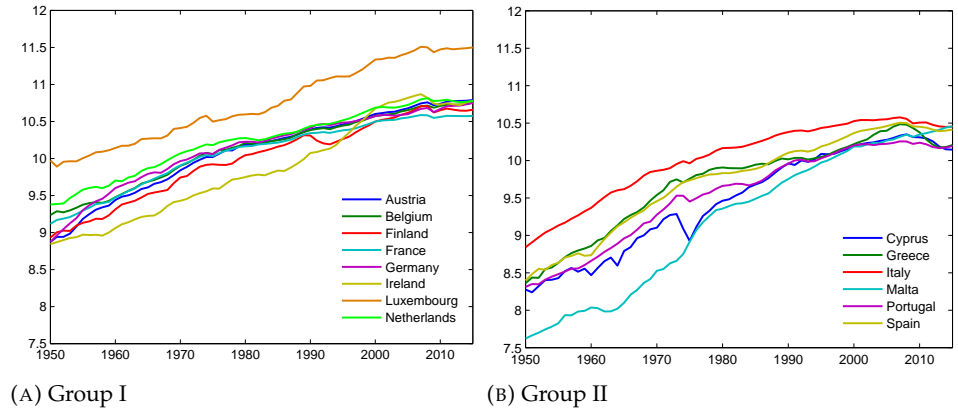
FIGURE 2: Log of Real per capita Output.

Source: The Conference Board Total Economy Database™

this variability in the working hours over time, real per capita output and labor productivity should not be used indiscriminately, as labor productivity turns out to be an alternative measure of convergence which is achieved through technology advances that spread out across countries. This negative evolution in the labor market reflects the negative effects of the financial crisis on the potential output, due to reductions of the productive capacity of these economies, as a result of reductions in demand motivated, *inter alia*, by reductions in investment.
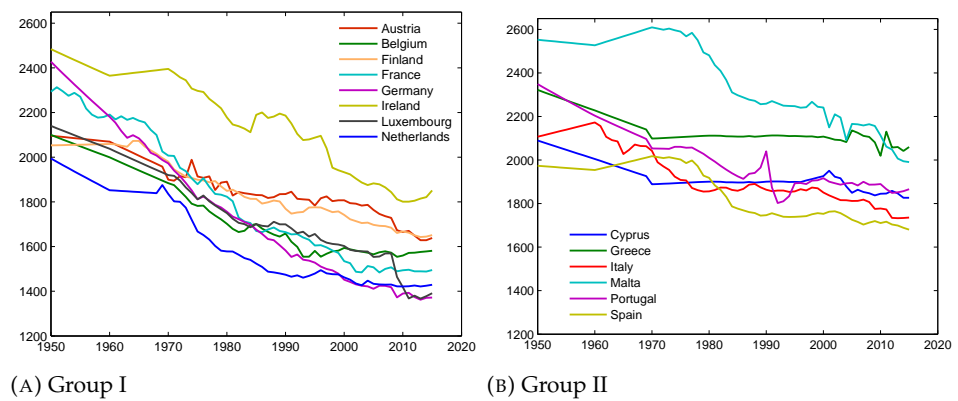

FIGURE 3: Annual hours worked per worker.

Source: The Conference Board Total Economy Database™

Over the last decades, all economies experienced a slowdown of labour productivity, being this particularly observed in Group II when compared to Group I. Although there have been improvements over time it seems that the differential between the countries in Group I and in Group II has in general not been bridged yet.
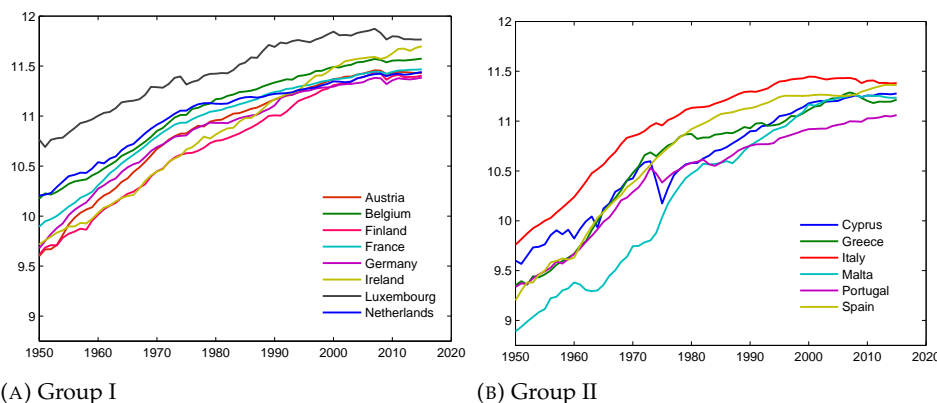

(A) Group I   (B) Group II

FIGURE 4: Output per worker in 2014 US$.

Note: Data is converted to 2014 price level with updated 2011 PPPs. Source: The Conference Board Total Economy Database™

Labor productivity can also be measured in terms of hours worked. This definition of productivity is particularly informative as the evolution of the number of working hours follows closely the economies' business cycles. As expected, Figure 4 shows that labor productivity per hour worked in Group I is generally higher than in Group II, and a slowdown is again observed over the last years in all countries as a result of the 2008 financial crisis.

Output differentials of European economies in the period 1950-2015

For a country by country analysis of convergence, in this section we evaluate the per capita output differentials as suggested in Section 2. Considering the log-linearised output of a country as given in (2), the time series notions of convergence imply that per capita output disparities between converging economies follow a stationary process. Therefore, divergence is related to the unit root hypothesis (or trending differentials) in relative per capita output. To analyse the properties of per capita output differentials across these economies, we consider the log real per-capita output differences of countries i and j, $y_{it} - y_{jt}$, $i = 1, ..., N-1$, and $j = i+1, ..., N$, over the period from 1950 to 2015. Hence, we consider a total of $N(N-1)/2 = 91$ log real per-capita output differentials.
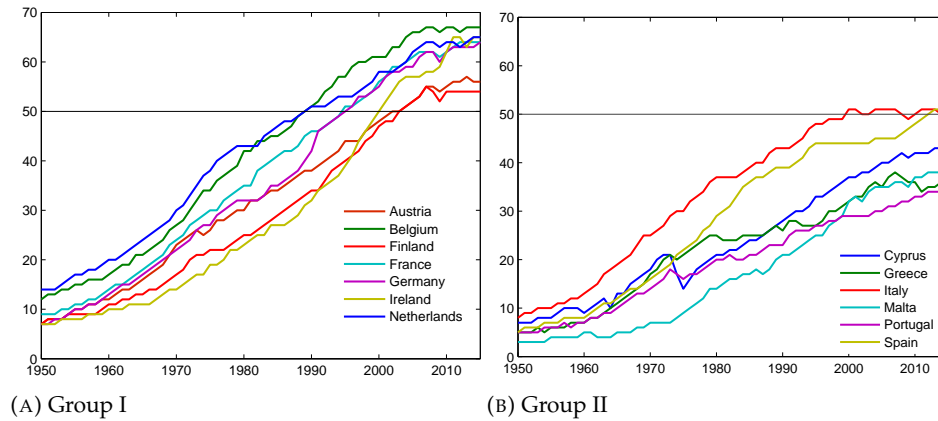
FIGURE 5: Output per hour worked in 2014 US$

Note: Data is converted to 2014 price level with updated 2011 PPPs. Source: The Conference Board Total Economy Database™

We start by analysing the nonstationarity properties of output disparities using conventional unit root tests, and complement this analysis with persistence change tests (which are briefly described in the Appendix) to draw more robust conclusions about the stationarity or nonstationarity of countries output differentials. The rejection of the null hypothesis of nonstationarity, I(1), or its rejection in favor of a change from nonstationarity to stationarity, *i.e.* I(1)-I(0), can be indicative of convergence.

Table 1 summarises the results and presents information of which countries' pairs report persistent convergence/divergence paths over the sample period, and which of them exhibit changes of the convergence path. We should attend to the fact that 15% of the observations at the beginning and at the end of the sample period are excluded by the persistence change tests. Therefore, in practice, the results report to the period from 1960 to 2006. The first column of Table 1 refers to the reference country considered and the following four columns indicate the conclusion of the tests computed on the output differential with the countries listed in that column. For instance, considering the first line of Table 1, we observe that the output differentials of Austria (the reference country) with, for instance, Ireland is stationary (I(0)), whereas with Italy, the Netherlands, Portugal and Spain are nonstationary (I(1)). For the remaining countries considered, we observe that the output differentials of Austria with Belgium, Finland, France, Germany and Luxembourg show persistence change from nonstationarity (I(1)) to stationarity (I(0)), whereas the output differentials of Austria with Cyprus, Greece and Malta also display persistence change, but in this case from stationarity (I(0)) to nonstationarity (I(1)).

In general, results provide evidence of stationary (or changes to stationary) output differences in around 72% of the cases in Group I, 47% of cases in Group II, and in around 43% of cases overall. No persistence change was found in 8 series, representing 8.8% of total. The no persistence change hypothesis was rejected for 83 series. Evidence of I(0) - I(1) changes was detected in 46 series, representing 50.5% of all series, which corresponds to cases of economic divergence. Evidence of I(1) - I(0) changes is present in 37 series, or 40.7% of total. Therefore, the results suggest that 39 (two of the series for which no persistence change was found are stationary) out of 91 series represent potential cases of convergence while 52 series represent situations of economic divergence between countries.

The results suggest that there has been a persistence change from stationarity to nonstationarity in most countries of Group II relatively to most countries of Group I. In fact, there is evidence that Portugal, Malta, Cyprus, Spain and Greece started a process of reduction of output differentials with all, or almost all of the countries in Group I. In particular, Greece and Cyprus report evidence of changes from I(0) to I(1) with all countries in Group I; Portugal and Spain report such changes relatively to five countries in Group I. Results also suggest evidence that the output differentials of these countries relatively to some other countries in Group I are unstable over the sample period. Malta reports changes for I(0) to I(1), corresponding to unstable output differentials, relatively to four countries, while the output differentials between Italy and three other countries seem to be I(1). From this perspective, results seem to suggest that there is heterogeneity in the evolution of the output differentials between the two groups of countries.

The intra-groups analysis also reveals interesting results. For instance, Ireland seems to be the only divergent country inside Group I. The other countries report a change to convergence in the period. This suggests that these countries managed to reduce their output differentials and consolidated the proximity of their income levels. The countries in Group II report mixed evidence with several output differentials reporting unstable paths. The most remarkable result concerns to Greece which reports a change from I(0) to I(1) in the output differentials with almost all countries. The other countries, such as Portugal, Italy, Malta and Spain report a change to stable output differentials relatively to three countries and Cyprus seems to have enacted convergence with two countries.

Table 1: Persistence of European Output Differentials (1950-2014)

	I(0)	I(1) to I(0)	I(0) to I(1)	I(1)
Austria	**Ireland**	**Belgium, Finland,** France, Germany, Luxembourg	Cyprus, Greece, Malta	Italy, Netherlands Portugal, Spain
Belgium	—	**Austria,** France, Germany, Malta, **Netherlands,** Luxembourg**, Italy**	Cyprus, Finland, Greece, Ireland, Portugal, Spain	—
Finland	—	Germany, **Spain,** Luxembourg **Austria,** France, **Netherlands, Italy**	Belgium, Portugal, Cyprus, Ireland, Greece, Malta	—
France	—	Austria, Belgium, **Malta,** Finland, Netherlands, **Germany,** Italy, Luxembourg	Ireland, Portugal, Cyprus, Greece, Spain	—
Germany	Netherlands	Austria, **Malta,** Belgium Finland, **France,** Luxembourg	Cyprus, Greece, Ireland, Italy, Spain	Portugal
Ireland	**Austria**	—	Belgium, Italy, Luxembourg, Finland, Cyprus, Greece, Germany, France, Malta, Netherlands, Portugal, Spain	—
Netherlands	Germany	Belgium, Finland, **France,** Italy, Luxembourg	Cyprus, Greece, Ireland, Malta, Portugal, Spain	Austria
Luxembourg	—	Austria, Belgium, Finland, France, **Malta,** Portugal, Spain, Germany, Netherlands, **Italy**	Ireland, Greece, Cyprus	—

Table 1: Persistence of European Output Differentials (1950-2014) - Cont.

|	I(0)	I(1) to I(0)	I(0) to I(1)	I(1)
Cyprus	—	**Italy**, **Spain**	Austria, Belgium, France, Finland, Germany, Ireland, Greece, Malta, Luxembourg, Netherlands, Portugal	—
Greece	—	—	Austria, Belgium, Finland, Italy,France, Malta, Netherlands, Portugal, Cyprus, Germany, Ireland, Luxembourg	Spain
Italy	—	**Belgium, Cyprus**, Malta, **Netherlands Finland**, France, **Luxembourg**, Portugal	Germany, Spain, Ireland, Greece	Austria
Malta	—	Belgium, Italy, **Portugal** France, Germany, **Spain**, **Luxembourg**	Austria, Finland, Cyprus, Ireland, Netherlands	Greece
Portugal	—	**Spain,** Luxembourg, Italy, **Malta**	Belgium, Finland, France, Ireland Greece, Cyprus, Netherlands	Austria, Germany
Spain	—	Luxembourg, **Finland, Cyprus**, **Portugal, Malta**	Belgium, France, Germany, Ireland Italy, Netherlands	Austria, Greece

Source: Authors' calculation.
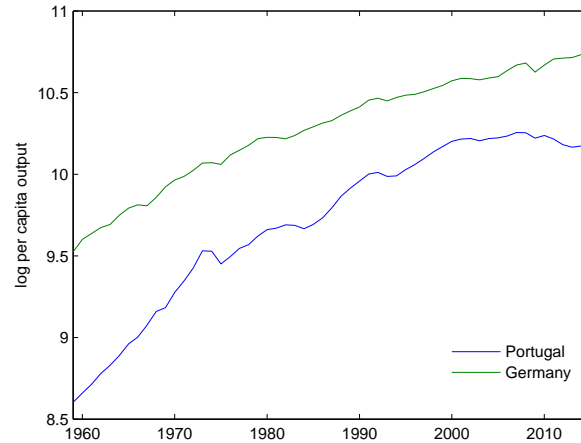
FIGURE 6: Log of per capita output in Germany and Portugal.

Source: The Conference Board Total Economy Database™.

Hence, according to equation (2) the possible countries that have converged with the reference countries considered are the ones which are listed in the stationarity column (I(0)) and those that observed persistence change from nonstationarity ($I(1)$) to stationarity ($I(0)$). Note that the conclusions for the countries in the other two columns do not necessarily mean that these countries are diverging. In effect, many of these countries went (and are still going) through a catching up process, which means that their log per capita outputs show dynamic profiles which differ from that of the reference country considered.

As an example consider for instance the evolution of the log per capita output in Portugal and Germany between 1960 and 2015 in Figure 5. Although the test tells us that the output differential between these two countries is nonstationary (I(1)), hence the steady state behaviour of the two countries has still significant differences, this nonstationarity is clearly a reflection of the catching up growth path followed by Portugal.

Therefore, from equation (2) and the definition of convergence considered, to conclude for convergence the deterministic trend also needs to be statistically insignificant. After establishing stationarity in the previous analysis we observe that the only pairs of countries for which the time trend is not significant are (countries in bold letters in Table 1): Austria - Ireland, Austria - Belgium, Austria - Finland, Belgium - Netherlands, Belgium - Italy, Finland - Netherlands, Finland - Spain, Finland - Italy, France - Malta, France - Germany, Germany - Malta, Luxembourg - Malta, Luxembourg - Italy, Cyprus - Italy, Cyprus - Spain, Malta - Portugal, Malta - Spain and Portugal - Spain. For these pairs, the test suggests that there has been convergence

over the sample period, or that there has been a change from divergence to convergence. For illustration purpose on this point, consider Figure 6 which exhibits the evolution of per capita output in log levels of Portugal and Spain, on the one hand, and Luxembourg and Malta on the other, for which we gathered evidence of convergence.

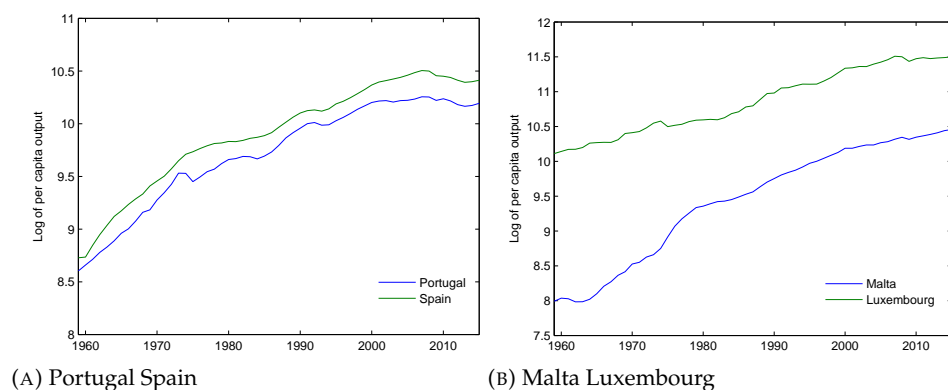(A) Portugal Spain   (B) Malta Luxembourg

FIGURE 7: Log of per capita output in Portugal, Spain, Luxembourg and Malta.

Source: The Conference Board Total Economy Database™.

A further important piece of information that we can draw from equation (2) relates to the intercept term, which, according to this model, measures differentials in the countries' initial conditions; see Table 2.

Table 2: Intercept estimates from (2)

Country pairs	$\widehat{\delta}$	
Belgium - Austria	0.0078	
Finland - Austria	-0.0299	***
Ireland - Austria	0.0026	
Italy - Belgium	0.0137	
Netherlands - Belgium	0.0299	***
Italy - Cyprus	0.1143	
Spain - Cyprus	0.0531	*
Italy - Finland	0.0252	
Netherlands - Finland	0.0616	**
Germany - France	0.0097	**
Malta - France	0.0035	
Malta - Germany	0.0036	
Luxembourg - Italy	-0.0978	
Netherlands - Italy	-0.0094	
Malta - Luxembourg	0.0972	
Portugal - Malta	0.0074	
Spain - Malta	-0.0010	
Spain - Portugal	0.0567	***

Note: ***, **, * denote significance at 1%, 5% and 10%, respectively.

The statistical significance of the estimates of δ_{ij}, of the parameter that depends on the initial conditions in countries i and j in (2), indicates that these conditions are relevant in the pairs: Finland - Austria, Netherlands - Belgium, Netherlands - Finland, Germany - France and Spain - Portugal. In all these cases, a change from I(1) to I(0) was found.

Note that the sign of the intercept depends on the ordering of the countries considered, for instance, a negative (positive) sign indicates that the initial conditions in the reference country are larger (smaller) than in the country with which it is compared with. For example, the significant value of -0.0299 observed for Finland - Austria suggest that the initial conditions in Austria were more favourable than in Finland.

Conclusions

The results suggest that over the period under analysis, many log per capita output differentials are still not stable, particularly between Group I and Group II members and within Group II. In fact, Cyprus, Greece, Malta, Italy, Portugal and Spain, display unstable differentials relatively to countries in Group I, which in general may be indicative of the catching up process these countries are pursuing. Greece also displays unstable differentials relatively to

countries in group I, while Ireland has been on a diverging trajectory vis-à-vis almost all countries.

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Appendix A: Group Convergence

An alternative way to show the different dynamics of the countries, in line with the β-convergence concept, is to plot the average growth rate over a period of time (e.g. 1960 - 1980) against the initial level (1960) of real output per worker. A negative relationship between the initial level of output per worker and its average growth rate means that lesser developed countries tend to grow faster than developed ones and will eventually catch up with them. In graph A) of Figure A.1 we observe this phenomena, i.e. a convergence trend within the group of countries, and diversity of growth rates across countries. Although the period between 1960 and 1980 seems to provide some support to the idea that countries are converging to a common level of income, since a downward sloping relationship between growth and the initial income can be observed, this evidence seems to decrease after 1980. It is also observed that after 1980 the growth rates declined and became substantially lower particularly between 2000 and 2014.

(A) A) 1960 - 1980

(B) B) 1980 - 2000
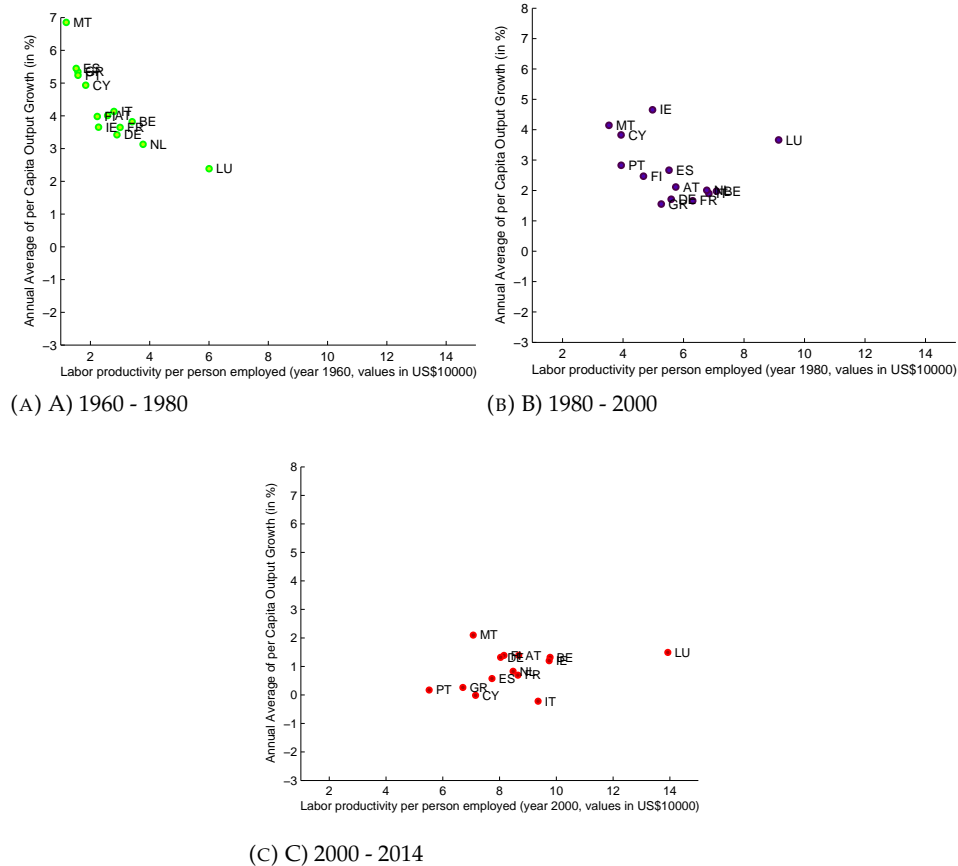
(C) C) 2000 - 2014

FIGURE A.1: Output growth vs labor productivity (1960, 1980, 2000)

Source: The Conference Board Total Economy Database™ and Author's calculations

To further corroborate these results, Figure A.2 looks at σ-convergence, which analyses convergence from a different angle. In particular, it evaluates whether the overall dispersion of per capita output or within the groups is increasing (divergence) or decreasing (convergence). From Figure A.2 we observe that until around 2008-2009, this indicator was decreasing, suggesting that lesser developed countries were catching up with developed countries. However, from 2009 onwards the dispersion seems to start to increase, mainly as a consequence of the divergence observed in the countries of Group II. Note that the progress of σ-convergence is not only a function of the differential rates of growth between lesser developed and developed countries, but also of the size of the initial output differential.
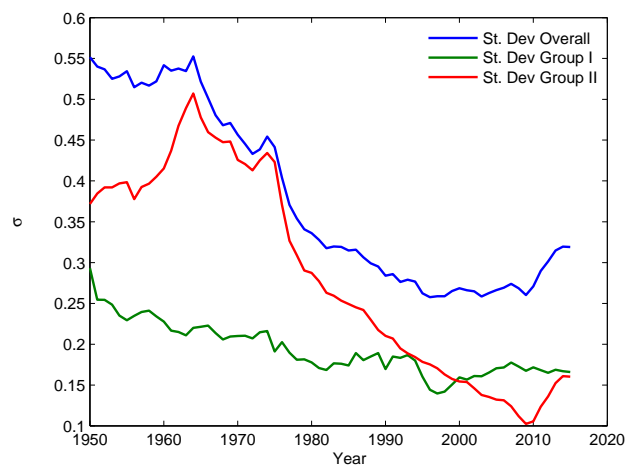
FIGURE A.2: Sigma-Convergence.

Source: The Conference Board Total Economy Database™ and Authors' calculations.

Appendix B: Appendix - Tests for persistence of output convergence

Testing for the persistence of macroeconomic time series, allowing for the classification of series as stationary or nonstationary is meaningful for the purposes of this paper in that it helps understand the position of each country in its catching-up process relatively to others and the effect of shocks on output differentials.

B.1. The persistence change model

For the purpose of presenting the persistence change tests, we follow Harvey et al. (2006) and Busetti and Taylor (2004) and consider the following data generation process,

$$
\begin{aligned}
y_t &= \mathbf{z}_t'\beta + x_t \\
x_t &= \rho_t x_{t-1} + \varepsilon_t
\end{aligned}
$$

with $x_0 = 0$. In our particular context z_t is a set of deterministic variables, such as a constant or a time trend (if necessary). The $\{x_t\}$ is assumed to satisfy the mild regularity conditions of Phillips and Xiao (1998) and the innovation sequence $\{\varepsilon_t\}$ is assumed to be a mean zero process satisfying the familiar α-mixing conditions of Phillips and Perron (1988, p.336) with strictly positive

and bounded long-run variance, $\omega^2 \equiv \lim_{T\to\infty} E\left(\sum_{t=1}^{T} \varepsilon_t\right)^2$; see Harvey et al. (2006, p. 444) for details.

Four relevant hypothesis can be considered:

1. $H_1 : y_t$ is $I(1)$ (i.e. nonstationary) throughout the sample period. Harvey et al. (2006) set $\rho_t = 1 - c/T$, $c \geq 0$, so as to allow for unit root and near unit root behaviour.

2. $H_{01} : y_t$ is $I(0)$ changing to $I(1)$ (in other words, stationary changing to nonstationary) at time $[\tau^*T]$; that is $\rho_t = \rho$, $\rho < 1$ for $t \leq [\tau^*T]$ 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) which is symmetric around 0.5;

3. $H_{10} : y_t$ is $I(1)$ changing to $I(0)$ (i.e. nonstationary changing to stationary) at time $[\tau^*T]$;

4. $H_0 : y_t$ is $I(0)$ (stationary) throughout the sample period.

B.2. The persistence change ratio-based tests

In the context of no breaks, Kim (2000), Kim et al. (2002) and Busetti and Taylor (2004) develop tests for the constant $I(0)$ DGP (H_0) against the $I(0) - I(1)$ change (H_{01}) which are based on the ratio statistic,

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

where $\widehat{v}_{i\tau}$ is the residual from the OLS regression of y_t on x_t for observations up to $[\tau T]$ and $\widetilde{v}_{i\tau}$ is the OLS residual from the regression of y_t on x_t for $t = [\tau T] + 1, ..., T$.

Since the true change point, τ^*, is assumed unknown Kim (2000), Kim et al. (2002) and Busetti and Taylor (2004) consider three statistics based on the sequence of statistics $\{K(\tau), \tau \in \Lambda\}$, where $\Lambda = [\tau_l, \tau_u]$ is a compact subset of

[0,1], *i.e.,*

$$K_1 = T_*^{-1} \sum_{s=[\tau_l]}^{[\tau_u]} K(s/T); \qquad \text{(B.1)}$$

$$K_2 = \ln\left\{ T_*^{-1} \sum_{s=[\tau_l]}^{[\tau_u]} \exp\left[\frac{1}{2}K(s/T)\right] \right\}; \qquad \text{(B.2)}$$

$$K_3 = \max_{s\in\{[\tau_l],...,[\tau_u]\}} K(s/T) \qquad \text{(B.3)}$$

where $T_* = [\tau_u] - [\tau_l] + 1$, and τ_l and τ_u correspond to the (arbitrary) lower and upper values of τ^*. Limit results and critical values for the statistics in (B.1) - (B.3) can be found in Harvey et al. (2006).

Note that the procedure in (B.1) corresponds to the mean score approach of Hansen (1991), (B.2) is the mean exponential approach of Andrews and Ploberger (1994) and finally (B.3) is the maximum Chow approach of Davies (1977); see also Andrews (1993).

In order to test H_0 against the I(1) - I(0) (H_{10}) hypothesis, Busetti and Taylor (2004) propose further tests based on the sequence of reciprocals of K_t, $t = [\tau_l], ..., [\tau_u]$. They define K_1^R, K_2^R and K_3^R as the respective analogues of K_1, K_2 and K_3, with K_j, $j = 1, 2, 3$ replaced by K_j^{-1} throughout. Furthermore, to test against an unknown direction of change (that is either a change from I(0) to I(1) or vice versa), they propose $K_i^M = \max\left[K_i, K_i^R\right]$, $i = 1, 2, 3$. Thus, tests which reject for large values of K_i, $i = 1, 2, 3$ can be used to detect H_{01}, tests which reject for large values of K_i^R, $i = 1, 2, 3$ can be used to detect H_{10} and K_i^M, $i = 1, 2, 3$ can be used to detect either H_{01} or H_{10}.