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Inflation convergence in the EMU☆,☆☆,☆☆☆

M. Karanasos[a,*], P. Koutroumpis[b], Y. Karavias[c], A. Kartsaklas[a], V. Arakelian[d]

[a]Brunel University London, UK
[b]Queen Mary, University of London, UK
[c]University of Birmingham, UK
[d]Panteion University of Social Political Sciences, Greece

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ABSTRACT

We study the convergence properties of inflation rates among the countries of the European Monetary Union over the period 1980–2013. Recently developed panel unit root/stationarity tests cannot reject the stationarity hypothesis. This implies that some countries have been in the process of converging absolutely or relatively. By using a clustering algorithm we statistically detect three absolute convergence clubs in the pre-euro period, which comprise early accession countries. In particular, Luxembourg clusters with Austria and Belgium, while a second sub-group includes Germany and France and the third The Netherlands and Finland. We also detect two separate clusters of early accession countries in the post-1997 period: a sub-group with Germany, Austria, Belgium and Luxembourg, and one with France and Finland. For the rest of the countries/cases we find evidence of divergent behavior. Robustness is checked by testing pairwise convergence in a Bayesian framework. The outcome broadly confirms our findings.

1. Introduction

Divergences in inflation rates could lead to imbalances in real interest rates, since the policy rate is the same for all the euro area countries.[1] These disparities among the member states' inflation rates could be exacerbated further by circular patterns. For instance, when a country's economic activity is relatively weak then low inflation rates are observed and thus real interest rates increase, which in turn contribute towards inflation divergence. There is an argument, which supports that inflation differentials

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* Corresponding author at: Economics and Finance, Brunel University London, West London UB3 3PH, UK.
E-mail address: menelaos.karanasos@brunel.ac.uk (M. Karanasos).

[1] As pointed out by Busetti et al. (2007) differences in real interest rates are effective on private consumption and might be relevant for investment expenditure depending on the degree of market integration.

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within euro-area countries increased in magnitude since the start of the third Stage of the Economic and Monetary Union (EMU) in 1999. The implication of that (if true) could lead to difficulties not only on the field of the common currency but also on the production of the proper and harmonic macroeconomic policies for the individual countries. Moreover, diversifications among the Eurozone countries may occur due to the Balassa-Samuelson effect (Balassa, 1964; Samuelson, 1964), which states that dissimilarities exist among the countries' relative productivity of tradable and non-tradable sectors.

Since 1999 (with the implementation of Stage three of EMU), the elimination of the national stabilizers made euro-area economies vulnerable to economic shocks. Hence among others, relative prices and wage flexibility became extremely important factors in order to sustain the balance among the euro-area countries. Inflation differentials could be a part of this adjustment procedure and not the obstacle to economic policy (ECB, 2003). Thus, it is not surprisingly that inflation convergence within the Eurozone countries attracted much of attention the last twenty years, and that quite a few studies have addressed this issue (see e.g. De Grauwe, 1996a,b).

In this paper we analyze the process of inflation convergence among the EMU countries by considering the stationarity properties of inflation differentials. Contrary to the studies examined so far (with a few notable exceptions, see for example, Busetti et al., 2007 and Lopez and Papell, 2012), we investigate whether the introduction of the euro currency has made any difference in this process. We use twelve EMU countries and taking advantage of the third stage of EMU mentioned before we split the sample into two parts. The first subsample consists of the period before the introduction of the common currency that is 1980–1997 and the second subsample commences after the birth of the common currency, namely 1998–2013.

We examine whether inflation rates in the EMU countries converge using four testing procedures: Some recently developed panel unit root tests, pairwise unit root/stationarity tests on bilateral inflation differentials, a clustering algorithm to identify stability sub-groups using multivariate stationary tests, and a Bayesian pairwise convergence framework. These procedures allow us to consider whether the inflation convergence process differs for the early accession countries and the late accession ones. Our analysis will attempt to answer three distinct questions regarding the dynamics of national inflation rates in the euro-area. The first two are whether convergence actually occurred by 1997 as required by the Maastricht criteria for joining the EMU, and did the Exchange Rate Mechanism (ERM) supported the stability process? And the third, if yes, was inflation convergence among the Member States sustained during the post-euro period?

Four alternative methodologies are used in order to address these three issues. We employ some recently developed panel unit root tests, tests for long memory and tests for other forms of persistence. Since globalization there is a high dependence among economies. Thus, we investigate stationarity properties using a testing procedure which takes into account cross-sectional dependence (CSD)-see also Arestis et al. (2014).

We then test the hypothesis of absolute convergence, that is, whether or not inflation differentials were converging to zero. Of particular interest is whether convergence took place since the launch of the common monetary policy (pre-euro period) and whether it halted in subsequent periods (post-1997 period). Relative convergence is tested by applying tests which allow for structural breaks.[2]

European countries are certainly heterogeneous and therefore there might be convergence only within specific groups. Following Busetti et al. (2007) we employ an algorithm developed by Hobijn and Franses (2000) in the context of multivariate stationarity tests, that allows us to identify separate clusters of countries or convergence clubs for the pre-1998 and post-euro periods in terms of either absolute or relative convergence. Fourthly, we also consider an alternative approach for robustness purposes. In particular, we employ the methodology of Arakelian and Moschos (2008) for testing pairwise relative convergence in the presence of transitional dynamics, which is a flexible approach as it allows the parameters (both in the mean and the variance) of the underlying process to change over time.

By applying panel unit root tests, we show that the stationarity hypothesis seems to hold, before and after the birth of the common currency in 1997. This means that some differentials are stationary and therefore there might be clubs of countries which have been in the process of converging. Next, we examined the possibility that stability had occurred only for some subset of the countries. For the pre-euro period three absolute convergence clubs were identified all of which included early accession countries. A sub-group with Germany and France, one with The Netherlands and Finland, and a bigger sub-group with Austria, Belgium and Luxembourg. For the post-1997 period, Germany turned out to belong to a big sub-group together with Austria, Belgium and Luxembourg while France clustered with Finland. For the rest of the countries/cases we find evidence of divergent behavior. The evidence produced by the Bayesian framework points also to the same direction as the one of the clustering algorithm. Specifically, the decline in the mean is achieved in five out of the six pairs (for both the pre-1998 and post-euro periods) of the Austria, Belgium, Luxembourg sub-group, and for all three pairs (for the post-1997 period) of the Germany, The Netherlands and Finland cluster.

The reminder of the paper is organized as follows. Section 2 describes the data (for a literature review see supplementary Appendix C). In Section 3 we report the empirical results and discuss them within the concept of whether or not ERM promoted the convergence process between Eurozone inflation rates even before 1997 (as claimed by the European Commission, 2014), and of whether or not these inflation rates remained stable after the implementation of the common currency. Section 4 summarizes and concludes.[3]

[2] We should mention that Conrad and Karanasos (2015a) demonstrate that in the presence of volatility spillovers, if this transmission mechanism is ignored, unit root tests will have poor power and size properties (see also, Conrad and Karanasos, 2015b and Canepa and Karanasos, 2016 and Karanasos and Kim, 2006).

[3] The four appendices A, B, C and D are relegated to the supplementary material. This can be found at the author's homepage http://www.mkaranasos.com/.

Table 1
Classification of European countries.

Category 1-ERM Early accession	Austria, Belgium, Finland France, Germany, Ireland Italy, Luxembourg, The Netherlands
Category 2-ERM Late accession	Greece, Spain, Portugal

2. Data

In this paper we study the convergence of inflation rates among the countries of the EMU covering a period from 1980 to 2013. The main data source is Datastream. The data we employ consist of quarterly and monthly log-differences of the Consumer Price Index (CPI), $\log(CPI_t/CPI_{t-1})$, for each individual country. Busetti et al. (2007) distinguish the group of countries into two categories, low inflation countries (i.e., Germany, France, and Austria) and high inflation ones (i.e., Spain, Portugal, and Greece). Further, we divide the countries in two alternative categories, that is the early accession countries (i.e., Germany, France, The Netherlands, and Italy) and the late accession ones: Spain, Portugal and Greece (see Table 1 below).

Taking advantage of the third stage (a pre-established deadline -January 1, 1999- by which the creation of a single currency and the foundation of a ECB should initiate) we split the sample into two parts. The first subsample consists of the period before the birth of the common currency that is 1980Q1–1997Q4 and the second subsample commences after the launch of the euro currency, namely 1998Q1–2013Q4.

Before analyzing our results, we hypothesize that the inflation convergence between the countries that adopted the ERM from the beginning would be stronger. In total we could say that the implementation of the ERM led European inflation rates to lower levels and possibly (at least for some sub-groups of countries) to convergence, see Fig. C1 in Appendix C.

3. Empirical results

3.1. Panel tests

This section tests for joint stationarity of all the inflation differential series. The attraction of this method is to produce more powerful tests because a single time series may not be powerful enough to reject the null hypothesis. We conduct both panel unit root and stationarity tests. For the unit root tests, the null hypothesis of divergence is $H_0 : \rho = 1$, i.e., all differentials are unit root processes against either $H_{1a} : \rho_i = \rho < 1$ for all i or $H_{1b} : \rho_i < 1$ for all i, depending on the type of the test used. The tests are summarized in Table C1, in Appendix C. The tests below are the panel unit root tests of: Im et al. (2003), or IPS, Levin et al. (2002), or LLC, Harris and Tzavalis (1999), or HT, Breitung and Das (2005), or BD, Pesaran (2004, 2007b), or CADF, Karavias and Tzavalis (2014, 2015), or KT14 and KT15 respectively.

First, we test for the null hypothesis of a unit root using the panel unit root tests with no constant. The results are reported in Panels A of Tables 2 and 3 (for more details see Tables A1 and A2 in Appendix A). For this case we can see that all tests reject the null hypothesis at 1% level. This means that some differentials are stationary and therefore there might be clubs of countries which have been in the process of converging absolutely. This result holds firmly for both the pre-1998 and post-euro periods.

When testing for the null hypothesis of unit root/stationarity using panel unit root/stationarity (i.e., the KPSS) tests with constant but with no breaks the results (not reported) are mixed. One reason for why this is the case could be structural breaks in the intercepts of the series. This means that there is stationarity but the level of this stable relationship changed at one or more points in time. However, when we apply the KT14 and KT15 tests for various break specifications we find evidence of stationarity for both pre-euro and post-1997 periods (see Panels B in Tables 2 and 3 respectively). We favour the results of the KT15 test which are more general and, for the pre-1998 period, we find that there might be one or two breaks late in the sample. For the post-euro period we detect one or two breaks sometime in the middle of the sample.

Table 2
Panel unit root tests-pre euro period.

Panel A Panel unit root tests (no constant)				
BD	BD CSD	LLC	HT	CADF
−12.55(1%)	−2.74(1%)	−13.07(1%)	−18.68(1%)	−3.56(1%)
Panel B Panel unit root tests with breaks				
KT14(1)	KT15(1) CSD	KT15(2) CSD		
−151.63(1%)	−110.79(1%)	−113.76(5%)		

Notes: The number in the parenthesis is the significance level. The breakpoints 1 for the three KT tests are: 1997:01, 1994:02, and 1994:03. The breakpoint 2 is 1995:03.

Table 3
Panel unit root tests-post euro period.

Panel A Panel unit root tests (no constant)			
BD	LLC	HT	CADF
−16.35(1%)	−17.31(1%)	−54.19(1%)	−4.31(1%)
Panel B Panel unit root tests with breaks			
KT14(1)	KT15(1) CSD	KT15(2) CSD	
−241.48(1%)	−47.08(1%)	−56.35(1%)	

Notes: The number in the parenthesis is the significance level. The breakpoints 1 for the three KT tests are: 2013:01, 2005:02, and 2005:02. The breakpoint 2 is 2008:01.

Since due to globalization there is high dependence among economies, we also investigate the stationarity properties using the testing procedure, which takes into account CSD (see also Arestis et al., 2014). As shown in Tables 2 and 3 , for both periods and all tests under investigation [BD CSD, CADF, KT15 (1) or (2) CSD] the results suggest that the stationarity hypothesis seems to hold when CSD is accounted for. In other words, the application of cross-sectional panel unit root testing procedures leads to the same conclusions as before. The null hypothesis of a unit root is rejected both in the pre-euro and the post-1997 periods. The persistence parameters for the case of no intercepts (absolute convergence scenario) are 0.91 for the pre-euro period and 0.50 for the post-euro period. These parameters imply a half life of 7.7 quarters in the pre-euro period and 1.1 quarters in the post-euro period; these values are similar to the averages of Busetti et al. (2007).

It appears that the ERM sped up inflation convergence. Factors that could possibly contribute towards that direction in the EMU include among others, macroeconomic stability as well as vigorous fiscal policies. Furthermore, a higher degree of elasticity in product and labour markets and the more effective employment of capital and labour in the economy could promote convergence among the euro area countries.

3.2. Univariate tests

3.2.1. Pre-euro period

The panel data unit root tests easily rejected the null hypothesis of divergence but they are not informative on how many, and most importantly, which series converge. This can be checked by univariate unit root tests. First, we investigate the behavior of European countries' inflation rates before the birth of the euro currency, 1980Q1–1997Q4. In particular, we will apply stationarity tests, namely KPSS tests, and unit root tests, namely, Augmented Dickey Fuller (ADF), Zivot and Andrews (1992) (ZA), and the Lumsdaine and Papell (1997) (LP) tests (the results of the three unit root tests are presented in the supplementary Appendix).[4]

Regarding the principal findings from the pairwise contrasts, for the pre-euro period we report our results in Table 4 (and in more detail in Table A3 in Appendix A).[5] The pairwise contrasts include the 9 countries in category 1: Germany (GE), France (FR), Italy (IT), The Netherlands (NE), Austria (AU), Belgium (BE), Finland (FI), Luxembourg (LU), and Ireland (IR), and the three countries in category 2: Spain (SP), Portugal (PT) and Greece (GR), see Table 1. Similarly to Busetti et al. (2007) we ordered the countries based on their GDP weights in the euro-area. The analysis of the results will group the inflation differentials into three different groups. The first two consist of pairwise contrasts including countries only from either category 1 or from category 2 (36 and 3 pairs respectively). The third group incorporates inflation differentials between one country from category 1 and one from the second category (27 pairs). Thus in total we have 66 pairs.

By testing the time series properties of differentials in each group, we are able to examine whether there is inflation convergence within each of the three groups. In other words, apart from convergence within each category (that is, $N = 36$ for group 1 and $N = 3$ for group 2), it is of interest to explore any pattern of convergence considering both early and late accession countries as a single group, i.e. when the countries are grouped together irrespective of when they adopt the ERM (that is, $N = 27$ for group 3).

The results of the stationarity tests with either no intercept or with intercept and one break (the results of the tests with intercept and two breaks are presented in the supplementary Appendix) on the pairwise contrasts are displayed in Table 4 (for more details see Table A4 Appendix A). As regards the KPSS tests with no intercept for group 1 the null hypothesis of absolute stability is rejected at 1% significance level in 28 cases out of 36, and in all three cases for group 2 (alternatively 78% and 100%

[4] Given the fact that we consider all possible differentials, a potential problem that may be raised is that of CSD (see Arestis et al., 2014). Such issues, however, can be circumvented by performing the CDS test proposed by Pesaran (2007a). Therefore, for robustness tests purposes we also use a pairwise testing procedure developed by Pesaran, which takes into account all pairwise differential combinations and the existence of CSD- the so called cross sectional ADF tests or CADF, see also Arestis et al. (2014). The results (not reported) are very similar to those of the ADF tests.

[5] The ADF tests with no intercept are displayed in the first three columns of Table A3 and are jointly labeled ADF no intercept. The first column reports the inflation differentials, the second the ADF statistic and the third one the power of the rejection of the null hypothesis (using three alternative significance levels: either 1% or 5% or 10%). Rejection of the null indicates that the two inflation rates are in the process of converging.

Table 4
Stationarity Tests. Pre euro period.

	Rejection rates		
	Group 1	Group 2	Group 3
KPSS-no intercept	78%	100%	81%
KPSS-1 break	0%	0%	0%

Notes: Each entry shows the percentage rate of rejection of the null hypothesis at 1%.

of the cases respectively). Similarly for group 3 the null hypothesis is rejected at 1% significance level in 22 out of 27 cases or 81% of the inflation differentials. Thus there is very weak evidence of absolute stability (in only 8 pairs of group 1 and 5 pairs of group 3).[6]

As regards the KPSS tests with one break for all the three groups, the null hypothesis of relative stability is not rejected in all cases (66) of the inflation differentials (for the results of the KPSS test, which allows for two breaks in the intercept instead of one see columns 7–9 in Table A4).

The results of breakpoint analysis from the KPSS test with one break report that for the early accession countries (club 1) the breaks occur more frequently between 1981–83 covering the period of the early 1980s recession (in 16 out of 36 cases; see Table A2) and secondly during 1991 and 1993 (in 9 out of 36 cases) capturing the inauguration of the European Bank for Reconstruction and Development (EBRD) in London and the beginning of the single European market (which guarantees the free movement of goods, capital, services and people, the so-called "four freedoms" between the 28 Member States) respectively. Regarding club 2 results, the break in 2 out of 3 pairwise contrasts occurred during the first quarter of 1992 when the Treaty on the European Union was signed in Maastricht by the finance and foreign ministers of the EU member states. The estimated breakpoints for club 3, in 14 out of 27 pairwise contrasts, cover the periods firstly from 1981 to 1983 (similarly to club 1 above) and secondly from 1985 to 1986 when European Union foreign ministers reached a political agreement towards the amendment of the Treaty of Rome by finalising the text of the Single European Act (SEA). The Act was signed at Luxembourg in early 1986.

To conclude, using three different KPSS tests we tried to explore whether the inflation differentials were stable or not from 1980 to 1997. The results (from the KPSS test with no intercept) indicate weak absolute stability, but those provided by the KPSS tests with one and two breaks suggest that there is strong relative stability and, therefore concur with the ones from the ZA and LP tests (see the supplementary Appendix).

3.2.2. Post-euro period

In this section we use stationarity tests in order to assess whether the behavior of European countries inflation rates was stable or not after the adoption of the common currency, 1998Q1–2013Q4. For convergence purposes we also run unit root tests without intercept (ADF tests) and with intercept and either one or two breaks (ZA and LP tests, respectively; see the supplementary Appendix). Results are reported on Table 5. In other words, we consider the stationarity of each differential through the use of unit root/stationarity tests.

The results of the stationarity tests with no intercept on the pairwise contrasts are displayed in the first row of Panel A in Table 5 (for more details see columns 1–3 in Table A5 in Appendix A). For groups 1 and 2 the null hypothesis (of stability) is rejected at 1% significance level in only 4 out of 36 and in 1 out of the 3 cases respectively (alternatively 11% and 33% of the cases). Similarly for group 3 the null hypothesis is rejected at 1% significance level in only 6 out of 27 cases or 22% of the inflation differentials. Therefore there is strong evidence of absolute stability.

The second row in Table 5 reports, for the subsample: 1998Q1–2013Q4, the baseline results when we allow for one break in the intercept (for more details see the three columns jointly labeled 'KPSS-ONE BREAK' in Table A5). As shown in Table 5 the percentage of rejections is 0% in all the three groups. That is, the null hypothesis of relative stability is not rejected in all 66 cases. Details about the breakpoints and the results of the KPSS tests with two breaks are presented in Appendix C.

The more frequent breakpoint for group 1 (in 8 out of 36 cases) occurred during 2008 (especially in the first and second quarters). From late 2007 the global financial crisis began to appear. In the first quarter of 2008 Ireland, Finland and Portugal showed signs of recession. It was not until a few months later that the financial crisis erupted, affecting the European economy and causing the European sovereign-debt crisis of the following years. Regarding the breakpoint estimates for groups 2 and 3 (for more details see columns 4–6 in Table A5 in the additional Appendix) these seem to appear (in 13 out of 30 cases) either in 2011 (the last three quarters) or in 2012 (the first three quarters). During these years the European Parliament adopted a set of measures to support the European economy (Euro Plus Pact), Greece endorsed a package of austerity and structural reforms in an attempt to reduce the country's growing debt and the European Stability Mechanism inauguration was signed with an ability to lend up to 500 billion Euros to Eurozone countries that were severely affected by the crisis. In addition, in July and October of 2011 the EU approved a solidarity package with Greece amounting to 109 billion Euros and Eurozone Leaders agreed on a strategy plan to promote sustainable growth, fiscal consolidation/tighter cooperation and assistance to countries facing financial and other difficulties. To sum up, it was not until January of 2012 that the European Council agreed on a tighter

[6] That might be because the European inflation rates were in the process of converging but they were not yet stable.

Table 5
Stationarity tests. Post euro period.

	Rejection rates		
	Group 1	Group 2	Group 3
KPSS-no intercept	11%	33%	22%
KPSS-1 break	0%	0%	0%

Notes: Each entry shows the percentage rate of rejection of the null hypothesis at 1%.

system of governance that would be able to supervise the member states towards fiscal discipline and apply sanctions when it is necessary. With the Greek issue still active, Euro area ministers of finance agreed on a second programme (on 21st of February 2012) in order to avoid a Grexit from the Eurozone. As a response to the crisis, EU leaders promoted actions in June 2012 to restore investors' confidence in the European Economy by adopting the " Compact for Growth and Jobs".

To conclude, using three different KPSS tests, we tried to explore whether the inflation differentials were stable since the adoption of the common currency in 1998. The KPSS tests with no intercept in the post-1997 period reject the null hypothesis much less frequently than those in the pre-euro period. Thus we provide strong evidence of absolute stability. When we employ the KPSS test with either one or two breaks all European inflation rates appear to move relatively harmoniously after the introduction of the euro. Thus the inflation differentials are characterized by relative stability since the null hypothesis is not rejected in all 66 cases. In other words, there is strong evidence that the European inflation rates remained relatively stable after the adoption of the common currency for all the three groups despite the recent financial crisis of 2008/2009.

3.3. Clustering algorithm

The big degree of heterogeneity among the European countries also hints to the fact that there may be a middle way (between the panel and univariate methodologies), i.e. there are some clusters of countries in which convergence has taken place within the cluster. An explicit algorithm which detects sub-group formation has been proposed by Hobijn and Franses (2000), which uses multivariate stationarity tests on inflation differentials. Its core function is to start with all possible pairs of countries and test their differentials for stability. Suppose that two countries are found to form a cluster. Then all other countries are tested for whether they belong to that cluster or not by testing for joint stationarity of all involved differentials. If the evidence is in favour of stationarity the cluster grows otherwise other clusters are formed and it may be that some countries do not belong in any cluster. A great virtue of the algorithm is that it is independent of the ordering of the countries in the clusters. Below we apply the algorithm in terms of absolute and relative convergence/stability at both the pre-euro and post-1997 periods. The bandwidth parameter of the algorithm is set to 0.05 as in Busetti et al. (2007).

As regards absolute convergence, for the pre-euro period we find three convergence groups, all of which include early accession countries: a) Austria, Belgium and Luxembourg, b) Finland and The Netherlands and c) France and Germany, while for the post-euro era we find two sub-groups: a) Austria, Belgium, Luxembourg, Germany and b) Finland and France (see also Table A8 in Appendix A). The countries of south such as Greece, Italy, Portugal and Spain do not belong in the above clusters but are also heterogeneous enough to not form a cluster on their own.

These results broadly confirm that common monetary policies became more similar across countries during the pre-euro period. After the German reunification and the European monetary crisis of 1992–1993, fiscal positions especially for Benelux (Belgium, Netherlands and Luxembourg), France and Germany displayed substantial improvement. Key role in the fiscal consolidation was played by the Treaty of Maastricht as well as by the creation of the Stability and Growth Pact in 1997. In particular, France along with its trade partner Germany reduced their general government deficits drastically during the pre-euro period. Similarly Benelux, displayed a remarkable fiscal recovery during the mid and late 90s. Synchronized efforts towards fiscal consolidation by the aforementioned countries could be seen in the Convergence Plan adopted by Belgium in 1992 and in the fiscal framework that Netherlands introduced in 1994. As far as the post-euro period is concerned, the adoption of the EMU and the common exchange rate policies reduced the discrepancies between the Eurozone countries further. When testing for relative convergence, for the pre-1998 period we find three convergence sub-groups: a) Austria, Belgium and Luxembourg, b) Finland and Ireland and c) The Netherlands and Portugal, while for the post-euro era we find two 'early accession' sub-groups: a) Austria, Belgium and Luxembourg and b) Finland, Germany and The Netherlands (see also Table A9 in Appendix A).

In general the results from the clustering algorithm are consistent with the ones obtained from the panel and univariate unit root/stationarity tests.

3.4. A Bayesian approach

We additionally apply the methodology suggested by Arakelian and Moschos (2008) for modeling pairwise convergence in the presence of transitional dynamics, using a flexible approach, which allows the parameters of the underlying process to change over time. According to them, inflation convergence is achieved when the means and the variances of the inflation differentials diminish in successive time periods. If there are subperiods where the criteria do not hold, convergence is still achieved if the mean and the variance have been diminished since the start of the period examined. A key ingredient of this methodology is that the number of the subperiods is unknown. To implement the model a Markov chain Monte Carlo (MCMC) algorithm is adopted. The process explored for the inflation differentials is the white noise with drift. We run the algorithm from 1980Q1:1997Q4 and from 1998Q1:2013Q4 allowing 10 breaks whose distance is no less than 10 quarters. Starting with zero breaks and after a burn-in period of 5000 points we obtained the Markov chain output by collecting the next 10,000 points for the two distinct processes. An ergodic estimate of the posterior model probabilities was obtained. Among the models with different number of thresholds, we chose the one with the highest posterior probability (for more details, see Arakelian and Moschos, 2008).

Our results are reported in Table A9. The top row shows the breakpoints detected by the MCMC algorithm. The second and third rows show, for the various breakpoints, the values of the drifts in the mean and the variance respectively. The vertical line separates the two subsamples. 18 out of 66 pairs showed no regime change. In the rest of the pairs there is at least a regime change. According to the criterion of convergence, 39 pairs converged in the first subsample but only 10 pairs in the second subsample. The decline of the mean is achieved in more pairs (2 more in the pre-1998 period and 7 more in the post-euro period) but it was not accompanied by a volatility decline, breaking the second rule of the convergence definition. In other words, relaxing the assumption of volatility decrease, in the first and the second subsamples 41 and 17 pairs achieved convergence, respectively. During the first subsample, nineteen pairs exhibited a regime change during 1988 and eleven pairs during 1989. From 1998 until the end of the period, twenty one pairs exhibited a regime change during 2005.

As regards relative convergence the results from the Bayesian approach are consistent with the ones obtained from the clustering algorithm. That is, for the convergence club Austria-Belgium-Luxembourg, in five out of the six pairs for the two subperiods the decline in the mean is achieved and in four it was accompanied by a volatility decline. Regarding the Finland, Germany and The Netherlands sub-group for the post-euro period, in all three pairs the decline in the mean is achieved and in two was accompanied by a volatility decline.

3.5. Discussion

In this section we will further discuss and summarize our results. The empirical evidence from the panel unit root tests (with or without CSD) show that, for both the pre-1998 and the post-euro periods, the stationarity hypothesis seems to hold. This means that some differentials are stationary and therefore there might be clubs of countries which have been in the process of converging absolutely or relatively (see the first row of Panel A in Table 6).

The table above also shows that there is no evidence for overall absolute stability of inflation differentials in the pre-euro period (see the second row of Panel A). That is, for the pre-1998 period the results from the univariate stationarity tests show that there is a divergent behavior (around a zero mean) of the inflation rates.

This mixed evidence in favour of inflation convergence/divergence, using univariate unit root and stationarity tests, is in line with the results from the clustering algorithm. Overall, we find evidence of divergent behavior (either relative or absolute) for both periods. However, we are able to statistically detect separate clusters or convergence clubs, all of which include early accession countries. In particular, as regards absolute convergence we detect three(two) sub-groups in the pre(post)-euro period. Six out of the nine early accession countries, that is Germany, France, Austria, Belgium, Luxembourg and Finland are included in groups in both periods (see Panel B). Thus, overall, there is an indication of divergence of inflation rates in both subsamples. That is, it appears that inflation rates began to drift apart, and the inflation differentials to displaying unit root behavior. The outcome from the pairwise convergence Bayesian framework broadly confirms our findings. That is, relaxing the assumption of

Table 6
Principal findings.

	Pre euro		Post euro	
	Absolute convergence	Relative convergence	Absolute convergence	Relative convergence
Panel A				
Panel tests	Yes	Yes	Yes	Yes
Univariate tests	Yes/No[a]	Yes	Yes	Yes
Bayesian approach	NA[b]	Yes/No[c]	NA[b]	No[d]
Panel B (clustering algorithm)				
Multivariate Stationarity tests	Yes[e] (for some sub-groups of group 1	Yes (for some sub-groups) of group 1	Yes[e] (for some sub-groups) of group 1	Yes (for some sub-groups) of group 1

Notes:
[a] Stationarity tests: very weak evidence for all the three groups. Unit Root Tests: moderate evidence for group 3, around 40%.
[b] NA stands for Not Applicable.
[c] Moderate evidence: 62% of the cases.
[d] Weak evidence: 29% of the cases.
[e] I.e. for 3(2) sub-groups, which for the pre(post)-euro period include 7(6) countries out of 9 from group 1.

Table 7
Long-memory parameters for sixteen pairs (ELW Estimator).

GE-GR	GE-PT	GE-LU	FR-SP	FR-PT	IT-GR	IT-PT	SP-NE
0 .497	0.839	0.443	0.341	0.802	0.533	0.594	0.717
0 .421	0.575	0.495	0.143	0.463	0.207	0.462	0.559
0 .365	0.268	0.086	0.062	0.278	0.185	0.229	0.347
SP-AU	BE-GR	BE-PT	AU-PT	GR-FI	GR-IR	GR-LU	FI-PT
0.414	0.415	0.783	0.789	0.423	0.658	0.403	0.796
0 .426	0.275	0.494	0.561	0.377	0.492	0.324	0.399
0 .169	0.079	0.422	0.297	0.027	0.283	0.248	0.261

The first, second and third rows present the long memory parameters for the total, pre- and post-EMU periods respectively. ELW is the Exact Local Whittle estimator of Shimotsu and Phillips (2005).

volatility decrease in the first and the second subsamples 41 (62%) and 17 (only 29%) pairs are converged, respectively (see the third row of Panel A).

3.6. Long-range dependence

In this section we investigate the inflation differential dynamics and whether these have changed with the launch of the EMU. Jensen (2009) examines the inflation and interest rate dynamics in 17 developed countries and finds that they are highly persistent, fractionally integrated, mean-reverting processes with order of integration parameters significantly less than one. We measure inflation persistence by means of semiparametric and parametric methods. The exact local whittle (ELW) estimator of Shimotsu and Phillips (2005) is proposed here to estimate the fractional integration order or long memory parameter, d, in the frequency domain. In addition, we estimate an ARFIMA (p, d, 0) model in the time domain using the MLE estimator as described in Baillie (1996).[7]

Our results, reported in Table 7 (see also Table D1 in the supplementary Appendix), strongly support the fact that inflation differentials are highly persistent in most of the cases. For example, for the inflation differentials involving Portugal, we observe that the persistence parameter, d, is always above 0.5 when the whole period is examined, while in the pre-EMU period the long memory parameter lies close to 0.5. However, when we consider the post EMU period, the degree of persistence in the inflation differentials largely lies between 0.10 and 0.35. The findings for the sixteen pairs examined are in line with the ADF unit root test results where the null hypothesis of non-stationarity is not rejected before the launch of the EMU but is rejected in the post-EMU formation period (see Table A3 in the supplementary Appendix). Further, we use the Hassler and Meller test which detects and dates multiple changes in the persistence of a series using a modified LM-type test (see Hassler and Meller, 2014).[8] The results of the HM test (reported in Table D2 in the supplementary Appendix) reveal a few significant changes in the persistence of the inflation differentials that occurred before the Eurozone launch.[9]

4. Concluding remarks

This study provided evidence over the behavior of European inflation rates covering a period from 1980 to 2013. By applying panel unit root tests we show that the stationarity hypothesis seems to hold, before and after the birth of the common currency in 1997, even when CSD is accounted for. Therefore there may be groups of countries which are in the process of having convergent monetary policies. For the pre-euro period, regarding absolute convergence, the univariate stationarity tests provide weak overall evidence for the pairwise contrasts that include one early and one late accession country.

The use of multivariate stationarity tests and the clustering algorithm for the identification of stability clubs found no evidence of overall stability-around either a zero mean or a broken mean-of inflation differentials. However, inflation rates appeared to move homogeneously among sub-groups of early accession countries. For the pre-euro period three absolute convergence clubs were identified all of which included early accession countries. These are: Germany and France; The Netherlands and Finland; and Austria, Belgium and Luxembourg. In the post-1997 period Germany formed a big sub-group with Austria, Belgium and Luxembourg while France clustered with Finland. For the rest of the countries/cases we find evidence of divergent behavior.

Finally, Figs. 1.1 to 1.7 below show the average inflation rates of each of the twelve Eurozone countries distinguished into seven different periods. In particular, there are two periods before the launch of the EMU (1980–1983, 1984–1989), three EMU

[7] The lag order p of the ARFIMA (p, d, 0) is chosen using the Bayesian information criteria. Baillie and Kapetanios (2007, 2008) extend the fractionally integrated model with non-linear autoregressive terms and their model successfully captures the long-memory and non-linearities in many economic and financial time series.

[8] The test is performed as a max-Chow (or *supF*-type) test.

[9] We further report, in Table D2, the observed dates at which the test statistic achieves its maximum.

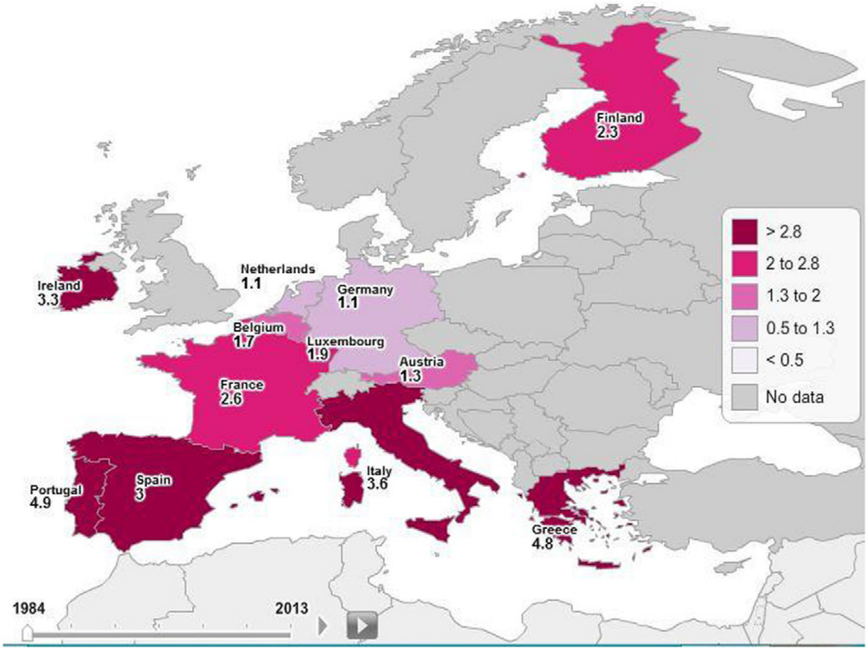

Fig. 1.1. Pre-EMU average inflation rates, 1980–1983.

stages, the post enlargement period (2004–2007) and the years covering the financial and EU sovereign-debt crisis (2008–2013). For example, Fig. 1.7 reports the deflationary dynamics that the financial crisis and the EU-sovereign debt crisis imposed to the Eurozone economies.

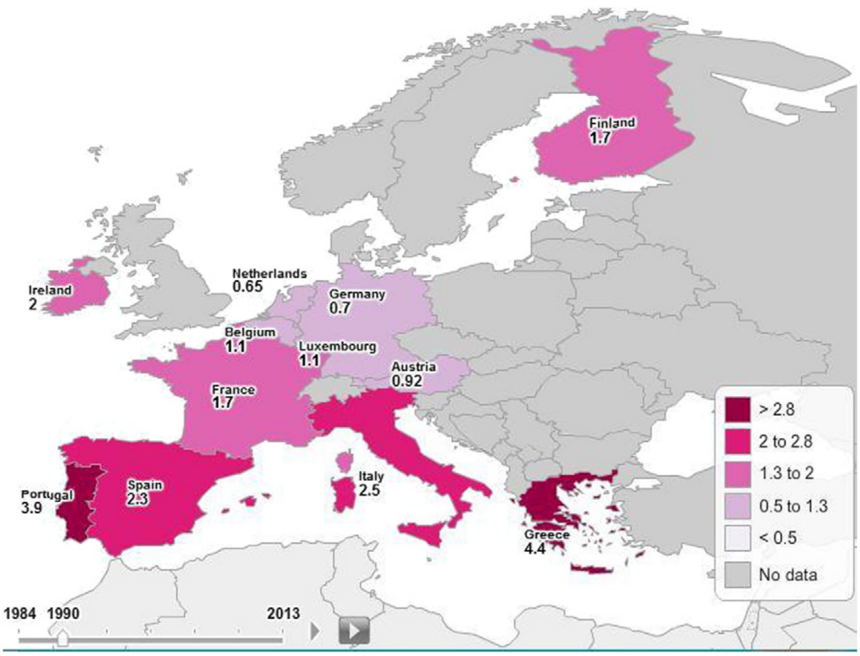

Fig. 1.2. Pre-EMU average inflation rates, 1984–1989.

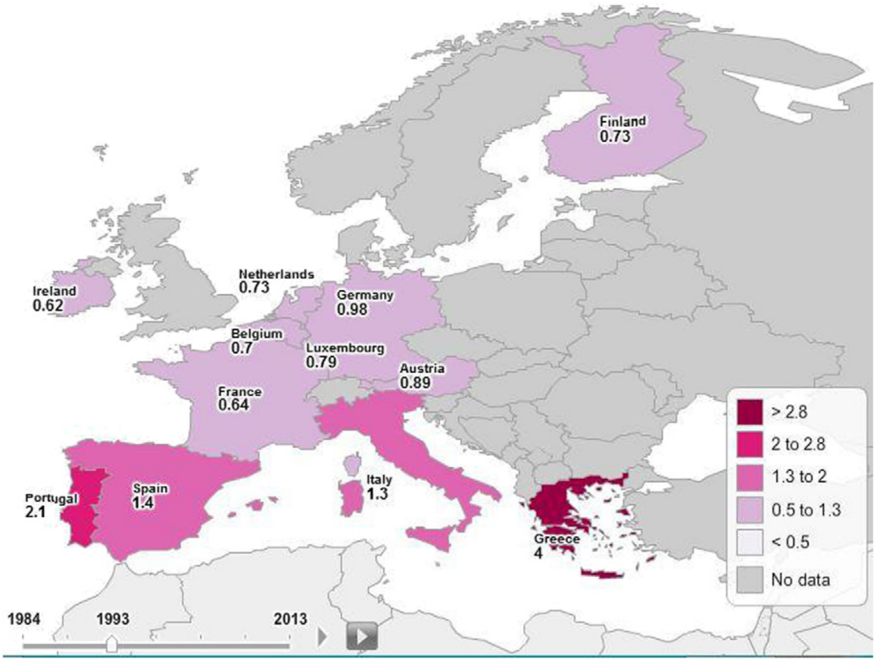

Fig. 1.3. 1st stage EMU average inflation, 1990–1993.

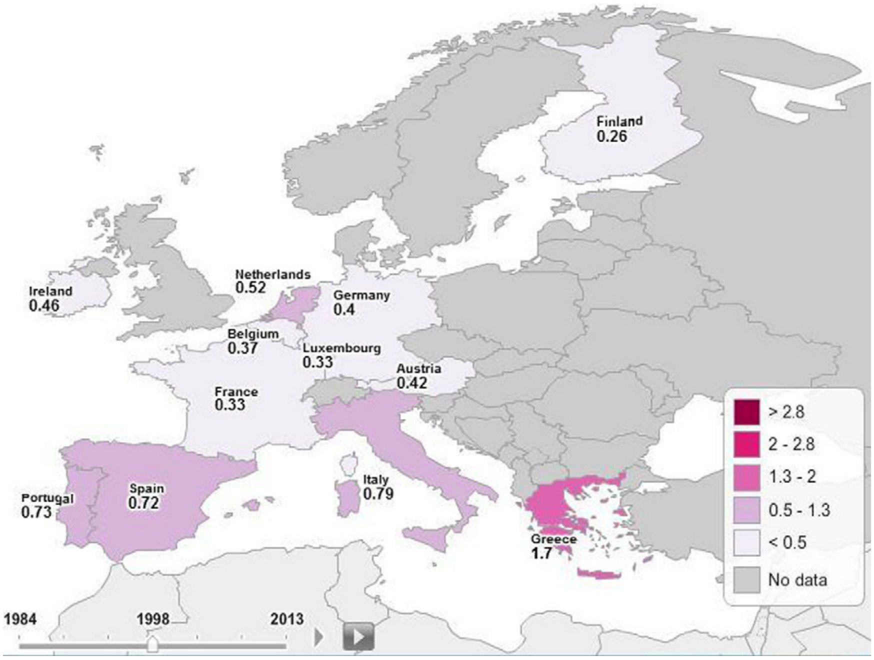

Fig. 1.4. 2nd stage EMU average inflation, 1994–1998.

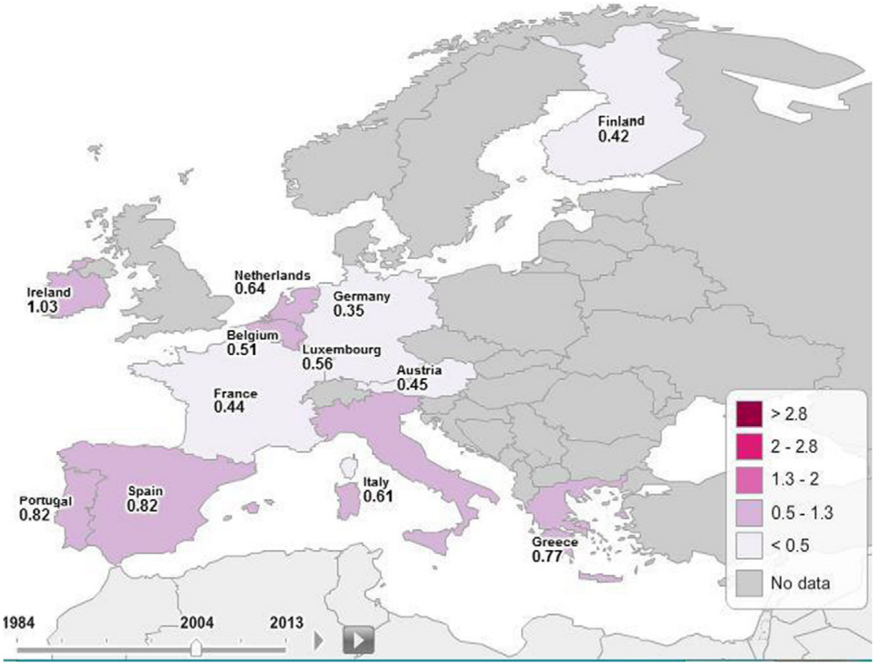

Fig. 1.5. 3rd stage EMU average inflation, 1999–2003.

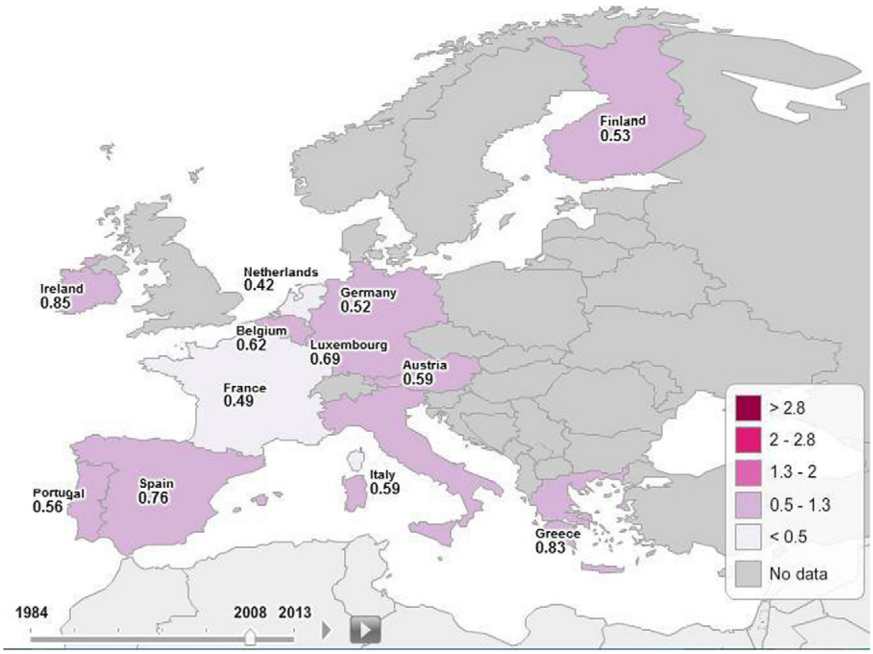

Fig. 1.6. Inflation after the EU Enlargement, 2004–2007.

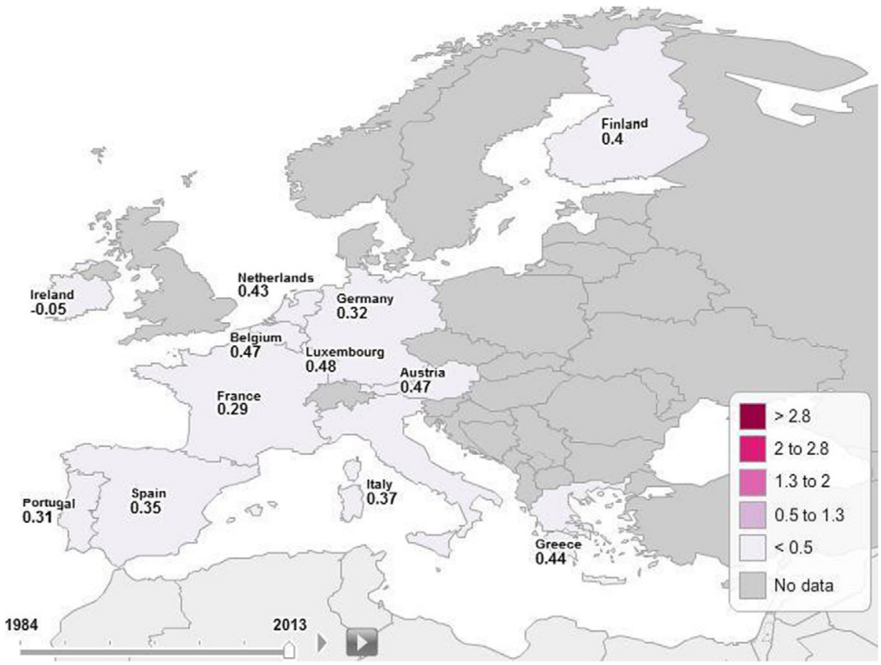

Fig. 1.7. Average inflation during the financial crisis, 2008–2013.

Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jempfin.2016.07.004.

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