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Price Convergence in the Eurozone: Panel Smooth Transition Regression Models

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ABSTRACT: The purpose of this article is to discuss price convergence within the Eurozone using Smooth transition models. The analysis focuses on annual data taken in logarithm. Indeed, our sample includes twelve Eurozone countries: Austria, Belgium, Portugal, Spain, the Netherlands, Italy, Luxembourg, Ireland, Greece, France, Finland and Germany. The study period runs from 1990 to 2018. These data are extracted from the OECD and Eurostat websites. The results found show that convergence is non-linear, and the speeds of adjustment are different depending on the country. This is explained by the differences in the evolution of price competitiveness and the rigidities of the labor market.

KEYWORDS: Euro zone, Price convergence, cointegrated VAR, smooth transition models, LSTR, ESTR.
JEL Classification: C22, E31, F15, F41.

1. INTRODUCTION

In the 1990s, there was a need to realize the importance of the evolution of the integration of the economies of the Member States of the European Union. In view of the above, in the sense of Balassa (1961), the independence of capital movements as well as the stability of the exchange rate and even the presence of the single currency, all contributed to converting and transforming the customs union into a monetary zone. It should not be ignored that within the single market, the reduction of transaction costs subsequently allowed for the promotion of price convergence. Indeed, according to the law of single prices, in an economic zone characterized by perfect integration and under the assumption of a competitive market, the existence of diversity between price levels would push economic agents to take into account "arbitrage opportunities" in favor of the lowest prices. This pushes economic agents to take the decision to reduce tariff diversification in the economic zone, which subsequently generates a movement of nominal convergence.

One of the controversial criteria for entry into EMU is inflation rate convergence, which is based on the similarity of inflation rates rather than the convergence of price levels. Following efforts in 1996-1997 to achieve the EMU criteria, inflation rates diverged within the euro area. Although the Balassa-Samuelson effect may partly explain this divergence, it led to significant real interest rate differentials within the area, with some countries experiencing negative real interest rates that fostered debt bubbles.

leming (1971) was the first to highlight the importance of price level convergence between members of a monetary union within the framework of the theory of optimal currency areas. According to him, the main criterion for optimality lies in the similarity of inflation rates between members: differences in relative costs not offset by productivity gains immediately lead to a loss of competitiveness via a deterioration in the terms of trade. This leads to a reallocation of demand from "high-inflation" countries to "low-inflation" countries, generating external imbalances between economies (deficits for high-inflation countries and surpluses for low-inflation countries). This risk materialized in the Eurozone between 1999 and 2009, with a number of high-inflation countries experiencing external imbalances and deficits. After the sovereign debt crisis of 2009-2011, the question is whether these countries will be able to adjust their price levels without the help of a nominal devaluation of the exchange rate and how long this will take.

The literature on price convergence is mainly based on the empirical verification of the law of a price or purchasing power parity (PPP). Some of the main approaches include: The approach is based on the consumer price index (CPI). Camarero et al. (2000) address price convergence between peripheral EU countries (Spain, Italy, UK) and Germany using time series unit root tests and find evidence of a catch-up effect. Cecchetti et al. (2002) assess price convergence between 19 US cities using unit root tests. According to Faber and Stockman (2009) and Crucini et al. (2005), the CPI may only be useful for testing relative PPP (convergence

of inflation rates) and not absolute PPP (convergence of price levels). By recalculating a CPI that takes into account price differences between countries, Faber and Stockman (2009) found that price dispersion had decreased over time for countries belonging to the euro area. Based on the price level index provided by Eurostat, Allington et al. (2005) and Égert (2007) show that price levels are heterogeneous across EU-27 countries. While Égert (2007) documents the reasons for inflation divergence and argues that despite the small impact of the Balassa-Samuelson effect, structural factors affecting tradable and non-tradable goods are the main explanations for differences in price dynamics, Allington et al. (2005) argued that the euro led to a reduction in price dispersion in the EMU.

In this approach, our goal is to study price convergence among twelve EMU countries. To this end, we examine annual data for the period 1990–2018. Using cointegration techniques, we show that the simple linear assumption regarding the price convergence process can be considered too restrictive. To overcome this limitation, we account for potential nonlinearities in the price adjustment process by estimating smooth transition regression models. These models allow us to predict different price behavior depending on whether price gaps are above or below a certain threshold. In other words, although price convergence may not be observed in a standard linear framework, it can only occur when price gaps are large in size. Moreover, from the estimation of these models, it is possible to infer mean reversion speeds in the case of convergence.

2. OVERVIEW OF RELATED LITTERATURE

After the completion of EMU, nominal convergence was practically achieved, with the notable exception of public debt. The fall in interest rates was accompanied by a significant process of integration of financial markets, particularly bond markets. In defining nominal convergence, we will rely on the view of Fränkel and Rose (1998):« …*The belief that the OCA criteria were "endogenous" became popular, namely that these criteria, although not satisfied ex-ante, would have been satisfied ex-post, thanks to the fact that EMU participation would have implied increased trade integration and a stronger degree of co-movement of economic cycles*…».

Indeed, convergence is of particular importance, it is considered as "... A hypothesis of catching up of rich countries by poor countries in the form of a long-term equalization of GDP per capita." Economists such as Gerschenkron (1952) and Abramovitz (1986) based this hypothesis on the spread of technical progress, particularly since the illusion of the neoclassical approach to growth (Solow model (1956)). According to this hypothesis, the different models of endogenous growth are opposed. Taking in this context, the example of Romer (1994), who shows that the characteristics of the economy develop the variety of economic growth rates. Still in the same vein of Romer's idea (1986), the initial conditions, the stock of physical capital or human capital determine the growth rate per capita. These analyses have given greater importance to the acceptance criteria of convergence, particularly, with the two concepts of δ-convergence and β-convergence by Sala-i-Martin (1990). Based on this idea, Bernard and Durlauf (1996), Evans and Karras (1996), studied an approach based on the specification of margins at the level of gross domestic products per capita.

Regarding real convergence, during the first ten years of EMU, it was made even more visible by the massive capital flows from the "core" to the "periphery" of the euro area, given the volatility of exchange rate risk and default risks. This process was accompanied by increasing current account deficits in the periphery and growing surpluses in the core. Capital inflows coincided with accelerated growth rates. Euro area countries, while receiving capital inflows and running current account deficits, also experienced sustained domestic demand and rapidly reduced unemployment. In short, real convergence during the first decade of EMU largely coincided with structural divergences.

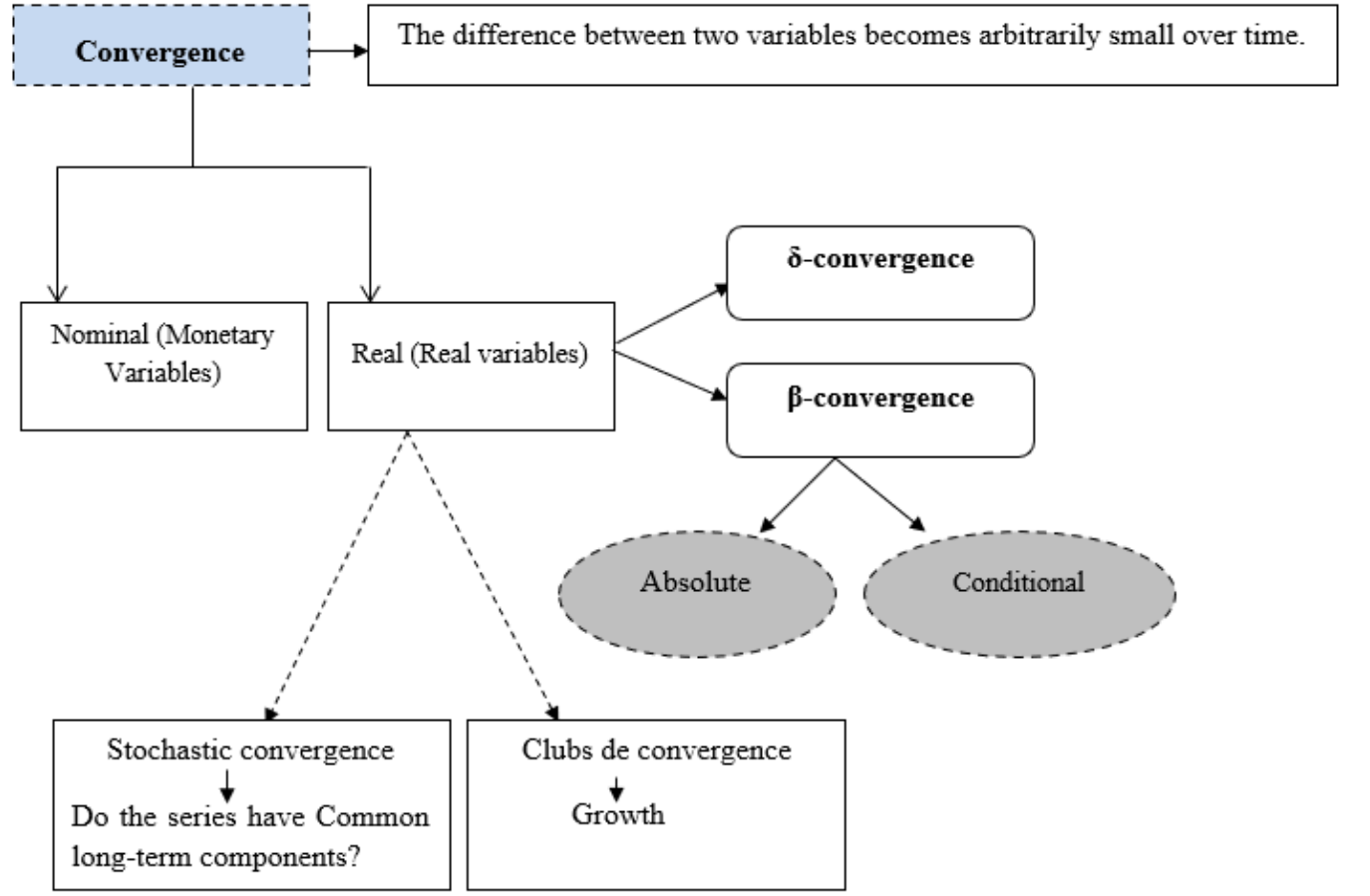

Figure 1. The concept of macroeconomic convergence

A potential increase in convergence following the introduction of the single currency in 1999 has been studied by several economists, such as Lutz (2002), Engel and Rogers (2004), and Goldberg and Verboven (2004). The latter's results focus on European market prices. The work of Engel and Rogers (2004) and Lutz (2002), which focuses on a variety of goods, tends to show, however, that there is no decline in prices after the euro's persistence. Continuing along the same lines, Engel and Rogers (2004) found that price convergence became increasingly slack between 1999 and 2003. Thus, Lafargue (2004) guarantees the existence of a tightening of prices in the EU during the period from 1996 to 1999, and subsequently of a remarkable improvement in dispersion. According to Honohan and Lane.2003, the period following the introduction of the euro, corresponding to the end of the application of the entry criteria into the single currency, saw an increase in the gap in inflation rates between the countries of the zone (Honohan and Lane (2003)). These margins at the level of inflation rates could be explained by a separation of price levels.

The literature identifies the main aspects of why maintaining price stability is important (European Central Bank, 2013). When prices are constant, it is much easier for companies to make investment decisions, as it is possible to determine relative price changes more accurately and increase price transparency, which allows for a more efficient allocation of market resources. Stable prices reduce the real interest rate, increase investment, and help avoid additional costs (Chintrakarn, 2008). Therefore, when assessing the country's integration possibilities into the European Monetary Union, inflation may not exceed 1.5 percentage points more than the average inflation in three EU Member States, where prices are most stable (Weyerstrass, Neck (2007). This price stability must be long-term.

Indeed, it was necessary to establish such criteria that countries of different economic levels meet the criteria across all economic cycles and thus contribute to the main objective of developing monetary union: maintaining price stability over the long term without resorting to short-term manipulation of economic stimulus (Grauwe, 2012).

We also adopted the view of Buiter (2008), who argued that the "shock-absorbing" role of the exchange rate is rather limited and that market-determined exchange rates are primarily a source of shocks and instability, which subsequently implies that joining the euro would allow the United Kingdom to escape these destabilizing effects. Thus, Berka et al. (2012) argued that the adjustment of the real exchange rate in a monetary union like the Eurozone could be faster than under fluctuating rates because capital flows dominate movements in the nominal exchange rate.

Indeed, the adoption of the euro affected the rate at which member countries' real exchange rates adjust to deviations from purchasing power parity (PPP). In addition to providing evidence on how the euro affected market integration, this study also offers two broader insights into understanding real exchange rate dynamics. First, we distinguish between PPP convergence conditional on alternative shocks, which we term "conditional PPP." We show that real exchange rate convergence can differ considerably depending on the source of the real exchange rate. We believe it is important for international economists to make this distinction when characterizing the relevance of PPP as a theory of real exchange rate behavior.

Al-Mashat and Billmeier (2008) also employ a VAR model to examine the effectiveness of monetary policy. They find that the exchange rate channel plays an important role in the propagation of monetary shocks and producer prices, while bank lending and asset prices are weak.

In the literature, Cheung et al. (2004) found that the rapid convergence of PPP and real exchange rate persistence for several major currencies against the dollar during the floating rate period is mainly explained by the behavior of the nominal exchange rate, with the exchange rate responding much more slowly than price shocks. However, unlike other analyses, they do not construct orthogonal shocks to allow measurement of the relative contributions of exchange rates and price shocks. They also did not consider the effects of monetary regime changes, such as the adoption of the euro, on real exchange rate persistence. Parsley and Popper (2001) find faster real exchange rate convergence, but they do not study the case of the common euro currency. Although they study the nominal exchange rate as an adjustment mechanism in detail, they do not examine the competing role of the nominal exchange rate as a source of shocks.

Along similar lines, several papers have examined the PPP adjustment during the euro period. Koedijk et al. (2004), Lopez and Papell (2007), and Zhou et al. (2008) conduct PPP unit root tests, finding greater evidence of convergence for samples including the euro period. These papers, however, do not pursue explanations for this finding by estimating a VECM. Unlike the other papers, Huang and Yang (2015) find that convergence is weaker after the introduction of the euro compared to earlier periods.

Veysov and Stolbov (2011) investigate the existence of convergence for financial institutional characteristics for the dataset of 102 countries from 1980 to 2009. The authors conclude that there is a global trend towards stable financial development, as well as convergence of financial depth indicators; nevertheless, their study suggests that this speed of convergence is not sufficient to allow developing countries to catch up. Artis and Ehrmann (2006) compared the exchange rate as an adjustment mechanism and a source of shocks using a different methodology named structural VAR. Although their methodology offers a richer set of options for shock identification, it does not provide a formal measure of the contribution of exchange rate adjustment.

Krugman (2013) informally suggested: “After the creation of the euro, (...) there was a massive capital movement from Europe’s core – mainly Germany, but also the Netherlands – to its periphery, leading to an economic boom in the periphery and significantly higher inflation rates in Spain, Greece, etc. than in Germany.”

In light of the above, previous work, including Bergin et al. (2014), shares elements of the VECM methodology when studying the variation in volatility and persistence of the real exchange rate during the transition from Bretton Woods to the post-Bretton Woods periods. However, this paper does not study the competing roles of the nominal exchange rate as a source of buffers and an adjustment mechanism to shocks. Using the transition to the euro as a natural and clean experiment, this paper finds that distinguishing between shocks is essential for explaining the variation in the real exchange rate between periods.

More recently, Bahadir and Valev (2015) show that credit levels relative to GDP and other banking measures during the period 1965-2009 tend to converge over time. The authors, however, do not test the same convergence hypothesis for indicators of stock market development, which is an equally important component of financial development.

On the contrary, there are studies on convergence in the West African Economic and Monetary Union (WAEMU) that have not shown any real convergence. Bianco et al. (1997) find that convergence in the financial systems of the six EU countries is still limited. Whereas, Kočenda (2001) found little or no convergence of financial variables between transition economies in the 1990s. Studies of convergence in German monetary policy also suffer from several shortcomings. The first is that the time period examined covers disparate situations such as transitional recession, stabilization and then recovery, and conscious efforts to prepare for accession. Therefore, the degree of convergence of German or EU monetary policy is expected to change considerably over time. The second problem is that, especially for transition economies, it is difficult to determine which variable should be used to measure convergence. Along the same lines, Korhonen and Fidrmuc (2001) found that, based on data for 1991-2000; a number of countries did not have to meet the convergence criteria for membership in an optimal monetary area.

3. EMPIRICAL METHODOLOGY

3.1. Econometric Modelling

The cointegration analysis focuses in this work on annual data taken in logarithm. Indeed, our sample includes twelve countries of the euro zone: Austria, Belgium, Portugal, Spain, Netherlands, Italy, Luxembourg, Ireland, Greece, France, Finland and Germany.

The period of the study goes from 1990 to 2018. These data are extracted from the OECD and Eurostat website. Regarding the above, we found it necessary to work with the cointegration theory. First, we start with the unit root tests which are ADF test and PP and KPSS test, and then we determine the optimal number of lags of the VAR model. This number is chosen according to the following two criteria: AIC (Akaike Information Criterion) and SC (Schwarz Criterion). Second, we will determine the number of cointegrated vectors as well as the persistence of a long-term relationship following the Johansen cointegration test (1988). In the short term, the dynamics are found according to the error correction vector model.

3.2. Usual Econometric Tests

3.2.1. Stationarity test

When the expectation and variance moments of a data series remain constant over time, it is considered stationary. In other words, a series is said to be stationary when its moments are not dependent on the time factor. Therefore, a series is said to be stationary when it suffers neither from seasonality nor from a trend. To test the stationarity of the variables in our model, we used the stationarity tests of Im, Pesaran and Shin (1997). This test is based on the principle of heterogeneity of the unit root unlike the Augmented Dickey-Fuller (ADF) test which assumes the homogeneity of the unit root. The test of Im, Pesaran and Shin (1997) also assumes the inter-individual independence of the residuals.

3.2.2. Cointegration test

Generally, before proceeding to the cointegration test, it is necessary to first determine the optimal number of lags to incorporate into the autoregressive process. Indeed, vector autoregressive (VAR) models are distinguished by their dynamic structure; more precisely this is done by modeling each endogenous variable in the system as a function of the lagged values of all other endogenous variables. Still in the same vein of idea, the purpose of cointegration is to detect the existence of a long-term relationship between two or more time series.

3.2.3. Causality test

The Granger causality test is a statistical hypothesis test to determine whether one time series is useful in predicting the other. A key question regarding model specification is whether one variable has a causal relationship with the other or not. Indeed, it is a matter of testing the null hypothesis of absence of causality in the Granger sense between two variables. Concretely, if the p-value is strictly greater than 10%, we can conclude from this result that the null hypothesis is accepted, while otherwise, we can say that one of the variables does not cause the other in the Granger sense.

4. DATA AND RESULTS

4.1. Data and Descriptive Statistic

Testing for price level convergence is equivalent to testing absolute PPP. Therefore, we use the definition of the "external" real exchange rate:

$$RER = NER.\frac{P^*}{P}$$

With;

RER: this is the real exchange rate, NER: this is the nominal exchange rate (expressed as the number of units of domestic currency per unit of foreign currency), P the domestic price level, and P^* the foreign price level. The price series P and P* must be selected. From a macroeconomic perspective, the Consumer Price Index (CPI) is the key indicator. While useful for describing price changes (inflation), it does not provide any indication of the price level. The CPI, therefore, cannot be used to test for price level convergence. To overcome this problem, we rely on the World Bank's International Comparison Program (ICP), which aims to provide comparisons at the international price level. Based on this framework, Eurostat and the OECD have calculated comparative price level (CPL) series for each European country. The OECD defines these CPIs as the ratio of the purchasing power parity conversion factor for private consumption to the nominal exchange rate. This ratio measures the price level differences between two countries and can be expressed as follows:

$$PLI_{i,t} = \frac{PPP_{i,t}}{NER_{i,t}} \times 100 \quad (1)$$

With $PLI_{i,t}$ is the Price level index, $PPA_{i,t}$: represents the PPP conversion factors for private final consumption of country i at time. This indicator is measured in national currency units per US dollar, and $TCN_{i,t}$ is the exchange rate of country i at time t. Regarding data availability, the CPLs are calculated by Eurostat and the OECD for each European country only each year from 1990 to 2018.

4.2. Stylized facts

A stylized fact is a term used in economics to refer to empirical findings. Due to their general nature, they are often qualitative in nature (Sewell, 2006). Indeed, stylized facts are observations that have been made in many contexts; they are widely understood as empirical truths, to which theories must adapt and are used especially in macroeconomic theory. Indeed, we present in this section a set of graphs that illustrate the price levels of the eleven countries belonging to the Eurozone compared to Germany during the period from 1990 to 2018.

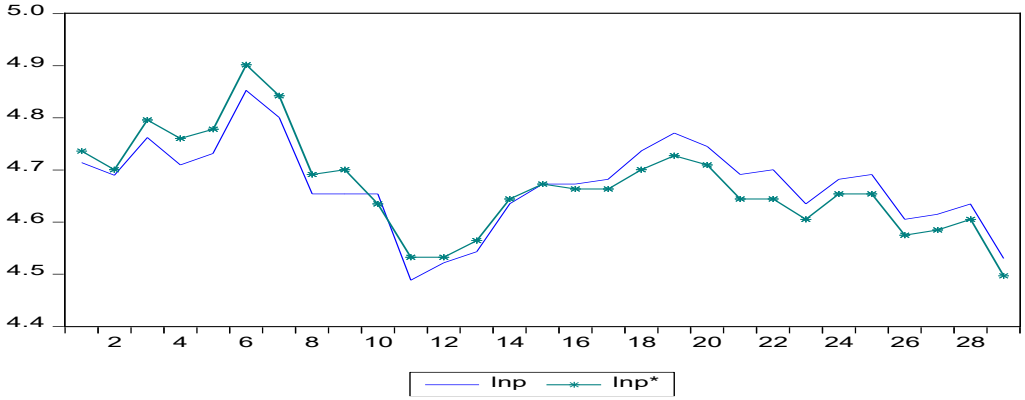

Figure 2. Price level index in log (Austria)

Source: By the Author's (on Eviews) using OECD data.

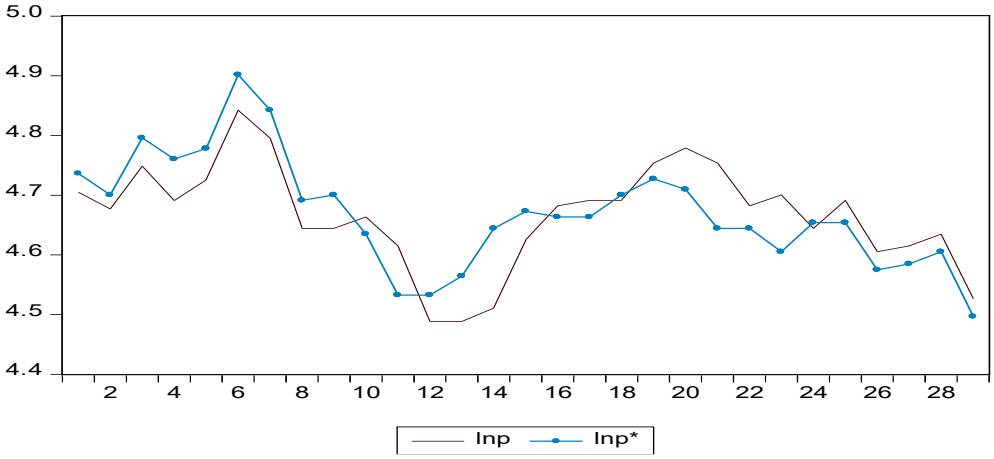

Figure 3. Price level index in log (Belgium)

Source: By the Author's (on Eviews) using OECD data.

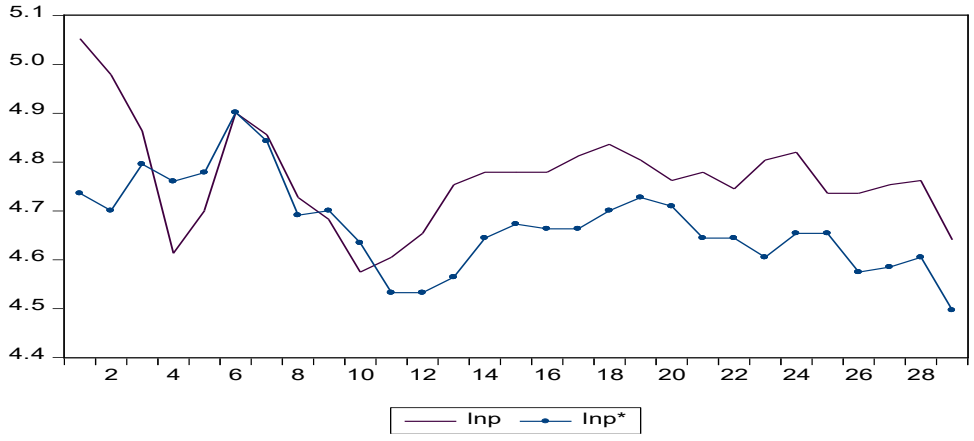

Figure 4. Price level index in log (Finland)

Source: By the Author's (on Eviews) using OECD data.

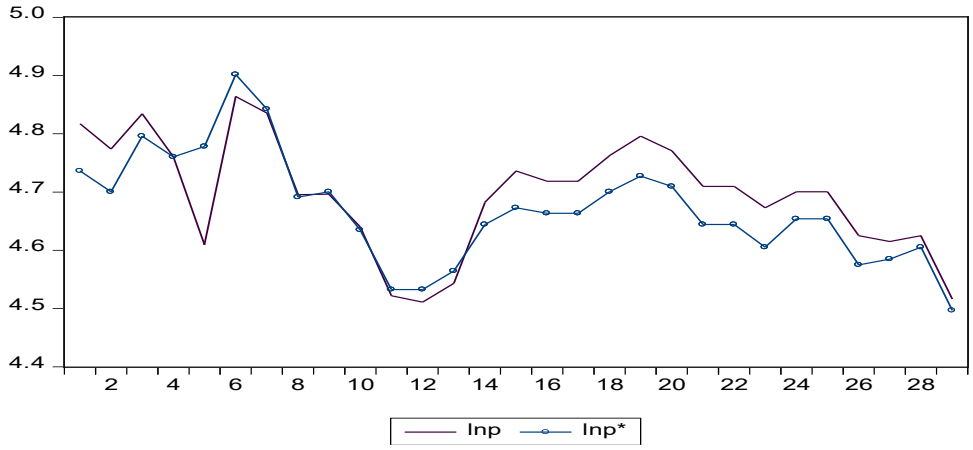

Figure 5. Price level index in log (France)

Source: By the Author's (on Eviews) using OECD data.

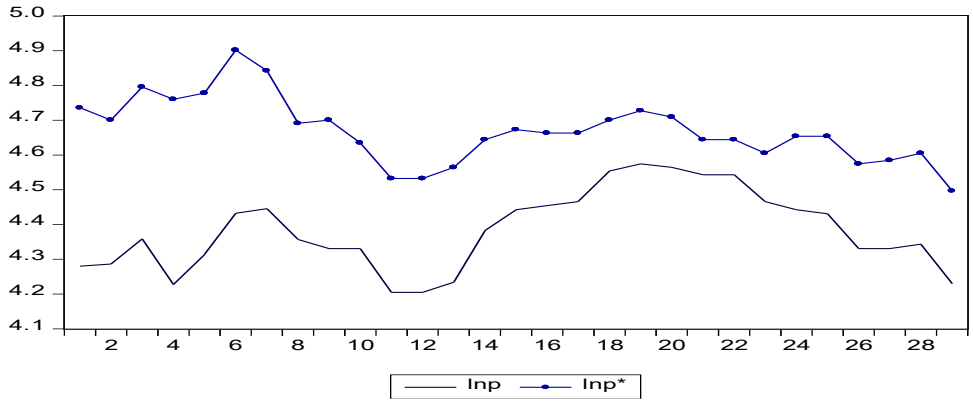

Figure 6. Price level index in log (Greece)

Source: By the Author's (on Eviews) using OECD data.

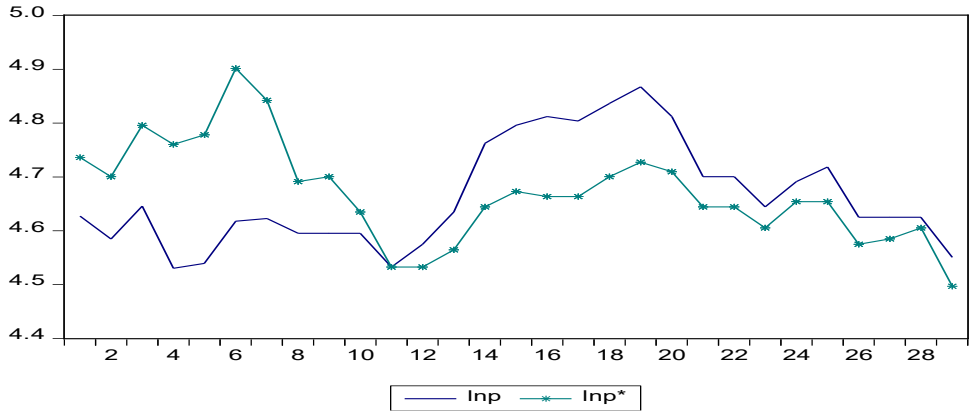

Figure 7. Price level index in log (Ireland)

Source: By the Author's (on Eviews) using OECD data.

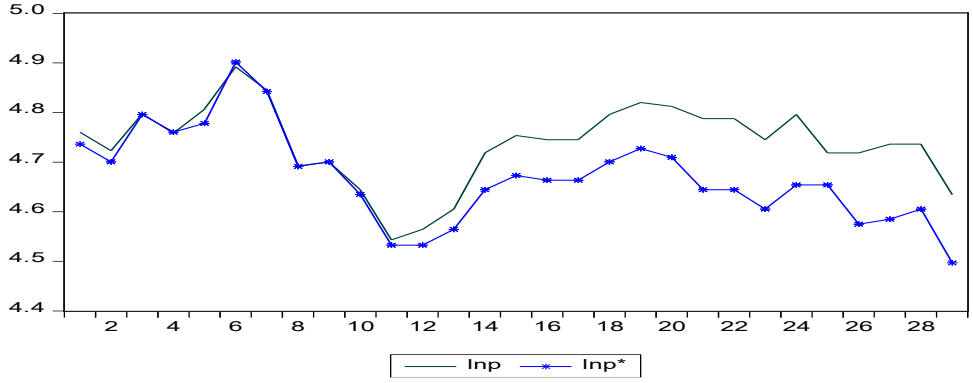

Figure 8. Price level index in log (Luxembourg)

Source: By the Author's (on Eviews) using OECD data.

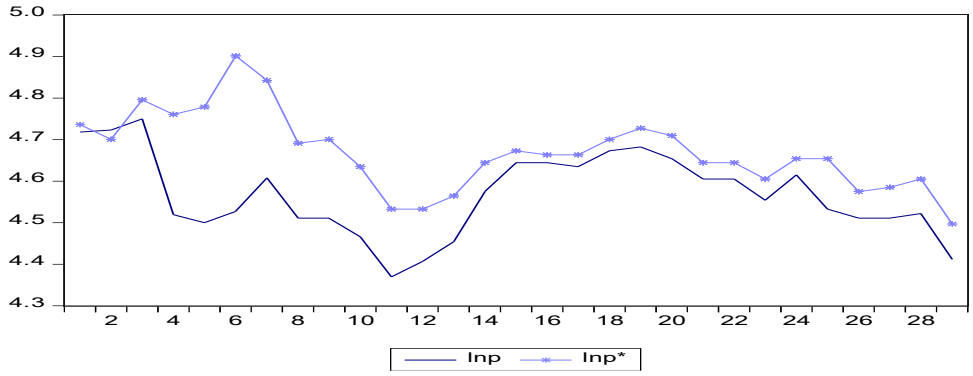

Figure 9. Price level index in log (Italy)

Source: By the Author's (on Eviews) using OECD data.

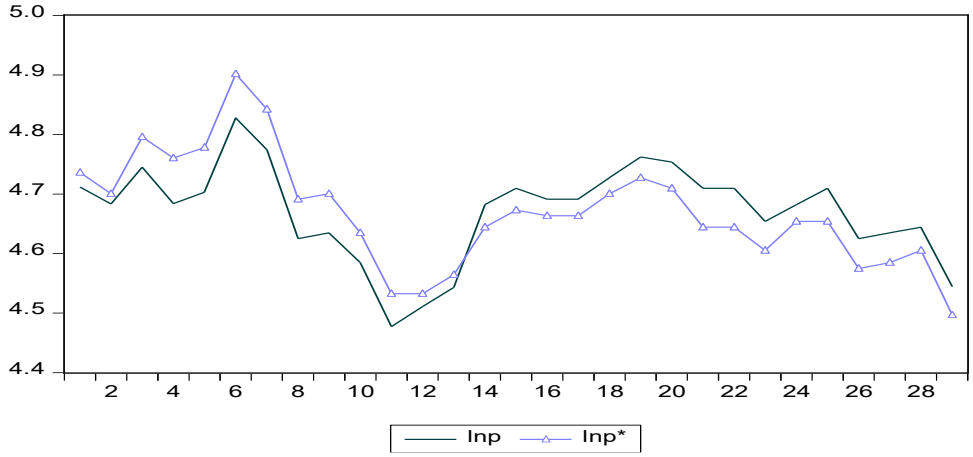

Figure 10. Price level index in log (Netherlands)

Source: By the Author's (on Eviews) using OECD data.

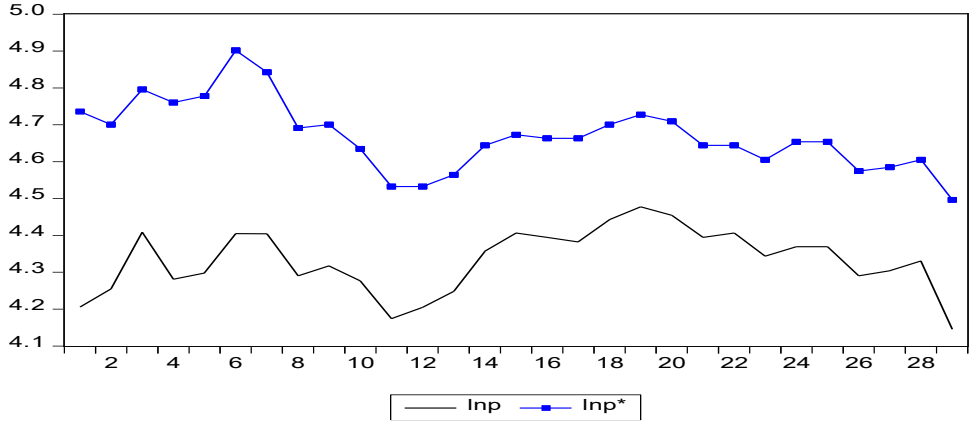

Figure 11. Price level index in log (Portugal)

Source: By the Author's (on Eviews) using OECD data.

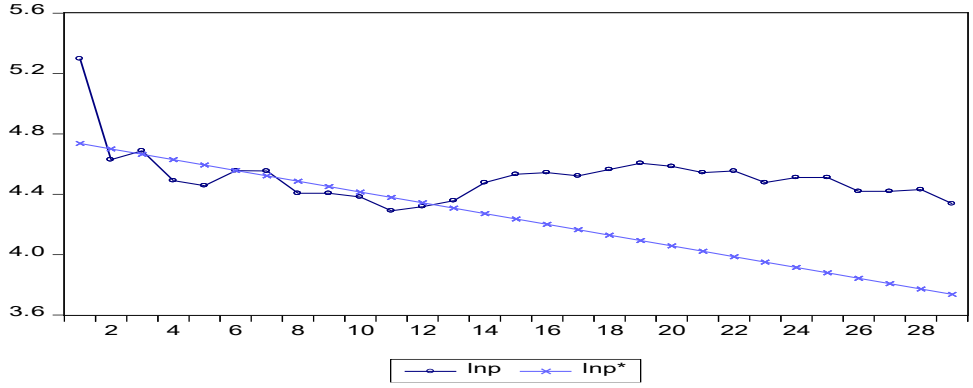

Figure 12. Price level index in log (Spain)

Source: By the Author's (on Eviews) using OECD data.

The various figures above illustrate the price levels of eleven countries belonging to the Eurozone compared to Germany during the period from 1990 to 2018. Indeed, the evolution of price gaps varies considerably from one country to another throughout the period considered. Still in the same vein of idea, there are three groups: The first group is characterized by price differences at the beginning of the period that tend to disappear over time, such as Austria, the Netherlands, Belgium, France, Italy and Luxembourg. Within this group, however, it is worth mentioning certain differences between countries. Austria and the Netherlands present a similar pattern in the sense that price gaps with Germany tend to disappear at the end of the period, the series of price levels being indeed very narrow in the 2000s.

The second group consists of Finland and Ireland, where domestic prices are mostly higher than the price level in Germany. The third group, which consists of Portugal and Spain, exhibits significant negative price differentials, with domestic prices always being lower than the external level. For these three countries, price differentials tend to decrease over time. In conclusion, all price series show an overall upward trend and evidence of non-stationarity; the series appear non-stationary.

5. MAIN RESULTS AND DISCUSSIONS

There are two types of cointegration tests: First, Granger cointegration tests (1987) where both the rank of the cointegration space and the form of the relationship in this test are known (Pedroni, 1995, 1997; Kao, 1999; Bai 2004). It should also be said that these tests must test the unit root hypothesis of cointegration residuals as well as first and second generation cointegration tests. Second, there are Johansen multiple cointegration tests (1991) where the cointegration rank is a priori unknown (Larsson and Ali, 2001; Groen and Kleibergen, 2003; Breitung, 2005).

5.1. Cointegration analysis

To assess price convergence, we use unit root and cointegration techniques by estimating an ADF-type equation:

$$\Delta x_t = k + \theta x_{t-1} + \sum_{i=1}^{p} \theta_i \Delta x_{t-1} + \varepsilon_t \quad (2)$$

With K representing the constant, Θ groups the coefficients of the deterministic trends for each individual, x_t is the differential between P_t and P_t^* (with log):

$$x_t = \ln P_t - \ln P_t^* \quad (3)$$

If the null hypothesis is rejected, it is then possible to calculate τˆ (which provides an indication of the speed of return to the mean of prices);

$$\frac{-\ln(2)}{\ln(1+\theta)}$$

Before moving on to estimation, it is first necessary to ensure the stationarity of time series using the Phillips Perron (PP) test and the Augmented Dickey–Fuller (ADF) and KPSS tests.

Table 1. Unit root tests in I (0)

Country	*Ln (P)-Ln (P*) in I(0)*			
	p-value (ADF)		***p-value (PP)***	
	Sans tendance	*Avec tendance*	*Sans tendance*	*Avec tendance*
Austria	0,568	0,105	0,588	0,031**
Belgium	0,513	0,065*	0,967	0,082
Finland	0,246	0,079*	0,094	0,194
France	0,292	0,111	0,335	0,120
Greece	0,508	0,144	0,307	0,989
Ireland	0,418	0,137	0,498	0,664
Italy	0,258	0,089*	0,140	0,137

Luxembourg	0,623	0,106	0,200	0,002***
Netherlands	0,554	0,105	0,472	0,464
Portugal	0,542	0,172	0,522	0,905
Spain	0,555	0,132	0,391	0,515

Table 2. Unit root tests in I(1)

Country	*Ln (P)-Ln (P*) in I(1)*					
	p-value (ADF)			***p-value (PP)***		
	Sans tendance	*Avec tendance*	*Sans tendance et constante*	*Sans tendance*	*Avec tendance*	*Sans tendance et constante*
Austria	0,442	0,707	0,000***	0,442	0,707	0,000***
Belgium	0,816	0,936	0,000***	0,816	0,936	0,000***
Finland	0,811	0,015**	0,000***	0,005***	0,020**	0,000***
France	0,795	0,000***	0,000***	0,795	0,000***	0,000***
Greece	0,515	0,001***	0,000***	0,515	0,001***	0,000***
Ireland	0,551	0,057**	0,001***	0,551	0,057**	0,001***
Italy	0,754	0,007***	0,000***	0,754	0,007***	0,000***
Luxembourg	0,261	0,688	0,000***	0,261	0,688	0,000***
Netherlands	0,518	0,0026***	0,000***	0,518	0,002***	0,000***
Portugal	0,681	0,178	0,0001***	0,681	0,003***	0,0001***
Spain	0,077*	0,770	0,000***	0,077*	0,770	0,000***

Source: Eviews based on OECD and Eurostat data.

Note: ****: significant at the 1% level; **: significant at the 5% level; *: Significant at the 10% threshold.*

Table 3. Cointegration test results

	p-value	τˆ
Austria	0,826	
Belgium	0,471	
Finland	0,340	
France	0,022**	1,05
Greece	0,016**	1,15
Ireland	0,117	
Italy	0,130	
Luxembourg	0,142	
Netherlands	0,189	
Portugal	0,004**	1,07
Spain	0,123	

Source: Eviews based on OECD and Eurostat data.

Note 1: ****: significant at the 1% level; **: significant at the 5% level; *: Significant at the 10% threshold.*

(τˆ: Mean reversion speed is expressed in years).

Note 2: $\tau\hat{} = \frac{-\ln(2)}{\ln(1+\theta)}$

According to the table below, only τˆ of the following countries must be calculated: Greece, France and Portugal. Indeed, the results of the cointegration tests are presented in Table 3, which presents the p-values for the ADF-type test and the speed of reversion to the mean is expressed in years. With the exception of a few special cases, there is no convergence, as the tests fail to reject the null hypothesis of non-cointegration between domestic prices and German prices. This lack of evidence of convergence may stem from the linearity assumption implicit in the ADF-type tests and the Johansen cointegration test. Even though the economic integration of the euro area members has generally increased over time, there remain certain characteristics such as economic policy that could prevent price convergence at a given point in time. However, this lack of convergence may be only temporary and depend on the size of the price differential. Indeed, while convergence may not be observed for small price gaps, it can occur when the difference in domestic prices relative to Germany is very different. In other words, it seems reasonable to assume that convergence can only be observed if the price differential exceeds a certain threshold since the loss of competitiveness. In these circumstances, domestic prices may therefore diverge from German prices until a gap is closed. This hypothesis will be tested in the next part.

5.2. Nonlinear analysis

Teräsvirta (1998) emphasizes an important point that before moving on to the estimation of the nonlinear model, it is first necessary to test the existence of nonlinearity. Rejecting the null hypothesis of linearity assumes that a nonlinear model could be adopted. Similarly, this test allows determining the transition variable as well as the type of the nonlinear model.

To study the non-linearity of the price convergence process, we estimate the smooth transition regression (STR) models proposed by Teräsvirta (1994): "*…An interesting interpretation of the smooth transition is suggested by Granger and Teräsvirta (1997), according to which the change at the aggregate level will be more adequately represented by an STR model if the economy consists of a large number of individuals or firms, each of which changes regime abruptly but at different dates.*" Indeed, these models are characterized by the existence of two regimes corresponding respectively to low and high price differentials. The transition from one regime to another is regular and determined endogenously according to the value of an observed transition variable. They are particularly suitable for our purpose, because they allow us to take into account the fact that the correction of imbalances can be at play when price gaps exceed a certain threshold. More specifically, the STR specification is given by:

$$\Delta x_t = \left[\propto_1 + \beta_1 x_{t-1} + \sum_{i=1}^{p} \theta_{1i} \Delta x_{t-i} \right] + \left[\propto_2 + \beta_2 x_{t-1} + \sum_{i=1}^{p} \theta_{2i} \Delta x_{t-i} \right] . F(\gamma, c; \Delta x_{t-d}) + \varepsilon_t \quad (4)$$

$\Delta \mathbf{x_{t-d}}$: The transition variable, $\boldsymbol{F}\ (\boldsymbol{\gamma}, \mathbf{c};\ \Delta \mathbf{x_{t-d}})$: It is a continuously differentiable transition function on the interval [0,1]. $\boldsymbol{\varepsilon_t}$: It is a random error assumed to have zero mean and constant variance. ***C*:** Specifies the location parameter that indicates where the transition occurs (threshold parameter).

γ: This is a parameter that characterizes the slope of the transition function; otherwise, it is the slope parameter that constitutes an indicator of the speed of transition from one regime to another (the lower the value of this parameter, the smoother the transition; the higher the value, the faster the transition). Indeed, there are two transition functions generally considered by Teräsvirta and Anderson (1992):

The Logistic function (LSTR model) $F(\gamma, c; \Delta x_{t-d}) = (1 + \exp(-\gamma(\Delta x_{t-d} - c)))^{-1}$ (5)

The Exponential function (ESTR model) $F(\gamma, c; \Delta x_{t-d}) = 1 - \exp(-\gamma(\Delta x_{t-d} - c)^2)$ (6)

Speaking first of all about the logistic function; if $\gamma \to \infty$, the transition functions translates in this case brutal transformations. The logistic model then merges with the exponential model. Whereas in the case where $\gamma = 0$, it admits a linear model since $\boldsymbol{F}\ (\boldsymbol{\gamma}, \mathbf{c};\ \Delta \mathbf{x_{t-d}})$ equal to 0.5. This last function indicates the transition function associated with a transition variable $\mathbf{x_{t-d}}$, to a threshold parameter c and a smoothing parameter γ. Alternatively, the logistic specification allows us to account for asymmetric dynamics depending on the regime.

Indeed, the ESTR function defines a correspondence between, on the one hand, the values of the transition function continuously derivable on the interval [0, 1] close to the threshold and one of the regimes, and on the other hand, between the values of the transition variable diverging and distant from the threshold by different values or much higher or lower and the other regime. Indeed, according to Teräsvirta (1994), for the specification of STR processes, we start by applying first of all linearity tests by using the delayed price differential as a transition variable.

According to the results found in Table below (Table 4), Austria, Belgium, France, Greece, Italy, Luxembourg and the Netherlands show price convergence only in the non-linear regime, while Portugal and Spain show convergence in both the linear and non-

linear regimes. The fact that price convergence is achieved for most countries in the non-linear regime validates our previous hypothesis: the correction of imbalances only occurs when price gaps exceed a certain level. This is given by the value called the "threshold parameter".

The value of $\widehat{c_1}$ is quite heterogeneous from one country to another. It is low in Austria which confirms the graphical analysis, in other words, this graph shows very small price gaps between Austria and Germany. Indeed, the value of $\widehat{c_1}$ in the LSTR specification is lower for Italy with -1.3% and in France with -1.01%, then in Belgium with -2.9%. In Ireland, it is not corrected except in the case where the price margin is significant and remarkable around 18.4%, while the imbalances in Portugal are not corrected if the gaps are in the interval (-0.3 and 0.3). The case of Luxembourg is particularly important insofar as the imbalances are only corrected with higher values (10%) compared to the other countries.

The null hypothesis of linearity is rejected for all countries except Finland. The LSTR model is retained for the seven countries: Austria, France, Greece, Ireland, Italy, Luxembourg and the Netherlands. While Belgium, Portugal and Spain are the countries for which the null hypothesis is rejected in favor of the ESTR alternative. Following the strategy developed by Teräsvirta (1994) for the specification of STR processes, we start by applying linearity tests using the lagged price differential as a transition variable. The table below (Table 4) highlights the interest of our nonlinear modeling. However, the result found shows no sign of price convergence, while according to the STR estimation; the convergence phenomenon is observed in all countries except the Netherlands.

The mean reversion speeds in our work are characterized by homogeneity from one country to another. Specifically, speaking of the non-linear regime, Austria, France, Italy and Luxembourg present a very rapid convergence, that is to say that the mean reversion speeds do not exceed one year at the level of these countries. To a lesser extent, Greece and Portugal find a relatively rapid convergence where the speeds range between 1.44 for Greece and 1.96 for the case of Portugal, while Belgium, the Netherlands and Spain experience a relatively weak convergence (τˆ superiors than 2 years) which goes against the short-term purchasing power parity.

Speaking a little about the result found in Finland, which is the only country that did not find price convergence. This may be due to the « modèle scandinave »… according to which the economic structures of Finland are quite different from those of continental or Mediterranean countries, which makes this economy relatively more "independent" from the Eurozone than other members. Following the above, Finland could have experienced idiosyncratic economic fluctuations without correlation with the rest of the Eurozone, taking as an example the case of the banking crisis in the early 1990s. However, entry into the European Union in 1995 and into the EMU in 1999 could have strengthened the correlation of the economy with the rest of the Eurozone and even erased its economic fluctuations.

Table 4. Estimation results of the STR model

	Model	$\boldsymbol{\beta_1}$	$\boldsymbol{\beta_2}$	$\boldsymbol{\beta_1+\beta_2}$	τˆ ***linear***	τˆ ***non linear***	$\widehat{c_1}$	$\widehat{c_2}$
Austria (2)	LSTR	-0,213004	-0,588056**	-0,80106		0,43	-0,035131	
Belgium (1)	ESTR	1,882253	-1,591170***	0,291083		2	-0,029885	0,028885
Finland	Rejection of the Null hypothesis of linearity							
France (1)	LSTR	0,317460**	-1,046846**	-0,729386		0,53	-0,010153	
Greece (1)	LSTR	0,8994130***	-1,278863**	-0,37945		1,44	-0,21776	
Ireland (3)	LSTR	-1,782090***	1,410974***	-0,371116	1,89		-0,184219	
Italy (3)	LSTR	5,405790**	-5,411540**	-0,00575		0,46	-0,013177	
Luxembourg (2)	LSTR	0,758343 **	-1,275265***	-0,516922		0,53	0,106928	
Netherlands (1)	LSTR	2,053526***	-2,323360***	-0,269834		2,48	-0,050668	
Portugal (1)	ESTR	-0,946684*	-1,701937 *	-2,648621	0,23	1,96	-0,398923	0,398923

Spain (1)	ESTR	-0,545548**	-1,825803 ***	-2,3713578	0,88	3,60	0,080761	0,0080761

Source: Eviews based on OECD and Eurostat data.

Note: ****: significant at the 1% level; **: significant at the 5% level; *: Significant at the 10% threshold.*

CONCLUSION

The basic principle of the price convergence process is the law of one price, which implies that, in a fully competitive market, the prices of the same goods expressed in the same currency must be equal. Theoretically, the prices of tradable goods and some services can be subject to arbitrage, which under certain assumptions leads to similar prices. These assumptions are very difficult to satisfy in the real world and the law of one price is often empirically rejected (based on the work of Isard, 1977; Parsley and Wei, 1996; Lutz, 2004; Cruccini and Shintani, 2008). Nevertheless, even if the single price cannot be achieved, globalization and market integration allow for some price convergence (Crucini and Smith, 2016).

It is true that price convergence in the Eurozone has not always been shared by literature reviews of different economists, for this reason we found it necessary to fill this gap, to study the convergence between the price levels of twelve members of the Eurozone from 1990 to 2018. Based on smooth transition regression (STR) models proposed by Teräsvirta (1994), we show that the price adjustment process is non-linear, depending on the magnitude of the price differential: For the majority of countries, price convergence only occurs when price differentials between members exceed a certain threshold.

Continuing along the same lines, our results highlight certain heterogeneity among the members of the Eurozone in terms of price convergence speed, which we develop and explain based on competitiveness indicators and technological specialization of each country. For example, Austria, France and the Netherlands are characterized by relatively high price convergence speeds compared to those of Germany, which is consistent with their price competitiveness and subsequently justified by their specialization in high-tech products. Now, speaking of convergence speed for the countries of Greece and Portugal, which are among the countries specialized in low-tech products, stemming from their loss of competitiveness. While the results obtained for the country of Ireland show that the latter has experienced a Balassa-Samuelson catch-up phenomenon.

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