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NAIRU AS A PROXY FOR BUSINESS CYCLE SYNCHRONIZATION ANALYSIS IN EURO AREA ECONOMY: AN EMPIRICAL APPROACH

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Abstract

Estimates of NAIRU (Non-Accelerating Inflation Rate of Unemployment) affect indirectly the assessment of structural balance, which has been increasingly used by policymakers as an indicator for the needs of an economy. Therefore, the study of NAIRU deserves a special attention given that it has necessarily impact on business cycle developments.

With the previous reasoning in mind, we analyze the NAIRU synchronization between Euro Area member states from 1999 until 2014. Such exercise is useful to assess whether their cyclical position moves in tandem with each other and a single policy is supported in such context or not.

The NAIRU estimates are obtained by employing a system of equations that combines a Phillips curve with the Okun law and allows the parameters to vary over time. The estimation problem is handled via Extended Kalman Filter (EKF), which is justified by the presence of non-linearity in the problem.

Our results suggest that Euro Area member states have a low degree of synchronization, contrarily to what would be desirable in a monetary union context. It is, therefore, crucial to stimulate the further integration at a European Union (EU) level in the future as one of the possible paths to take with the objective of promoting economic convergence in the region.

JEL classification: C32, E24

Keywords: NAIRU, Euro Area, Synchronization, EKF

Resumo

As estimativas da NAIRU (taxa de desemprego compatível com uma taxa de inflação constante) afetam indiretamente o cálculo do défice estrutural, que tem vindo a ser crescentemente utilizado por agentes políticos como indicador das carências de uma economia. Assim, o estudo da NAIRU merece toda a atenção, dado que esta tem necessariamente impacto no desenvolvimento do ciclo económico.

Considerando o disposto no parágrafo anterior, pretendemos analisar a sincronização da NAIRU entre os diversos estados membros da Zona Euro, tendo em atenção o período compreendido entre 1999 e 2014. Este exercício é útil para entender se a posição cíclica das diversas economias que compõem a união monetária tem vindo a evoluir no mesmo sentido e, dessa forma, concluir se a política única que se verifica nesta região será justificável.

Com o objetivo de obter estimativas da NAIRU, utilizamos um sistema de equações que combina a curva de Phillips com a lei de Okun e confere flexibilidade aos parâmetros para que estes sejam variáveis ao longo do tempo. Durante o processo de estimação recorremos ao uso do filtro de Kalman aumentado (EKF), justificado pelo facto de o problema ser não-linear.

Os nossos resultados sugerem que os estados membros da Zona Euro apresentam um reduzido grau de sincronização entre si, ao contrário do que é desejável no contexto de uma união monetária. É, assim, crucial estimular a crescente integração ao nível da União Europeia (EU) como uma das possíveis alternativas a seguir para atingir um nível superior de convergência económica entre os países que a compõem.

Classificação JEL: C32, E24

Palavras-chave: NAIRU, Zona Euro, Sincronização, EKF

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1 Introduction

Worldwide policymakers have been increasingly recognizing the importance of structural balance as indicator of which economic policies may the countries pursue year after year. Estimates of potential Gross Domestic Product (GDP) are essential in order to assess structural balance. In turn, NAIRU (Non-Accelerating Inflation Rate of Unemployment) influences directly the estimation of potential GDP by the European Commission, since it is assessed by using a Cobb-Douglas production function approach, where NAIRU appears as component of potential labor input — see D'Auria et al. (2010). Therefore, we can easily understand that the NAIRU affects structural balance, indirectly, playing a relevant role on the determination of which economic policies should be taken and so, it has necessarily impact on business cycle.

NAIRU is a concept that closely relates to structural unemployment however, there are subtle differences between them that, when ignored, may lead to opposite conclusions in practice, as referred in the following section.

In other perspective, policymakers have been concerned and committed over time with meeting the goal of price stability. This objective is only attainable in case the most adequate economic policies are efficiently implemented. To do so, policymakers and economic analysts need to possess a variety of powerful indicators that allow a reliable tracking, as well as prediction, of the overall state of the economy. Generally, all kinds of economic policy give a fundamental contribute to achieve the target outlined above. Nevertheless, we should highlight the special importance of monetary policy, acting a key role in managing policy instruments that transmit an impact to inflation and therefore, is architected with the main purpose of promoting price stability.

This dissertation focuses on NAIRU as one of the possible indicators that are able to give an important contribute in assessing the cyclical position of an economy. In order to operationalize any exercise involving NAIRU, there is a need to estimate this indicator since it has a non-observable nature. Particularly, this work estimates NAIRU for each country of Euro Area, excluding Lithuania, and for Euro Area as a single entity in the period comprehended between 1999 and 2014. As presented next, NAIRU is usually estimated in the literature by means of a Phillips curve, given the strict relation between inflation and unemployment that is in the core of NAIRU's definition itself.

In fact, the estimates presented in this study are relative to a short-run NAIRU concept. This specific form of NAIRU is acknowledged to have a greater predictive capacity regarding inflationary pressures in comparison to a generic NAIRU concept, as explained ahead in the literature review. To do so, we follow Us (2014) in combining a Phillips curve with the Okun law and allowing the parameters to be time-varying. The latter specificity transforms the problem into non-linear and therefore Extended Kalman Filter (EKF) is employed in the estimation process instead of standard Kalman Filter (KF).

Investigation relating NAIRU was quite active in end of 1990's and in the beginning of 2000's and only recently there was a form of resurrection of such trend in the literature — see Gordon (2013) and Watson (2014), for instance. We argue that the period characterized by the lack of investigation in this area is associated to the fact that short-run NAIRU concept was not considered with the attention it deserved in most of these studies until then. For that reason, the potential usefulness of NAIRU as an economic indicator was undervalued at that time.

In the context of an Economic and Monetary Union (EMU), business cycle synchronization across the different countries is determinant to reduce economic stabilization cost. This is the main argument that justifies the study of NAIRU synchronization specifically in Euro Area, as object of the present work. This happens mainly because a greater synchronization in Euro Area implies that the needs from its member states will be more in accordance with each other, making easier the task of the European Central Bank (ECB) of conducting a single monetary policy. Furthermore, considering the monetary policy of the ECB in the form of "Inflation Targeting", any indicator that contributes to a better understanding of inflationary developments in the near term should be treated considering its unarguable relevance.

These are the main reasons why we consider of interest to analyze business cycle synchronization accounting for NAIRU as indicator in such context.

Our results suggest that Euro Area member states have a low degree of business cycle synchronization, contrarily to what would be desirable in a monetary union context. In such way, the findings point to the further integration at a European Union (EU) level in the future as one of the possible paths to take with the objective of promoting economic convergence in the region.

The remainder of this dissertation is as follows. The next section contains the literature review on the most relevant investigation concerning NAIRU. Section 3 presents the methodology and data employed in order to estimate the NAIRU series, while section 4 presents and analyzes the results in several dimensions and perspectives, incorporating a subsection of policy implications that stem from the results. Section 5 summarizes the findings and concludes.

2 Literature Review

In the present chapter, we will review the most relevant conclusions of the studies published regarding NAIRU and its importance to economic policy. Naturally, this is a very controversial subject because the relation between inflation and unemployment is in the core of its definition. The discussion about the existence of a trade-off between inflation and unemployment is well known to be a central issue in macroeconomics, beginning with Phillips (1958) that found a negative relationship between both variables, using data from the United Kingdom between 1861 and 1913, and being perpetuated with the intervention of neoclassical, monetarist and Keynesian economists.

As a controversial issue it is, there are studies that support NAIRU as a useful concept for economic policy, some others pointing to the opposite conclusion and also works that recognize the importance of NAIRU if and only if certain conditions are in place.

Starting with the branch of literature that find the NAIRU to be of little help for economic policy, Staiger et al. (1997a, 1997b), King et al. (1995), Cross et al. (1997) and Laubach (2001) highlight the imprecision of NAIRU estimates. In order to conclude in favor of precision or imprecision, there must be a measure that assesses the uncertainty surrounding those estimates. Together, these studies constitute the first group of works that provided confidence intervals of NAIRU estimates and, this corresponds to their most important contribution. Until then, a measure of uncertainty such as standard errors of NAIRU estimates was lacking and so it was not possible to evaluate their precision. This is justified by the fact that, usually, NAIRU is derived as a nonlinear function of estimated coefficients and, standard errors are not automatically computed by regression packages in such circumstances.

In Staiger et al. (1997a), confidence intervals are computed by means of Gaussian confidence intervals, which according to the authors are more accurate than Delta-method confidence intervals for finite samples. In this investigation, different model specifications for measuring the NAIRU were considered. First, by using a reduced-form Phillips curve to deal with several statistical models of the NAIRU, specifically to estimate it as being a constant or a deterministic function of time. Second, using a structural approach, based on labor market theories and third, employing a univariate method with unemployment assumed to be the only explanatory variable for NAIRU.

Methodologies assuming the NAIRU to be a non-observable variable, as the first of three referred above, usually solve the estimation problem by means of maximum likelihood handled by KF. This is a very powerful algorithm aimed at solving linear state-space problems and it is widely used in the literature — an example is given by Gerlach & Smets (1999), that makes use of KF to derive the output gap of the EMU area from a system of equations.

Different variables for determining NAIRU, such as to account for supply--side shocks, different measures of inflation and data with both monthly and quarterly frequency were also used in Staiger et al. (1997a). The main sources of uncertainty that contribute to the imprecision of NAIRU estimates were found to be the absence of knowledge about model parameters, the model specification and also the nature of NAIRU. The major conclusion pointing to estimates imprecision turns out to be insensible to all these specifications.

Staiger et al. (1997b) follows Staiger et al. (1997a), however it focuses on a single methodology that consists in using a flexible polynomial to model the NAIRU. As in the previous study, authors neglect the importance of this concept to forecast inflation. In turn, they argue that actual unemployment rate is relevant to predict future developments of inflation rate mainly in the short-run, along with several other indicators — for example the capacity utilization rate that is a useful predictor of inflation not only in the short--run.

The same conclusion is taken from King et al. (1995). In this case, authors intended to study how did the relationship between unemployment and inflation vary over time and found it to become considerably less stable since World War II, especially during the second subsample period considered by the authors, between 1974 and 1992. An important finding worth of highlighting is that a stable relationship between the two variables is evident during the entire sample period, from 1954 until 1994, if we restrict the analysis to the short-run only. Contrarily, in the long-run this relationship was found to be inexistent and for that reason the predictive role of unemployment must be considerably higher in the short-run. Staiger et al. (1997a, 1997b) and King et al. (1995) use data from the United States economy.

Cross et al. (1997) extend the work presented in Staiger et al. (1997a) by using data from G7 countries and conclude that results for the United States economy are valid to an even larger extent when considering all other G7 countries. Employing a more flexible methodology, as far as data dynamics and model specification are concerned, better results are obtained relatively to the first study presented here, however large confidence intervals continue to be the outcome. Contrasting with Staiger et al. (1997a), authors pointed the issue of model specification as the primary barrier to precision of NAIRU estimates.

A few years later, Laubach (2001) investigated the implications of different model specifications in precision of NAIRU estimates, assuming a stochastic nature for this. To do so, the author considered G7 countries' data, including Australia instead of Japan. As previously emphasized, conclusions stemming from this article support those presented in Staiger et al. (1997b) and Cross et al. (1997). According to the author, an implication for this result is the inexistence of economic meaning in NAIRU determination when this variable is assumed to be stochastic.

It is important to notice that the primary objective of these works was in fact to understand whether NAIRU is a useful component to take into consideration when discussing monetary policy issues or not. The conclusion pointed by the authors, against the use of such indicator was based on the evidence of large confidence intervals regarding NAIRU estimates that in turn translate into imprecision. This imprecision becomes crucial when discussing determinant subjects such as monetary policy.

Another segment of the literature contrasts with the previous one by supporting the usefulness of NAIRU as an indicator for inflationary pressures. Examples of works that compose this branch are Ball & Mankiw (2002), Fabiani & Mestre (2000) and Gordon (1997).

Starting with Ball & Mankiw (2002), the argument states that a negative relationship between inflation and unemployment implies that there is some level of unemployment for which inflation remains stable. There is wide agreement in the literature that in the short-run such a negative relationship exists between both variables. Therefore, the authors conclude that NAIRU constitutes an important concept for business cycle theory and conclude in favor of its role as a forecasting tool regarding future developments of inflation in the near term.

When some studies argue in favor of NAIRU as useful to assess inflationary pressures, it is not in absolute terms but rather as a component of the unemployment gap, which is determined by the difference between actual unemployment and NAIRU. According to the "Natural Rate Hypothesis" (NRH), when actual unemployment is below NAIRU, inflation is expected to increase and vice-versa.

Hysteresis effect is a phenomenon that is present in labor markets when NAIRU depends on past values of actual unemployment rate. In such conditions, when a recession hits the economy and unemployment rate increases, NAIRU will rise along with the previous and not return to the initial state even after the recession is no longer affecting the economy. Instead, it will remain at a new equilibrium level, higher than the previous.

Ball & Mankiw (2002) consider that the existence of hysteresis effects in the labor market will provide a reason for the NAIRU to vary over time rather than threat its usefulness as a forecasting tool. In the opinion of Fabiani & Mestre (2000) instead, NAIRU will be different from the natural rate of unemployment in the short-run when hysteresis effects are present on labor market. The natural rate of unemployment is defined to be the level of unemployment that is consistent with the long-run, when there are no frictions in the market and therefore is associated with structural characteristics, such as institutional factors. This is the reason why it is occasionally called as structural unemployment as well.

In what concerns methodology, Ball & Mankiw (2002) use data from the United States economy between 1960 and 2000, estimate a constant NAIRU and a time-varying NAIRU by using the Hodrick-Prescott (HP) filter to decompose a series into trend (NAIRU) and cyclical component. A more complex approach is taken by Fabiani & Mestre (2000), which test a variety of methods, including univariate, multivariate, filtering techniques and estimate constant as well as time-varying NAIRU's — using several different models including Elmeskov method and the break model, among others — for the Euro Area as a single entity, from 1972 until 1997. The main conclusion provided by Fabiani & Mestre (2000) is that the break model, allowing for time variation of NAIRU, performs better than the remaining model specifications, despite all perform quite well the task of forecasting inflation.

In a direct comparison between the ability of univariate filters such as HP filter and multivariate filters, Laxton & Tetlow (1992) support the use of multivariate filters. In this paper, authors intend to estimate potential output rather than NAIRU and compare results obtained by using a multivariate filter that incorporates information about unemployment and inflation developments, with the outcome from a standard HP filter. The main conclusion states that more reliable estimates are obtained when using multivariate filtering techniques comparing with univariate ones. Nevertheless, estimates that stem from the multivariate approach still have a large degree of uncertainty surrounding them.

Finally, Gordon (1997) argues that the relationship between inflation and unemployment is both crucial for monetary policy and time varying. Author proposes the so called “triangle model” to incorporate this relationship, which implies the inflation rate to be affected by its own lagged values, by the unemployment gap and also by supply side factors — including changes in the real effective exchange rate, for example. This three-prunged approach enables to capture inertia, demand side and supply side effects, respectively, while allowing to quantify the influence of each one on inflation variations, separately.

When NAIRU is assumed to be non-observable and so there are model coefficients and an explanatory variable to estimate together, usually researchers apply the KF as previously referred. In order to use this algorithm, there is need to define a transition equation to extend the Phillips curve with a law of motion for the NAIRU. Gordon (1997) has defined the transition equation as a random walk. The final shape of NAIRU will depend exclusively on the ratio between the variance of the error term in the transition equation and the equivalent coming from Phillips curve. The ratio between these two values is called “signal-to-noise” and despite it is possible to be estimated by means of KF, usual results are very disappointing. For such reason, this ratio is usually arbitrarily defined across many studies, implying that the shape of NAIRU will be arbitrary as well. According to Gordon’s opinion, this aspect constitutes the main weakness of the approach.

Findings of this paper contrast with the main idea presented in the first group of studies referred in this review, since King et al. (1995) found confidence intervals for time-varying NAIRU estimates to be narrow and consequently, NAIRU estimates to be precise. The main reason for this difference relies on different assumptions regarding the ratio introduced above. While for the first papers that use KF, "signal-to-noise" ratio is set according to statistical criteria, Gordon (1997) proposed a "smoothness prior" that sets this ratio to be 0.1 or 0.2 — given that 0 implies a constant NAIRU and 0.4 a highly volatile — subject to the restriction that sharp fluctuations between consecutive periods are not allowed.

Therefore, the most relevant conclusion is that NAIRU is not only a useful concept for the conduct of monetary policy as a forecasting tool for inflation, but also that the monetary authority can achieve a stable outcome of inflation if it is capable to manage the actual unemployment rate to equal NAIRU.

A third strand of the literature composed by Estrella & Mishkin (1999), Turner et al. (2001) and Richardson et al. (2000) recognize the usefulness of NAIRU for economic policy however, only in case a short-run version is considered.

Short-run NAIRU corresponds to the rate of unemployment that is compatible with stable inflation in the next period, for example the next quarter, considering the current one as reference. Estimates of short-run NAIRU are more volatile than the "unqualified" NAIRU because the first are affected by all supply influences, whether these include temporary or "long-lasting" effects, while the latter incorporates only supply influences that have a long-run nature. The natural rate of unemployment instead, is the unemployment rate that will verify when the economy has fully adjusted to all supply disturbances, with both horizons.

With the previous distinction in mind, it is easy to understand that short-run NAIRU will correspond to the unqualified NAIRU when temporary supply influences are absent from the economy and all three concepts will be equivalent in the absence of any supply influence. Taking into consideration that a short-run trade-off between inflation and unemployment is widely accepted in the literature, while a long-run trade-off is not, it makes sense that the dominant view should attribute a short-run nature to a useful NAIRU concept. In this regard, Richardson et al. (2000) gives the United States economy as an example, from 1996 until 1998 when the actual unemployment rate was below the estimated NAIRU and therefore inflation has been expected to increase. However, inflation actually decreased, because the actual unemployment rate was still above the estimated short-run NAIRU. In other perspective, Estrella & Mishkin (1999) found short-run NAIRU estimates to have "more than twice the precision than standard NAIRU" despite they are much more volatile, in some cases even more than actual unemployment.[1] Actually, this volatility is what makes short-run NAIRU estimates unfeasible as a target for the actual unemployment rate. The last point is generally accepted in the literature and as an example, in this review only Gordon (1997) suggests using NAIRU estimates as a target for actual unemployment.

In addition, again excluding Gordon (1997) that argues in favor of NAIRU concept for economic policy purposes, for reasons outlined above, all the studies that do not distinguish between NAIRU and natural rate of unemployment render NAIRU as a concept with limited role for economic policy. Essentially, this implies they are studying the estimation and implications of a long-run NAIRU. Following exactly the same methodologies but redefining the nature of the concept underlying the analysis, perhaps the conclusion of the first group of works would converge to the one of the last group.

A different approach, which is also used in Staiger et al. (1997a), is a called "structural approach" that, by exploring the structural characteristics of an economy, derive estimates of the natural rate of unemployment rather than of NAIRU. An example that follows such an approach is Weiner

[1] See Richardson et al. (2000) and Turner et al. (2001).

(1993) using data from the United States economy. In this work, the author incorporates the effect of demographic and structural factors into estimates, and concludes that the natural rate of unemployment is unlikely to be lowered, either by demographic or structural forces.

Both Turner et al. (2001) and Richardson et al. (2000) are papers that give insight and support the way the Organization for Economic Co-operation and Development (OECD) estimates NAIRU, with a reduced--form approach similar to the one presented by Gordon (1997) and a law of motion for NAIRU, using KF to solve the state-space problem. In these investigations, not only a NAIRU is estimated for each OECD member, as authors do conclude in favor of using such estimates for monetary and fiscal policy assessments because NAIRU is used for calculation of potential output and consequently of budget balances.

Finally, a general conclusion in the literature about NAIRU corresponds to the idea that this is only one of the many possibly useful indicators to forecast inflationary developments and the ideal scenario must be to complement one with another in order to possess a more robust indicator to assist policy makers in their key decisions.

The analysis of the current research will follow Us (2014), which estimates NAIRU for the Turkish economy between the first quarter of 2000 and the third quarter of 2013. This paper assumes itself to be an extension of Fabiani & Mestre (2004) in using a systems approach that combines a Phillips curve with an Okun-type relationship and assuming a stochastic nature for NAIRU and potential output. This is the first paper that estimates NAIRU assuming that parameters are time varying, justified by the volatile nature of Turkish economy. Adding the assumption of time varying parameters to the usual state-space problem brings nonlinearity into the model. As previously emphasized, standard KF is only adequate to solve linear state-space problems. In this situation, EKF must be employed to solve the estimation problem.

Some examples of studies that apply the EKF are available in the literature, such as McKiernan (1996) and Bacchetta & Gerlach (1997), however they do not relate to NAIRU. Instead, these specific papers are concerned in studying the implications of credit market conditions on aggregate consumption. In this view, the contribute of Us (2014) for the NAIRU related literature is unquestionable and so we take the natural first step of following such analysis, justified essentially on the basis that it constitutes a more complex approach and a recent trend in the literature. Despite such analysis was not employed for estimating Euro area NAIRU in the literature so far, it can be viewed as especially important due to the considerably larger volatility existent in Euro area economy after the global financial crisis in 2008 and the European sovereign debt crisis in 2010 — see Gächter et al. (2012). The present dissertation is intended to fill this gap. Moreover, recently there is little research regarding NAIRU estimates for Euro Area economy in any form. Together with my main objective of studying the synchronization of unemployment gap among all Euro area economies — extending Fabiani & Mestre (2000, 2004) —, these are the most valuable contributions to the literature that stem from this work.

Table 1 shows a brief synthesis of the characteristics and conclusions highlighted in this section, focusing on works that study NAIRU.

Table 1: Articles which analyze the usefulness of NAIRU as economic indicator

Author	**Methodology for modeling NAIRU**	**Supply Factors**	**Is NAIRU useful for economic policy?**
Staiger et al. (1997a)	Constant; Spline; Break; Time-varying parameter; Theories of labor market; Univariate method	A measure that accounts for the wage-price controls of Nixon-era in 1971; Food and energy inflation	No
Staiger et al. (1997b)	Cubic spline	A measure that accounts for the wage-price controls of Nixon-era in 1971; Food and energy inflation	No
King et al. (1995)	Reduced-form Phillips curve	———————	No
Cross et al. (1997)	Constant; Cubic spline; Specification for each country	Impact of changes in VAT; Import price shocks	No

Table 1: Continued from previous page

Author	**Methodology for modeling NAIRU**	**Supply Factors**	**Is NAIRU useful for economic policy?**
Ball and Mankiw (2002)	Constant; Univariate filtering	———————	Yes
Fabiani and Mestre (2000)	Constant; Time-varying; Filtering methods	Direct taxes; Social security contributions	Yes
Gordon (1997)	Constant; Triangle model	Changes in relative import prices; Food and energy inflation; Changes in real effective foreign exchange rate	Yes
Estrella and Mishkin (2001)	Triangle model	Oil price shocks	Short-run NAIRU
Boone et al. (2001)	Triangle model	Changes in real import prices; Changes in real oil prices	Short-run NAIRU
Richardson et al. (2000)	Multivariate filter; Triangle model	Changes in real import prices; Changes in real oil prices	Short-run NAIRU

3 Methodology and Data

3.1 Methodology

As previously emphasized, this research follows closely the work presented in Us (2014), which in turn is motivated by Fabiani & Mestre (2004) in what regards employing a system of equations combining both the Phillips curve and an Okun-type relationship. Therefore, the framework to be used in this dissertation is quite similar to the one described in the first study and it is explained in detail from now on.

The model is composed by nine equations assuming the following specification.

$$\pi_t = \alpha_{1,t}\pi_{t-1} + \alpha_{2,t}\pi_{t-2} + \alpha_{3,t}ugap_{t-1} + \alpha_{4,t}z_t + \epsilon_t^{\pi} \tag{1}$$

$$ygap_t = \beta_{1,t}ugap_{t-1} + \epsilon_t^{ygap} \tag{2}$$

$$ugap_t = \delta_{1,t}ugap_{t-1} + \epsilon_t^{ugap} \tag{3}$$

$$y_t = y_t^* + ygap_t \tag{4}$$

$$u_t = u_t^* + ugap_t \tag{5}$$

$$y_t^* = y_{t-1}^* + \gamma_{t-1} + \epsilon_t^{y^*} \tag{6}$$

$$u_t^* = u_{t-1}^* + \eta_{t-1} + \epsilon_t^{u^*} \tag{7}$$

$$\gamma_t = \gamma_{t-1} + \epsilon_t^{\gamma} \tag{8}$$

$$\eta_t = \eta_{t-1} + \epsilon_t^{\eta} \tag{9}$$

Equation (1) defines the Phillips curve, where π_t is inflation rate at time t, $ugap_{t-1}$ is unemployment gap at $t-1$ and z_t is a supply side variable at time t, represented by changes in real oil prices. We can easily understand that this Phillips curve is a three-prunged approach accounting for inflation inertia by means of inflation lagged terms π_{t-1} and π_{t-2}, and also for demand and supply sides of the economy, using unemployment gap and changes in the real oil prices as a proxy, respectively. The choice of the change in the real oil prices to account for the economy's supply side influence upon inflation was based on the prior that Euro Area members are all net importers of crude oil — according to the World Economic Outlook of International Monetary Fund (IMF). Moreover, this is certainly one of the few commodities that are essential for the development process of an industrial based economy and perhaps the most important one. The intermediate consumption of crude oil that is made in order to produce plastics, medicines, energy for transportation and many other goods, allows us to recognize the difficulty there is to substitute this natural resource in all the production processes it is involved. All together, fluctuations in oil price will probably reflect into changes on the consumption goods price, given the increase in the production cost of all the above-mentioned products. As described above, this effect emerges from the supply side of the economy and it is transversal to the monetary union member states. Consequently, this variable possibly constitutes one of the best options to assess inflation changes resulting from supply influences at the Euro Area level. Also, Richardson et al. (2000) and Turner et al. (2001) have considered a similar variable, with the purpose of measuring NAIRU in OECD economies.

In turn, equation (2) expresses an Okun-type relationship, that links unemployment gap with output gap, represented by $ygap_t$.

The remaining equations are also essential because they provide structure to the model, by specifying the relationship between the variables and the law of motion for NAIRU as well as for potential output. According to equation (3), unemployment gap follows an autoregressive process of order one. Equations (4) and (5) are based on the Beveridge & Nelson (1981) decomposition method. This method states that actual unemployment is composed by a cyclical component and a trend, given by unemployment gap and NAIRU, respectively. Exactly the same reasoning applies to actual output, as presented in equation (4) — the cyclical component corresponds to output gap and the trend to potential output. As far as the law of motion of potential output and NAIRU are concerned, equations (6) and (7) state that they follow a local linear trend model, with stochastic trends γ and η. The latter variables follow a random walk process, in agreement with equations (8) and (9).

All the variables represented by ϵ, such as ϵ_t^{π}, ϵ_t^{ygap}, ϵ_t^{ugap}, $\epsilon_t^{y^*}$, $\epsilon_t^{u^*}$, ϵ_t^{γ} and ϵ_t^{η} are disturbance terms, following a Gaussian distribution and assumed to be uncorrelated between them.

One of the most important contributions from Us (2014) was the incorporation of time varying parameters in the NAIRU estimation problem. These time varying coefficients are represented by $\alpha_{1,t}$, $\alpha_{2,t}$, $\alpha_{3,t}$, $\alpha_{4,t}$, $\beta_{1,t}$ and $\delta_{1,t}$. Clearly, the problem becomes much more complex in this situation, because we have to estimate not only NAIRU, but also those parameters. In fact, this detail transforms the problem into nonlinear. Nevertheless, this incorporation allows taking interesting conclusions that were not possible otherwise, since it permits to estimate the relative impact of each variable on inflation across time.

In the previous section we have referred that KF is a widely used tool in the literature with the purpose of estimating NAIRU. Nevertheless, for nonlinear problems KF is no longer a valid option and EKF emerges as the most natural alternative.

In order to make EKF operational there are some prior steps we need to perform. First of all, the model has to be re-written in state space form, as follows.

$$x_t = Fx_{t-1} + Gu_t + e_{1t} \tag{10}$$

$$y_t = Hx_t + e_{2t} \tag{11}$$

Equation (10) is known as transition equation, while equation (11) is the measurement equation, incorporating the problem's main variables as dependent — inflation rate, actual output and actual unemployment. Matrix F is called update matrix, G is a known matrix and H is the extraction matrix. Variables e_{1t} and e_{2t} are vectors composed by independent and identically distributed (i.i.d.) shocks, which are uncorrelated and have covariance matrices R_1 and R_2, respectively. Applying this structure to our model, it comes:

$$\begin{bmatrix} \pi_t \\ \pi_{t-1} \\ ygap_t \\ ugap_t \\ y^*_t \\ u^*_t \\ \gamma_t \\ \eta_t \end{bmatrix} = \begin{bmatrix} \alpha_{1,t} & \alpha_{2,t} & 0 & \alpha_{3,t} & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \beta_{1,t} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & \delta_{1,t} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 & 0 & 1 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \pi_{t-1} \\ \pi_{t-2} \\ ygap_{t-1} \\ ugap_{t-1} \\ y^*_{t-1} \\ u^*_{t-1} \\ \gamma_{t-1} \\ \eta_{t-1} \end{bmatrix} + \begin{bmatrix} \alpha_{4,t} \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \\ 0 \end{bmatrix} \begin{bmatrix} z_t \end{bmatrix} + \begin{bmatrix} \epsilon^{\pi}_t \\ 0 \\ \epsilon^{ygap}_t \\ \epsilon^{ugap}_t \\ \epsilon^{y^*}_t \\ \epsilon^{u^*}_t \\ \epsilon^{\gamma}_t \\ \epsilon^{\eta}_t \end{bmatrix} \tag{12}$$

$$\begin{bmatrix} \pi_t \\ y_t \\ u_t \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 1 & 0 & 0 \end{bmatrix} \begin{bmatrix} \pi_t \\ \pi_{t-1} \\ ygap_t \\ ugap_t \\ y^*_t \\ u^*_t \\ \gamma_t \\ \eta_t \end{bmatrix} \tag{13}$$

Also, there are some initial values we need to specify in order to be able to initialize the estimation process. Namely, there is need to explicit the value of each variable's first observation, the time varying parameters estimate and the covariance estimate relative to each of the nine equations. After all the outlined components are estimated and specified, the EKF may be readily applied. Technical appendix provides an insight on the functioning of this filter.

Estimations and computations were handled by using Gretl, STATA and Matlab.

After the estimation of NAIRU series for each Euro Area member, we calculate the Spearman's rank correlation coefficient in order to understand how does the NAIRU for a given country relate to the one of Euro Area as a single entity. This is our attempt to analyze the business cycle synchronization among the different Euro Area members. The option to use Spearman's rank correlation coefficient instead of Pearson correlation coefficient was due to the fact that the first is a nonparametric measure of statistical relation between two variables, while the latter is a parametric one. Therefore, the Pearson correlation coefficient must be used when the variables follow a normal distribution and the Spearman correlation coefficient does not require any distributional assumption. Given that most of the data to be employed in this exercise does not follow a normal distribution — see table 6 — the option was to use Spearman's rank correlation coefficient. In both cases, the coefficient may vary between -1 and 1. The first result applies when two series are perfectly negatively correlated between each other and the latter applies in the opposite situation, this is, a perfect positive relation. In case the coefficient assumes a value of 0, there is existence of no relation at all.

3.2 Data

In this research we opted to use data from individual Euro Area members instead of restricting the analysis to Euro Area as a single entity. This choice was made considering the main purpose of studying Euro Area synchronization employing NAIRU as a proxy. Therefore, we estimated this indicator for each country belonging to the monetary union plus Euro Area as a single economy, in order to have a benchmark when comparing individual evolutions. Eighteen Euro Area member states were taken into account in this study, namely Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Greece, Ireland, Italy, Latvia, Luxembourg, Malta, Netherlands, Portugal, Slovak Republic, Slovenia and Spain.

This work makes use of quarterly data, covering the period between the first quarter of 1999 and the third quarter of 2014. The beginning of this time span coincides with the official implementation of Euro Area, with eleven of its current member states adopting Euro as domestic currency — see table 7 in the appendix for the adoption date of each country. Obviously, Lithuania is not considered in this study because it joined the monetary union in January 2015.

The remaining lines of this section are intended to give insight about each variable employed in the model specified above.

Inflation is assessed by the logarithmic difference of harmonized Consumer Price Index, obtained from International Financial Statistics database, available at the IMF's website. Unemployment rate, in percentage, is available at the same source and represents the actual unemployment variable. Output is measured by the logarithm of harmonized real GDP, available at the Statistical Data Warehouse from European Central Bank. Finally, changes in real oil prices are assessed by the logarithmic difference of real oil price, available at the Statistical Data Warehouse (SDW) from ECB.

Inflation, unemployment and output data were further submitted to a seasonal adjustment, operated with TRAMO/SEATS software.

4 Estimations and Results

After the execution of the previously described methodology, we are able to analyze the estimations and results. In the next pages, the estimated NAIRU series are represented graphically in figure 1, together with the actual unemployment rate for each country in study. Each chart has an adjusted scale for the sake of a clearer representation.

An immediate finding when observing the figure is that NAIRU constitutes a lag variable relating actual unemployment. This characteristic applies to each and every Euro Area member state, perhaps due to the nature of the estimates, which in part are extracted from the trend of actual unemployment and follow a reduced form approach.

Another analysis that can be easily conducted concerns the relative volatility of NAIRU regarding actual unemployment. In this case, the results are quite interesting given that they suggest stronger economies to have a more volatile NAIRU than its own actual unemployment series. This group of countries comprehends Austria, Belgium, Finland, France, Germany, Italy, Luxembourg and Netherlands. Curiously, all these eight countries were part of the group of eleven that was in the origin of the monetary union in 1999. Euro Area as a single entity follows the same result, which is mainly justified by the fact that stronger economies should have more weight in the behavior of an aggregate such as a monetary union, composed by several countries with different specificities between them. The result of a larger volatility regarding NAIRU rather than actual unemployment may reflect the short-run characteristics of the estimates, which relates to the concept of short-run NAIRU that we have covered in the literature review chapter and many studies make reference to as the most useful and reliable NAIRU concept to assess inflationary pressures.

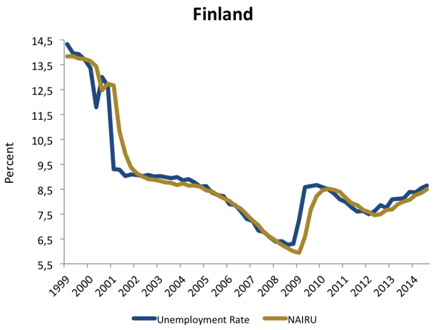
The remaining countries are divided in two groups. One of them is a group of countries whose the volatility of NAIRU is lower than the one of

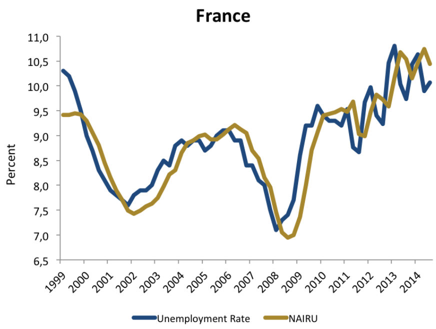
Figure 1: Actual unemployment rate and NAIRU estimates for Euro Area member states

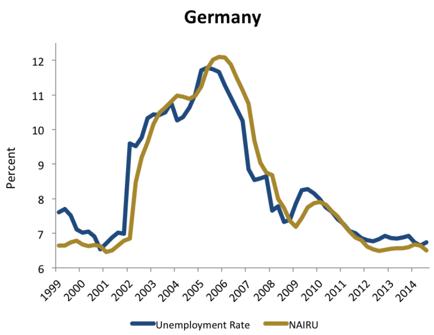
Source: IMF's International Financial Statistics Database and calculations by the author

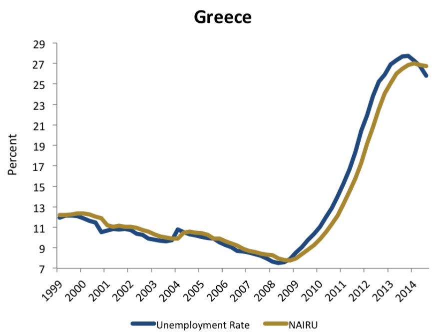
Figure 1: Continued from previous page

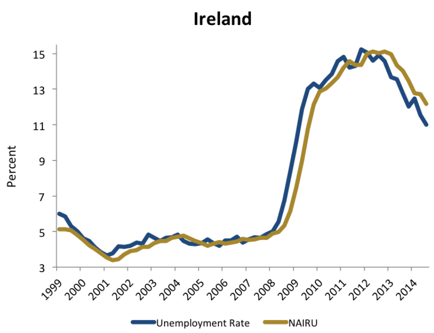
Source: IMF's International Financial Statistics Database and calculations by the author











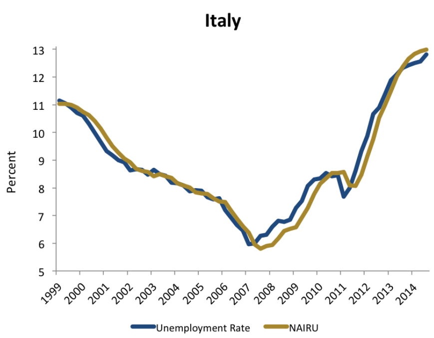


Figure 1: Continued from previous page

Source: IMF's International Financial Statistics Database and calculations by the author

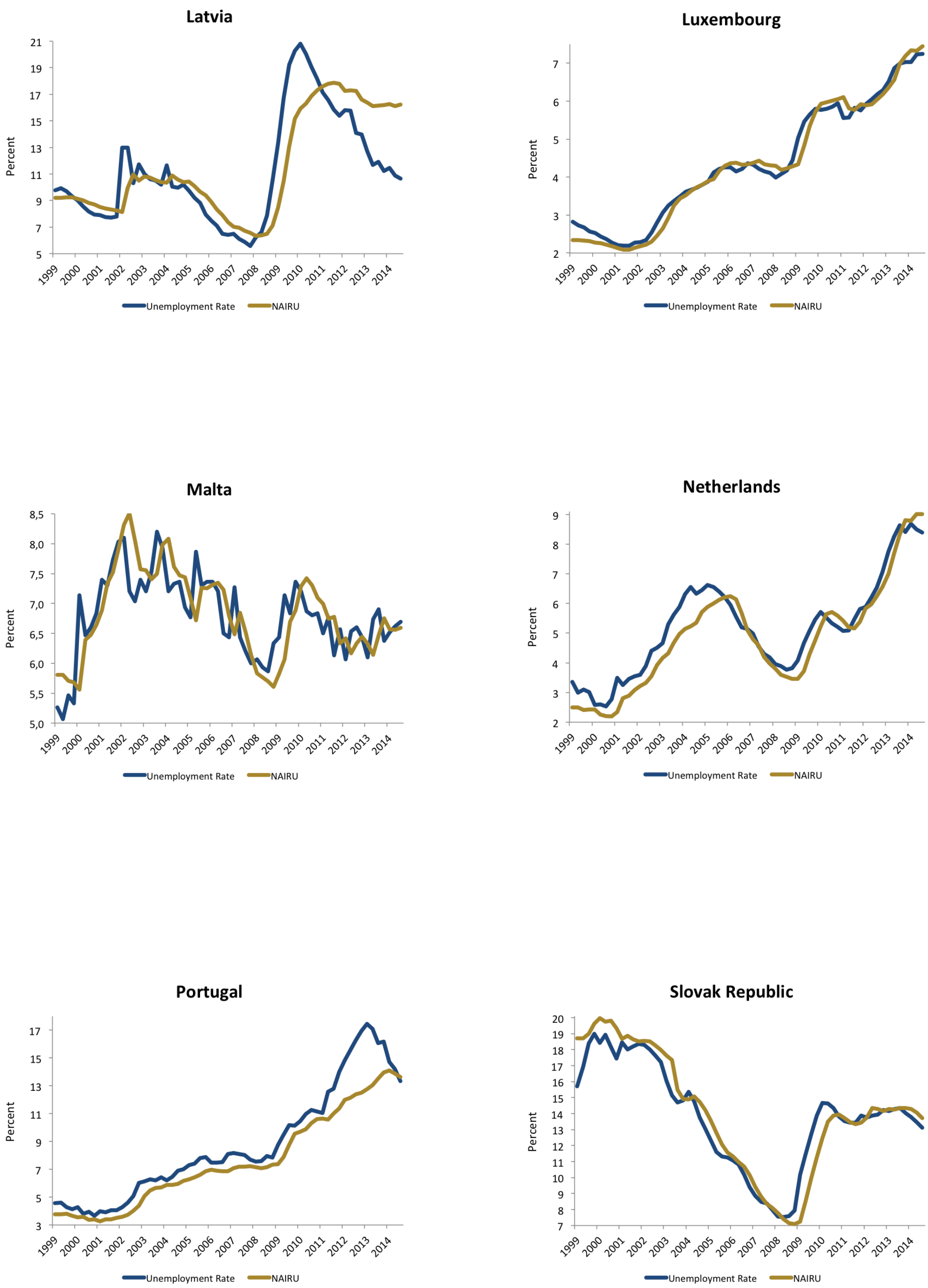
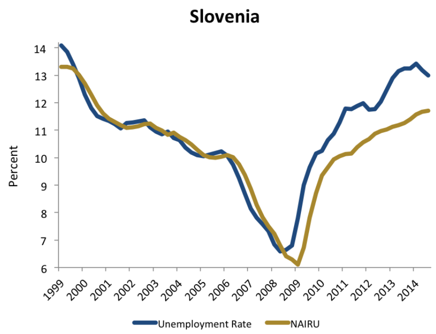
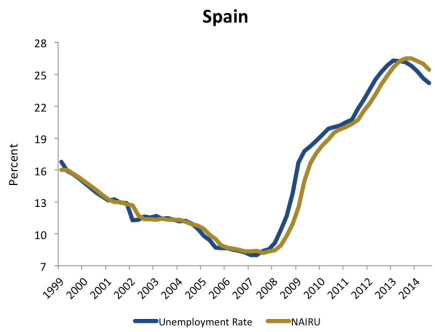


Figure 1: Continued from previous page

Source: IMF's International Financial Statistics Database and calculations by the author





actual unemployment. This group is composed by Cyprus, Estonia, Latvia, Portugal, Slovak Republic and Slovenia. In turn, for the second group of countries it is not clear whether NAIRU has a larger volatility when comparing to actual unemployment or not. This case applies to Greece, Ireland, Malta and Spain.

Again, the constitution of these groups reveals to be interesting. Portugal is the only country in the former group that was in the initial constitution of the monetary union. All the other countries in this group joined Euro Area from 2007 — the case of Slovenia — onwards, with Latvia in 2014 being the most recent case. In the latter group are represented the two remaining countries that were part of the Euro Area project from its very beginning, in this case to be Ireland and Spain.

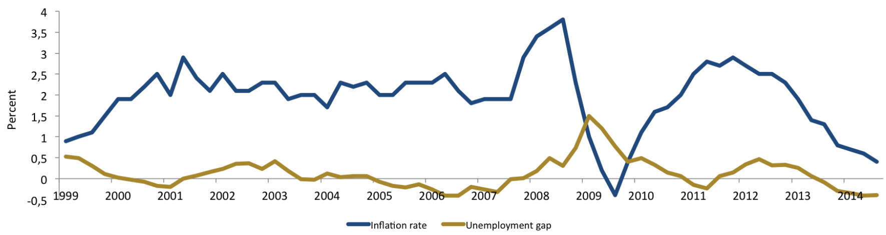
When both groups are analyzed together, there is evidence of the pattern described above. The countries where NAIRU estimates are not as volatile as actual unemployment, at least in a clear manner, are those that were not in the origin of the monetary union and also the ones that are more fragile among the Euro Area member states, as it was clearly demonstrated by the global financial crisis in 2007 and the sovereign debt crisis in 2010. Greece is the only country that is represented in both cases since it joined Euro Area in 2001 and was the most affected with the crises, as it is well known.

The larger volatility of NAIRU regarding unemployment rate for countries that were in the origin of Euro Area — excluding Ireland, Portugal and Spain — may be associated to several issues. First of all, the fact that short-run NAIRU is more volatile than medium to long run NAIRU, provides to the first a larger predictive capacity relating inflation pressures. Together with the credibility of ECB and its commitment to the primary objective of maintaining price stability, these facts make easier the task of predicting inflation in the near term in the countries that belong to the monetary union from longer time. Therefore, in such countries, the short--run characteristics of NAIRU are more evidenced, in the form of larger volatility. Secondly, it should be easier to predict developments in stronger and more stable economies than in the most fragile ones. This aspect refers to the specificities of each country that are reflected in the variables used in the estimation process and should explain why Ireland, Portugal, Spain and even Greece that joined Euro Area in 2001, do not belong to the first group of countries presented above. In conclusion, although there are different specificities between each country in analysis, one of the main objectives of this dissertation was attained, by estimating the same short-run NAIRU concept for every member state.

As far as Euro Area is concerned individually, it is easy to understand through figure 1 that the analysis can be divided in two periods: prior to 2008 and after 2008. In regard to the first period, from 1999 until 2008, NAIRU series followed actual unemployment very closely and, as expected according to the concept of NAIRU, the inflation rate was fairly constant around 2% and 2.5%, quite near to the explicit primary objective of the ECB's monetary policy — *"(. . .) The ECB aims at inflation rates of below, but close to, 2% over the medium term"*. The relation between unemployment gap and inflation rate for the Euro Area economy is represented in figure 2.

Figure 2: Inflation rate and Unemployment gap for Euro Area economy

Source: IMF's International Financial Statisctics database and calculations by the author



Nevertheless, the global financial crisis took place in 2007, affecting Euro Area economy mostly in 2008 and the scenario did not remain unchanged. Actual unemployment started to rise at larger rates than NAIRU, what implied an increase in the unemployment gap reaching its peak in the first quarter of 2009, with a value of 1.5%. Inflation started by increasing from 1.9% in the third quarter of 2007 to 3.8% in the third quarter of 2008 and then it dropped sharply to −0.4% in the third quarter of 2009, constituting the first time that Euro Area experienced a period of deflation. This negative development was caused by the slump in oil price. In exactly two years, the inflation rate reached its peak and trough, in a period of approximately fifteen years. When inflation first rose, the negative relationship with NAIRU was not apparent, but from the third quarter of 2008 until the first quarter of 2013 that relationship seemed clear, with the peak of unemployment gap and the trough of inflation rate differing only about 2 quarters between each other.

The baseline idea of using short-run NAIRU estimates instead of a more generic concept promoted in the literature review and incorporated in the methodology, following Us (2014), seems to provide reliable results and it has been supported by recent studies. Specifically, both Gordon (2013) and Watson (2014) have argued that the relation between inflation and unemployment must be stable in order to find a meaningful NAIRU estimates.

By making use of the triangle model, both of these works have found the relation between short-run unemployment and inflation to be more stable than total unemployment and inflation. Obviously, the immediate result is that short-run NAIRU series are incomparably more useful than the generic NAIRU.

In conclusion, this model seems to capture properly the dynamics of NAIRU for the Euro Area economy, when accounting for the actual unemployment and the inflation rate dynamics in the analysis.

4.1 Business Cycle Synchronization

In the previous section, it was highlighted that the Spearman's rank correlation coefficient will be used as a measure to assess business cycle synchronization. This coefficient is applied to each country's NAIRU series along with the one of Euro Area as a single entity. In this way, it is obtained a measure of association between the developments of NAIRU series from one member state in relation to the monetary union as a whole. The results of this exercise are presented in table 2.

The first result that should be highlighted is the negative and statistically significant correlation of Germany, the greatest economy of Euro Area, with -0.3593 in relation to the average of the monetary union. This coefficient suggests that a higher NAIRU in most Euro Area economies is related with a lower NAIRU in Germany and vice-versa.

This evidence may be justified by two ways. The first is an analysis of Germany per se. When the crises hit Euro Area economy and other countries, such as the United States of America for instance, Germany was able to direct its exports to countries that were not so subject to the difficult consequences of both global financial crisis and sovereign debt crisis. According to statistics from the Observatory of Economic Complexity[2],

[2]Project developed at the MIT Media Lab Macroconnections group. It is intended to provide data about trade between different countries.

Germany and Malta are the only countries from the group of eighteen whose China belongs to the group of top five export destinations, representing 6.4% and 8% of the total exports, respectively. Additionally, the World Bank statistics show that from 1978 onwards, China had an economic growth of 10% a year, on average. Focusing again on Germany, this country depends a lot on the relations with the exterior, essentially in the form of exports, given that they sum up 45% of the GDP — whereas GDP corresponds to 3.2 trillion euros, approximately. The latter indicators are also in accordance to the World Bank statistics. Again, Germany was the only country in Euro Area that was able to impose this virtuous dynamic in its own economy, justifying part of the negative correlation coefficient.

It is well known that economic globalization is extremely developed. In a specific adverse period such as the one in study, the contagious effects from each country to another may justify some of the results. That is the main reason why we opted to analyze most correlation coefficients relating with the trade relations between the different countries.

The second explanation of the German negative correlation coefficient may be related to the fact that the ECB's monetary policy was naturally constructed accounting mostly for the needs of its largest economy. The choice of the monetary policy objective was not so influenced by the remaining largest economies and it was certainly not conditioned by the weakest economies in Euro Area. In fact, Germany is one of the few countries that would have prefer an inflation targeting policy instead of a policy intending to promote economic growth, with some concerns about inflation as well. This fact is understandable and is due to the German hyperinflation experience 1922 and 1923.

In conclusion, if the monetary policy is designed essentially considering the needs of the largest economy in a monetary union, it is likely that the economic cycle differs from this to the remaining economies and consequently such lack of synchronization may arise.

Table 2: Spearman's rank correlation coefficients between the NAIRU series from each member state and Euro Area as a single entity. In the right hand side column are presented the p-values — the null hypothesis of the test states that the series are independent

Source: Calculations by the author

Member States	**Correlation Coefficient**	**P-Value**
Austria	0.8348	0.0000
Belgium	0.5638	0.0000
Cyprus	0.6935	0.0000
Estonia	0.2066	0.1043
Finland	0.0555	0.6658
France	0.8996	0.0000
Germany	-0.3593	0.0038
Greece	0.7629	0.0000
Ireland	0.6574	0.0000
Italy	0.5941	0.0000
Latvia	0.8574	0.0000
Luxembourg	0.6389	0.0000
Malta	-0.0910	0.4783
Netherlands	0.6950	0.0000
Portugal	0.6017	0.0000
Slovak Republic	0.1617	0.2054
Slovenia	0.3520	0.0047
Spain	0.7832	0.0000

The result of Germany contrasts with the one relative to the second-largest economy. The NAIRU series of France is positively and also significantly related with the Euro Area NAIRU. In fact, France has the largest coefficient from the eighteen countries in analysis, with 0.8996, despite Latvia and Austria have large coefficients as well, of 0.8574 and 0.8348, respectively. Following France, Latvia and Austria, with lower but still high coefficients, are Spain with 0.7832 and Greece with 0.7629. Notice that the latter economies have suffered and are still struggling with severe consequences of both recent crises already outlined in this work and at the same time are the fourth and fifth with the largest coefficient amongst all the member states — the third and fourth if we exclude Latvia from the analysis, given that it joined Euro Area in 2014, several years after those crises.

Delimiting the analysis to the countries whose NAIRU series are not independent from the one relative to Euro Area — those members with a p-value lower than 0.05 — and also excluding Germany that possesses a negative correlation, Italy is the member state with the antepenultimate lower correlation coefficient, of 0.5941. This value is still high however it is clear that does not have the same weight than the results previously highlighted. Following the same reasoning, Belgium would be the country with the penultimate lower correlation coefficient with 0.5638, quite similar to the Italian one. The lowest coefficient in the same context is referent to Slovenia, with 0.3520. This value allows a conclusion pointing to the same direction than the ones of the previous countries, however it applies in a much lower degree, given that it is less than half of the Greek correlation coefficient, for example.

Accounting for the fact that the largest economies contribute differently to the evolution of the NAIRU series in the Euro Area aggregate, the smaller economies play a determinant role in the sense that they are the ones defining what the behavior of the NAIRU series will be for the union as a whole. With this reasoning in mind, Netherlands (0.6950), Cyprus (0.6935), Ireland (0.6574) Luxembourg (0.6389) and Portugal (0.6017) are the countries that make the difference and are more aligned with both France and Italy.

Despite these countries have very different specificities between each other, they all compose the group of member states with statistically significant and positive correlation coefficients comparing with Euro Area as a single entity. This is mainly due to two different effects. The first effect is that member states have suffered severe consequences from the crises and therefore the series incorporate more volatile evolutions. In such way, these countries influence the Euro Area aggregate series more than other countries and the likelihood of a positive and significant correlation between both series is higher. The second effect is the size of the economies in study. Obviously that a country being responsible for a large percentage of the monetary union's GDP is also more likely correlated to the aggregate series than the remaining countries, if the economic evolution in these countries is in line with the average — which does not happen with Germany for instance.

The definition of whether the country is strongly correlated or not, is a result of these two effects combined together. Greece and Latvia are examples of the case where the first effect presented above is clearly manifested. These represent small economies in the Euro Area context, however their sharp evolutions, in tandem with the generality of the remaining countries, did result in larger correlation coefficients, because they influence the average aggregate series. On the other hand, France and Austria are two countries responsible for a significant share of the Euro Area's economy and due to the second effect, they also have significant correlation coefficients. An example of a mix between the two effects is Spain, which is the fourth largest economy in Euro Area and is part of the most affected group of countries in Euro Area with the crises. All the remaining countries have different degrees of combination between both effects and different specificities that make the correlation coefficients to vary and are not taken into account in this analysis.

The remaining countries belong to a specific group whose NAIRU series are statistically independent from the one relative to the monetary union, according to the p-values presented in the right hand side column of table 2. In our view, the most interesting result in this regard is referent to Finland, because it constitutes the only Nordic country in the group of eighteen and the behavior of its NAIRU is not in line with the Euro Area dynamics. Moreover, the correlation coefficient of 0.0555 is the most neutral one when comparing with all the other member states — meaning that is the closest to zero, value that implies the existence of no relation between two series. This result is consistent with the fact that Finland possesses the largest p-value, of 0.6658.

Besides Germany, Malta is the only country with a negative correlation coefficient, of -0.0910, despite the series are also independent from the one of Euro Area.

Finally, Estonia with 0.2066 and Slovak Republic with 0.1617, are the countries that complete the latter group of results. The result relative to Estonia is in line with the strict relation there is in reality between the Estonian, the Finnish and, in a smaller degree, the German developments, among the countries that constitute the monetary union.

This last group of countries is not so dependent of the monetary union's economic developments, in comparison to the countries that were previously presented. The main reason for this is that the main trading partners do not belong to the monetary union. Take the illustrative examples of Finland and Malta — the source of the data about main export partners outlined below is the Observatory of Economic Complexity. In the case of Finland, the top five export destinations include Sweden, Germany, Russia, the United States of America and Netherlands, where Germany and

Netherlands sum 15% in a total of 42% in this list of exports. In turn, the five main export partners of Malta are Bunkers, Singapore, China, Germany and Hong Kong, where Germany represents 6% in a total of 41% within these countries. Again, Malta and Germany are the only countries that have China as one of the top five export destinations and the same reasoning that we have applied to the German case, applies equally to Malta.

Note that Finland is the only country of its group that was in the origin of Euro Area constitution. This result enhances the fact that Latvia, the most recent country joining Euro Area, is the member with the second largest correlation coefficient of an analysis covering the period between the first quarter of 1999 and the third quarter of 2014.

The argument to use the Spearman's rank correlation coefficient instead of the Pearson correlation coefficient was based on the fact that most NAIRU series did not follow a normal distribution — see table 6 — and therefore, the use of Spearman's rank correlation coefficient would be more appropriate to perform this exercise. Even so, in order to demonstrate that our results do not rely on this choice, the Pearson correlation coefficients are made available in table 3 for each country in study.

We can understand that the results differ substantially between both measures of correlation regarding Cyprus, Estonia, Greece, Ireland, Italy, Portugal and Slovenia. Nevertheless, considering the p-values of the Doornik--Hansen normality test, presented in table 6 of the appendix, there is evidence that the series of these countries do not follow a normal distribution. For that reason, the results are not biased by the choice of employing the Spearman's rank correlation coefficient and this option was properly made.

Table 3: Pearson correlation coefficients between the NAIRU series from each member state and Euro Area as a single entity

Source: Calculations by the author

Member States	**Correlation Coefficient**
Austria	0.8252
Belgium	0.5200
Cyprus	0.8789
Estonia	0.0798
Finland	0.0068
France	0.8952
Germany	-0.3312
Greece	0.9053
Ireland	0.7831
Italy	0.7559
Latvia	0.8559
Luxembourg	0.7135
Malta	-0.0798
Netherlands	0.7751
Portugal	0.7752
Slovak Republic	0.1961
Slovenia	0.4764
Spain	0.8966

4.2 Individual Analysis

This subsection is intended to justify some of the sharpest evolutions in the NAIRU estimates by country. According to the methodology presented in the previous chapter, the NAIRU series are estimated by making use of the actual unemployment variable, which is clear from figure 1. In principle, a direct conclusion from such relation is that, in order to justify sharp variations in the NAIRU series, one should aim to explain large variations in the unemployment rate and extrapolate that the same reason applies to the case of NAIRU. Therefore, the best strategy to justify these variations is to analyze the most relevant economic events that took place during the years in study and that might be specific, or not, to each country.

A group of countries that went through severe consequences with the global financial crisis and also with the sovereign debt crisis is composed by Cyprus, Greece, Ireland, Portugal, Italy and Spain. As it is widely known, the first four countries requested financial assistance programs in the sequence of the crises developments. Nevertheless, the nature of the crises was different from each country to another. Specifically, the crises in Cyprus and Ireland were essentially explained by the banking sector, while in Greece and Portugal were mainly due to structural debilities of the respective economies, with a minor component related to banking activity as well. Obviously, the impact of banking crisis and structural debilities are inter-connected and for some cases it may be difficult to attribute a specific nature to a crisis that results from global developments. This case applies not only to Spain and Italy, but also to the remaining countries identified in this subsection.

The Greek condition is the most difficult in the monetary union, given that the program aimed towards the recovery of this country was not properly designed and therefore failed to support the economy in the hardest times. In turn, despite the fact that the Cypriot economy is giving signs of recovery, contrarily to the Greek one, the actual condition of this economy is far from perfect as well. Cyprus was confronted with high pressure after the global financial crisis in 2007 and 2008, just as most countries of the EU. Initially, the increase of unemployment rate — along with the shrinking of economic activity — was justified by the unfavorable developments of tourism, which is the main service industry in this country.

The sovereign debt crisis was the main responsible for the sharp increase of the unemployment rate from 2011 onwards, due to the overexposure of the Cypriot banks to Greek government bonds and other financial instruments that credit rating agencies revised downward their grade to junk status. As suggested above, the final consequence was correspondent to the implementation of an economic adjustment program requested by the Cypriot government in June 2012 that covers the period from 2013 until 2016. Regarding all the four member states, these financial assistance programs were intended to promote fiscal consolidation and structural reforms with a direct impact on economic activity. All those unfavorable developments together, contribute in a direct or indirect way to a large increase in the unemployment rate, as evidenced by figure 1.

As far as Estonia is concerned, it was verified a sudden increase in the unemployment series from 3.86% in the first quarter of 2008 to 18.40% in the second quarter of 2010. This indicator provides a reason to leave some explanation about the Estonian economy developments as well. In the sequence of the subprime crisis, aggregate consumption and investment in Estonia suffered a contraction. In previous years, a great investment on the real estate market was made and on the sequence of the events in the United States' economy, there was an overheating of the same market that resulted in severe consequences. Specifically, Estonia recorded the worst unemployment rate in the EU. The characteristics of such crisis were shared by the remaining Baltic states, from which Latvia is also represented in this study. Indeed, the charts for both countries show a very similar behavior of the unemployment rate series from 2008 onwards.

Considering the intention of the analysis conducted in this subsection, Slovenia and Slovak Republic are two member states with more similarities than disparities. From the beginning of the period in study until 2008, approximately, it is perceptible a strong recovery of unemployment that in the first place was high mainly due to the structural change of the economies. In early 1990s, these countries transited to independent states and adopted a market type economy. In 2008, the trend of decreasing unemployment rate reverted and both were result of a banking crisis, similarly to many other states. Prior to 2007, it was verified a strong growth of easy credit, which burst a bubble in the real estate sector. Enterprises whose activity was dependent from credit, saw their assets being devalued as easy credit growth faded away, which reflected into the balance sheet of monetary and financial institutions. These banks recorded such loans as nonperforming and as result, the sovereign debt crisis in both economies constituted a natural consequence of their developments.

The only Nordic country in Euro Area, Finland, is referred in this subsection due to the behavior of unemployment series in the beginning of the period considered for this study. The large rate of unemployment verified in 1999 is an outcome of the banking crisis in the early 1990s. Essentially, the latter corresponded to the result of poor banking supervision and regulation, which contributed to the systemic component of the crisis, shared by the whole financial system. An analysis from the chart gives a clear suggestion that the nefarious impact of this banking crisis was incomparably larger than the effects of both the global financial crisis and the sovereign debt crisis.

Finally, Germany is emphasized in light of the period between 2001 and 2006, which was justified by the global telecoms crash. In the sequence of such crisis, the German government at the time adopted some austerity measures in order to revert the unfavorable economic cycle. The peak of the unemployment rate was correspondent to 11.79% and took place in the second quarter of 2005. France was also affected by this crisis, however in a smaller degree, as evidenced by the graphical representation.

4.3 Time-Varying Parameters

In this subsection, the time-varying parameters that stem from the estimation of NAIRU series via EKF are interpreted and analyzed. Only the coefficients relative to Euro Area as a single entity are taken into consideration to avoid a repetitive analysis.

According to O'Reilly & Whelan (2005), the sum of lagged inflation coefficients is a good proxy of inflation persistence. Following such argument, it is considered the sum of coefficients $\alpha_{1,t}$ and $\alpha_{2,t}$ as a single parameter, in order to assess the developments of Euro Area inflation inertia from 1999 until 2014.

Figure 3: Euro Area Inflation persistence

Source: Calculations by the author

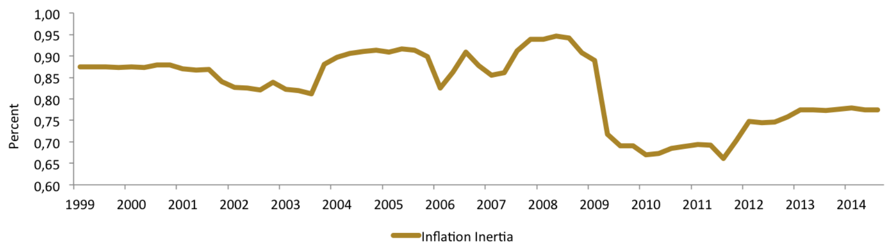


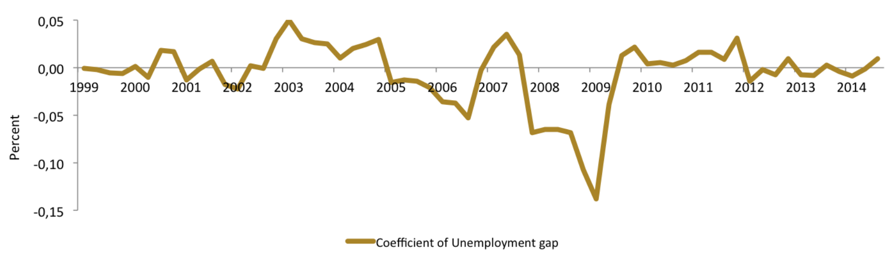
Figure 3 suggests that inflation persistence at the Euro Area level remained stable around 0.85% from the first quarter of 1999 until the last quarter of 2001, when it decreased to 0.80%, approximately. This evolution was coincident with the Euro adoption by Greece in 2001 and, most importantly, with the effective implementation of the Euro as a domestic currency in all member states at date, through the physical introduction of notes and coins in 2002. In the third quarter of 2003, a positive development of the coefficient led inertia back to a similar level than the one verified in the beginning of the sample. In fact, from 1999 until 2008 the mean value for Euro Area inflation was about 0.88%, with a larger volatility after the introduction of physical notes and coins than in the first two years, as expected.

In 2009 seems to exist a structural break in the series, a result of the sharp decline of inflation rate, from 3.8% in the third quarter of 2008 to −0.4% in the third quarter of 2009. As referred in the beginning of the present section, this was the first time that Euro Area experienced deflation. The interest rate cuts by ECB from approximately 4.25% to 1% during the same period, contributed to the evolution of inflation persistence in 2008 and 2009. Similarly to the slight decrease of inflation inertia in 2001, this development coincided with the Euro adoption by Slovak Republic in 2009. Overall, from 2009 onwards the series assumed approximately 0.73% as mean, which suggests a diminishing role of past inflation on the present one as years go by.

After analyzing the inflation persistence developments in Euro Area from 1999 until 2014, it is time to understand how did the relation between unemployment gap in period $t-1$ and inflation rate in period t evolve over the same period of time. This coefficient is represented by $\alpha_{3,t}$ in the model employed and is on the basis of the Phillips curve definition – see figure 4.

Figure 4: Impact of Unemployment gap in $t-1$ on Inflation rate at t

Source: Calculations by the author

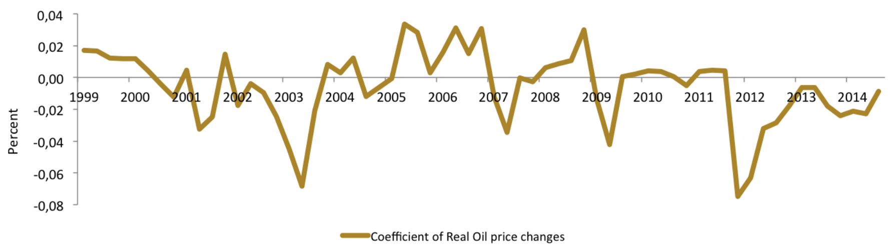


An immediate finding is the absence of a stable relationship between both variables, either positive or negative. The most likely justification for this fact is the form of monetary policy defined by the ECB, following a variant of a Taylor rule, with concerns about inflation rate and considerably less with economic growth or unemployment, for instance. Obviously, economic relations such as the one defined by Phillips curve are a theoretic consideration that might verify in practice or not, depending on the actual circumstances. In this case, given the primary objective from the ECB to promote price stability, the instruments available will be used in favor of this objective and not to promote other objectives that would be desirable as well, such as promoting low unemployment.

After presenting the results relative to coefficient $\alpha_{3,t}$, we are able to analyze the dynamics of $\alpha_{4,t}$ that corresponds to the effect of real oil price changes on the inflation rate — see figure 5.

Figure 5: Impact of real oil price changes on Inflation rate

Source: Calculations by the author



Similarly to the relation between unemployment gap and inflation rate, the impact of real oil price variations on inflation rate is not stable over time. This result enhances the volatile nature of real oil price that apparently transmits instability to the relation with inflation rate. Nevertheless, most peaks and troughs tend to coincide with the evolution of both series. An example is the peak of the inflation rate and the oil price series in 2008, followed by the trough in 2009 — the evolution of oil price series is represented in figure 8, which is made available in the appendix. The reason why the relationship between the two variables does not remain positive is that these developments are not exactly coincident. While the real oil price started to decline in the second quarter of 2008, the inflation rate did so in the third quarter of the same year. Later on, while the real oil price started to increase in the first quarter of 2009, the inflation rate only followed the same path in the third quarter. In other words, inflation rate is a lag variable regarding oil price, as expected. During the periods when the developments of both variables are not coincident, the coefficient $\alpha_{4,t}$ assumes negative values. Again, this finding does not imply that real oil price changes is not a good variable to predict inflation rate variations, as it is illustrated with the previous example.

All coefficients present in the reduced-form Phillips curve were analyzed — all the coefficients represented by α. The two coefficients that still remain to analyze are $\beta_{1,t}$ and $\delta_{1,t}$.

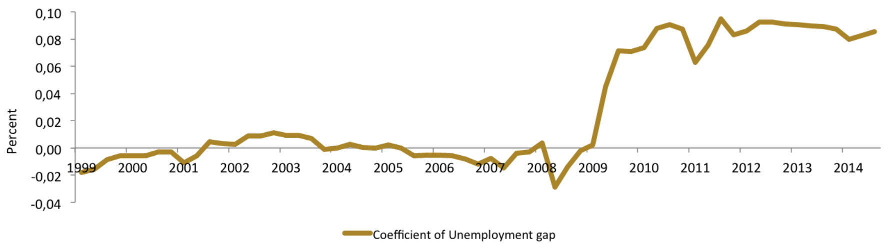
Starting with $\beta_{1,t}$, this coefficient expresses the relationship between output gap at period t and unemployment gap at period $t-1$. According to the Okun law, such parameter should take negative values because product above its potential must be related with unemployment being lower than the respective potential, *ceteris paribus*. In other words, with everything else held constant, the intensive use of labor as a production factor must result in more product and vice-versa.

Considering the Okun law, clearly that figure 6 is not the expected. From 1999 until 2009 there is no evidence of a stable negative relation between both variables. In fact, during the first ten years of the sample, the mean value of the series is 0.00%, which means that there is no evidence of a relation between both variables, on average. In 2009 exists a structural break in the series and the coefficient assumes positive values instead of negative ones, with a corresponding mean of 0.08% between 2009 and 2014.

This result can only be justifiable by the fact that Euro Area statisti-

Figure 6: Impact of Unemployment gap in $t-1$ on Output gap at t

Source: Calculations by the author



cal series are an aggregation of individual series from the different member states. In order to verify which countries are responsible for this variation, we prosecute an analysis of correlation between the GDP series from each country and the one corresponding to Euro Area, between 2009 and 2014. Additionally, to complete the analysis we account for the correlation coefficient between the unemployment rate and the GDP series from each member state, covering the same period of time.

To understand which correlation coefficient must be used in this exercise, the Doorkin-Hansen normality test was applied to the GDP series from 2009 onwards. The results are presented on table 9 in the appendix. Contrarily to the previous exercise, in this case the p-values are not mostly below 0.05, meaning that we do not reject the null hypothesis for most countries, which states the series follow a normal distribution. For that reason, the Pearson correlation coefficient is considered instead of the Spearman's rank correlation coefficient.

Table 4 presents the correlation coefficients relating the GDP series from each member state and the Euro Area.

We consider only the member states with a correlation coefficient larger than 0.90 for the sake of simplicity, by restricting the analysis on the countries that are more aligned with Euro Area GDP developments. These countries are Germany (0.9266), Belgium (0.9204), Austria (0.9075) and

Table 4: Pearson correlation coefficients between the GDP series from each member state and Euro Area as a single entity (2009 – 2014)

Source: Calculations by the author

Member States	**Correlation Coefficient**
Austria	0.9075
Belgium	0.9204
Cyprus	-0.2534
Estonia	0.7920
Finland	0.8376
France	0.9045
Germany	0.9266
Greece	-0.7491
Ireland	0.5859
Italy	0.0599
Latvia	0.4481
Luxembourg	0.8515
Malta	0.8032
Netherlands	0.7316
Portugal	-0.3253
Slovak Republic	0.8379
Slovenia	0.1651
Spain	-0.3406

France (0.9045). Curiously, the relative position between these four countries is the opposite comparing with the relative position of the correlation coefficients of NAIRU series.

Moving on to the second part of the exercise, the table presenting the correlation coefficients between individual series of GDP and unemployment rate is made available in table 5.

The countries with an unexpected positive correlation between GDP and the unemployment rate series are the ones with the higher correlation between individual GDP and Euro Area GDP series, exception made for Germany. This is the reason why the Euro Area aggregate series point to a positive correlation between both variables.

Luxembourg and Slovak Republic are the two remaining countries that share this form of positive correlation between GDP and unemployment rate series. At the same time, these countries have the individual GDP series positively correlated with the GDP relative to Euro Area in a strong manner, with coefficients of 0.8515 for Luxembourg and 0.8379 for Slovak Republic.

The initial question of why there is a positive correlation between GDP and unemployment rate series applies to the individual countries that were specified previously. The answer is not obvious, however it is probably related with the low value assumed by the unemployment rate series amplitude for these countries. For instance, the fact that the amplitude of the Austrian unemployment rate series in the period of 2009 up to 2014 is 2.95% makes it easier that there may be a sort of positive correlation between both series.

As previously argued, the Okun law is a theoretic construction, which obviously applies to the real world by principle. Nevertheless, sometimes in practice there is no strict relation between two indicators as in theory. This means that a marginal increase in the unemployment rate is not necessarily reflected into a decrease of GDP in practice, also because labor is not the

Table 5: Pearson correlation coefficients between the GDP and the Unemployment rate series from each member state (2009 – 2014)

Source: Calculations by the author

Member States	**Correlation Coefficient**
Austria	0.5035
Belgium	0.1173
Cyprus	-0.8766
Estonia	-0.8516
Finland	-0.5487
France	0.5588
Germany	-0.9685
Greece	-0.9893
Ireland	-0.3664
Italy	-0.8161
Latvia	-0.9790
Luxembourg	0.8433
Malta	-0.3949
Netherlands	-0.1906
Portugal	-0.8499
Slovak Republic	0.5106
Slovenia	-0.3446
Spain	-0.9216

only production factor. Even so, the last argument cannot be dissociated of the low amplitude relating the unemployment series. The contrast of extreme cases is usually able to provide an easier understanding of arguments. Therefore, considering the amplitude of the Greek unemployment rate series in the same period, which is 20.21%, it is clear that despite the reasoning presented above, the sharp increase of unemployment rate would necessarily be associated with a decrease of GDP.

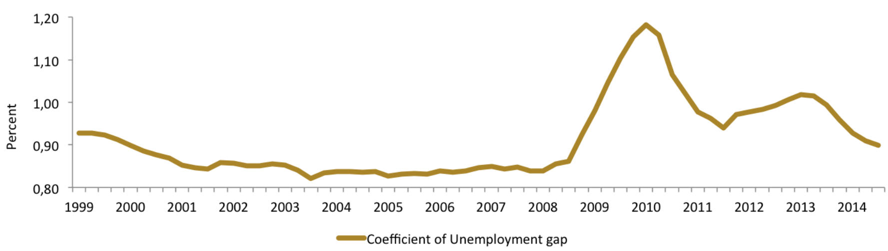
Another element that may contribute to this result would be the low synchronization between both series, which implies that an increase of the unemployment rate would only reflect into a decrease of GDP one or two periods ahead and not immediately. The latter is a more appropriate justification for the result concerning Slovak Republic, due to the fact that the amplitude of the unemployment rate series is quite large, of 11.47%.

In conclusion, the specific evolution of $\beta_{1,t}$ at the Euro Area level is quite biased by the weight of a few countries and does not reflect the generality of member states' behavior in the monetary union.

Finally, $\delta_{1,t}$ corresponds to the unemployment gap inertia, which similarly to the inflation case reflects the weight of previous periods' unemployment gap values on the actual unemployment gap. As specified in equation (3), in this case it is only considered the effect of unemployment gap with one lag.

Figure 7: Euro Area Unemployment gap persistence

Source: Calculations by the author



According to figure 7, in 1999 the unemployment gap persistence assumed a value of 0.93%, decreasing to 0.84% in 2001. From 2001 until 2008, the unemployment gap persistence was fairly constant around 0.84%. In the third quarter of 2008 the series suffered a sharp increase together with the boom in the unemployment gap series.

The positive association between the unemployment gap development and its persistence was an expected result. When the crisis hit the Euro Area economy and the unemployment gap rose to 1.5% in the first quarter of 2009, it was clear this indicator would be subject to a much larger influence of the previous developments, comparing with the first quarter of 2008, when unemployment gap was 0.18%, for instance. Generally, as the economic context becomes more adverse, the more persistent are the economic indicators.

Overall, most of the coefficients' evolution between 1999 and 2014 correspond to the expected, considering the economic reasoning and also the actual developments of the series.

4.4 Implications for Economic Policy

This chapter provides the link between the estimation results mentioned in the previous sub-section and the current practical issues associated to economic policy in Euro Area. Specifically, it will focus on the results regarding NAIRU series correlation between some of the member states.

The German NAIRU series has a negative and statistically significant correlation relating the one of Euro Area and contrarily, France has the largest, positive correlation coefficient from the group of eighteen countries. Also, the Italian coefficient is about two-thirds as the one of France. These observations allow the understanding that the three largest economies in Euro Area have a very different degree of synchronization between each other and that should be seen as a barrier to the optimal conduction of monetary policy in the context of a monetary union. The reason is that in such conditions there will be no monetary policy that covers the needs from these three member states simultaneously.

A much more complex problem arises with the addition of all the remaining member states to the analysis. In reality it is very difficult to make strategic decisions regarding a policy that applies to each and every country, if those member states' economies do not need the same kind of stimulus. Therefore, it is difficult to pursue policies that are directed to fulfill the needs of specific countries, given that these policies will not serve as useful for some of the largest economies in the Euro Area, for instance. Furthermore, it is difficult to manage the political and economic consequences of such lack of synchronization at a EU level.

Nowadays, the Greek's economy situation is an example of this divergence across Euro Area member states' developments. It is clear that the attainment of a consensus relating the economic measures associated to the 2015's financial assistance program for this country was arduous. The political dimension of this type of agreement is very complex. As an example, note that the economic measures that Greece has to apply in the sequence of the third financial assistance program follow the same line as the previous two, that the own IMF admitted in mid-2013 were not properly designed. Nevertheless, the IMF is still involved in the conception of the last program.

Obviously that the diverse dynamics from each economy in the EU also contribute to the political complexity. This fact verifies because in such circumstances there is little common interest in place and it does not seem correct to delimit the economic policy instruments choice to a fragile economy, as there are many in Euro Area. The lack of business cycle synchronization across Euro Area member states is due, in the first place, to distinct economic structures of each country, which in turn relates to different productive specialization for instance.

The monetary union is a project that initially was intended to promote the economic and financial convergence between the member states. Nevertheless, the distinct economic structure across countries, that was mentioned in the previous lines, led to divergent specificities in the trade dynamics and fiscal policy options that were pursued in each member state. Nowadays, according to Bekiros et al. (2014), the individual specificities are even more pronounced with the effects of both crises.

One of the possible paths to take in the future in order to avoid this problem is to increase the integration of EU further than the monetary union, with the intent of promoting the overall convergence. Recently, the first step was taken by the ECB with the implementation of the Single Supervisory Mechanism (SSM) as the first established part of the banking union. This idea is supported by Goodhart (2014), which argues that a banking union is strictly necessary to promote convergence between member states of a monetary union with different specificities, such as Euro Area. The reason is that a banking union in place would be able to attenuate the asymmetric and country specific shocks, especially relevant in crisis periods. More generally, Estrada et al. (2013) attributes the responsibility of desynchronization to the absence of devices that allow the risk-sharing between all countries in the monetary union in order to stabilize shocks that may be specific to one or a restricted group of countries.

As previously outlined, the history has proven that a monetary union may be insufficient to sustainably develop the economic activity, especially when involving member states with very different specificities. An economic and political union along with the monetary one would therefore provide more consistency in several dimensions. Clearly, the primary barrier to evolve in such way is the willingness of each member state to lose sovereignty in favour of a true union at a European level, similarly to the structure of the United States of America, with the obvious and inevitable differences between both regions.

The above-mentioned further integration corresponds to the main challenge in the medium term that the EU will be facing. For now, it is certain that the EU has to solve its own problems internally, to focus next on global concerning issues with social implications. Nevertheless, when economic disparities between the different countries are resolved, a larger degree of convergence will be easily attained in all dimensions.

5 Conclusion

In this dissertation, we have examined NAIRU synchronization among Euro Area member states in the period comprehended between 1999 and 2014. The main motivation associated to such purpose is connected to the fact that Euro Area constitutes a monetary union whose member states have much different specificities between each other. Therefore, it is relevant to understand whether NAIRU synchronization of each economy moves in tandem with the remaining countries and it may endorse the existence of a single policy in the Euro Area context or not.

NAIRU emerges as the chosen indicator to assess such synchronization for two reasons. The first is that NAIRU affects the estimation of the structural balance — via estimation of potential GDP —, which in turn influences the economic policies that countries pursue. In such way, if NAIRU developments are in line across the countries, the policies followed by those countries will be potentially more in accordance than in the opposite scenario. The second reason is that the concept of NAIRU employed in this dissertation is in fact of short-run NAIRU. By doing so, this work follows and supports a recent branch in the literature that finds short-run NAIRU to provide reliable and unbiased results, along with a larger predictive power regarding inflationary developments, in comparison to the "unqualified" NAIRU concept. The latter is also extremely opportune in the context of a monetary union.

In order to estimate NAIRU for each Euro Area member state and for the monetary union as a single entity, we have followed the methodology presented in Us (2014), combining a Phillips curve with the Okun law to have more robust estimates and allowing parameters to be time-varying. The latter specificity incorporates non-linearity into the estimation problem, which justifies the application of EKF instead of standard KF in the estimation process, as most works do. Finally, we have conducted the synchronization analysis by making use of Spearman's rank correlation coefficient, recommended by the results of the Doorkin-Hansen test to NAIRU estimates.

Estimates with time-varying parameters enable to obtain results that would be difficult to access otherwise. From such results, we enhance the finding that during the period in study the overall inflation persistence in Euro Area decreased. Specifically, from 1999 until 2008 the average of inflation persistence was considerably larger than in the period between 2009 and 2014 as a result of first time experience of deflation in the monetary union that occurred in 2009.

From the analysis of NAIRU estimates synchronization, we concluded that Euro Area economies are not synchronized in what regards their cyclical position. This result is enhanced by the fact that even the three largest economies in Euro Area — Germany, France and Italy — are not synchronized, since they behave in a very distinct manner. In the one hand, the correlation coefficient of the German NAIRU is negative and statistically significant regarding the series from Euro Area as a whole. In fact, Germany is the only country that possesses a negative and still statistically significant coefficient in the monetary union context. We have associated this finding to the distinct trade dynamics of Germany comparing with the other member states, especially in the sequence of both global financial crisis and also the sovereign debt crisis. On the other hand, France has the largest correlation coefficient in the same context from the group of eighteen countries, while Italy has a positive correlation coefficient but still quite low comparing with most countries — the correlation coefficients from both countries are statistically significant.

An obvious conclusion from the results mentioned above is that the eighteen member states of Euro Area are not synchronized, as it would be desired in the context of a monetary union. Nevertheless, this is an expected result when accounting for the different economic structures across countries and considering the distinct economic developments within Euro Area member states in the last years.

Given that the monetary union project failed to promote the convergence between its member states, the desirable path to take in the future is to further increase the EU integration. The next necessary development is the implementation of a banking union, whereas the first step has already been given by ECB with the establishment of the SSM. In the long term, one possible scenario is the existence of a monetary, economic and political union at a European level, in order to force the disparities between the countries to be minimized.

There are several potential extensions to this work that are not in the scope of the present dissertation. The first corresponds to prosecute exactly the same analysis, however excluding Greece from the set of countries in study in order to avoid the Euro Area aggregate series to be influenced by the extreme developments this country has been experiencing.

Another potential extension is to break the time span in several periods. As an example, instead of studying synchronization from 1999 until 2014, one could perform the same exercise from 1999 until 2008 and then from 2009 up to 2014 and analyze the differences between the two sub-samples and also the results presented in this study.

A third potential extension is to estimate NAIRU series by using specific variables depending on the country we are dealing with. In this work, one of the main purposes from the very beginning was to apply the same methodology to every member state in study, in order to avoid biased results stemming from methodological issues. Nevertheless, it would be interesting to understand the differences in results related to the use of variables accounting for the specificities of each country.

Finally, instead of using NAIRU as an indicator to assess the cyclical position of each economy, one could study the synchronization between the unemployment gap from each member state, as an indicator of inflationary pressures. This would be a useful exercise for monetary policy concerns, for instance.

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7 Technical Appendix

Consider the following non-linear state-space model.

$$x_{t+1} = F_t(x_t) + G_t(u_t) + \xi_t \tag{14}$$

$$y_t = H_t(x_t) + \eta_t \tag{15}$$

In order to apply EKF, the matrices of the outlined system need to be written as a function of some unknown parameter θ_t that follows a random walk process. Accounting for this parameter in the state space form, equations (14) and (15) become:

$$\begin{bmatrix} x_{t+1} \\ \theta_{t+1} \end{bmatrix} = \begin{bmatrix} F_t(\theta_t)x_t \\ \theta_t \end{bmatrix} + \begin{bmatrix} G_t(\theta_t) \\ 0 \end{bmatrix} \begin{bmatrix} u_t \end{bmatrix} + \begin{bmatrix} \xi_t \\ \varsigma_t \end{bmatrix} \tag{16}$$

$$y_t = \begin{bmatrix} H_t(\theta_t) & 0 \end{bmatrix} \begin{bmatrix} x_t \\ \theta_t \end{bmatrix} + \eta_t \tag{17}$$

Again, ξ_t, ς_t and η_t represent normally distributed shocks, assumed to be uncorrelated with each other.

As described in section 3, we need to specify some initial values corresponding to the estimate of x_0 and θ_0, and also to their covariances. This is justified by the fact that KF are usually applied upon variables following Gaussian distributions. In the functional form we need to specify:

$$\begin{bmatrix} \hat{x}_0 \\ \hat{\theta}_0 \end{bmatrix} = \begin{bmatrix} E(x_0) \\ E(\theta_0) \end{bmatrix} \tag{18}$$

$$P_0 = \begin{bmatrix} cov(x_0) & 0 \\ 0 & cov(\theta_0) \end{bmatrix} \tag{19}$$

Applying the EKF to the system of equations (16) and (17), subject to the initial values coming from (18) and (19), we arrive at the following equations:

$$\begin{bmatrix} x_{t|t-1} \\ \hat{\theta}_{t|t-1} \end{bmatrix} = \begin{bmatrix} F_{t|t-1}(\hat{\theta}_{t-1})x_{t-1} \\ \hat{\theta}_{t-1} \end{bmatrix} \tag{20}$$

$$P_{t|t-1} = FP_{t-1}F' + E_x \tag{21}$$

$$K_t = P_{t|t-1}H'[HP_{t|t-1}H' + E_z]^{-1} \tag{22}$$

$$P_t = [I - K_tH]P_{t|t-1} \tag{23}$$

$$x_t = x_{t|t-1} + K_t(y_t - y_{t|t-1}) \tag{24}$$

Where

$$F = \begin{bmatrix} F_{t-1}(\theta_{t-1}) & \frac{\partial}{\partial\theta}(F_{t-1}(\theta_{t-1}))x_{t-1} \\ 0 & I \end{bmatrix},$$

$$E_x = \begin{bmatrix} G_{t-1}(\hat{\theta}_{t-1})\hat{\theta}_{t-1}G'_{t-1}(\hat{\theta}_{t-1}) & 0 \\ 0 & S_{t-1} \end{bmatrix},$$

$$H = \begin{bmatrix} H_t(\hat{\theta}_{t-1}) & 0 \end{bmatrix},$$

and $y_{t|t-1} = Hx_{t|t-1}$.

Equation (20) represents the updated state estimate, while equation (21) provides the updated estimate covariance, where $P_{t|t-1}$ is the predicted covariance, P_{t-1} the prior covariance and E_x is the expected covariance in the state. Equation (22) gives the optimal Kalman gain represented by

K_t, and E_z corresponds to the expected covariance in the measurement. Kalman gain works as a weighting factor regarding the information it measures, because as less informative the measurement becomes, the larger will be the values of E_z and consequently the lower the values assumed by K_t.

Equation (23) represents the predicted estimate covariance, where P_t is the final covariance and I is the identity. The covariance does not change if there is no information in the measurement ($K_t H = 0$). The more informative the measurement is — larger values for $K_t H$—, the smaller $I - K_t H$ will be and the final covariance will be just a fraction of the predicted covariance. Therefore, the more informative the measurement is, the tighter the covariance will be. This is the expected result because in that situation we have a better estimation of the final state.

Finally, equation (24) provides the final state prediction, with $x_{t|t-1}$ representing the state prediction and $K_t(y_t - y_{t|t-1})$ the correction term. The larger $(y_t - y_{t|t-1})$ becomes, the more we should care about this term since there is more information to correct. Nevertheless, if the measurement is not that informative, there is little we can do to correct that difference and for that reason K_t will be small.

8 Appendix Tables and Figures

Table 6: P-value of Doorkin-Hansen Normality Test relating the NAIRU series of each member — null hypothesis states that the variable follows a normal distribution

Source: Calculations by the author

Member States	**P-value**
Austria	0.6296
Belgium	0.0101
Cyprus	0.0000
Estonia	0.0303
Euro Area	0.0198
Finland	0.0000
France	0.6824
Germany	0.0000
Greece	0.0000
Ireland	0.0000
Italy	0.0387
Latvia	0.0000
Luxembourg	0.0498
Malta	0.5320
Netherlands	0.1486
Portugal	0.0025
Slovak Republic	0.2430
Slovenia	0.0193
Spain	0.0000

Table 7: Euro adoption date from each member

Source: European Central Bank Website

Member States	**Adoption Date**
Austria	1st January 1999
Belgium	1st January 1999
Cyprus	1st January 2008
Estonia	1st January 2011
Finland	1st January 1999
France	1st January 1999
Germany	1st January 1999
Greece	1st January 2001
Ireland	1st January 1999
Italy	1st January 1999
Latvia	1st January 2014
Luxembourg	1st January 1999
Malta	1st January 2008
Netherlands	1st January 1999
Portugal	1st January 1999
Slovak Republic	1st January 2009
Slovenia	1st January 2007
Spain	1st January 1999

Table 8: Detailed description of each variable and respective source

Variable	Description (Unit)	Source
Inflation	Harmonized CPI (Index, 2010=100)	IMF's elibrary Data – International Financial Statistics database
Unemployment	Unemployment Rate (%)	
Output	Real GDP (Index, 2010=100)	
Oil Price	Brent Crude Oil 1-month forward (Euros)	ECB's Statistical Data Warehouse

Figure 8: Brent Crude Oil Price

Source: ECB's Statistical Data Warehouse

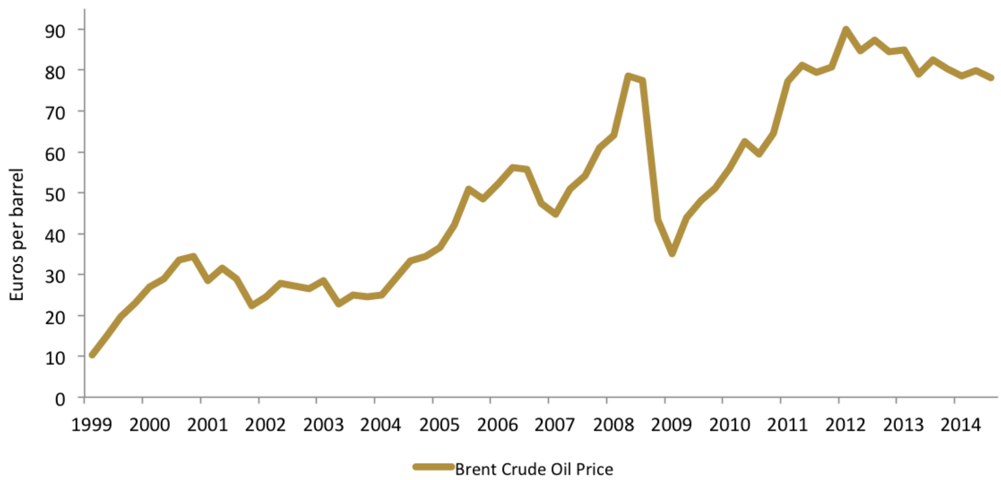

Table 9: P-value of Doorkin-Hansen Normality Test relating the GDP series of each member from 2009 onwards — the null hypothesis of the test states that the variable follows a normal distribution

Source: Calculations by the author

Member States	**P-value**
Austria	0.0030
Belgium	0.3354
Cyprus	0.0014
Estonia	0.0009
Euro Area	0.0032
Finland	0.7467
France	0.0008
Germany	0.0013
Greece	0.0156
Ireland	0.0334
Italy	0.2741
Latvia	0.1415
Luxembourg	0.6461
Malta	0.5500
Netherlands	0.2229
Portugal	0.0530
Slovak Republic	0.2204
Slovenia	0.2760
Spain	0.1606

9 List of Abbreviations and Acronyms

ECB	European Central Bank
EKF	Extended Kalman Filter
EMU	Economic and Monetary Union
EU	European Union
G7	Group of seven major advanced economies
GDP	Gross Domestic Product
HP	Hodrick-Prescott
IMF	International Monetary Fund
KF	Kalman Filter
NAIRU	Non-Accelerating Inflation Rate of Unemployment
NRH	Natural Rate Hypothesis
OECD	Organisation for Economic Co-operation and Development
SDW	Statistical Data Warehouse
SSM	Single Supervisory Mechanism