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How have inflation dynamics changed over time? Evidence from the euro area and USA[4]

Abstract

This paper analyzes euro area and U.S. inflation dynamics since the beginning of the 1990s by estimating New Keynesian hybrid Phillips curves with time-varying parameters. We measure inflation expectations by subjective forecasts from Consensus Economics survey and so do not assume rational expectations. Both rolling regressions and state-space models are employed. The results indicate that in both economic areas the inflation dynamics have steadily become more forward-looking over time. We also provide evidence that the impact of the output gap on inflation has increased in recent years. Overall, diminished inflation persistence emphasizes the role of credible monetary policy in inflation dynamics.

JEL Classification: E31, C22, C51

Key words: inflation, Phillips curve, time-varying parameters, survey expectations

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Tiivistelmä

Tässä tutkimuksessa analysoidaan euroalueen ja Yhdysvaltojen inflaatiodynamiikkaa 1990-luvun alusta lähtien estimoimalla uuskeynesiläisiä Phillips-käyriä, joiden parametrit muuttuvat ajan mittaan. Tutkimuksessa inflaatio-odotuksia mitataan Consensus Economics -kyselytutkimuksen subjektiivisilla ennusteilla, joten odotuksia ei oleteta rationaalisiksi. Sekä rullaaviin estimointeihin että tila-avaruusmalleihin perustuva tarkastelu osoittaa, että molemmilla talousalueilla inflaatiodynamiikka on ajan myötä tullut pysyvästi enemmän eteenpäin katsovaksi. Lisäksi tulokset osoittavat, että tuotantokuilun vaikutus inflaatioon on kasvanut viime vuosina. Kaiken kaikkiaan inflaation jäykkäliikkeisyyden väheneminen korostaa uskottavan rahapolitiikan merkitystä inflaatiodynamiikassa.

1 Introduction

Inflation dynamics is a crucial issue in macroeconomics and monetary policy. Nowadays inflation is typically analyzed using the New Keynesian Phillips curve, which is explicitly based on micro foundations, monopolistically competitive firms and sticky prices. The original purely forward-looking New Keynesian Phillips curve relates current inflation to the expected future inflation rate and some measure of cyclical cost pressure. The hybrid specification of the New Keynesian Phillips curve includes the lagged inflation term as an additional explanatory variable.

Since the onset of the financial crisis, inflation has been surprisingly stable in many advanced economies despite remarkable drop-offs in output and highly accommodative monetary policy. The observed price developments have been explained by changes in price setting behavior and in the responsiveness of inflation to cyclical stance. Moreover, credible monetary policies may have contributed to stable inflation. In order to interpret the observed price developments and assess inflation risks in the future, we need a deep understanding of the determinants of inflation.

This paper investigates changes in inflation dynamics over time in the euro area and United States since the beginning of the 1990s. We estimate New Keynesian hybrid Phillips curves (hereafter HPC) with time-varying parameters. Instead of imposing rational expectations, we use subjective short term inflation expectations from survey data. We measure cyclical demand pressure by output gaps. Output gap estimates are obtained, as in most of the relevant empirical literature, via the Hodrick-Prescott filter. As a robustness check we also estimate HPCs using OECD's output gap estimates, which are constructed using the production function method. A robustness check is also performed to identify a possible nonlinearity of the Phillips curve relationship. Our aim is to study whether Phillips curve parameters have changed since 1990, especially during the recent crisis. We estimate time-varying parameters of the HPC using two alternative methods: rolling regressions and state-space models estimated via the Kalman filter procedure. In rolling regressions parameters are fixed over an ad-hoc chosen estimation window, whereas state-space models use the available information more efficiently.

Instead of assuming that inflation expectations are rational, we measure them directly using Consensus Economics survey data. When rational expectations are not explicitly imposed, expectations may adjust gradually and so we need not make specific assumptions about expectations formation for the Phillips curve relationship. Since survey expectations are real time information, they reveal the thinking at the time of pricing decisions. New Keynesian Phillips curves entailing survey expectations have been estimated before for example by Roberts (1997), Paloviita (2006), and Adam and Padula (2011)[5]. So far only IMF (2013) has used survey expectations in the Phillips curve context in state space models with the Kalman filter procedure.

The results indicate that the hybrid Phillips curve with directly measured expectations is able to capture well the inflation dynamics in both the euro area and United States. We observe that the role of expectations in inflation dynamics has steadily increased over time in both economic areas. We also provide evidence that the output gap coefficients have increased in recent years. These patterns might be explained by more forward looking price setting and decreasing price stickiness. Monetary policy credibility also seems to have contributed increasingly to stable price developments via firmly anchored inflation expectations.

Our results complement the recent study by IMF (2013), which examines inflation dynamics in 21 advanced economies since the 1960s. IMF (2013) estimates Phillips curves using long term survey expectations and cyclical unemployment as a proxy for economic slack. IMF (2013) also finds that inflation has become more forward-looking over time, but contrary to our study, IMF (2013) finds evidence of declined responsiveness of inflation to cyclical demand pressure. Koop and Onorante (2012) argue that the crisis strengthened the role of expectations in euro area inflation dynamics, but we find evidence of increased forward lookingness considerably earlier in both the euro area and United States. Montoya and Döring (2011) studied core inflation in the euro area in 1990 – 2010 and reported that the Phillips curve output gap coefficient has decreased remarkably since 1999. We find a somewhat similar flattening of the euro area Phillips curve in the pre-crisis years, but our results indicate that the slope has increased substantially since 2007.

[5] See Pesaran and Weale (2006) and Sinclair (2010) for basic references for survey based studies.

This paper proceeds as follows. Section 2 presents the New Keynesian hybrid Phillips curve and describes the data. Section 3 presents on the empirical results and puts them in the context of other empirical studies. It also includes some sensitivity analysis. Section 4 concludes.

2 The New Keynesian hybrid Phillips curve

The New Keynesian Phillips curve is a widely used structural model of inflation dynamics (see for example Clarida et al. 1999 and Galí et al. 2001). The Phillips curve parameters depend on the underlying economic structures, i.e. price rigidities and flexibility in the product and labor markets[6].

The hybrid new Keynesian Phillips curve is based on the assumption that some economic agents are forward-looking in setting prices, while the rest of the agents set prices according to backward-looking rules of thumb (Galí and Gertler, 1999) or indexation (Christiano et al. 2005)[7,8].The hybrid Phillips curve can be expressed in a reduced form as

$$\pi_t = \alpha^{FL} E_t^* \{\pi_{t+1}\} + \alpha^{BL} \pi_{t-1} + \lambda gap_t + \varepsilon_t . \quad (1a)$$

This is an unrestricted form, where the forward-looking, α^{FL}, and backward-looking parameters, α^{BL}, are estimated freely. The corresponding restricted HPC with relative weights of forward-looking, α, and backward-looking price setters, $1-\alpha$, is

$$\pi_t = \alpha E_t^* \{\pi_{t+1}\} + (1-\alpha)\pi_{t-1} + \lambda gap_t + \varepsilon_t . \quad (1b)$$

In equations (1a) and (1b) the term π_t denotes the period t inflation rate, and the variable gap_t is the period t output gap, i.e. the balance between aggregate demand and potential output[9,10].

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[6] Nominal price setting is assumed to be staggered in the New Keynesian approach. In this framework, each monopolistically competitive firm maximizes profits subject to stochastic constraints on the frequency of price adjustments (Calvo, 1983) or subject to menu costs of changing prices (Rotemberg, 1982).

[7] See Ólafsson (2006) for an extensive survey of the New Keynesian Phillips curve literature.

[8] Woodford (2007) has questioned the ad hoc interpretation of backward looking behaviour in the hybrid Phillips curve. He argues that the lagged inflation term could reflect a departure of expectations from rationality.

[9] Theoretically, real marginal cost is the cyclical driver of inflation in the New Keynesian Phillips

Survey expectations in period t are denoted as E_t^* . The term λ is a function of the probability of price adjustment and the subjective discount factor. The last term ε_t is an independently and identically distributed error term.

Our quarterly data set for the period 1990Q1-2012Q2 includes five variables. We measure inflation by the year-on-year percentage change in consumer prices and the output gap series is based on Hodrick-Prescott filtering (HP).[11] For the robustness analysis, we alternatively use the production function-based OECD output gap estimates[12]. Inflation expectations are constructed using monthly Consensus Economics survey data[13]. Following Gerlach (2007) we compute the one year ahead expected inflation as a weighted average of the two forecasts, with weights depending on the month in which the forecast is made[14]. For example, the expected inflation rate in February is the weighted sum of two forecasts: the average expected inflation rate for the current year and for the next year. In this example, we use the weights 10/12 and 2/12. We use three month averages in order to construct quarterly series. In sensitivity analysis, the alternative inflation expectations are obtained from the ECB Survey of Professional Forecasters and the US Survey of Professional Forecasters. In our data set we represent the euro area by the weighted average of the four biggest economies (Germany, France, Italy and Spain), which dominate the euro area, with a combined weight of over 80 per cent.[15]

Data reported in Appendix 1 show that inflation rates have varied considerably in the euro area and United States in recent decades. In both economic areas, inflation decreased

curve. In empirical studies, it is commonly proxied by the output gap or labour income share (real unit labour cost). Some recent studies have shown that the output gap is a better measure of cyclical demand pressure than labour income share, at least in the euro area (for example Montoya and Döhring 2011 and Henzel and Wollmershaeuser 2008). Furthermore, Mazumder (2011) and Rudd and Whelan (2007) point out that labour income share seems to be countercyclical, whereas the theory suggests that it should be procyclical.

[10] Theoretically, the HPC has the form (1b) when the discount factor is equal to one in the Calvo model.

[11] Since the HP-filtering method is very sensitive to the end point problem, real GDP series are updated until 2016 using IMF WEO forecasts before constructing the output gap series.

[12] For details of the OECD's production-function-based methodology, see Beffy et al. (2006) and OECD (2009): Chapter 4 in Economic Outlook No. 85.

[13] Consensus Economics survey, which has been conducted since 1989, publishes forecasts for the US and many other industrialized countries every month. Respondents in this survey are public and private economic institutions in all major economies.

[14] The same method has been used in several studies (see e.g. Kortelainen et al. 2011 and Dovern et al. 2012).

[15] For the OECD output gap we use euro area aggregate data, which are available for the whole sample. The ECB SPF also comprises euro area aggregate data.

gradually in the 1990s, but lower and more stable inflation was observed in the next decade. Inflation rates accelerated notably in 2006-2007, in the context of robust economic growth and rapidly rising energy prices. After mid-2008 energy prices fell dramatically due to the global crisis and subsequent recession. Negative inflation rates were temporarily measured in 2008 and 2009, but prices have returned to pre-crisis levels in the aftermath of the crisis. Since 1990 the average inflation rate has been slightly higher and more volatile in the United States than in the euro area, but the output gap histories have been quite similar.

3 Empirical analyses

3.1 Philips curve estimations with fixed coefficients

First, we estimate unrestricted and restricted HPCs with fixed-coefficients as a benchmark for models with time-varying parameters. Two alternative estimation methods are applied to the data: least squares (LS) and generalized method of moments (GMM). With least squares, we assume the expectations term and contemporaneous output gap are correctly measured and not correlated with each other or with the error term. Since this assumption is not necessarily reasonable, we also estimate the Phillips curve via the GMM method using lagged model variables as instruments[16].

[Insert table 1 about here]

Estimation results for the whole sample, reported in table 1, show that all estimated coefficients have reasonable signs and size and are statistically significant at the 5 per cent level. The relative weight of the forward-looking inflation term always exceeds 0.5. Slightly higher α coefficients are obtained for the U.S. For the unrestricted HPCs, the Wald test does not reject the restriction on the sum of forward-looking and backward-looking inflation terms. The choice of estimation method does not seem to affect the results excessively. In the GMM estimations, the overidentifying restrictions are never rejected. All in all, the

[16] It is useful to compare least squares and GMM results in the present context in order to investigate the impact of estimation method on parameter estimates (both identification problems and weak instruments related to GMM estimations have been discussed by Ma 2002 and Mavroeidis 2005).

estimation results in table 1 suggest that the empirical performance of the unrestricted and restricted HPCs are quite reasonable for the euro area and the United States.

3.2 Philips curve estimations with time-varying parameters

Next, we investigate how HPC parameters have changed over time. Patterns in parameters are studied using both rolling regressions and the state space method with Kalman filtering techniques. The state space method is a more efficient way to estimate time-varying parameters, but as a robustness check we first apply rolling regressions to the data.

3.2.1 Rolling regressions

Using LS and an eight year rolling window, we estimate unrestricted HPCs separately 55 times: the first estimation period is 1990Q1-1998Q4 (pre-EMU years for the euro area), and the last is 2003Q3-2012Q2. Estimation results are reported in Appendix 2. The estimated coefficients and corresponding t-values are dated as at the end of each rolling window.

Rolling regressions show that price developments were quite stable until 2005 – 2006, after which we obtain unequivocally higher coefficients for the forward-looking inflation terms and slightly larger output gap coefficients. The estimated coefficients for the backward looking inflation terms decrease dramatically in the end of the sample. We find very low t-values for the estimated output gap coefficients in mid-2000. All in all, the rolling regressions seem to emphasize that the inflation dynamics have undergone considerable change in recent years. State space models are needed, however, for a more detailed analysis of inflation dynamics and the timing of observed changes[17].

3.2.2 State space models

In a rolling regression, parameter estimates are fixed over a given estimation window. This causes sub-optimal use of the data, as the choice of the window size is essentially ad hoc. The

[17] We estimated the HPCs also using six year rolling window. The results (not reported here) are qualitatively quite robust with respect to the choice of the rolling window.

main idea in state space models is to allow all HPC parameters to change periodically by assuming that they follow random walk processes[18,19]. In every period these parameters are subject to change simultaneously in response to new information and structural changes in the economy. Using the Kalman filtering procedure, model parameters can be updated optimally for every period. The main advantage of this approach is that it uses available information more efficiently than do rolling regressions. It also provides more precise information on the timing of parameter changes in the HPC, as we need not assume any estimation window. A state-space system of the unrestricted Phillips curve estimation consists of a signal equation and three state equations[20]:

$$\pi_t = \alpha_t^{FL} E_t\{\pi_{t+1}\} + \alpha_t^{BL}\pi_{t-1} + \lambda_t gap_t + \varepsilon_t, \quad (2)$$

$$\alpha_t^{FL} = \alpha_{t-1}^{FL} + \eta_{1t}, \quad (2a)$$

$$\alpha_t^{BL} = \alpha_{t-1}^{BL} + \eta_{2t}, \quad (2b)$$

$$\lambda_t = \lambda_{t-1} + \eta_{3t}. \quad (2c)$$

In this model, all parameters are allowed to have maximum flexibility. They are assumed to follow random walks, and errors (η_{it}, for i=1,2,3) are assumed to be uncorrelated with each other and normally distributed. In order to enable convergence, we set initial values of estimated parameters and define the variances of the signal equation and the state equations. As a robustness check we ran our estimations applying several different assumptions as to error term variances and initial values. The chosen variances affect the volatility of the parameters, but do not substantially affect the observed trends of parameters over time[21]. As starting values for iterations we use pre-crisis coefficients of fixed-coefficient HPCs. We define the pre-crisis period to end in 2008Q2, just before the collapse of the investment bank

[18] See Lütkepohl (2007) for state space models.

[19] Several studies have used the state space approach in analyzing Phillips curves. For example, Kichian (2001) investigates the stability of the Canadian Phillips curve. Ball and Mazumder (2011) examine US inflation dynamics and the great recession.

[20] Only two state equations are included in the restricted HPC.

[21] The chosen variances in the unrestricted HPC are $\sigma_\varepsilon^2 = 0.01$; $\sigma_{\eta_1}^2 = 0{,}0001$; $\sigma_{\eta_2}^2 = 0{,}0001$; $\sigma_{\eta_3}^2 = 0{,}00005$.

Lehman Brothers[22]. When the crisis period is excluded from the estimations (not reported here), we get somewhat smaller coefficients for the forward-looking inflation term and slightly smaller output gap coefficients.

[Insert figure 1 about here]

[Insert figure 2 about here]

The estimated time-varying parameters for unrestricted and restricted HPCs and corresponding conditional two-standard-deviation upper and lower confidence bands are reported in figures 1 and 2. The figures reveal that in both economic areas the inflation process became have turned steadily more forward looking over time. The inflation dynamics have been more forward-looking in the U.S. than in the euro area. The forward-looking inflation parameter for the euro area has increased gradually to 0.6 – 0.7 and for the U.S to 0.6 – 0.9. A closer look at figures 3 and 4 reveals that for both areas the sum of forward-looking and backward-looking inflation term coefficients in the unrestricted models is quite stable and close to unity for the whole sample. Thus, both models are able to capture inflation processes quite properly.

The output gap effects on price developments seem to have been quite limited, but we find somewhat larger output gap coefficient for the U.S. For the euro area the Phillips curve slope started to increase after 2006; for the United States we see the same pattern starting in the early 2000s. The U.S. output gap coefficient peaked in 2008 at 0.3 and decreased slightly after that. The euro area output gap coefficient in contrast has remained at the higher level since the start of the crisis. Overall, we find some evidence of increased responsiveness of inflation to cyclical stance in recent years. These observations are also visible in the data. As the figures in Appendix 1 show, before 2008 euro area inflation was relatively stable in spite of a fairly volatile output gap. At the same time, U.S. inflation tracked more closely output gap developments.

Our empirical results relate closely to IMF (2013), which examined inflation dynamics since the 1960s in 21 advanced economies using long term survey expectations in the Phillips

[22] Lehman Brothers collapsed in September 2008.

curve framework[23]. They use the unemployment gap as a cyclical measure instead of the output gap. IMF (2013) finds that inflation has become more forward-looking over time, but contrary to our study, they find evidence of declined responsiveness of inflation to cyclical demand pressures.

Koop and Onorante (2012) use the European Central Bank's Survey of Professional Forecasters and regression-based and VAR-based methods to investigate euro area inflation dynamics in 1999Q4 – 2012Q2. They find that forward looking expectations are important for the euro area Phillips curve, and have become even more important with the crisis. Our results suggest that the role of expectations had started to increase already before the crisis and has occurred also in the U.S. Montoya and Döhring (2011) study core inflation in the euro area in 1990 - 2010. They find a statistically and economically significant, though rather small, impact of output gap on core inflation. Moreover, they additionally note that the impact of the output gap on inflation has decreased over time. We observe a similar diminishing impact in the euro area until 2006, but since then the output gap coefficient has roughly doubled.

3.2.3 Sensitivity analysis

The above estimation results suggest that inflation persistence has decreased over time and that after 2006 inflation rates have become slightly more sensitive to cyclical stance. Qualitatively, the same result is obtained for both unrestricted and restricted specifications of the Phillips curve. Next, we investigate in more detail the general validity of the estimation results of the previous section. We examine how sensitive our analysis is with respect to the choice of expectations variable. We also consider how the results change when oil price change is included in the HPC as a proxy for energy prices. Finally, we study whether the results are robust with respect to the choice of output gap variable.

[23] IMF (2013) data include eleven euro area countries, the United States, Japan, the United Kingdom and 9 other advanced economies. Estimations in that study are based on maximum likelihood in a constrained, non-linear Kalman filter approach.

Alternative proxies for inflation expectations are obtained from the ECB Survey of Professional Forecasters[24] and the Survey of Professional Forecasters provided by the Reserve Bank of Philadelphia[25]. For the euro area we use the mean one year ahead HICP inflation expectations and for the U.S. the mean one year ahead CPI inflation expectations. As figure 3 in Appendix 1 shows, the alternative expectations variables are highly correlated (correlation coefficient 0.898 for the euro area and 0.906 for the U.S.). We re-estimate unrestricted and restricted state space models using alternative expectations variables. For the euro area, we estimate the models since 1999q1 and since 1990q1 (in this case we used Consensus Economics survey data until 1998q4). Compared with our results in the previous section, the estimation results are roughly unchanged.[26] They confirm that both in the euro area and the United States inflation has become more forward looking over time and the impact of the output gap on actual inflation has increased recently.

Next, we include oil price change as an additional explanatory variable in the HPC. Volatile energy prices have typically contributed substantially to variation in inflation rates since direct pass-through effects of energy prices on consumer prices are typically substantial. Indirect effects of energy prices on production costs and second-round effects on wages can also be considerable. Oil price change is measured by the annual percentage change of Brent crude oil spot price in euros or US dollars. Estimation results are reported in Appendix 3. Again, we find similar larger forward looking inflation and output gap coefficients than in our previous specifications. However, the U.S. output gap coefficient drops suddenly in 1999 and increases steadily after that. In addition, after 1999 the oil price change coefficient starts increasing steadily in both cases. The sudden drop of the output gap coefficient in 1999 can be explained by huge oil price increases, which did not finally show up in actual inflation rates. The increasing role of oil price changes in the inflation processes dramatically reflects higher oil price levels and therefore a larger share of oil in consumption expenditures in the 2000s. Overall, the HPCs with oil price change also seem to support our basic estimation results.

[24] Since the beginning of 1999 the European Central Bank has conducted a quarterly Survey of Professional Forecasters. In this survey the ECB asks a panel of approximately 75 forecasters their short- and long-term views of HICP inflation, real GDP growth and unemployment in the euro area. Respondents represent financial sector, non-financial research institutes and employer and employee organizations in the European Union (EU).

[25] The US SPF is a quarterly survey, launched already in 1968Q4, that includes over 30 variables for different forecast horizons.

[26] Results for this specification are available upon request.

Finally, we consider how the results change when excess demand is measured using OECD's output gap estimates, which are based on production function method. It is worth noting that after 2008 our alternative output gap measures indicate very divergent cyclical conditions: for both economic areas OECD output gaps have remained permanently clearly negative, but HP-filtered gaps have become slightly positive toward the end of the sample (see Appendix 1). In 2008Q3-2012Q2 the average HP-filtered gap is -0.5 for the euro area and -1.0 for the U.S. The corresponding figures for average OECD output gaps are -2.8 and -3.7. The substantial difference between the alternative output gap measures indicates that it is very challenging to assess excess demand in the aftermath of the crisis.

[Insert figure 3 about here]

[Insert figure 4 about here]

The unrestricted HPC estimation results based on OECD output gaps confirm the earlier results that inflation processes have become more forward-looking over time and that the crisis led to larger output gap coefficients (see figures 3 and 4). Compared to the euro area, U.S. inflation is again slightly more sensitive to cyclical stance. However, a closer look reveals that these results are somewhat puzzling, since the estimated output gap coefficients are constantly very small (close to zero) in the pre-crisis years and for the U.S. the sum of the forward-looking and backward-looking inflation coefficients clearly exceeds unity after mid-2008. In addition, when the restricted HPCs are estimated, the output gap coefficients are negative toward the end of the sample. These puzzling results may be due to a misspecified restricted model.

In order to analyze the previous results further, we consider possible non-linearities in the Phillips curve relationship. Without making any specific assumption about the exact form of non-linearity, we add a quadratic output gap variable to the OECD output gap –based HPCs:

$$\pi_t = \alpha_t^{FL} E_t^* \{\pi_{t+1}\} + \alpha_t^{BL} \pi_{t-1} + \lambda gap_t + \mu gap_t^2 + \varepsilon_t . \quad (3a)$$

$$\pi_t = \alpha E_t^* \{\pi_{t+1}\} + (1-\alpha)\pi_{t-1} + \lambda gap_t + \mu gap_t^2 + \varepsilon_t . \quad (3b)$$

Non-linear HPCs are reported in figures 5 and 6. In all cases the inflation processes seems to become more forward-looking over time and the estimated coefficients for the linear output gap term are positive - also toward the end of the sample. The quadratic output gap term is not significantly different from zero in the unrestricted models. However, in the case of restricted models the nonlinear term is needed during the crisis period in order to improve the empirical fit of the model. These results indicate that the impact of large output gaps on inflation might be nonlinear.

[Insert figure 5 about here]

[Insert figure 6 about here]

Overall, alternative excess demand measures give a slightly different picture of how the slope of the Phillips curve has evolved in recent years.

4 Conclusions

We studied changes of inflation dynamics in the euro area and the United States since the beginning of the 1990s. We proxied inflation expectations from Consensus Economics survey data and estimated hybrid New Keynesian Phillips curves. Several interesting results emerged.

According to our estimations inflation expectations play an important role in driving inflation processes in both economic areas, whereas the output gap effects on price developments have been quite limited. The inflation dynamics have been more forward-looking in the U.S, but we find that in both economic areas the role of expectations in the inflation process has steadily increased over time. The effect of the output gap on euro area and U.S. inflation has also strengthened in recent years. Our results are robust with respect to the choice of expectations variable and HPC specification (with or without energy prices). However, alternative output gap variables provide a slightly picture of recent changes in the cyclical sensitivity of inflation.

Changing pricing behavior and more frequent price setting are possible reasons for the observed changes in inflation dynamics. The decreasing share of backward looking price setters may be due to increased credibility of monetary or lower costs of changing prices. Higher sensitivity of actual inflation to cyclical stance in the crisis period may reflect increased economic uncertainty. It is plausible that price changes have become more frequent in recent years, since it has been very challenging to assess future economic prospects.

The observed differences between euro area and U.S. inflation processes can be explained by the different monetary policy strategies, namely inflation targeting in the euro area and the dual mandate in the United States. Also, economic convergence in the euro area had a definite impact on euro area inflation rates since the second half of the 1990s, while accommodative monetary policy contributed to price developments in the United States in the 2000s.

A deep understanding of inflation dynamics is essential for the conduct of monetary policy. The appropriate response of monetary policy to shocks depends on inflation persistence. It also depends on the way in which inflation is linked to cyclical demand pressure. If monetary policy is credible and inflation expectations are well anchored, the central bank can ensure that actual inflation stays close to the inflation target in the medium term. Overall, the observed changes in inflation dynamics emphasize that credible communication and careful analysis of cyclical stance are central to monetary policy.

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Appendix 1. Phillips curve variables for the euro area and United States.

Figure 1. Output gaps, actual inflation and expected inflation for the euro area.

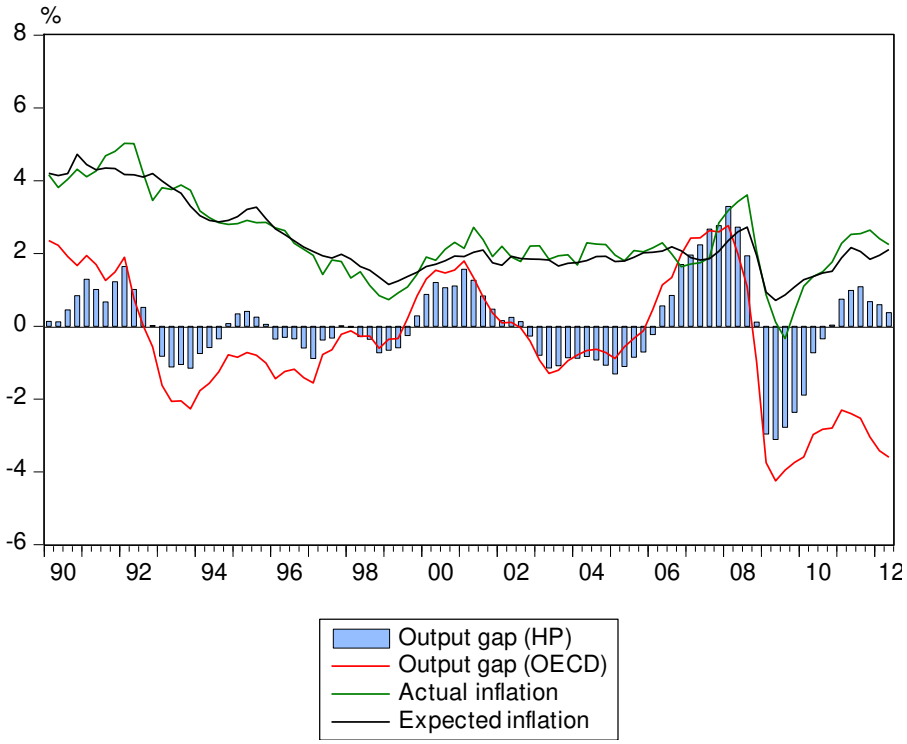


Figure 2. Output gaps, actual inflation and expected inflation for the United States.

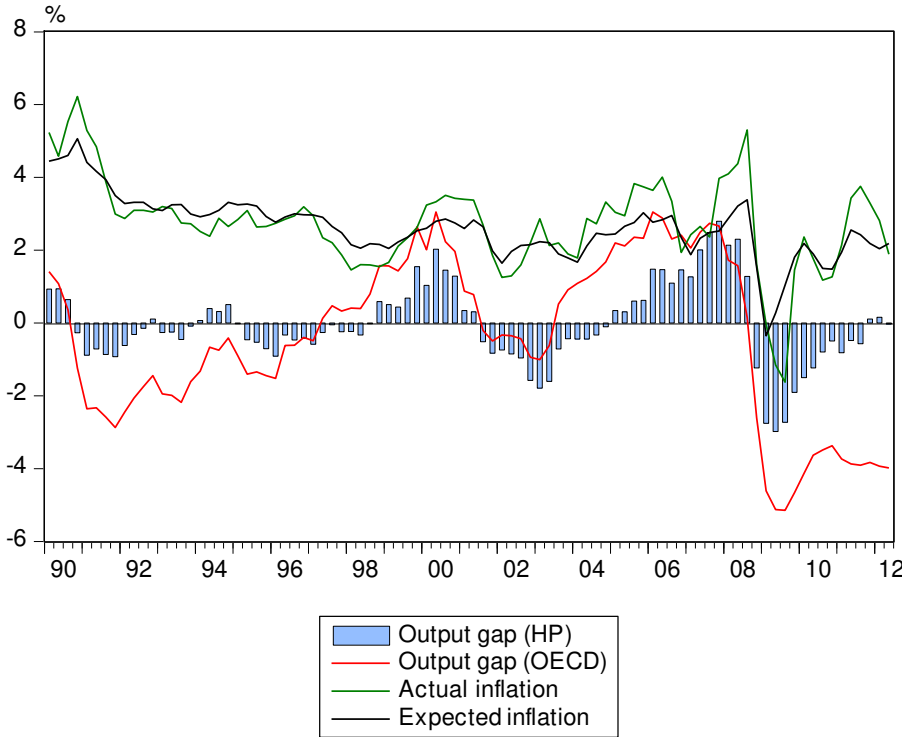
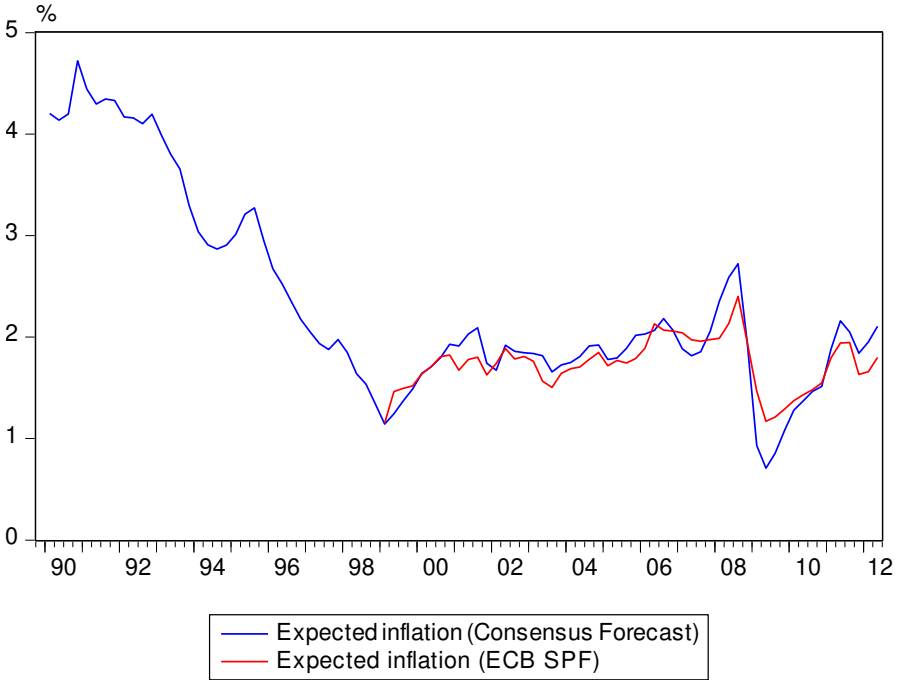


Figure 3. Alternative expectations variables.

Euro area



United States

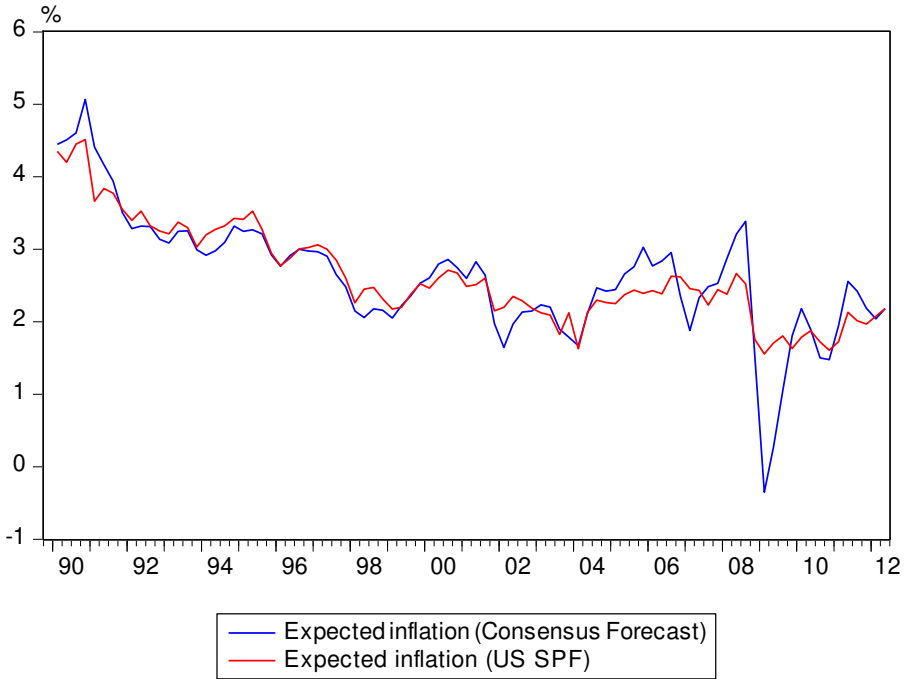
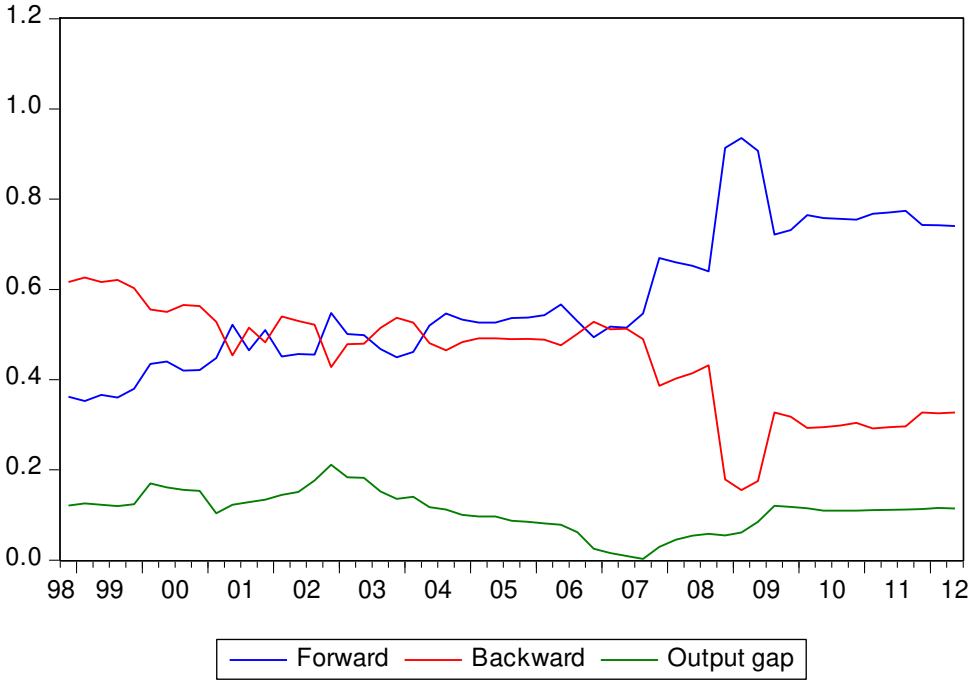


Table A.1. Basic statistics for Phillips curve variables.

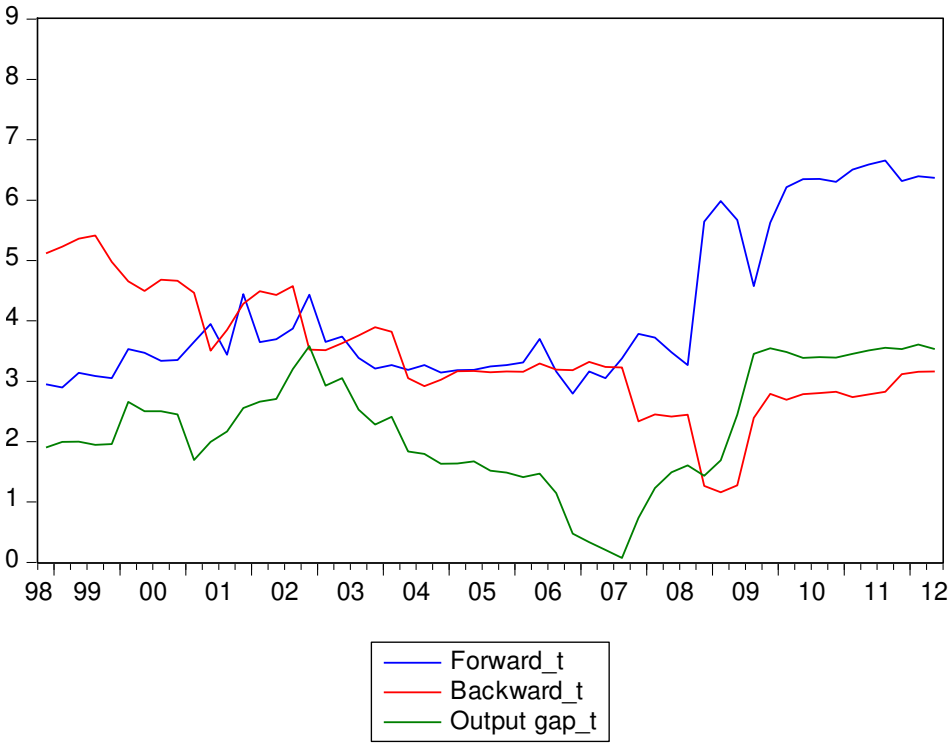
	GAPEA	CPIEA	ECPIEA					
Mean, whole period	0.070	2.394	2.336					
Std. Dev, whole period	1.202	1.087	0.975					
Mean, pre-crisis period	0.188	2.546	2.491					
Std. Dev, pre-crisis period	1.067	1.040	0.979					
	GAPUS	**CPIUS**	**ECPIUS**					
Mean, whole period	-0.046	2.745	2.628					
Std. Dev, whole period	1.109	1.235	0.838					
Mean, pre-crisis period	0.160	2.940	2.817					
Std. Dev, pre-crisis period	0.987	0.998	0.701					
Correlations, whole period								
	GAPEA	**CPIEA**	**ECPIEA**			**GAPUS**	**CPIUS**	**ECPIUS**
GAPEA	1.000	0.439	0.302		**GAPUS**	1.000	0.520	0.373
CPIEA	0.439	1.000	0.934		**CPIUS**	0.520	1.000	0.854
ECPIEA	0.302	0.934	1.000		**ECPIUS**	0.373	0.854	1.000
Correlations, pre-crisis period								
	GAPEA	**CPIEA**	**ECPIEA**			**GAPUS**	**CPIUS**	**ECPIUS**
GAPEA	1.000	0.234	0.142		**GAPUS**	1.000	0.268	0.032
CPIEA	0.234	1.000	0.941		**CPIUS**	0.268	1.000	0.835
ECPIEA	0.142	0.941	1.000		**ECPIUS**	0.032	0.835	1.000

Appendix 2. Rolling regressions

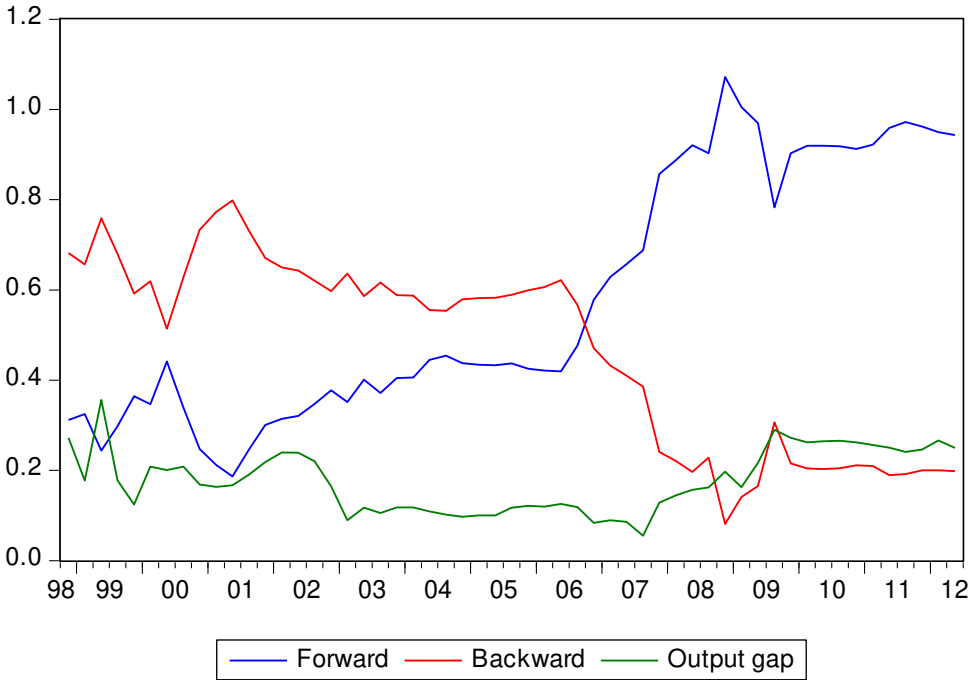
Euro area coefficients



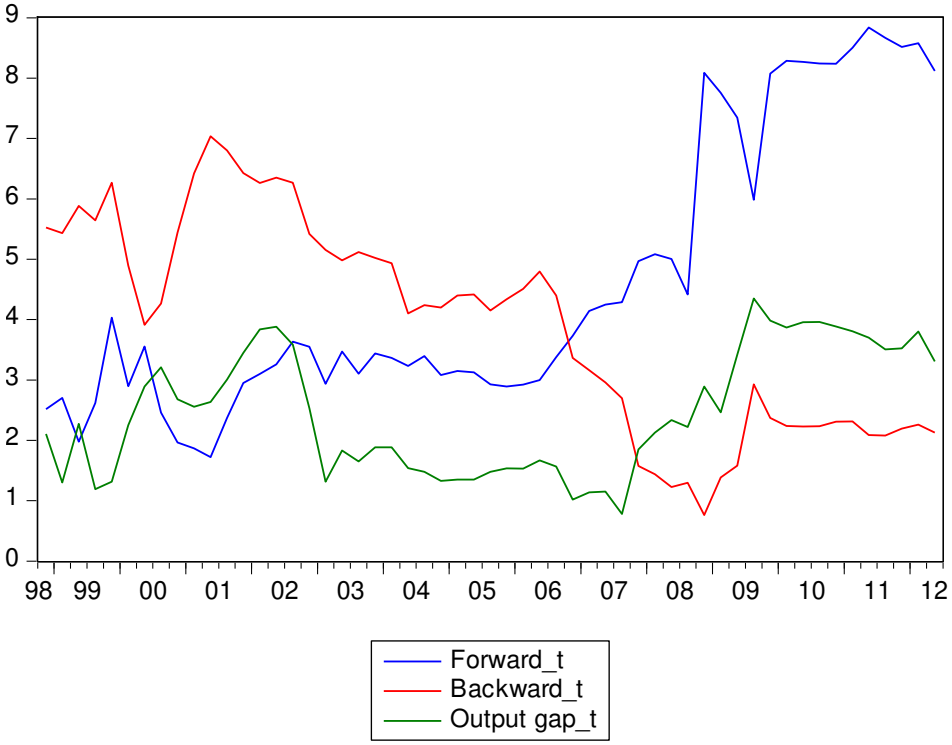
Euro area t-values



United States coefficients



United States t-values



Appendix 3. Phillips curve parameters with energy prices

Euro area

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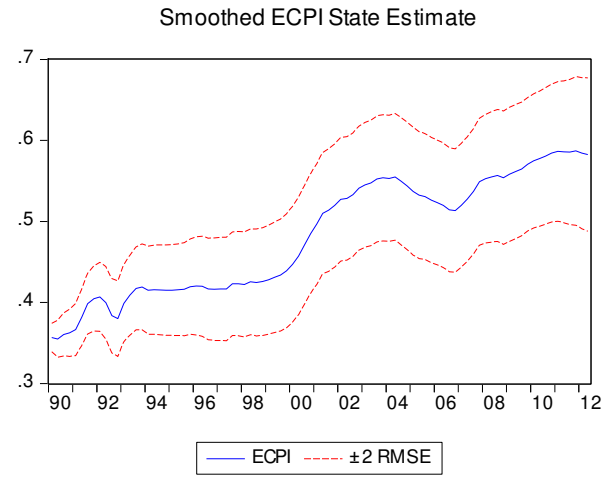

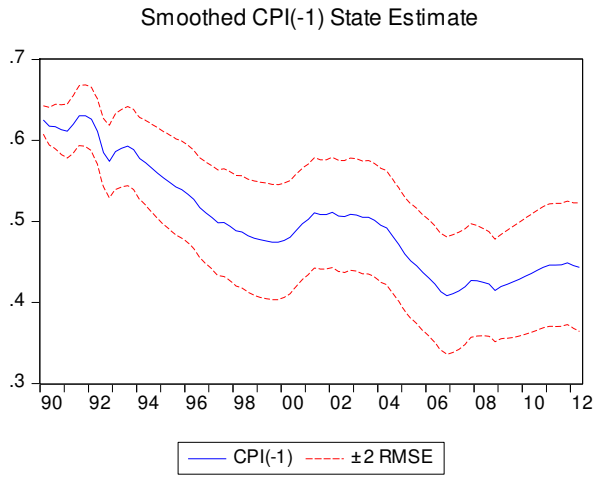

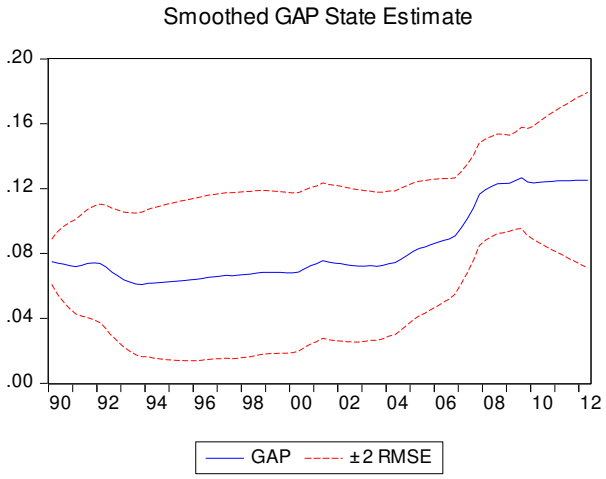

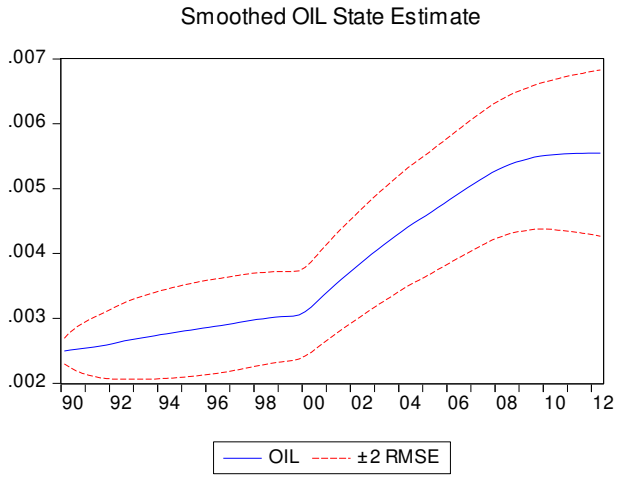

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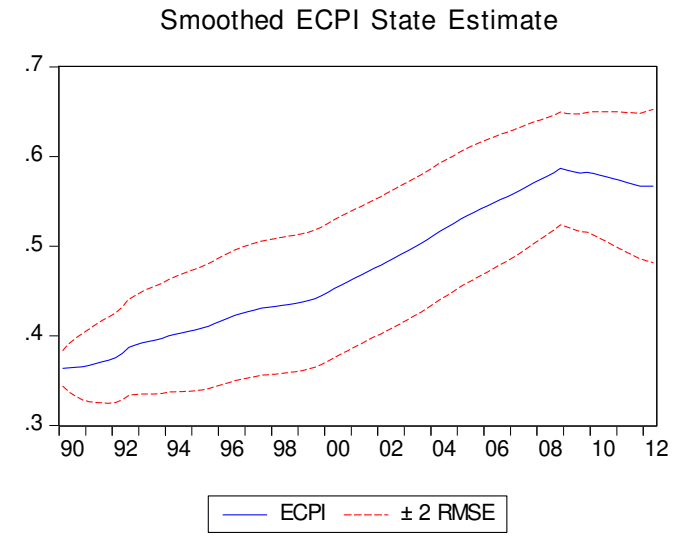
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.3
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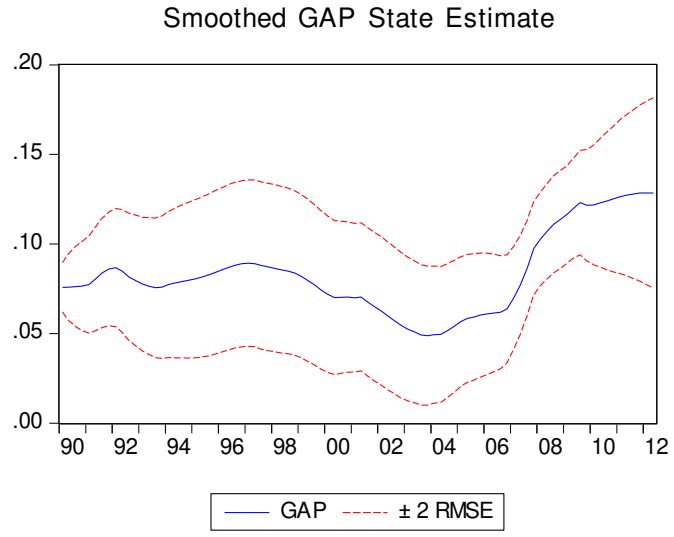
ECPI
± 2 RMSE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GAP
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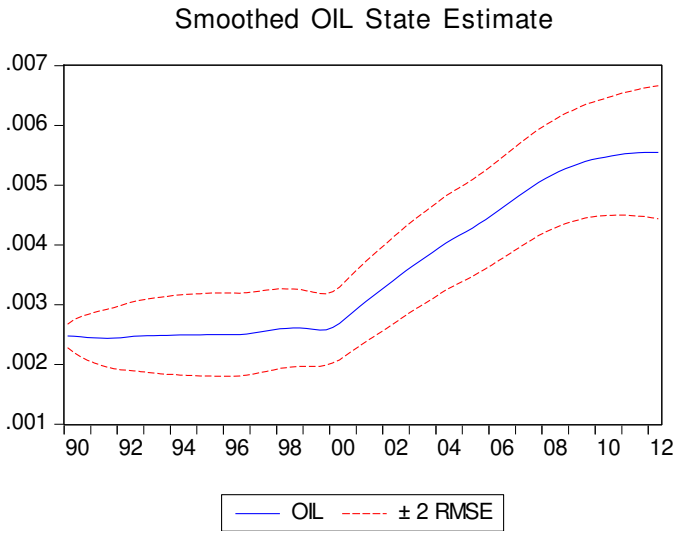
Smoothed OIL State Estimate
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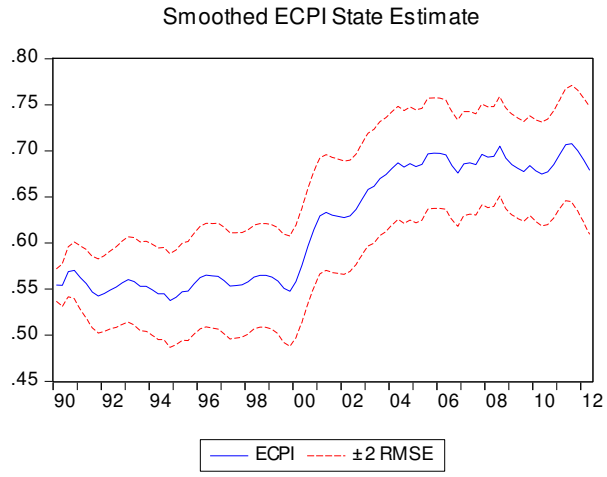
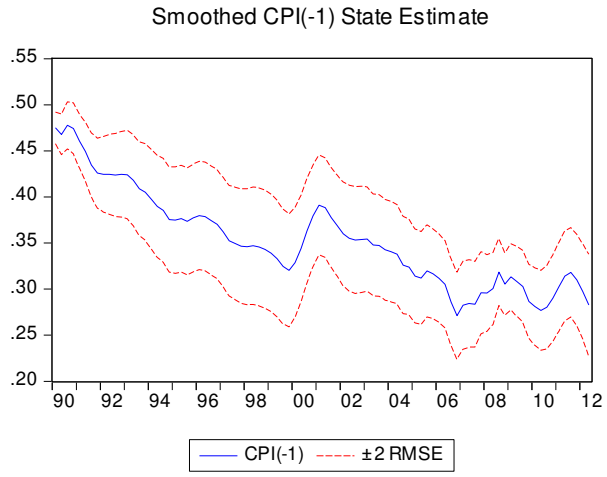
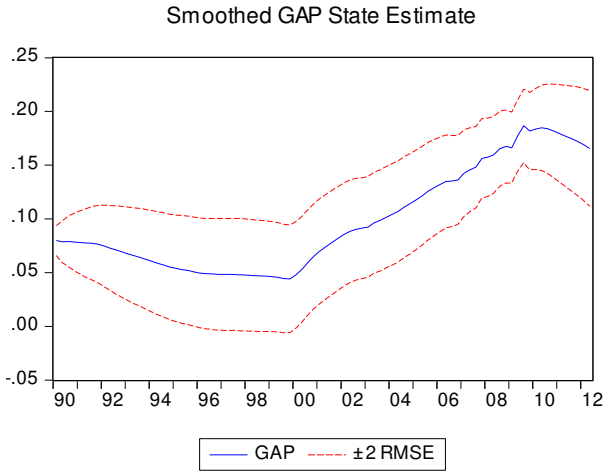
90 92 94 96 98 00 02 04 06 08 10 12
OIL
± 2 RMSE

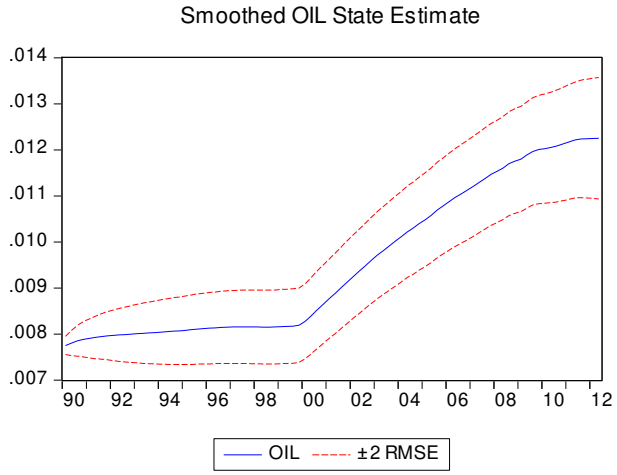
United States

Unrestricted:









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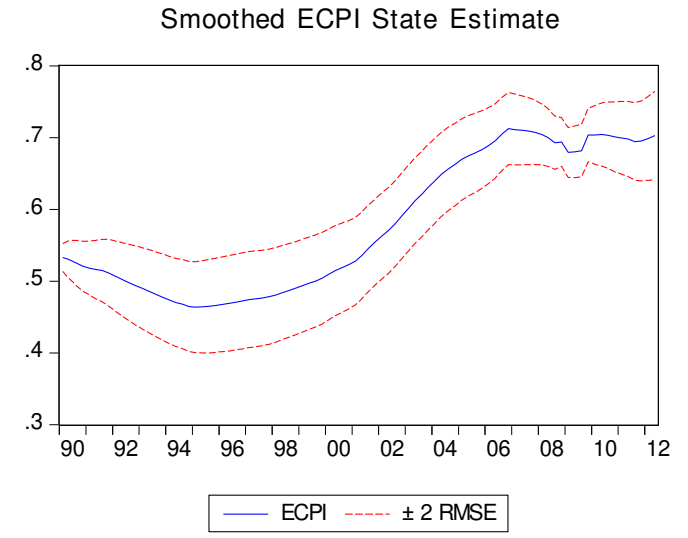
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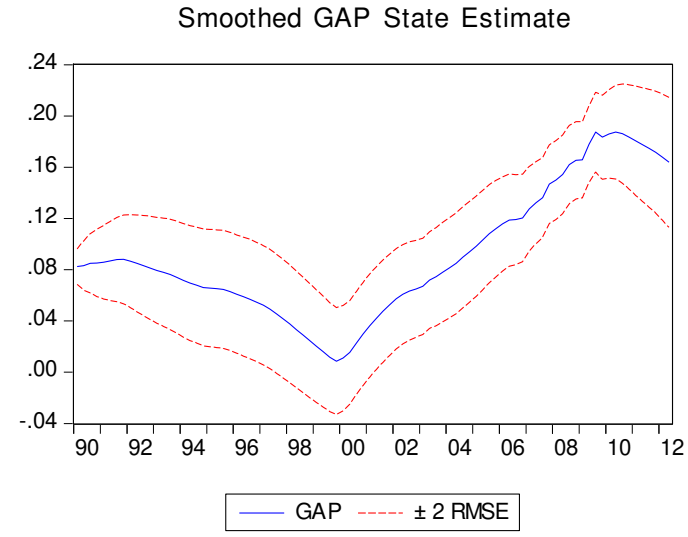
.8
.7
.6
.5
.4
.3
90 92 94 96 98 00 02 04 06 08 10 12
ECPI
± 2 RMSE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.16
.12
.08
.04
.00
-.04
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GAP
± 2 RMSE

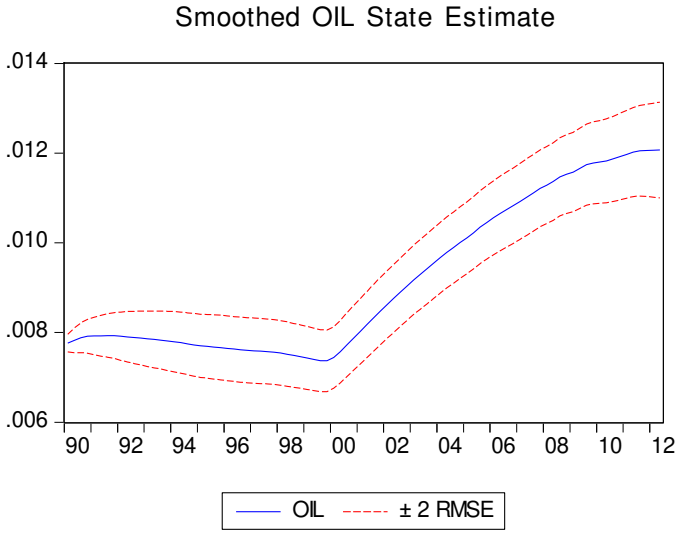
Smoothed OIL State Estimate
.014
.012
.010
.008
.006
90 92 94 96 98 00 02 04 06 08 10 12
OIL
± 2 RMSE

Table 1. Phillips curve estimates for the euro area and United States.

	Euro area				U.S.			
	LS		GMM		LS		GMM	
	Unr.HPC	Restr.HPC	Unr.HPC	Restr.HPC	Unr.HPC	Restr.HPC	Unr.HPC	Restr.HPC
α^{FL}	0.551** (0.090)		0.612** (0.095)		0.691** (0.085)		0.627** (0.109)	
α^{BL}	0.450** (0.087)		0.391** (0.089)		0.345** (0.072)		0.396** (0.100)	
α		0.549** (0.085)		0.599** (0.087)		0.634** (0.075)		0.555** (0.103)
λ	0.125** (0.039)	0.125** (0.039)	0.139** (0.039)	0.142** (0.038)	0.235** (0.065)	0.239** (0.067)	0.254** (0.054)	0.256** (0.054)
R^2 D-W J-stat.	0.931 1.400	0.931 1.401	0.928 1.335 4.107 [0.128]	0.928 1.345 3.954 [0.266]	0.828 1.525	0.822 1.512	0.816 1.519 3.313 [0.191]	0.808 1.540 3.705 [0.295]
Wald test	F=0.005 (0.945)		F=0.034 (0.853)		F=1.930 (0.168)		F=0.920 (0.340)	

Note: Numbers in parentheses are Newey-West HAC standard errors, ** indicates significance at 5 per cent level and * significance at 10 per cent level. For GMM estimations the J-statistic refers to the Hansen test of overidentifying restrictions. Corresponding probabilities for J-statistics are in square brackets. Instruments in GMM estimations: 1st and 2nd lags of the output gap and 2nd and 3rd lags of inflation.

Figure 1. Phillips curve parameters for the euro area (HP-filtered output gap).

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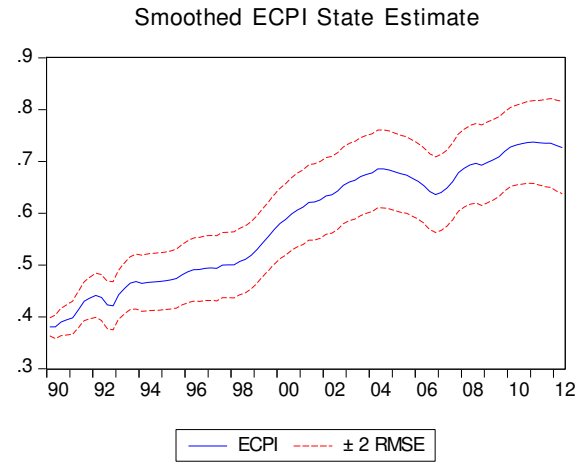

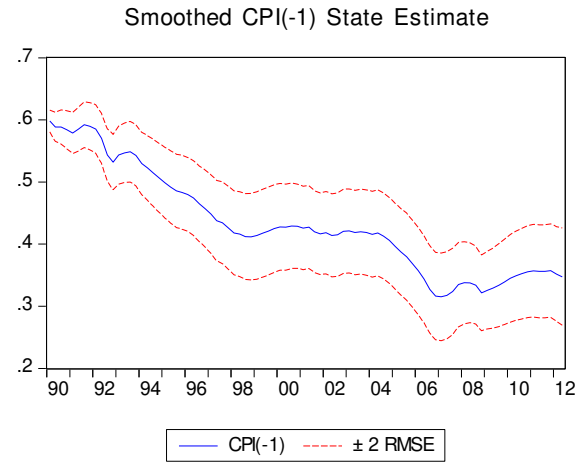

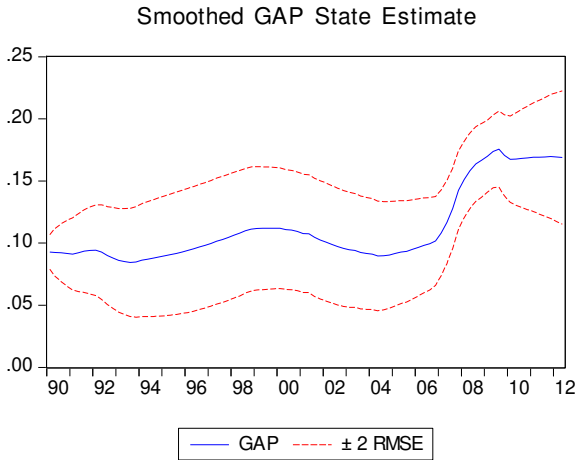

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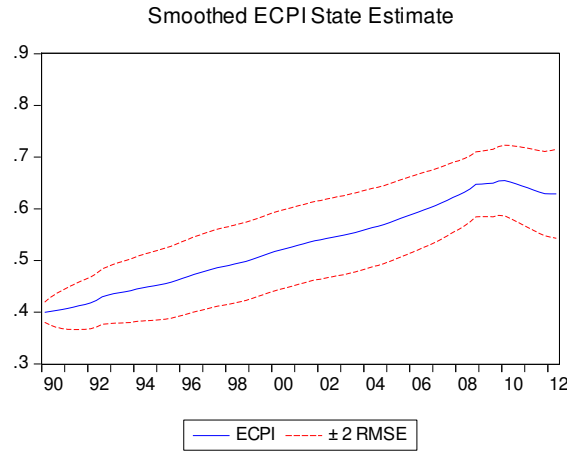

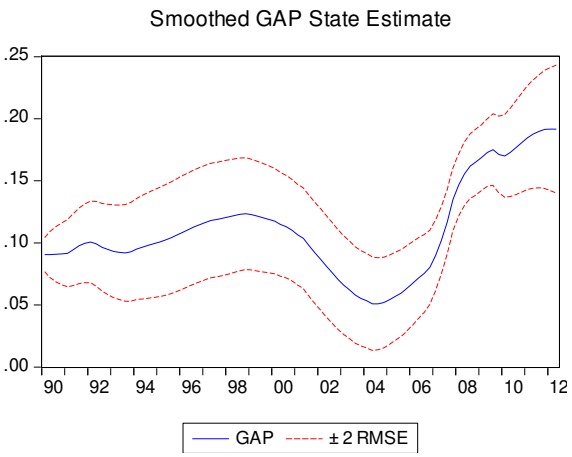

Figure 2. Phillips curve parameters for the United States (HP-filtered output gap).

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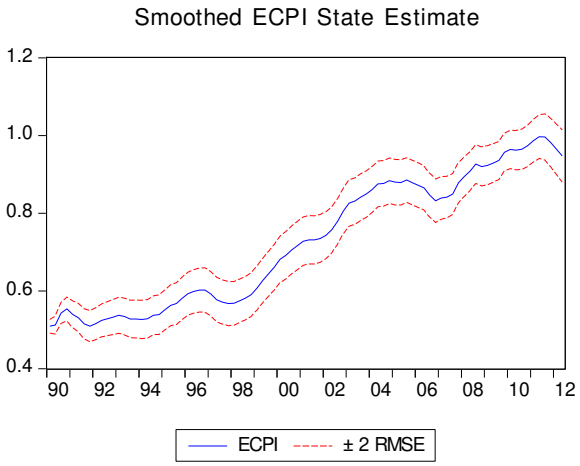

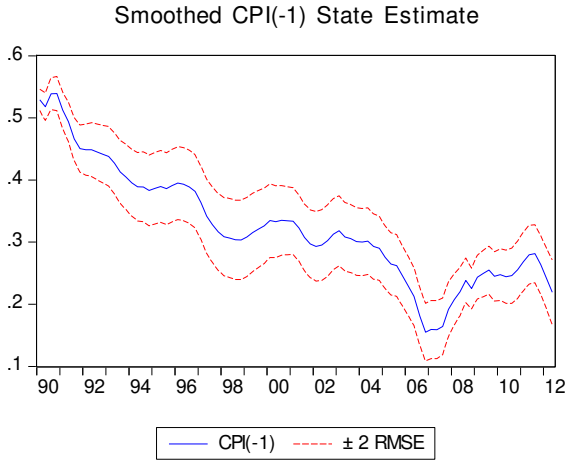

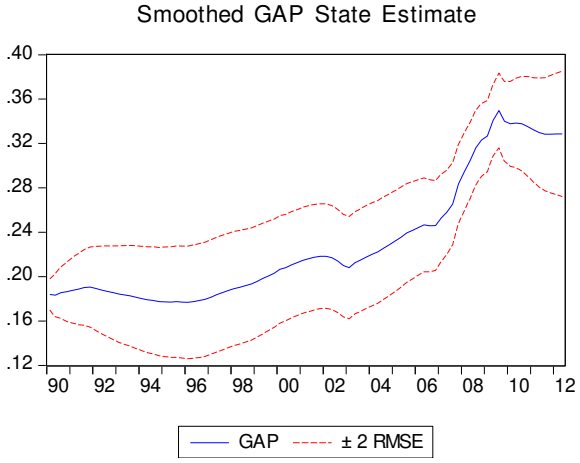

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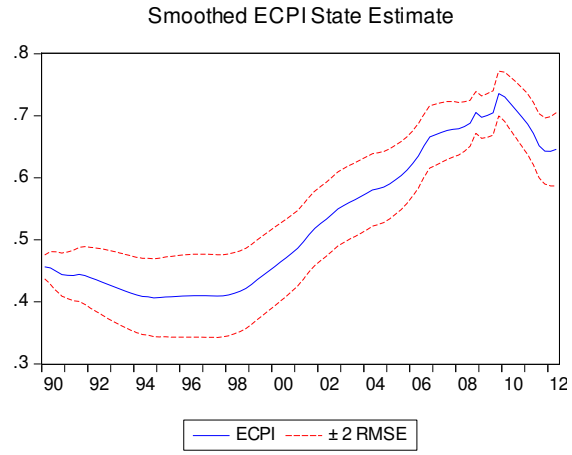

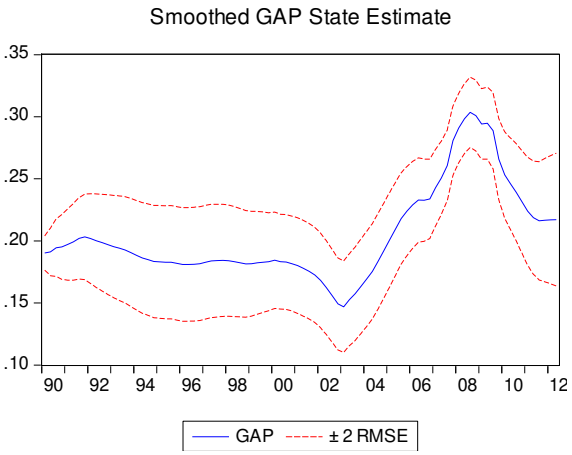

Figure 3. Phillips curve parameters for the euro area (OECD output gap).

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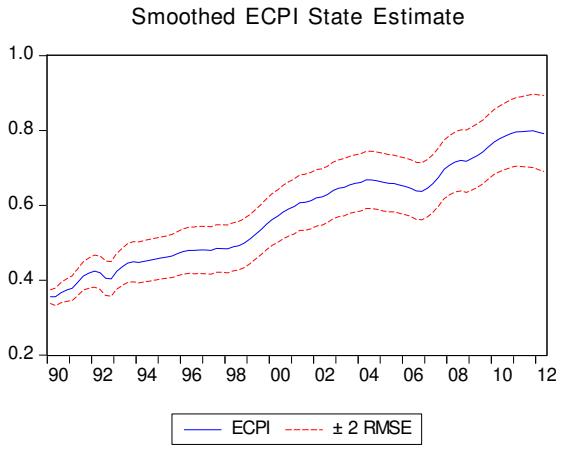

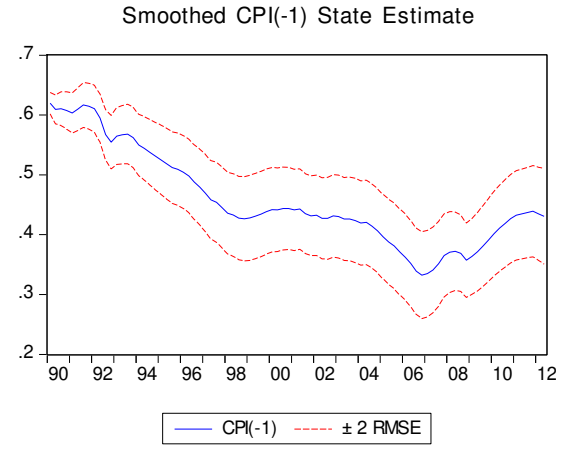

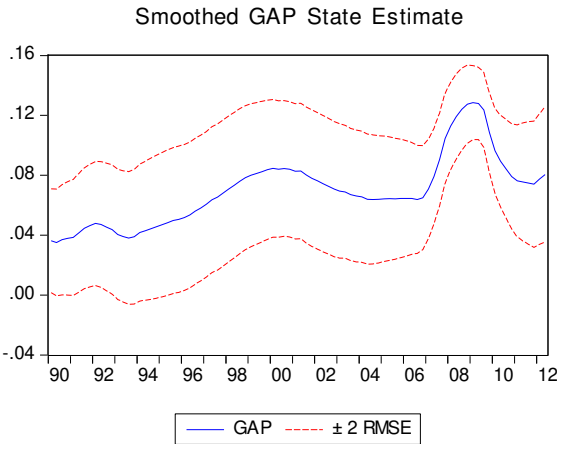

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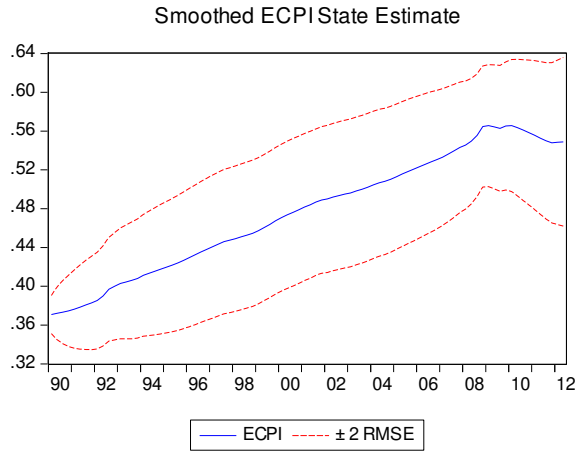

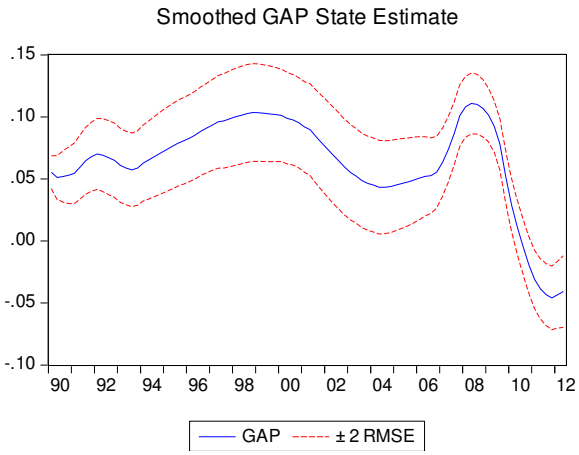

Figure 4. Phillips curve parameters for the United States (OECD output gap).

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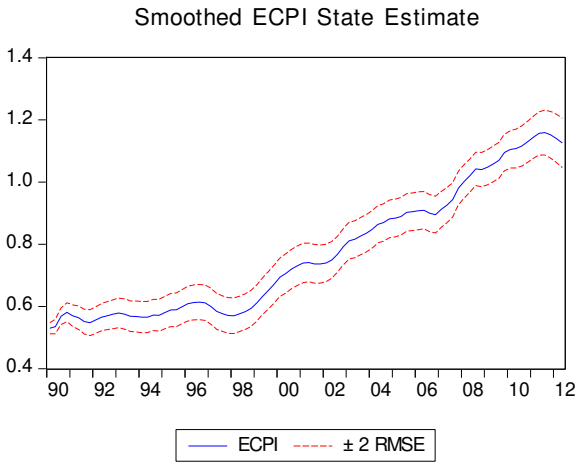

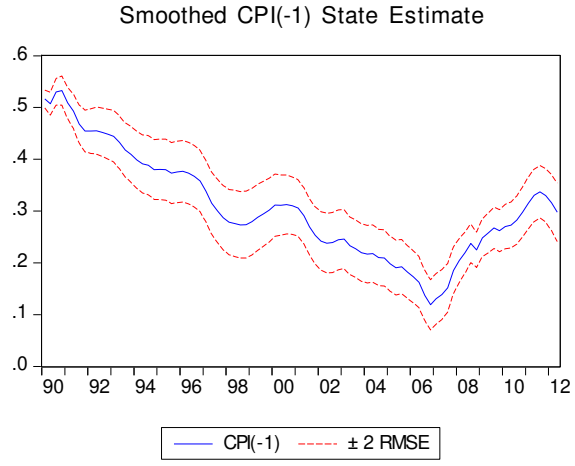

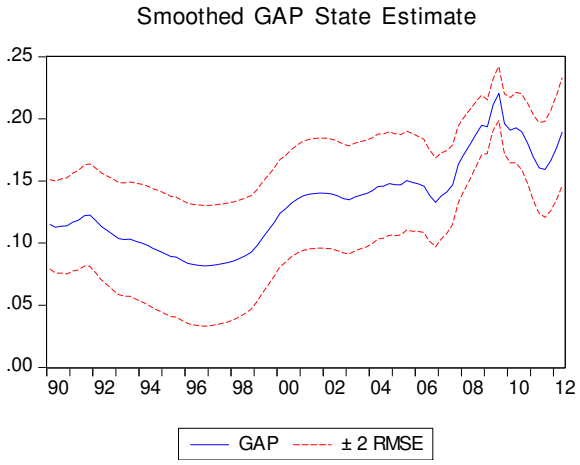

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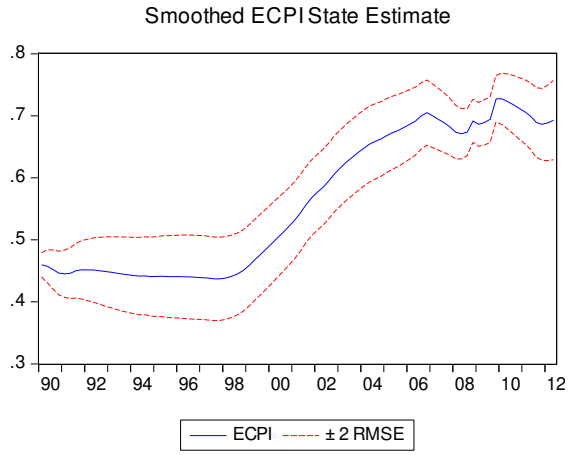

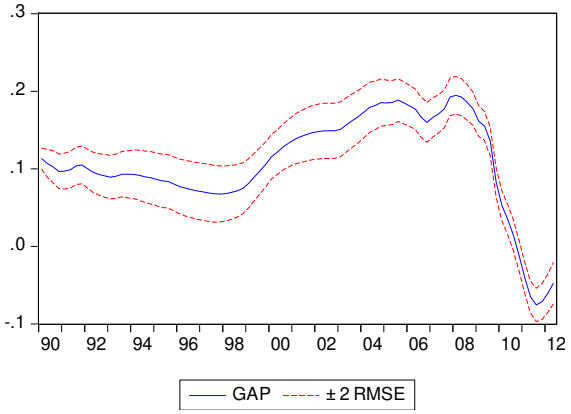

Figure 5. Non-linear Phillips curve parameters for the euro area (OECD output gap).

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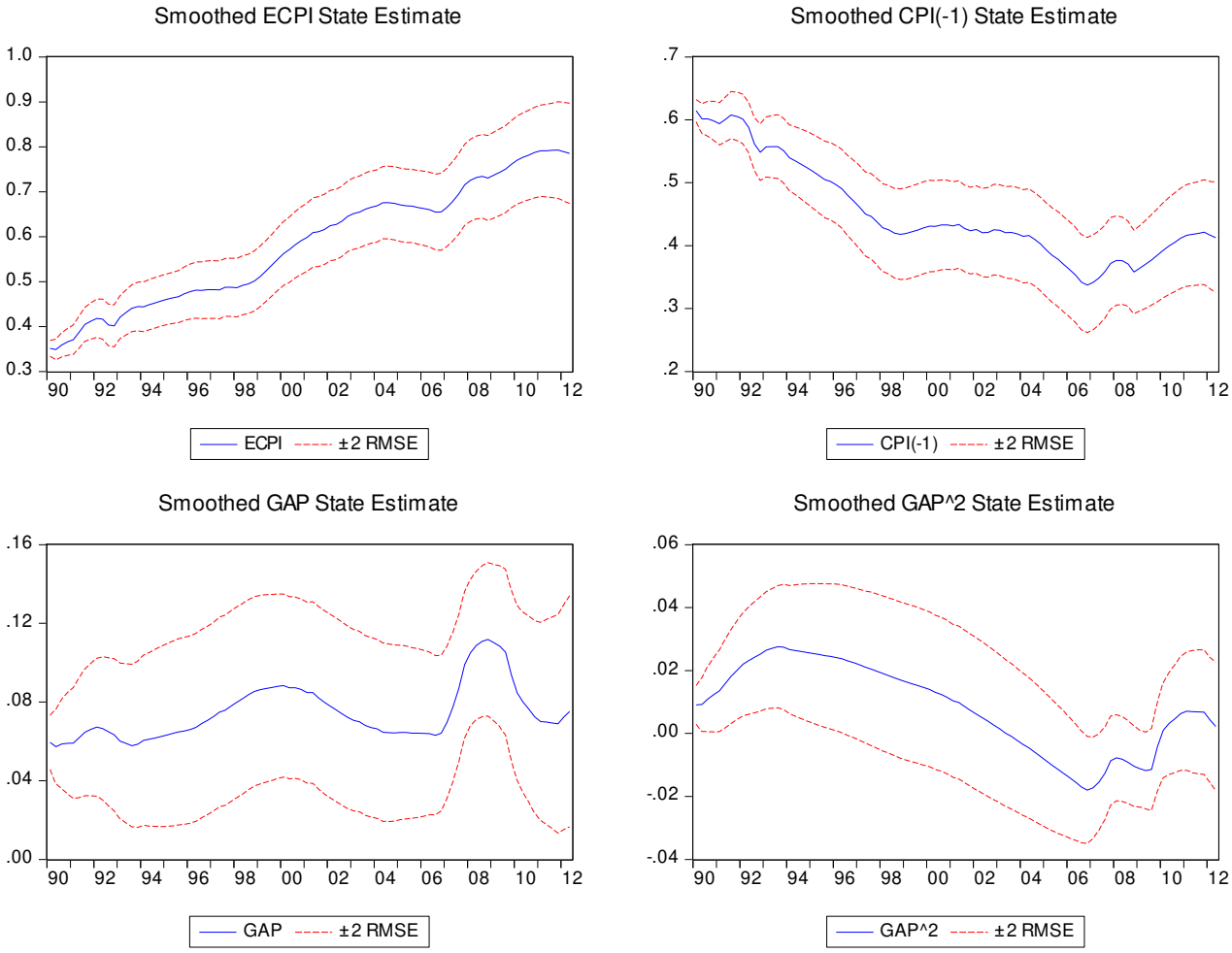

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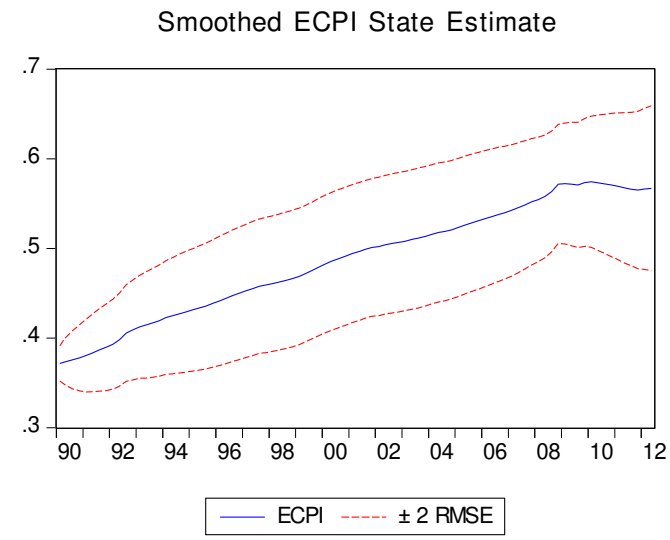
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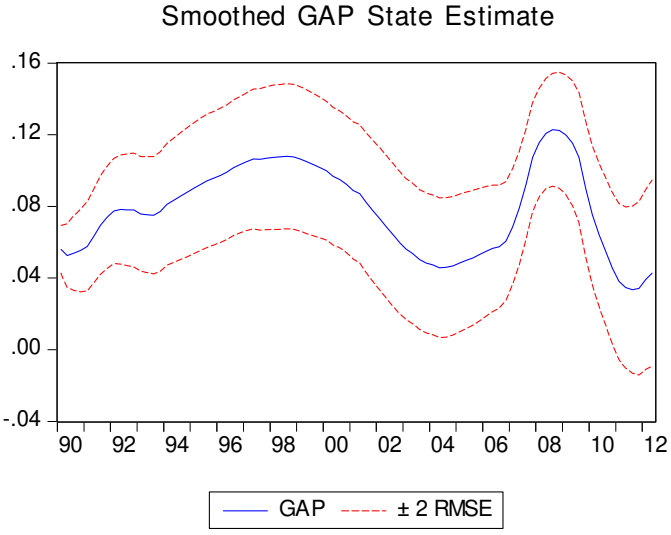
ECPI
± 2 RMSE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.08
.04
.00
-.04
90 92 94 96 98 00 02 04 06 08 10 12
GAP
± 2 RMSE

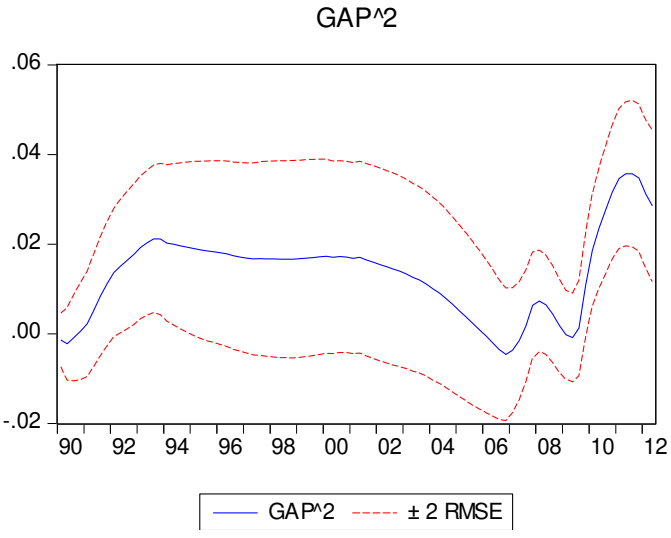
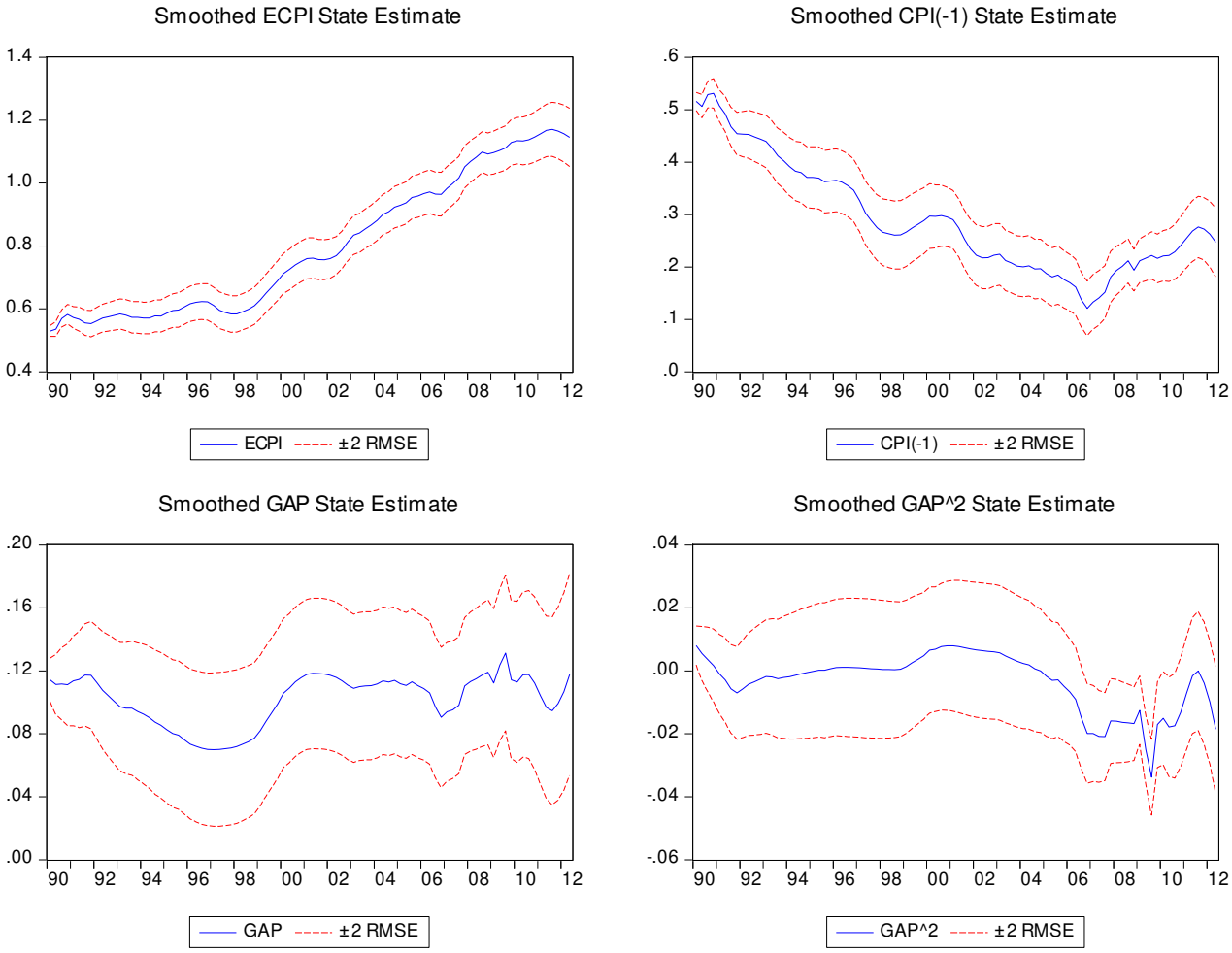
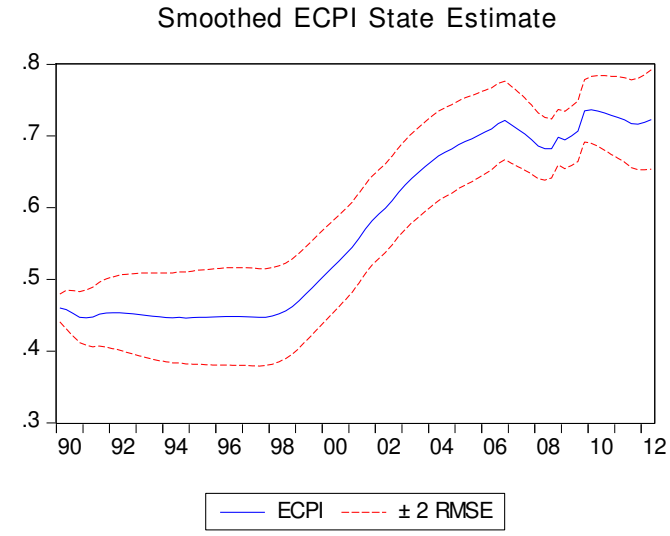

GAP^2
.06
.04
.02
.00
-.02
90 92 94 96 98 00 02 04 06 08 10 12
GAP^2
± 2 RMSE

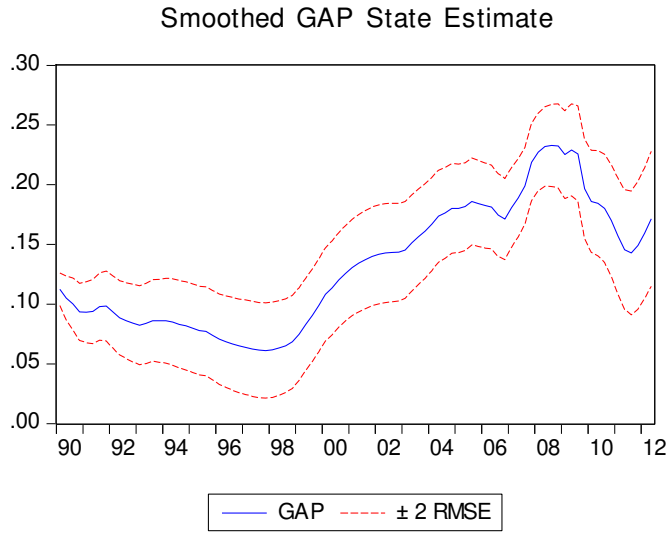
Figure 6. Non-linear Phillips curve parameters for the United States (OECD output gap).

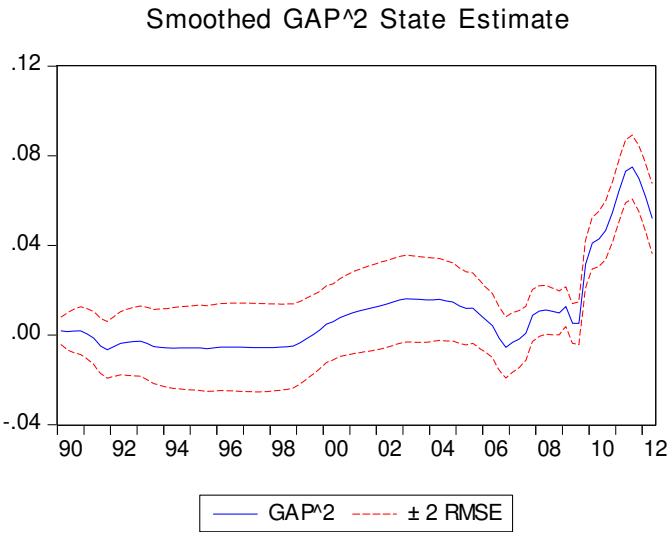
Unrestricted:



Restricted:


Smoothed ECPI State Estimate
.8
.7
.6
.5
.4
.3
90 92 94 96 98 00 02 04 06 08 10 12
ECPI
± 2 RMSE


Smoothed GAP State Estimate
.30
.25
.20
.15
.10
.05
.00
90 92 94 96 98 00 02 04 06 08 10 12
GAP
± 2 RMSE


Smoothed GAP^2 State Estimate
.12
.08
.04
.00
-.04
90 92 94 96 98 00 02 04 06 08 10 12
GAP^2
± 2 RMSE

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