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Abstract

This paper analyzes the inflation processes of twelve Euro Area countries over the period 1984:q1-2017:q4. The stylized features of inflation uncover its changing nature and cross-country heterogeneity, in terms of mean, volatility and persistence. After estimation of a wide array of unobserved components models, we isolate trend inflation rates in a framework that allows for time-varying inflation gap persistence and stochastic volatility in both the trend and transitory components. On average, a sizeable share of overall inflation dynamics is accounted for by movements in the trend. In explaining trend dynamics, we consistently find a signficant role for short-term inflation expectations, economic slack, and openness variables. However, the cumulated impacts of these are fairly small, except in certain, sustained episodes. This is of policy relevance since the monetary authority might want to respond to shocks that are prone to affect the inflation trend in order to ensure that long-term inflation expectations remain anchored.

Keywords: trend inflation, inflation dynamics, UCSV models, monetary policy.

JEL classification: E31, E52.

Resumen

Este trabajo analiza los procesos de inflación de 12 países del área del euro para el período I TR 1984-IV TR 2017. Los hechos estilizados muestran que la inflación tiene una naturaleza cambiante y heterogénea entre países, en términos de media, volatilidad y persistencia. Tras estimar un abanico de modelos de componentes inobservados para la inflación, se aísla la tendencia de cada país y se permite la variación en el tiempo tanto de la persistencia de la brecha de inflación como de las volatilidades de la tendencia y del componente transitorio. En promedio, una proporción significativa de la dinámica de la inflación se explica por movimientos en su tendencia. A continuación, utilizando un análisis de panel, se encuentra que las expectativas de inflación a corto plazo, la brecha de producción y determinados factores de economía abierta desempeñan un papel significativo para explicar la dinámica de la inflación tendencial. No obstante, los efectos acumulados de estas variables son reducidos, a excepción de aquellos episodios en los que el cambio es sostenido en el tiempo. A la luz de este resultado, la autoridad monetaria podría considerar una respuesta ante perturbaciones que, con mayor probabilidad, se trasladen a la tendencia de la inflación, de cara a asegurar que las expectativas de inflación a largo plazo permanezcan ancladas.

Palabras clave: inflación tendencial, dinámica de la inflación, modelos de componentes inobservados, política monetaria.

Códigos JEL: E31, E52.

1 Introduction

Understanding the determinants of inflation dynamics remains a key research subject in macroeconomics. Furthermore, in the decade since the onset of the global financial crisis, advanced economies have navigated through the missing disinflation period into the low inflation era, making the study of the changing inflation process as pressing as ever. Over the years, several approaches have been taken to explore inflation dynamics (see, e.g., Gordon, 2011). Empirically, the inflation process is often modeled by means of reduced-form specifications in which inflation is influenced by inflation expectations (backward-looking, forward-looking, or a hybrid of these), a proxy of cyclical position or excess demand (the output or the unemployment gap) and the evolution of production costs or unanticipated cost shocks (import price inflation, tax changes, among others).[1] The structural underpinning of such specifications is usually found in extended price-setting and wage-setting rules that eventually configure a variant of the Phillips curve. Notably, most structural models, including those in the DSGE tradition, assume either a constant (often zero) or an exogenously time-varying inflation trend, pinned down by the reaction function of the monetary authority (see, e.g., Ascari and Sbordone, 2014).

In recent years, newer, non-structural approaches to model inflation dynamics have emerged, as in the unobserved components (UC) framework of Stock and Watson (2007), Chan et al. (2013) and Garnier et al. (2015), among others. Broadly speaking, these studies develop univariate inflation models with a time-varying trend while allowing for stochastic volatility in either the transitory, the trend, or both components of inflation.[2] These modeling features intend to jointly accommodate the evidence showing that the mean, volatility, and persistence of inflation have changed over time (e.g., Cogley et al., 2005, Koop and Potter, 2007, Stock and Watson, 2007, Clark, 2011). Importantly, the time-varying inflation trend in this class of models may be interpreted as the expected value of inflation at an infinite horizon. Recent applications of such approaches, spanning also the low inflation era, are found in, e.g., Garnier et al. (2015), Cecchetti et al.

[1]The literature is extensive, see, e.g., Bowdler and Nunziata (2007), Musso et al. (2009), Correa-López et al. (2014).

[2]For the US, the literature has shown that, in producing forecasts, univariate models are generally better, in point forecasting accuracy terms, than multivariate ones (see, e.g., Atkeson and Ohanian, 2001, Stock and Watson, 2007, Dotsey et al., 2018). More particularly, Clark and Doh (2014) evaluate the inflation forecasting ability of a wide array of models for trend inflation in the US. Their results suggest that a small set of models, including the local mean model of Stock and Watson (2007), tend to perform relatively well.

(2017), and Forbes et al. (2017) for a group of advanced economies, the US, and the UK, respectively. In particular, Cecchetti et al. (2017) and Forbes et al. (2017) estimate each a variant of the statistical models just described to extract the low frequency component of inflation. The estimated trend is then used to explore the set of factors, among them inflation expectations and economic slack, that contain information about the evolution of inflation once its low frequency movement is controlled for. These authors continue to explore whether those factors have a reliable statistical connection with the trend component itself. In the context of time-varying trend inflation, establishing a relationship between variables often associated to high frequency inflation movements and the inflation trend opens avenues to further our understanding of the inflation process.

Against this background, the aim of this paper is to carry out a comprehensive analysis of inflation dynamics in Euro Area (EA) countries, a subject much less explored than in the US. Using quarterly data for headline and core inflation measures, we first characterize the stylized facts of inflation for a sample of twelve Euro Area countries over the period 1984:q1-2017:q4. Drawing from the observed statistical properties, we spell out a set-up for inflation that nests a wide array of UC models, most of them previously applied to the US inflation process. We estimate the models using Bayesian methods for each of the EA economies and both inflation measures. Importantly, this menu of models delivers differences in both trend inflation paths and sources of inflation persistence, with relevant consequences for the conduct of monetary policy. After an exercise of model selection, we arrive at our proposed variant, that we term the AR-trend-SV model, for inflation dynamics in EA countries. In our preferred model, inflation is described as the sum of a trend component, that is modeled as a driftless random walk, and an inflation gap, that exhibits time-varying persistence, while allowing for stochastic volatility in the shocks to the trend and inflation gap components. Once we back out our preferred inflation trends for EA economies, we first explore the variables that may help explain inflation performance while controlling for trend behavior. Then, we turn to investigate the variables that may drive the inflation trends in our panel of countries, consistent with the empirical strategy in Cecchetti et al. (2017) and Forbes et al. (2017).

Our results suggest that trend inflation significantly fell in those countries considered the high-inflation ones during the first 15 years of the sample (Spain, Greece, Italy and Portugal). The fall of trend inflation became more evident around 1997, when it settled within the 1-3% band for almost all countries. A reasonable explanation for the fall in trend inflation appeals to the efforts made by countries in order to fulfill the Maastricht criteria that would allow them to join the Economic and Monetary Union (EMU). Notably, the range within which trend inflation rates fluctuate has remained in a band of 2 percentage points over the last twenty years or so, coinciding with the introduction of the euro and a common monetary policy framework. Since the end of the 2012 euro debt crisis, the range seems to have shifted to the 0-2% band, below the 2% inflation target of the European Central Bank (ECB).

We also find that trend stochastic volatility displays a downward slope during the whole period in almost all countries. In other words, not only the level of trend inflation has declined, but also the magnitude of the shocks affecting its dynamics. At the beginning of the sample, trend stochastic volatility was generally larger for core inflation than for headline one, however, since around the 2000s the opposite holds. Given that the compositional difference between both series lies in the inclusion of food and energy products, this result suggests that permanent shocks to those items are now more prevalent than in the past. Regarding the evolution of inflation gap persistence, we do not seem to find a common cross-country pattern. Nonetheless, inflation gap persistence is higher for headline inflation than for core during most of the sample in all countries, possibly explained by the inclusion of typically more volatile components in the headline measure (i.e. food and energy). Finally, for both measures of inflation, we find that the estimated AR-trend-SV model delivers higher transitory volatility if compared to trend volatility for all countries in the sample. Hence, inflation dynamics within a period are mostly driven by transitory innovations around the trend while, over longer time horizons, a sizeable share (between 29 and 56 percent) of overall inflation dynamics is accounted for by movements in the trend component itself, in line with the results in Forbes et al. (2017) for the UK.

Regarding the panel specifications, our first set of results indicate that those macroeconomic variables that have been often considered the drivers of inflation may provide limited additional information for understanding inflation dynamics once movements in trend inflation are accounted for, possibly with the exception of trade and openness variables. This conclusion is broadly in line with the results reported in Cecchetti et al. (2017) and Forbes et al. (2017). However, unlike these authors, we provide evidence for a more relevant role -although still limited- of standard inflation determinants, such as short-term inflation expectations and economic slack, in the case of EA countries.

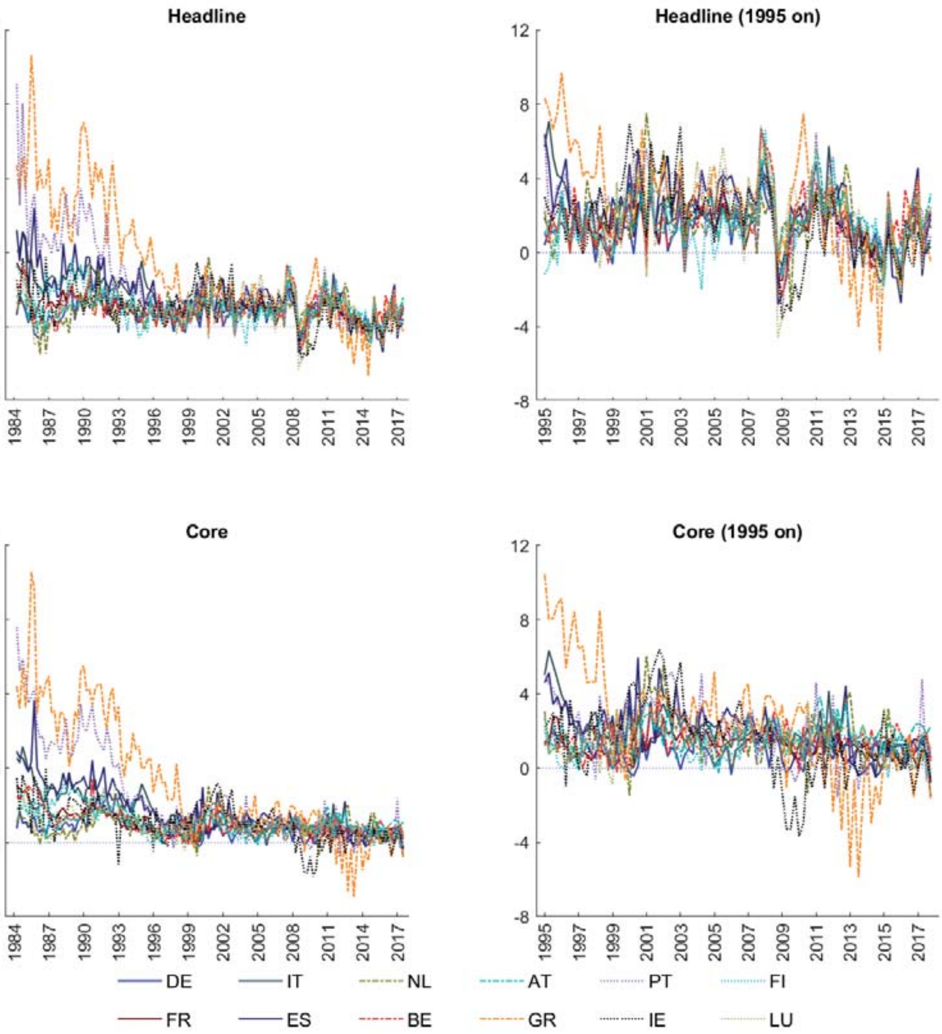
As for the candidate drivers of trend inflation, we consistently find that expectations and slack explain trend inflation dynamics, both for headline and core measures. Open economy variables, such as the real effective exchange rate and the Brent oil and commodities prices, also appear to drive trend headline inflation, while earnings growth may display relevance when slack is proxied by the unemployment gap. Trade and openness variables consistently relate to trend headline inflation but not to trend core, which might indicate that they play a larger role in the determination of food and energy prices if compared to other items. The magnitude of the cumulated effects is, in most instances, small, however, impacts may reach a relevant size in certain episodes, particularly if they are sustained. Compared to the US and the UK, our study finds that a wider set of factors systematically drive trend inflation dynamics in EA countries. For example, Forbes et al. (2017) only ascribe an economically meaningful role to the sterling exchange rate while Cecchetti et al. (2017) find evidence of a more prominent effect from domestic financial conditions, the trade-weighted dollar index and, to a lesser extent, the unemployment gap. Our findings are of policy significance for at least two reasons. On the one hand, the monetary authority might want to respond to a sequence of sustained shocks (e.g., oil price shocks) that are more likely to filter through to the inflation trend in order to ensure that long-term inflation expectations remain anchored and in line with the inflation target. On the other hand, the central bank may benefit from knowing how its policy influences different factors (e.g., short-term inflation expectations, economic slack) that may robustly relate to trend inflation itself.

The rest of the paper is organized as follows. Section 2 characterizes the stylized features of EA inflation across countries and measures. Section 3 presents and discusses the model set-up and estimations, the model selection, and the results of our proposed AR-trend-SV variant. Section 4 presents the panel data strategy and discusses the results on the drivers of trend inflation dynamics. Section 5 concludes.

2 Stylized facts

This section explores the stylized features that have characterized the dynamics of inflation in EA countries over the last three decades. We focus on two measures of inflation that are the most relevant for monetary policy, namely, inflation derived from the harmonized consumer price index (HCPI or headline inflation) and from the HCPI excluding food and energy (core inflation). We compute seasonally adjusted, annualized quarterly

Figure 1: Annualized quarterly inflation



inflation rates from price data for each country as: $\pi_t = 400 \times (log(P_t) - log(P_{t-1}))$, where t stands for a quarter. Our sample period spans from 1984:q1 to 2017:q4 and encompasses the twelve EA countries listed in Table 1 further below.

Figure 1 depicts the inflation rates for the whole sample period and for the post-1995 period, when EA countries were gearing towards the introduction of the single currency. The figure shows a reduction in the level and the volatility of inflation across countries and measures. On average, inflation was high until the early 1990s and then fell to a rate hovering within the 0-4% band, with some positive and negative spikes outside of it. In particular, countries such as Ireland and Greece experienced significant drops in inflation -to rates noticeably below 0%- during the global financial crisis and the euro debt crisis in the late 2000s and early 2010s. For most countries, a slight shift downwards took place around 2012 as the economic slowdown ensued in the midst of the euro debt crisis.

Table 1: Descriptive statistics of inflation

	Headline		Core		Headline (from 1995:q1)		Core (from 1995:q1)	
	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.	Mean	Std. Dev.
Germany	1.59	1.40	1.54	1.07	1.38	1.16	1.09	0.68
France	2.04	1.56	1.94	1.44	1.48	1.23	1.18	0.65
Italy	3.22	2.35	3.22	2.34	2.04	1.51	1.92	1.23
Spain	3.51	2.83	3.52	2.79	2.25	2.02	1.97	1.42
Netherlands	1.73	1.62	1.66	1.24	1.80	1.61	1.55	1.28
Belgium	2.11	1.68	2.18	1.40	1.83	1.60	1.49	0.75
Austria	2.02	1.41	2.14	1.23	1.73	1.19	1.63	0.80
Greece	6.67	6.68	6.50	6.82	2.72	2.76	2.44	2.98
Portugal	4.89	5.25	5.16	5.52	2.10	1.77	1.95	1.65
Ireland	2.28	2.28	2.25	2.33	1.77	2.13	1.55	2.01
Finland	2.34	1.95	2.34	1.72	1.53	1.48	1.41	0.90
Luxembourg	2.20	2.05	2.12	1.26	2.04	2.08	1.68	0.87

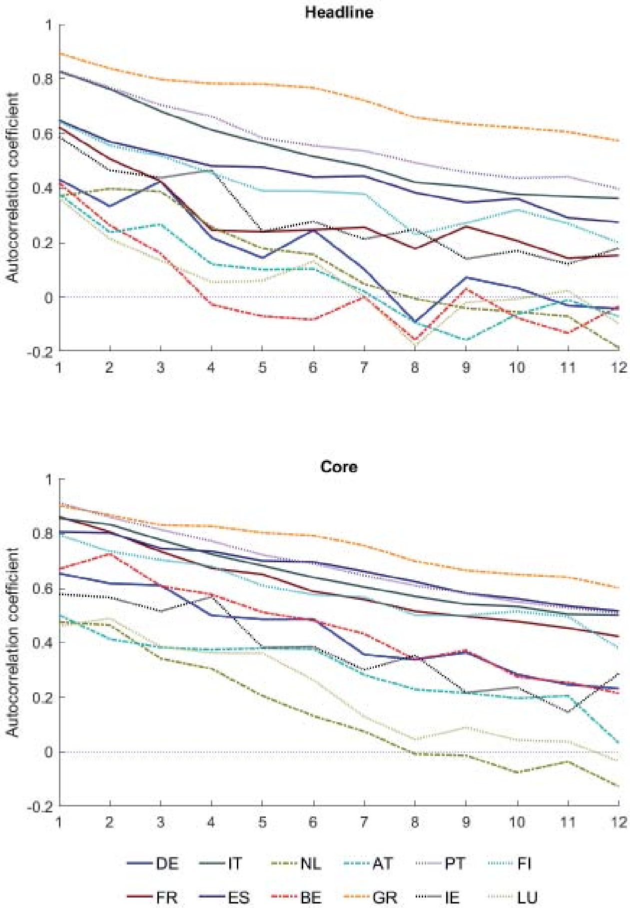
Notes: Figures are in percentages.

Although the ECB responded to persistently low inflation by cutting the policy rate and introducing unconventional monetary policy measures, inflation has not picked up much since, especially its core measure. On the other hand, the volatility of inflation rates across countries stayed generally low after its decline during the "Great Moderation" of the 1990s. Since then, inflation rates appear smoother, with greater comovement.

Table 1 reports descriptive statistics of the above series for the whole sample and for the post-1995 period. For the whole sample, the statistics in the table show that there has been a noticeable degree of cross-country heterogeneity in EA inflation rates. Average inflation varies strongly, from 1.6% in the case of German headline inflation to around 6.7% in Greece and 4.9% in Portugal, while standard deviations spread over a similar range. Despite the reduced dispersion in rates, post-1995 descriptives also suggest that the process that best describes inflation across EA countries is likely to be heterogeneous.

To further characterize the dynamics of inflation, we look into inflation persistence by calculating correlograms for each inflation measure. We compute the autocorrelation coefficients based on the first 12 lags, as depicted in Figure 2. By and large, the figure shows that inflation processes across EA countries exhibit a significant degree of persistence. The first autocorrelation coefficient tends to be large while the gradual decline at deeper lags that occurs in most countries suggests that any temporary shock to inflation, especially to core inflation, is likely to take time to disappear. Core inflation persistence

Figure 2: Correlograms of inflation



is especially pronounced in several countries, in line with a similar feature of US core inflation (Forbes et al., 2017). As we shall see below, our modeling framework intends to capture the various sources underpinning such persistence. Nonetheless, we also observe cross-country heterogeneity in the correlograms, suggesting that EA inflation processes are distinct across countries.

Finally, we test for the extent of autocorrelation of the changes in inflation over the following three quarters. After finding evidence for persistence in inflation levels, this exercise provides insights into the persistence in inflation changes. As Table 2 shows, the first lag of the inflation change is negative and significant for each country, indicating that positive and negative inflation movements follow each other. The second lag is also mostly negative and significant, implying another reversal of inflation in the direction of the initial change. Only the third lag is mostly insignificant, not following a clear pattern. This finding suggests that a positive (negative) inflation shock in a quarter is indeed partly corrected in the second quarter but does not die out completely as another positive (negative) change follows in the subsequent period. In EA countries, inflation

Table 2: Autocorrelations of changes in inflation

	Headline			Core		
	Lag 1	Lag 2	Lag 3	Lag 1	Lag 2	Lag 3
Germany	-0.575^{***}	-0.409^{***}	-0.016	-0.555^{***}	-0.304^{***}	-0.011
	(0.087)	(0.093)	(0.086)	(0.087)	(0.095)	(0.085)
France	-0.421^{***}	-0.192^{**}	0.0786	-0.371^{***}	0.0473	0.0514
	(0.087)	(0.092)	(0.087)	(0.086)	(0.084)	(0.078)
Italy	-0.372^{***}	-0.005	0.0309	-0.604^{***}	-0.054	0.0426
	(0.087)	(0.093)	(0.088)	(0.090)	(0.105)	(0.086)
Spain	-0.545^{***}	-0.356^{***}	-0.097	-0.657^{***}	-0.327^{***}	-0.211^{**}
	(0.085)	(0.092)	(0.086)	(0.086)	(0.099)	(0.086)
Netherlands	-0.718^{***}	-0.377^{***}	-0.077	-0.605^{***}	-0.257^{**}	-0.151^{*}
	(0.087)	(0.101)	(0.087)	(0.086)	(0.099)	(0.087)
Belgium	-0.459^{***}	-0.200^{**}	-0.004	-0.726^{***}	-0.149	-0.008
	(0.087)	(0.093)	(0.087)	(0.087)	(0.103)	(0.081)
Austria	-0.465^{***}	-0.313^{***}	-0.098	-0.539^{***}	-0.355^{***}	-0.240^{***}
	(0.086)	(0.090)	(0.086)	(0.084)	(0.091)	(0.084)
Greece	-0.359^{***}	-0.229^{**}	-0.186^{**}	-0.439^{***}	-0.236^{***}	-0.252^{***}
	(0.086)	(0.088)	(0.085)	(0.084)	(0.090)	(0.083)
Portugal	-0.541^{***}	-0.310^{***}	0.0791	-0.575^{***}	-0.254^{***}	0.0352
	(0.085)	(0.089)	(0.082)	(0.085)	(0.093)	(0.086)
Ireland	-0.542^{***}	-0.371^{***}	-0.209^{**}	-0.714^{***}	-0.448^{***}	-0.261^{***}
	(0.085)	(0.091)	(0.084)	(0.084)	(0.095)	(0.082)
Finland	-0.532^{***}	-0.329^{***}	-0.135	-0.473^{***}	-0.250^{***}	-0.133
	(0.085)	(0.092)	(0.085)	(0.083)	(0.090)	(0.083)
Luxembourg	-0.482^{***}	-0.276^{***}	-0.131	-0.566^{***}	-0.197^{**}	-0.154^{*}
	(0.086)	(0.091)	(0.085)	(0.087)	(0.091)	(0.080)

Notes: For each country, the table shows the results of a regression of the change in inflation on its first three lags for HCPI and HCPI core inflation. ***, **, * denote statistical significance at the 1 percent, 5 percent and 10 percent levels, respectively. Standard errors are in parentheses.

movements around the trend appear to be quite noisy or, put differently, high frequency innovations around trend inflation seem to be short-lived but not as much as in the US or the UK, where the second and third lags are mostly insignificant (Cecchetti et al., 2017, Forbes et al., 2017). In addition, the range of coefficient estimates displayed in Table 2 points towards cross-country heterogeneity in the extent of the negative serial correlation of inflation changes.

The stylized facts presented above indicate that the inflation processes of EA countries are likely to be heterogeneous, calling for a flexible approach to model inflation dynamics.

3 Trend inflation in Euro Area countries

3.1 The class of models

When modeling inflation dynamics, the class of unobserved components models often serves as a starting point. In this type of models, inflation (π_t) is described as the sum of a trend (τ_t), which is modeled as a driftless random walk, and an inflation gap (η_t):[3]

$$\pi_t = \tau_t + \eta_t \qquad \text{where } \eta_t \sim N\left(0, \sigma_\pi^2\right) \tag{1}$$

$$\tau_t = \tau_{t-1} + \varepsilon_t^\tau \qquad \text{where } \varepsilon_t^\tau \sim N\left(0, \sigma_\tau^2\right) \tag{2}$$

This very simple model, even though useful as a baseline, is not free from criticism. First, the possibility that the nonstationary component of inflation becomes relevant for the inflation process cannot be ruled out, which would be against the idea of central banks properly acting to keep inflation rates stable (see Mertens, 2016 or Chan et al., 2013, among others). Note that, in the above specification, the likelihood of an unusual behavior for the inflation process would primarily depend on the size of σ_τ^2. Second, the model does not account for some of the desirable characteristics in describing the evolution of inflation. As pointed out by Chan et al. (2013), there seems to be an agreement among researchers –at least in the US case– that the volatility and the persistence of inflation may not be fixed but changing over time, features that are not encompassed in Eqs. (1) and (2) above. Alternatively, the framework of Stock and Watson (2007) is commonly used to account for changes in volatility. In their model, the logarithm of the variance of both the inflation gap (η_t) and trend inflation (ε_t^τ) evolve as independent driftless random walks. Changes in the persistence of inflation within an unobserved components framework are also considered by Chan et al. (2013). Their model allows for an autoregressive behavior in the transitory component of inflation ($\pi_t - \tau_t$), with stochastic volatility only in the variance of the inflation gap.

[3]This kind of unobserved component models can be related to the Beveridge-Nelson decomposition of inflation. The latter implies that, conditional on an information set available at period t (Ω_t), the expected value of inflation at an infinite-horizon is equal to its trend:

$$E\left(\pi_{t+\infty}|\Omega_t\right) = \tau_t.$$

Consequently, the trend must follow a random walk process while the inflation gap needs to be stationary with zero mean. When Ω_t is unknown for the econometrician, the trend can be interpreted as an unobserved component (Mertens (2016)).

In this paper, we model inflation dynamics adopting a general specification that nests key features of the aforementioned models, as described by:

$$
\begin{aligned}
(\pi_t - \tau_t) &= \rho_t(\pi_{t-1} - \tau_{t-1}) + \exp\left(\frac{1}{2}h_t\right)\varepsilon_t & (3)\\
\tau_t &= \tau_{t-1} + \exp\left(\frac{1}{2}g_t\right)\varepsilon_t^\tau & (4)\\
\rho_t &= \rho_{t-1} + \varepsilon_t^\rho & (5)\\
h_t &= h_{t-1} + \varepsilon_t^h & (6)\\
g_t &= g_{t-1} + \varepsilon_t^g & (7)
\end{aligned}
$$

where $\varepsilon_t \sim N(0,1)$, $\varepsilon_t^\tau \sim N(0,1)$, $\varepsilon_t^\rho \sim TN(a-\rho_{t-1}, b-\rho_{t-1}; 0, \sigma_\rho^2)$,[4] $\varepsilon_t^h \sim N(0,\sigma_h^2)$ and $\varepsilon_t^g \sim N(0,\sigma_g^2)$. We will refer to this general specification as the autoregressive trend stochastic volatility model (AR-trend-SV). By modeling inflation in this way, it is feasible to individually analyze developments in both the inflation gap persistence term (ρ_t) and the changes in the rate of variation of trend inflation (g_t allows trend inflation to display low or high volatility periods). Moreover, the magnitude of the deviations around the trend is also allowed to vary over time (h_t governs this possibility).

An important feature of our model set-up is that it encompasses a wide range of unobserved components models, previously used in modeling inflation dynamics. For instance, the unobserved components stochastic volatility model (UCSV) of Stock and Watson (2007) can be recovered by just setting $\rho_t = \rho = 0$ in Eq. (3). Alternatively, the autoregressive parameter for the transitory component might be treated as a constant ($\sigma_\rho^2 = 0$), delivering the autoregressive UCSV model (ARSV) proposed by Forbes et al. (2017). If, in addition, the inflation gap and the trend inflation volatilities are not allowed to change over time –i.e. $\varepsilon_t^h = \varepsilon_t^g = 0$; $\varepsilon_t \sim N(0,\sigma_\pi^2)$ and $\varepsilon_t^\tau \sim N(0,\sigma_\tau^2)$–, then the autoregressive unobserved component model (ARUC) of Cecchetti et al. (2017) is recovered. Finally, the original specification of Chan et al. (2013) (AR-trend model) can be obtained by setting $\tau_t = \tau_{t-1} + \varepsilon_t^\tau$ where $\varepsilon_t^\tau \sim N(0,\sigma_\tau^2)$ in Eq. (4).[5]

[4] $TN(a,b,0,\sigma^2)$ refers to a truncated normal distribution with mean zero, variance σ^2 which is bounded in the (a,b) interval, as in Chan et al. (2013).

[5] In their original set-up, Chan et al. (2013) do not include stochastic volatility in the innovations to the trend, but their process is bounded by

$$\tau_t = \tau_{t-1} + \varepsilon_t^\tau, \qquad \text{where } \varepsilon_t^\tau \sim TN(a_\tau - \tau_{t-1}, b_\tau - \tau_{t-1}; 0, \sigma_\tau^2).$$

By bounding trend inflation the authors argue that their framework would be in line with the idea of central banks focusing on price stability (ideally the trend should not significantly depart from those public objectives).

Next, we present individual estimates of trend inflation rates in EA countries for the model variants just discussed. Furthermore, we arrive at our preferred specification after exhaustive analysis.

3.2 Baseline results

In order to estimate each of the models just described, we adopt a Bayesian approach. In particular, we follow Chan et al. (2013) in setting the priors and the Markov chain Monte Carlo algorithm (MCMC) –even though in the AR-trend-SV model we assume different dynamics for trend innovations–.[6]

Figure 3: Estimated trend inflation across models (Headline)

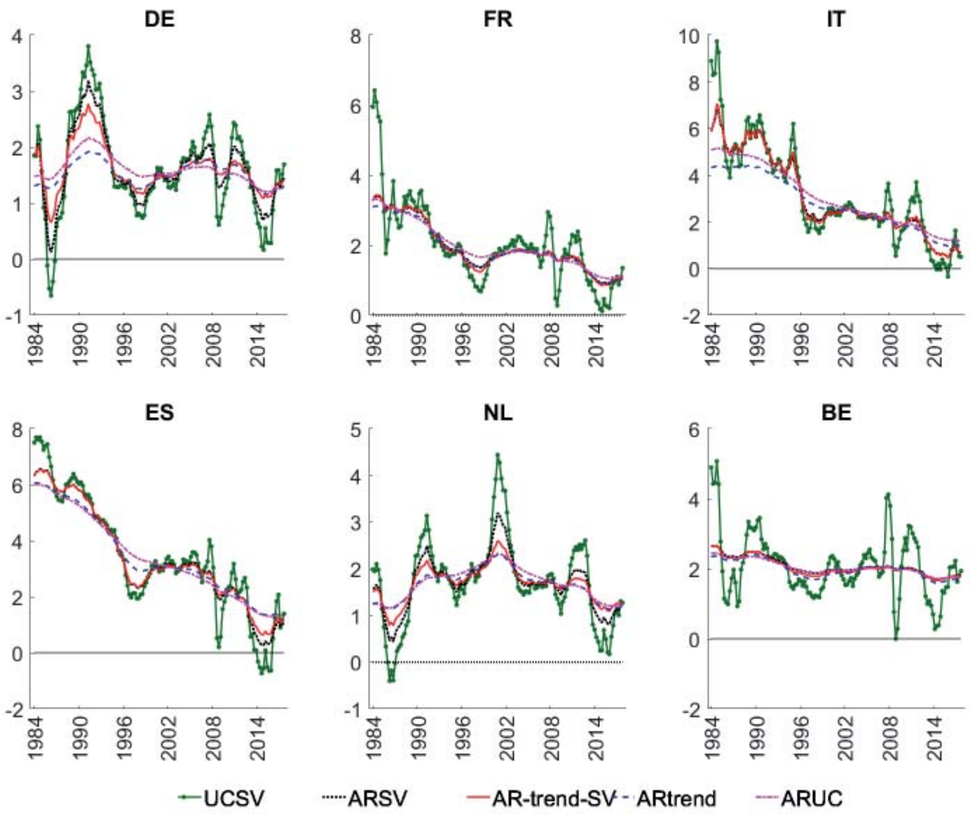
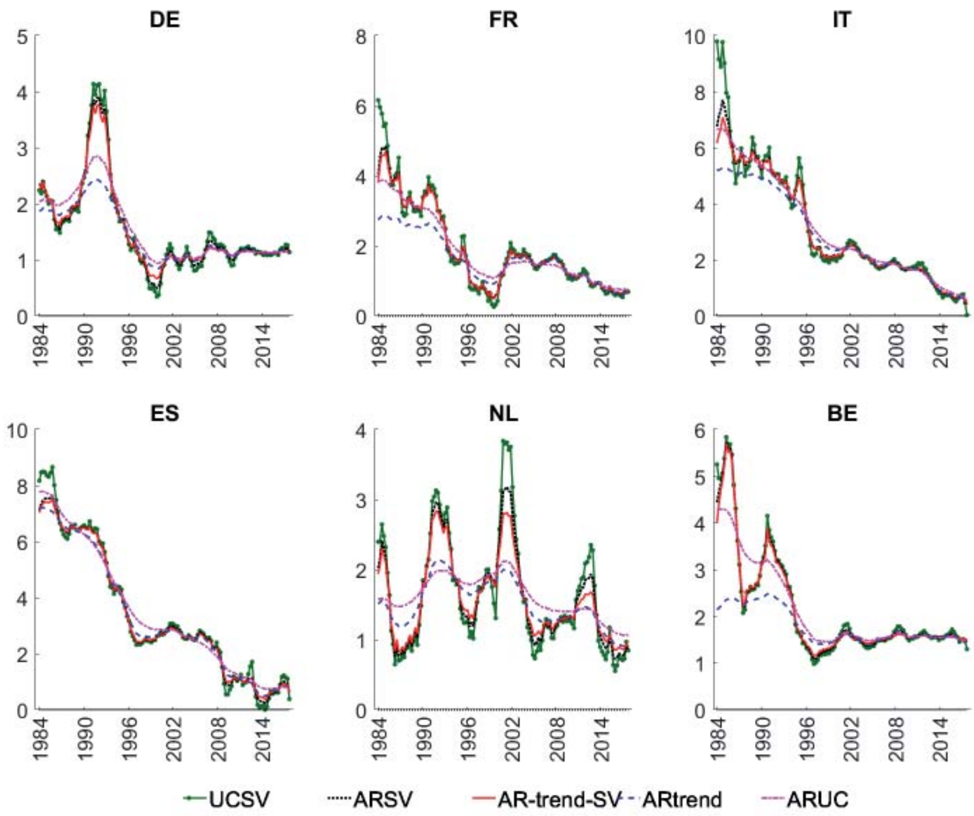


Figure 3 shows, for the larger EA countries, the estimates of headline CPI trend inflation rates (see Appendix A for the plots of the rest of the countries). As expected, the UCSV model generates more volatile trends, given that the UCSV trend captures a fraction of what is interpreted as inflation gap persistence in all of the other four models.

[6] The state equations given by Eqs. (4)-(7) need to be initialized and, following Chan et al. (2013), we set $\tau_1 \sim N(\tau_0, \omega_\tau^2)$, $\rho_1 \sim TN(0, 1, \rho_0, \omega_\rho^2)$, $h_1 \sim N(h_0, \omega_h^2)$ and $g_1 \sim N(g_0, \omega_g^2)$. As it is also described in Chan et al. (2013), the bounds in the case of ε_t^ρ are chosen to satisfy the requirement that the conditional expectation of the inflation gap process converges to zero at the infinite horizon.

In contrast, the smoothest trends are produced by the ARUC and the AR-trend models. This is because of, on top of allowing for inflation gap persistence, both models assume a constant volatility for the trend component. In this sense, the ARUC and the AR-trend models may be viewed as capturing the very low frequency dynamics of trend inflation. Our proposed model specification (AR-trend-SV) generates trend inflation series that, for the most part, lie between the most volatile trends (UCSV and ARSV) and the least volatile ones (ARUC and AR-trend).[7]

Figure 4: Estimated trend inflation across models (Core)

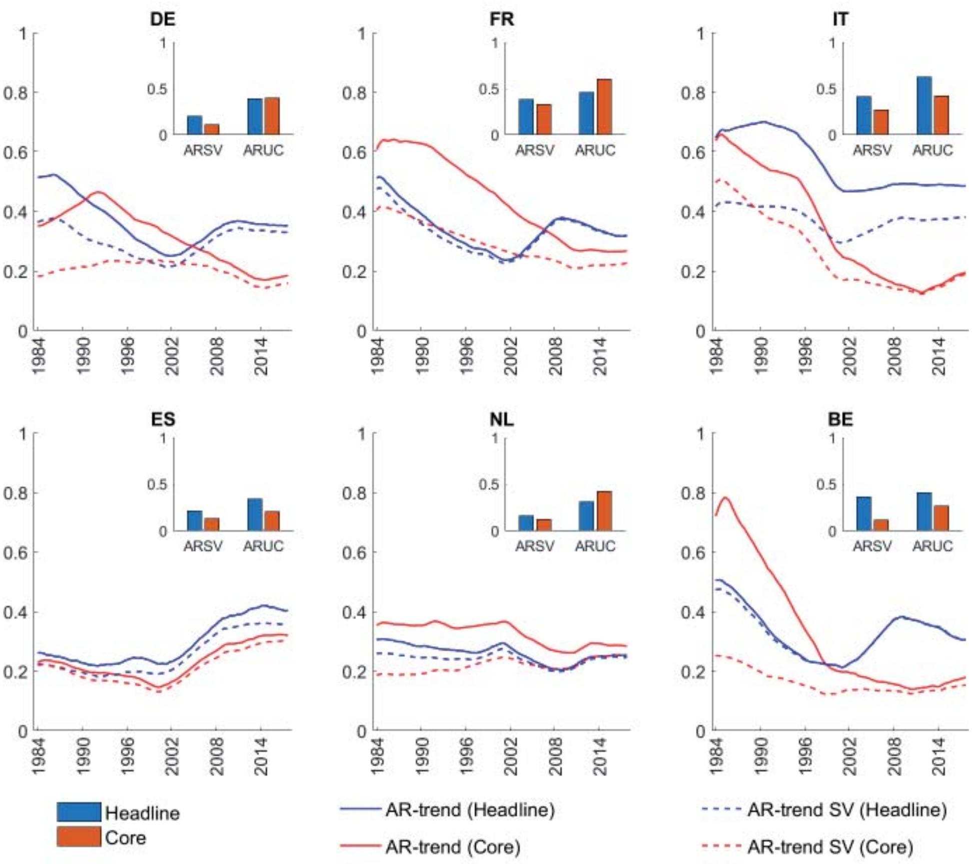


When the analysis is focused on core CPI inflation, as in Figures 4 and A.2, the differences across each model's estimated trends become less apparent, especially in the second half of the period. In particular, it is harder to distinguish among models which incorporate SV in the trend component (UCSV, ARSV and AR-trend-SV).

With regard to inflation gap persistence, several features emerge from Figures 5 and A.3. First, inflation gap persistence tends to be of a smaller magnitude in core measures if compared to headline ones. Therefore, food and energy prices are a relevant source

[7] For Portugal, it is difficult to find sensible dynamics for trend inflation in the ARUC model.

Figure 5: Estimated inflation gap persistence parameter across models

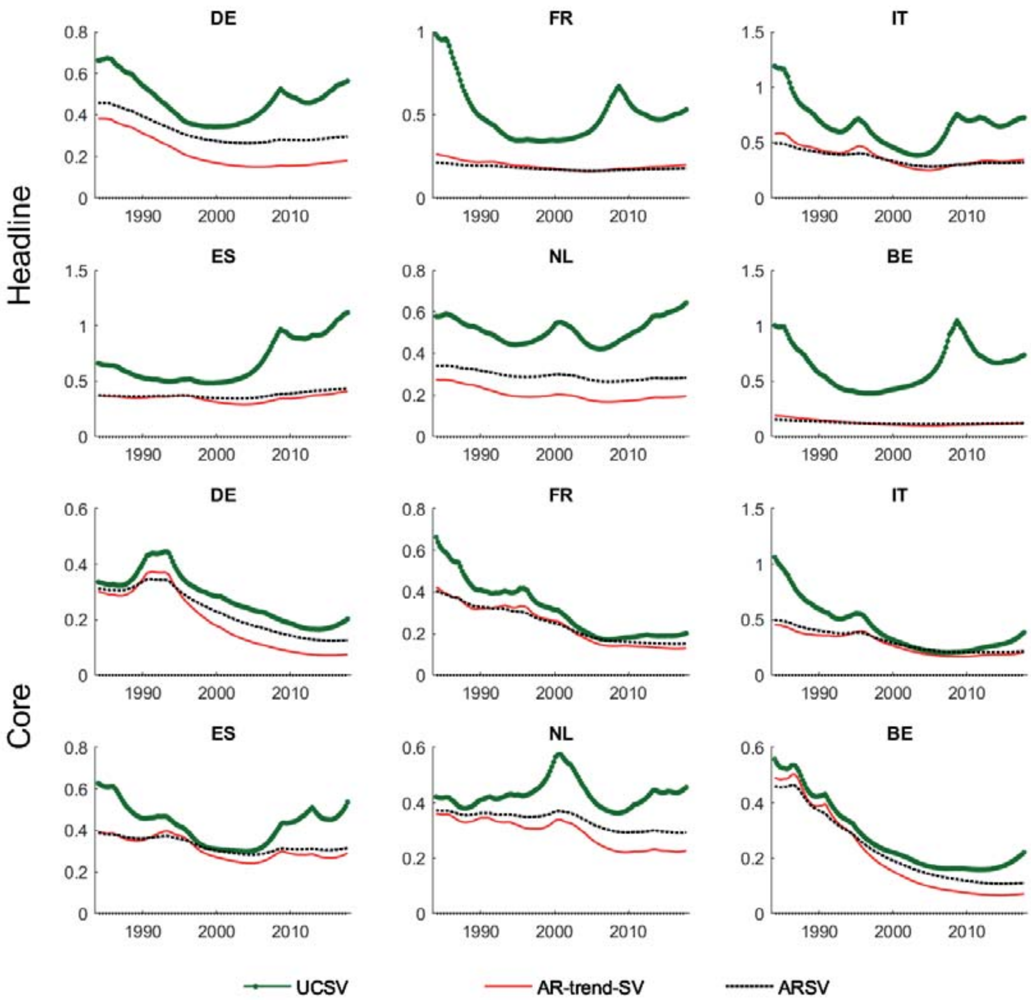


Note: in the case of the ARUC and the AR-trend models the estimated parameter is fixed over time.

of persistence for inflation series. In particular, the constant AR coefficient in both the ARUC and the ARSV models are, in general, smaller for core inflation when compared to the ones obtained for headline inflation. In contrast to the ARSV, where a fraction of persistence is picked up by SV in the trend, the ARUC model produces a higher degree of persistence in the transitory component.

When the AR coefficient is allowed to vary over time, time paths differ depending on whether the SV is incorporated in the trend component or not. Thus, the AR-trend model displays AR coefficients which, for most of the countries, have declined since the 1980s (Spain, Austria and Ireland are the exceptions) –especially in core inflation measures–, meaning the persistence of the inflation gap has diminished over the last three decades. This behavior is not so clearly observed when the AR-trend-SV model is used since the AR coefficients are mostly stable during those years. This is because part of the dynamics of inflation are attributed to variations in trend volatility which, in general, has also diminished over the years (Figures 6 and A.4). Once again, the latter is particularly the

Figure 6: Estimated trend stochastic volatility across models



case for core inflation. Overall, a model that combines inflation gap persistence with time-varying volatilities (AR-trend-SV and ARSV) produces a relatively stable estimate of trend volatility, while abstracting from the former introduces more variation. In the latest case (USCV), trend volatility in most of the countries shows a decline from the 1980s until the Great Recession, when a peak is often observed around 2009.

In summary, for those models that allow for trend stochastic volatility, the evolution of trend inflation is quite similar (Figures 3 and A.1). However, the underlying story differs in that the evolution of the trend might be accompanied by falling inflation gap persistence, falling trend volatility, or both, with important implications for monetary policy. Therefore, selecting the model that is the most appropriate to describe inflation dynamics in EA countries is an important task to perform.

3.3 Model selection

To choose the specification best suited to model EA inflation dynamics, we start by addressing the possibility of adding time-varying volatility to the inflation gap, the inflation trend, or both. We do so applying the Bayesian test developed in Chan (2018). In particular, relying on a noncentered parametrization for the state space representation, Chan (2018) proposes a method which allows for an easy way of computing the relevant Bayes factor between the models to be compared. One empirical application in Chan (2018) assesses the relevance of modeling the G7 countries' inflation including a stochastic volatility process in the inflation gap and the inflation trend, using a similar model to Stock and Watson (2007). Here, we perform the same test for each of the EA countries that we analyze. Table 3 shows the estimated log Bayes factors and the numerical standard errors for each of the tests. As in Chan (2018), the estimated log Bayes Factors refers to a model which assumes stochastic volatility in both the inflation gap and the inflation trend (M_u) against a model with a fixed variance in the inflation gap (M_h), in trend inflation (M_g) or in both (M_{hg}). In this sense, the logarithm of the Bayes factor of M_u against M_h will be named $logBF_{u,h}$ (and, respectively $logBF_{u,g}$ and $logBF_{u,hg}$). As explained in Chan (2018), a positive log Bayes factor in this case will represent evidence supporting the M_u against the alternatives.

For almost all EA countries the estimated $BF_{u,hg}$ is positive (both for headline and core inflation), with the notable exceptions of Germany, Netherlands and Finland.[8] Therefore, at least one stochastic volatility component is preferred in most instances. When the question of which component should exhibit stochastic volatility arises, the evidence is in favor of adding it to the trend component (more than to the inflation gap component).[9] This result suggests that, in the case of EA countries, stochastic volatility in the trend cannot be ruled out. This observation leads us to decide against the AR-trend and the ARUC models of inflation dynamics.

Regarding whether or not to include inflation gap persistence, the stylized features presented above suggest that both headline and core inflation display a substantial degree of persistence that, at least partially, might be attributed to the transitory component.

[8]In the case of Finland, the Bayes factor is positive only for core inflation.

[9]Using data starting in 1955 for G7 countries, Chan (2018) finds stronger evidence in favor of introducing stochastic volatility in the inflation gap component.

Table 3: Log Bayes factors and standard errors

	$logBF_{u,h}$		$logBF_{u,g}$		$logBF_{u,hg}$	
	Headline	Core	Headline	Core	Headline	Core
Germany	$-.35$	-2.08	$-.30$	1.37	$-.86$	$-.82$
	(.017)	(.006)	(.018)	(.049)	(.050)	(.056)
France	$-.65$	$-.71$	11.18	25.11	15.08	27.77
	(.018)	(.022)	(1.240)	(1.849)	(2.015)	(1.997)
Italy	1.03	2.15	16.72	43.37	29.95	76.37
	(.035)	(.090)	(2.040)	(3.283)	(2.730)	(3.150)
Spain	-1.28	18.71	5.88	15.98	11.85	121.94
	(.009)	(2.282)	(.338)	(1.390)	(1.583)	(4.468)
Netherlands	-1.79	$-.70$	$-.67$	.37	-2.65	$-.50$
	(.006)	(.020)	(.014)	(.027)	(.021)	(.029)
Belgium	-1.26	4.52	8.08	28.31	14.64	69.64
	(.018)	(.140)	(1.299)	(2.492)	(2.519)	(3.611)
Austria	$-.60$	$-.43$	$-.22$	3.92	34.00	46.77
	(.036)	(.016)	(.033)	(.210)	(1.522)	(3.126)
Greece	.73	2.00	19.13	43.64	65.16	109.64
	(.035)	(.050)	(2.390)	(3.933)	(4.327)	(5.083)
Portugal	-1.48	2.47	30.31	80.80	109.34	98.04
	(.005)	(.067)	(4.272)	(3.639)	(3.915)	(6.787)
Ireland	.36	3.27	2.83	.22	17.23	19.35
	(.018)	(.123)	(.094)	(.037)	(1.011)	(.731)
Finland	-1.67	-1.48	1.08	4.89	$-.68$	7.74
	(.007)	(.010)	(.023)	(.115)	(.027)	(.963)
Luxemburg	2.99	3.08	.98	4.89	8.96	46.15
	(.111)	(.077)	(.064)	(.131)	(1.073)	(3.350)

Note: $BF_{u,h}$, $BF_{u,g}$ and $BF_{u,hg}$ are, respectively, the Bayes factors in favor of having the stochastic volatility process in the inflation gap, in the trend, or in both components. The numerical standard errors are computed, as in Chan (2018), using 10 parallel chains of a length $100,000$ (burning-in: $10,000$).

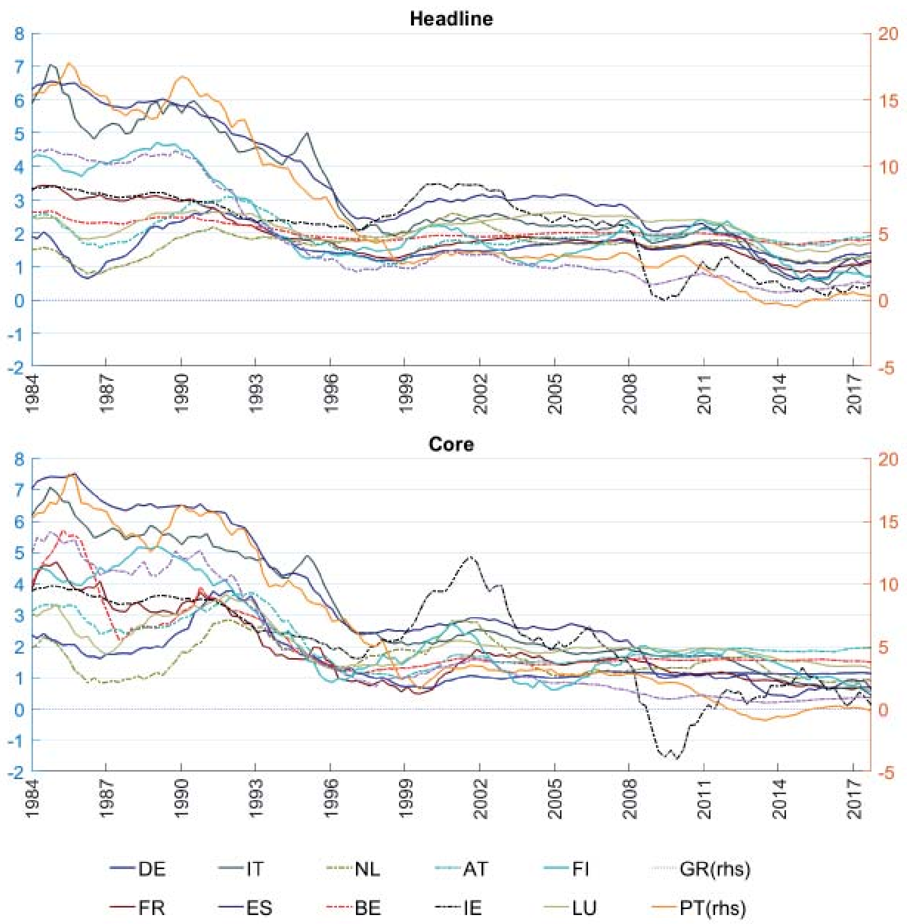
With this observation in mind, we conclude that the UCSV model is not the most suitable framework for modeling EA inflation dynamics.

In a final step, we decide between the AR-trend-SV and the ARSV models. As illustrated throughout the section, the differences between these two models are not significant in most countries. Nonetheless, we decide to choose the AR-trend-SV model as our preferred framework to analyze the EA inflation processes. Our decision is based on the fact that inflation gap persistence may have been significantly affected by the policy and institutional developments of the period, especially the introduction of the euro in 1999. By letting the possibility of time variation in the inflation gap persistence parameter, we believe that these developments can be better captured.

3.4 Trend inflation paths in the AR-trend-SV model

Focusing on the AR-trend-SV model, we can draw some conclusions when comparing inflation trends across countries. First, as expected from inflation data, the trends in Figure 7 have a downward slope and show evidence of a cross-country convergence process, for both headline and core inflation.

Figure 7: Trend inflation by country (AR-trend-SV model)

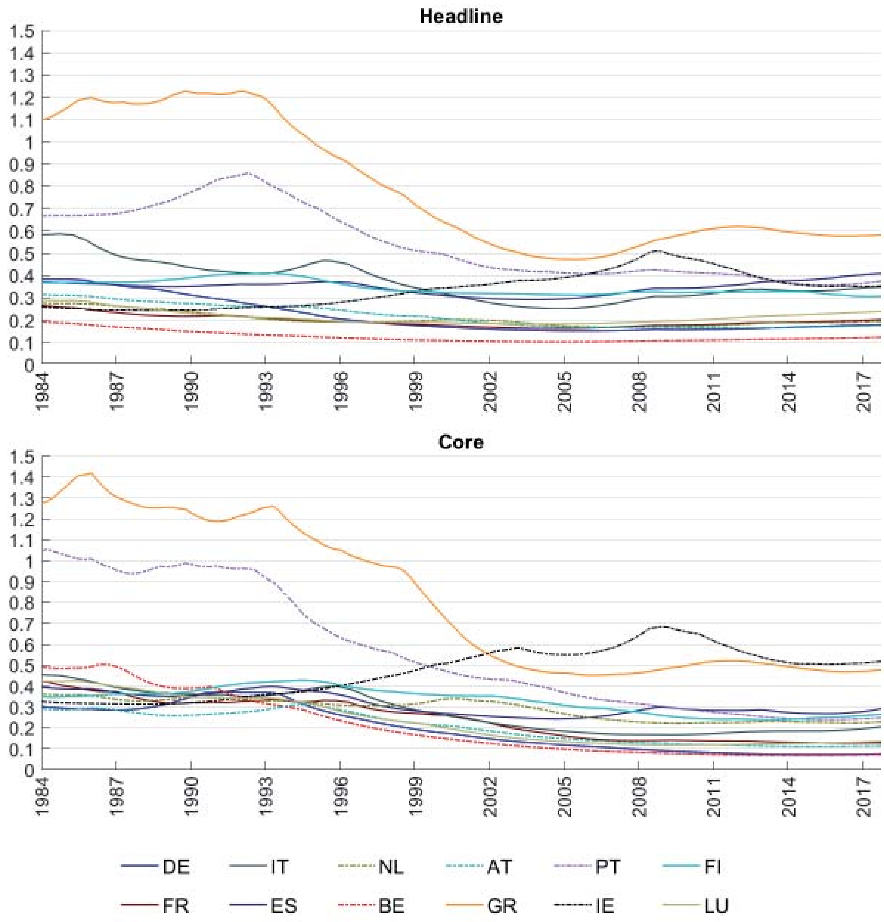


In particular, trend inflation significantly fell in those countries considered as the high-inflation ones during the first fifteen years of the sample (Spain, Greece, Italy and Portugal). The fall in trend inflation becomes more evident around 1997, when it lies within the 1-3% band for almost all countries. A sensible explanation for the observed convergence in trend inflation rates appeals to the efforts countries made to fulfill, by 1997, the Maastricht criteria that would make them eligible to join the EMU.[10] Notably, the range within which trend inflation rates fluctuate has remained in a band of 2 per-

[10] Four basic criteria were required to join the euro. These were related to inflation, the level of public debt, the interest rate and exchange rate policy.

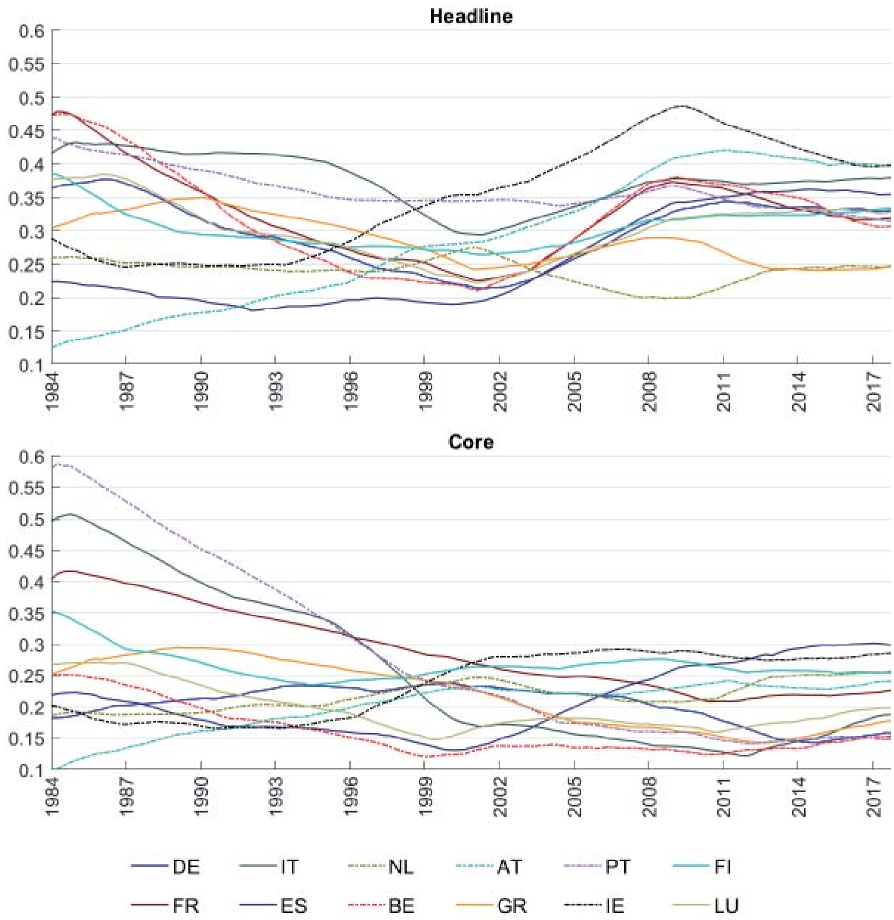
centage points (pp) over the last twenty years. Of course, this period coincides with the introduction of the euro and, consequently, of a common monetary policy framework across EA countries. It can also be noticed that, since the end of the 2012 European debt crisis, the range appears to have shifted to the 0-2% band, below the 2% inflation target of the ECB.

Figure 8: Trend stochastic volatility by country (AR-trend-SV model)



The Maastricht criteria and the effectiveness of a common monetary policy might also explain, at least in part, the observed reduction in magnitude of the shocks affecting trend inflation. Figure 8 shows that trend stochastic volatility displays a downward slope during the whole period in all countries but Ireland (for both headline and core inflation) and Spain (for headline inflation). In other words, not only the level of trend inflation has declined, but also the magnitude of the shocks affecting its dynamics. It is also worth noticing that, for most countries at the beginning of the sample, trend stochastic volatility is larger for core inflation than for headline (see also Figure A.7). However, in the second half of the 1990s, the size of the shocks to the trend component of the core falls significantly, making trend stochastic volatility of core inflation smaller than headline one. Given that the compositional difference between both series lies in the inclusion of food and energy products, this result suggests that permanent shocks to those items have become more prevalent than in the past. The exceptions are the Netherlands and Ireland, where the opposite holds.

Figure 9: Inflation gap persistence parameter by country (AR-trend-SV model)



Regarding the evolution of inflation gap persistence, we do not seem to clearly find a common cross-country pattern, as evidenced in Figure 9. Nonetheless, inflation gap persistence is higher for headline inflation than for core during most of the sample in all countries (Figures 5 and A.3). The latter might be explained by the inclusion of typically more volatile components in headline inflation (food and energy items), likely to generate substantial persistence.

Finally, for both inflation measures, we find that the estimated AR-trend-SV model produces higher transitory volatility if compared to trend volatility for all countries in the sample (Figures 6, A.4, A.5 and A.6). Hence, inflation dynamics within a period are mostly driven by transitory innovations around the trend while, over longer time horizons, a sizeable share of overall inflation dynamics is accounted for by movements in the trend component itself. In particular, we find that, on average, about 29 percent of the variation in headline inflation and about 56 percent of the variation in core inflation is explained by the respective low frequency component. Given the significance of the trend in driving overall EA inflation performance, the next section investigates what factors may explain its behavior.

4 An exploration of cross-country inflation dynamics in the Euro Area

This section interrogates the data to evaluate the candidate variables that may help explain the behavior of inflation among EA countries. For that purpose, we closely follow the empirical strategy implemented in Cecchetti et al. (2017) and Forbes et al. (2017). In a first exercise, we explore the set of variables that may add information on the dynamics of inflation once we control for the estimated trend. In other words, we evaluate the relevance of each variable in explaining movements of inflation around its low frequency component. Guided by theory, our candidate variables intend to capture the channels through which high frequency shocks may be transmitted to inflation. As an avenue to know the data, we estimate specifications that do not impose much structure on the relationship between inflation and its potential determinants.

In a second set of exercises, we investigate the variables that may relate to the trend component itself. The candidate variables are the same as in the first exercise, hence we effectively explore whether movements in variables typically related to the high frequency component of inflation may provide information about its low frequency. We carry out our empirical exercises in an unbalanced panel of twelve EA countries using quarterly data for the period 1995:Q1-2017:Q4.

4.1 Inflation behavior: the trend and other factors

In our first exercise, we estimate panel regressions that take the following form:

$$\pi_{it} = \alpha + \tilde{\tau}_{it} + \gamma X_{it} + \eta_i + \epsilon_{it}, \tag{8}$$

where subscripts $\{i, t\}$ refer, respectively, to country and time, π_{it} represents alternative measures of HCPI inflation -namely, headline and core-, $\tilde{\tau}_{it}$ denotes the corresponding estimated trend inflation in our preferred model, and X_{it} is a candidate variable that may help explain cyclical movements in inflation.[11] Notice that, to strive for consistency with our modeling strategy of the previous section, the coefficient on trend inflation is set equal to one.[12] Finally, the composite disturbance has two orthogonal components: fixed effects η_i that control for unobserved country-level heterogeneity and an idiosyncratic error ϵ_{it}. We use the fixed effects estimator on Eq. (8) when we run regressions introducing one candidate explanatory variable at a time.

The variables that may influence inflation dynamics are broadly classified as follows:

1. Inflation expectations: *Consumer-based survey of inflation over the next 12 months.*
2. Economic slack: *Output gap and unemployment gap.*
3. Labor costs: *Average hourly earnings and unit labor costs.*
4. Trade and openness: *Import prices (adjusted by openness), world export prices (adjusted by openness), the real effective exchange rate (REER), Brent oil price, and a commodity price index.*
5. Financial conditions: *Money supply, private non-financial debt, yields on 10-year government bonds, and the stock index.*

In Appendix B, we provide a detailed definition of the variables and the data sources used for their construction. All variables are country-specific with the exception of the Brent oil price and the commodity price index.

Table 4 reports the results of estimating Eq. (8) for our panel of EA countries. The results show that, after controlling for the slow-moving trend, two of the variables that are customarily related to inflation dynamics appear strongly significant and correctly signed. In particular, 12-months ahead inflation expectations are positively correlated to headline and core inflation while measures of economic slack are negatively correlated. In contrast, labor cost variables are largely unrelated to inflation once we control for the trend component since the only significant correlation is at the 10 percent level for earnings growth and core inflation. When coefficients are significant, their magnitude is generally small. Although an increase of one standard deviation in short-term inflation expectations is associated with an increase of 0.5pp in headline inflation and of 0.2pp in

[11] For country i, the estimated trend inflation $\tilde{\tau}_{it}$ may be thought of as the sum of a EA-wide common factor ($\tilde{\tau}_t^c$) and an idiosyncratic component ($\tilde{\tau}_t^i$).

[12] Forbes et al. (2017) introduce a β coefficient on the trend inflation term. We have checked that our results are generally robust to this modification.

Table 4: Determinants of EA inflation dynamics

Candidate variables:	Headline	Core
Inflation Expectations	0.499***	0.176***
	(0.039)	(0.029)
Output gap	0.164***	0.054***
	(0.037)	(0.012)
Unemployment gap	−0.092***	−0.047***
	(0.024)	(0.014)
Earnings	0.011	0.011*
	(0.008)	(0.006)
Unit labor cost	0.006	0.003
	(0.004)	(0.003)
Import prices	0.045***	−0.002
	(0.012)	(0.003)
World export prices	0.020***	0.001
	(0.003)	(0.001)
REER	−0.062*	0.024
	(0.037)	(0.024)
Brent oil price	0.016***	−0.003***
	(0.003)	(0.001)
Commodity price index	0.033***	−0.005***
	(0.005)	(0.001)
Money supply (M3)	0.004	0.003
	(0.005)	(0.004)
Private debt	0.007*	0.004**
	(0.004)	(0.002)
Yields (10-year bonds)	0.048**	0.003
	(0.023)	(0.013)
Stock index	−0.002	−0.005**
	(0.004)	(0.002)

Notes: ***, **, * denote statistical significance at the 1 percent, 5 percent and 10 percent levels, respectively. Robust standard errors in parentheses. See the text for further details.

core inflation, the quarterly variation in inflation expectations is most often (90 percent of the time) lower (the standard deviation of the change in inflation expectations is 0.48). Similarly, a 1pp increase in the output gap correlates to, respectively, 0.16pp and 0.05pp higher headline and core inflation. For the unemployment gap, the corresponding magnitudes are even smaller.

Growth in import prices and world export prices are both positively and significantly associated to headline inflation while a REER appreciation is negatively correlated, albeit with much less significance. Regarding EA-wide variables, growth in Brent oil prices (in US$) and in the S&P commodity price index (in US$) are positively and significantly correlated to headline inflation but negatively to core, albeit the latter coefficients are very close to zero. In most instances, the magnitude of these effects is economically relevant. For example, a one standard deviation increase in import price inflation (equivalent to 10.2 percent quarterly annualized) is associated with an increase of 0.46pp in headline inflation. Likewise, a one standard deviation increase in world export price inflation (equivalent to 19.2 percent quarterly annualized) correlates to headline inflation 0.38pp higher. With regard to oil, we find that a one standard deviation increase in the US$ Brent price (equivalent to an increase of 17.4 percent) correlates to headline inflation 0.28pp higher, while the correlation of a broader measure of commodity prices is even higher (0.43pp per standard deviation increase). For EA countries, these results suggest that, after controlling for the estimated trend, trade variables can contribute to our understanding of inflation dynamics, especially in the headline inflation measure.

Among the variables that capture financial conditions, there is a positive and significant association between private debt and inflation, however, the size of the correlations is very small, as it is the case for yields and stock prices. These results are suggestive of a reduced role for financial variables in explaining inflation behavior once we control for the inflation trend.

All in all, our results indicate that those macroeconomic variables that have been often considered the drivers of inflation may provide limited additional information for understanding inflation dynamics once the role of trend inflation is accounted for, possibly with the exception of trade and openness variables. This conclusion is broadly in line with the results reported in Cecchetti et al. (2017) for the US and Forbes et al. (2017) for the UK. However, unlike these authors, we find that standard determinants of inflation, such as short-term inflation expectations and economic slack, may have more relevance, albeit still limited, in explaining cyclical inflation for EA countries.

We carried out a number of robustness exercises after estimating Eq. (8). In the first exercise, we included dummy variables to pick up relevant developments during the global financial crisis. In another exercise, we introduced up to four lags of each regressor to account for possible time delays in their respective effects on inflation. Results are generally robust to these exercises. Finally, we replaced our trend estimates based on the AR-trend-SV model by, alternatively, the trend estimates based on the UCSV and the AR-trend models. Our results of a significant role for inflation expectations and economic slack still hold, albeit coefficients under the UCSV (AR-trend) model tend to be of a smaller (bigger) magnitude than those obtained using our preferred trends.

Regarding other variables, while the overall results using the UCSV trends track closely those reported in Table 4, there are some minor differences in the effects of the trade and financial variables using the AR-trend trends, e.g., a more prominent role for money growth and private debt.[13]

4.2 What has driven the inflation trend?

Given that, over long horizons, a substantial part of the inflation variation is explained by its low frequency component, we next investigate the factors that may influence the inflation trend. In particular, we focus on those factors that have been often associated with high frequency movements in inflation, as in the previous section. Exploring whether they contain useful information as drivers of trend inflation would improve our understanding of overall inflation dynamics. It would also provide a hint at the possibility that high frequency shocks may be more relevant for the lower inflation frequency than previously thought. We pay special attention to the role of inflation expectations and economic slack.

To begin our exploration, we estimate panel specifications of the form:

$$\Delta\tilde{\tau}_{it} = \alpha + \beta\Delta E[\pi_{it}] + \gamma\Delta Slack_{it-1} + \eta_i + \epsilon_{it}, \tag{9}$$

where Δ is the difference operator and $E[\pi_{it}]$ denotes inflation expectations. The specification is written in terms of the first difference of trend inflation to ensure consistency with our overall modeling strategy of the trend component. The measures of economic activity capturing the extent of slack in the economy, namely the output gap and the unemployment gap, enter lagged once as they may determine trend inflation with some delay due to, e.g., nominal wage and price rigidities.[14] Throughout the section, we estimate the unbalanced panels using the fixed effects estimator with robust standard errors.

Columns (1) and (2) of Table 5 report the estimates of Eq. (9) for headline and core trend inflation. Changes in inflation expectations are positively and significantly associated to changes in the inflation trend, both for headline and core measures. On the other hand, an increase in the output gap correlates positively and significantly with changes in trend inflation for headline but it is unrelated to core, while an increase in the unemployment gap correlates negatively for both measures. When reached, the

[13] The tables with all the robustness exercises are available from the authors upon request.

[14] Alternative lag structures are explored below.

Table 5: Trend inflation: short-term inflation expectations and the business cycle

	Δ. Trend headline			
	(1)	(2)	(3)	(4)
Δ. Inflation expectations	0.066***	0.064***	0.067***	0.067***
	(0.018)	(0.017)	(0.018)	(0.017)
Δ.L. Output gap	0.011***			
	(0.002)			
Δ.L. Unemployment gap		−0.036**		
		(0.016)		
L. Output gap			0.008***	
			(0.001)	
L. Unemployment gap				−0.005***
				(0.001)
	Δ. Trend core			
	(1)	(2)	(3)	(4)
Δ. Inflation expectations	0.049***	0.043***	0.051***	0.050***
	(0.014)	(0.012)	(0.013)	(0.013)
Δ.L. Output gap	0.010			
	(0.008)			
Δ.L. Unemployment gap		−0.071***		
		(0.021)		
L. Output gap			0.008*	
			(0.004)	
L. Unemployment gap				-0.002
				(0.003)

Notes: L is the lag operator. See the notes to Table 4.

statistical significance of these relationships is high, however, the size of the estimates would only imply reduced impacts. For example, a one standard deviation increase in inflation expectations is associated to a 0.07pp change in trend headline inflation and to a 0.05pp change in trend core inflation. Similarly, a 1pp increase in the output gap is associated to a 0.01pp increase in trend headline inflation, while a 1pp increase in the unemployment gap is correlated to, respectively, a 0.04pp and a 0.07pp decrease in trend headline and trend core inflation. These results indicate that changes in short-term inflation expectations and economic slack have some role in explaining trend inflation, albeit a small one.

The second specification that we explore links changes in the inflation trend with the level of economic slack instead of its first difference. The level of slack may reflect more accurately the (dis)inflationary pressures in the economy since, even if the output gap is falling, inflation may still rise in the context of a substantially overheated economy, and vice versa, even if the output gap is rising, inflation may still fall further if the economy is in a pronounced recession. This rationale may lead us to estimate specifications on trend inflation of the form:

$$\Delta\tilde{\tau}_{it} = \alpha + \beta\Delta E[\pi_{it}] + \gamma Slack_{it-1} + \eta_i + \epsilon_{it}. \tag{10}$$

The estimates of Eq. (10) displayed in columns (3) and (4) of Table 5 show that the level of economic slack also correlates with trend inflation. In particular, a higher output gap is associated with higher levels of headline and core trend inflation, while a higher unemployment gap is related to lower headline trend inflation but is unrelated to core trend inflation. Once again, these effects tend to be of small magnitude, however, they do confirm that changes in inflation expectations and economic slack have some role in explaining trend inflation in EA countries.

Next, we turn to explore whether changes in other variables, different from inflation expectations and slack, can help explain changes in trend inflation in our sample of EA countries. To do so, we estimate the following panel specification:

$$\Delta\tilde{\tau}_{it} = \alpha + \gamma(L)\Delta X_{it} + \eta_i + \epsilon_{it}, \tag{11}$$

where X_{it} includes one candidate regressor at a time entering under two alternative lag structures, namely a lag polynomial $\gamma(L)$ up to the 4th lag or up to the 8th lag, since each of these factors may only affect trend inflation with a relevant delay. In X_{it}, we also consider changes in inflation expectations and in measures of slack, to compare estimates from all candidate regressors.

The results of estimating Eq. (11) are found in Table 6. The results in columns (1) and (2) of the table show that, for both the shorter and the longer lag structures, most of the candidate variables are significantly correlated with subsequent trend headline inflation, the exception being unit labor costs and three of the financial variables. Moreover, the signs of the cumulated impacts are the expected ones. For example, a positive change in earnings growth or import price inflation leads to an eventual increase in headline trend inflation, both after four and eight quarters. However, the estimates also suggest that the magnitude of any impact is likely to be fairly small, with the exception of some episodic variations. For example, the largest economically meaningful effect is found in the relationship between US$ Brent oil prices and the trend. Since, over the sample period, the standard deviation of the change in oil price inflation is 24.2pp, a one standard deviation move in oil price inflation will lead to a change in trend headline inflation equal to 0.36pp after eight quarters. To place this magnitude in perspective, note that in 2014-2015, when oil prices fell strongly, the total fall in oil price inflation reached 28.9pp which, in the absence of other shocks, would have eventually translated into a reduction of 0.43pp in trend headline inflation, a large magnitude. Likewise, a one standard deviation move in earnings growth, which amounts to 8.7pp, will result in a 0.33pp change in headline trend inflation. However, a one standard deviation change in earnings growth is only observed occasionally.

Table 6: Trend inflation: other explanatory variables

	Δ. Trend headline		Δ. Trend core	
	4 lags	8 lags	4 lags	8 lags
Other variables:	(1)	(2)	(3)	(4)
Δ. Earnings	0.006	0.037	0.010	0.044
	[0.084]	[0.072]	[0.104]	[0.009]
Δ. Unit labor cost	−0.001	−0.005	0.008	0.010
	[0.771]	[0.647]	[0.025]	[0.003]
Δ. Import prices	0.006	0.009	0.002	0.009
	[0.046]	[0.099]	[0.137]	[0.038]
Δ. World export prices	0.003	0.003	0.001	−0.001
	[0.058]	[0.095]	[0.253]	[0.323]
Δ. REER	−0.028	−0.074	−0.015	−0.120
	[0.020]	[0.042]	[0.392]	[0.032]
Δ. Brent oil price	0.007	0.015	−0.001	0.003
	[0.000]	[0.000]	[0.150]	[0.147]
Δ. Commodity price index	0.009	0.013	0.000	0.008
	[0.000]	[0.000]	[0.844]	[0.007]
Δ. Money supply (M3)	−0.001	−0.002	0.001	0.005
	[0.446]	[0.486]	[0.480]	[0.130]
Δ. Private debt	0.003	0.006	0.006	0.012
	[0.143]	[0.149]	[0.034]	[0.127]
Δ. Yields (10-year bonds)	0.029	−0.031	0.016	−0.024
	[0.432]	[0.119]	[0.647]	[0.437]
Δ. Stock index	0.002	0.009	−0.006	−0.001
	[0.025]	[0.053]	[0.046]	[0.933]
Standard variables:				
Δ. Inflation expectations	0.080	0.054	0.123	0.148
	[0.003]	[0.105]	[0.001]	[0.004]
Δ. Output gap	0.056	0.080	0.072	0.092
	[0.000]	[0.005]	[0.001]	[0.024]
Δ. Unemployment gap	−0.107	−0.126	−0.149	−0.133
	[0.000]	[0.004]	[0.000]	[0.000]

Notes: Each reported estimate is the sum of the coefficients of the corresponding lag polynominal where, in square brackets, figures the p-value of an F test of their joint significance.

Columns (3) and (4) of Table 6 display the corresponding estimates for trend core inflation. Broadly speaking, the results are similar to the ones discussed above, however, we find more insignificant coefficients. When significant, cumulated effects tend to be larger in the trend core specification if compared to the headline one, possibly because food and energy products are less sensitive to variations in those variables. For example, a one standard deviation increase in inflation expectations is associated with a 0.15pp change in trend core inflation, while the corresponding magnitude for trend headline stands at 0.05pp. Similarly, a one standard deviation move in earnings growth will lead to a 0.38pp change in core trend inflation after eight quarters, a slightly higher impact than the one described above.

In the last step, we explore whether introducing combinations of explanatory variables alters the above results. We focus on those variables that have shown a significant relationship with trend inflation, either in the fourth lag or the eighth lag or both, as reported in Table 6. The simultaneous inclusion of several variables would control for potential correlations among them. In light of the results so far, we enter inflation expectations contemporaneously while the impact of slack and other regressors on the trend is allowed to unfold over four quarters. The general specification can be described by:

$$\Delta\tilde{\tau}_{it} = \alpha + \beta\Delta E[\pi_{it}] + \gamma(L)\Delta Slack_{it} + \phi(L)\Delta Z_{it} + \eta_i + \epsilon_{it}. \tag{12}$$

Our reporting strategy proceeds as follows, after systematic estimation of Eq. (12), Tables 7 and 8 present the results for trend headline and trend core, respectively, when specifications always include inflation expectations and a measure of slack, both shown to be consistently significant across estimations. The results in Panel I of each table account for the output gap as a measure of slack while those in Panel II use the unemployment gap. The specifications reported include those other variables in Z_{it} that, by entering one at a time, retain significance as drivers of trend inflation once inflation expectations and slack are controlled for. In the last two columns of each panel, we report the estimates of introducing those significant variables all together. Note that the Brent oil price and the commodity price index cannot be introduced simultaneously as the latter also includes energy-related components.

The results for trend headline inflation in Table 7 suggest that, after controlling for the simultaneous variation in a wide set of factors, the variables that are consistently significant as explanatory forces behind the trend are inflation expectations, economic slack,

Table 7: Explaining changes in headline trend inflation

Panel I	(1)	(2)	(3)	(4)	(5)	(6)
Δ. Inflation expectations	0.059	0.049	0.049	0.061	0.048	0.047
	[0.004]	[0.011]	[0.011]	[0.006]	[0.011]	[0.010]
Δ. Output gap	0.040	0.052	0.053	0.048	0.053	0.052
	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]	[0.000]
Δ. REER	−0.034				−0.041	−0.037
	[0.025]				[0.019]	[0.022]
Δ. Brent oil price		0.005			0.006	
		[0.000]			[0.000	
Δ. Commodity price index			0.006			0.007
			[0.000]			[0.000]
Δ. Stock index				0.002	0.000	−0.001
				[0.005]	[0.787]	[0.488]

Panel II	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Δ. Inflation expectations	0.060	0.056	0.061	0.050	0.048	0.060	0.047	0.046
	[0.002]	[0.003]	[0.002]	[0.006]	[0.006]	[0.003]	[0.004]	[0.005]
Δ. Unemployment gap	−0.084	−0.088	−0.087	−0.093	−0.095	−0.095	−0.095	−0.097
	[0.007]	[0.006]	[0.006]	[0.004]	[0.004]	[0.005]	[0.009]	[0.008]
Δ. Earnings	0.004						0.005	0.005
	[0.082]						[0.055]	[0.037]
Δ. Import prices		0.003					0.002	0.001
		[0.090]					[0.187]	[0.338]
Δ. REER			−0.031				−0.041	−0.038
			[0.051]				[0.023]	[0.026]
Δ. Brent oil price				0.005			0.005	
				[0.000]			[0.001]	
Δ. Commodity price index					0.007			0.007
					[0.000]			[0.000]
Δ. Stock index						0.003	0.000	0.000
						[0.008]	[0.885]	[0.981]

Notes: With the exception of inflation expectations, each reported estimate is the sum of the coefficients of the fourth-lag polynominal where, in square brackets, figures the p-value of an F test of their joint significance.

the real effective exchange rate, and a measure of input price pressures (oil, commodities). Furthermore, if slack is proxied by the unemployment gap, earnings growth appears as an additional significant determinant of trend headline inflation. All variables carry the expected sign and the size of the coefficients do not vary much from earlier results, which suggests that impacts are likely to be fairly small with the possible exception of trade and openness variables.

For trend core inflation, the results reported in Table 8 suggest, once again, that inflation expectations and economic slack, especially the unemployment gap, are statistically relevant variables in predicting the trend component of the core. For additional explanatory factors, however, the results are more mixed. It appears that earnings growth is positively and significantly correlated with trend core inflation when the unemployment gap measure is included, while the correlation coefficient of import price inflation, although small, may display the wrong sign.

Table 8: Explaining changes in core trend inflation

Panel I	(1)	(2)	(3)	(4)	
Δ. Inflation expectations	0.037	0.041	0.042	0.045	
	[0.010]	[0.010]	[0.009]	[0.009]	
Δ. Output gap	0.063	0.069	0.064	0.067	
	[0.002]	[0.003]	[0.002]	[0.003]	
Δ. Earnings	0.006			0.005	
	[0.088]			[0.162]	
Δ. Import prices		−0.004		−0.003	
		[0.049]		[0.059]	
Δ. Commodity price index			−0.003	−0.002	
			[0.011]	[0.143]	
Panel II	(1)	(2)	(3)	(4)	(5)
Δ. Inflation expectations	0.031	0.035	0.029	0.037	0.037
	[0.020]	[0.020]	[0.017]	[0.014]	[0.025]
Δ. Unemployment gap	−0.128	−0.131	−0.126	−0.123	−0.118
	[0.001]	[0.000]	[0.001]	[0.000]	[0.000]
Δ. Earnings	0.006				0.006
	[0.083]				[0.019]
Δ. Import prices		−0.002			0.000
		[0.065]			[0.571]
Δ. Commodity price index			−0.003		−0.001
			[0.024]		[0.456]
Δ. Stock index				−0.003	−0.003
				[0.088]	[0.149]

Notes: See the note to Table 7.

Albeit with differences in the strength of associations, sensitivity tests using, alternatively, the trend components from the UCSV and the AR-trend models confirm the role of short-term inflation expectations, economic slack, and Brent oil and commodities prices as determinants of trend inflation dynamics. Other trade and openness variables show more mixed results.[15]

All in all, for EA countries, we consistently find some relevance for changes in expectations and economic slack in explaining trend inflation dynamics, both for headline and core measures. Open economy variables, such as the real effective exchange rate and the Brent oil and commodities prices, also appear to drive trend headline inflation, while earnings growth may play role when slack is proxied by the unemployment gap. Note that open economy variables consistently relate to trend headline inflation but not

[15] Robustness exercises are available from the authors upon request.

to trend core, which might indicate that they are more important in the determination of food and energy prices if compared to other items. The magnitude of the cumulated effects is, in most instances, small, however, impacts may reach a relevant size in certain episodes, particularly if they are sustained. Compared to the US and the UK, our study finds that a wider array of factors systematically drive trend inflation dynamics in EA countries. For example, Forbes et al. (2017) only ascribe a meaningful role to the sterling exchange rate while Cecchetti et al. (2017) find evidence of a more prominent role for domestic financial conditions, the trade-weighted dollar index and, to a lesser extent, the unemployment gap.[16]

Our findings for EA countries are of policy significance for at least two reasons. On the one hand, the monetary authority might want to respond to sequential shocks (e.g., oil price shocks) that are more likely to filter through to the inflation trend in order to ensure that long-term inflation expectations remain anchored and in line with the inflation target. On the other, the central bank may benefit from knowing how its policy influences the short-term dynamics of factors (e.g., inflation expectations, economic slack) that may robustly relate to trend inflation itself. Notably, this simple, non-structural empirical approach is suggestive of a channel through which variations in macroeconomic determinants typically related to the high inflation frequency may persist into the lower frequency component of EA inflation rates, prompting the search for theoretical mechanisms that can explain the observed correlations.

5 Conclusion

In this paper, we have provided a comprehensive analysis of the inflation processes of twelve EA countries over the last thirty years or so. The stylized features of inflation, in terms of mean, volatility and persistence, have uncovered the changing nature and the cross-country heterogeneity that have characterized inflation dynamics across the EA. To accommodate such variability, we present a set-up that nests a wide array of unobserved components models. After a careful exercise of model selection, we choose the trend inflation rates estimated in a framework that allows for time-varying inflation gap persistence and stochastic volatility in both the trend and transitory components. We

[16]Note also that, for trend headline inflation, our results are robust to the introduction of slack in levels instead of first differences, while slack loses significance in levels for trend core inflation.

consider these elements necessary to capture, among other things, the various channels through which policy and institutional developments of the last few decades may have impacted the inflation processes of EA countries. Among several results, we find that, on average, a sizeable share of overall inflation dynamics has been accounted for by movements in the trend. In explaining trend dynamics, we consistently find a significant role for inflation expectations, economic slack, and trade and openness variables, such as the real effective exchange rate and the Brent oil price. The magnitude of the cumulated effects is generally small, yet impacts may reach a meaningful size in certain, sustained episodes. This is of policy relevance since the monetary authority might want to respond to shocks that are prone to affect the inflation trend in order to ensure that long-term inflation expectations remain anchored, in line with the inflation target.

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Appendices

Appendix A Figures

Figure A.1: Estimated trend inflation across models (Headline)

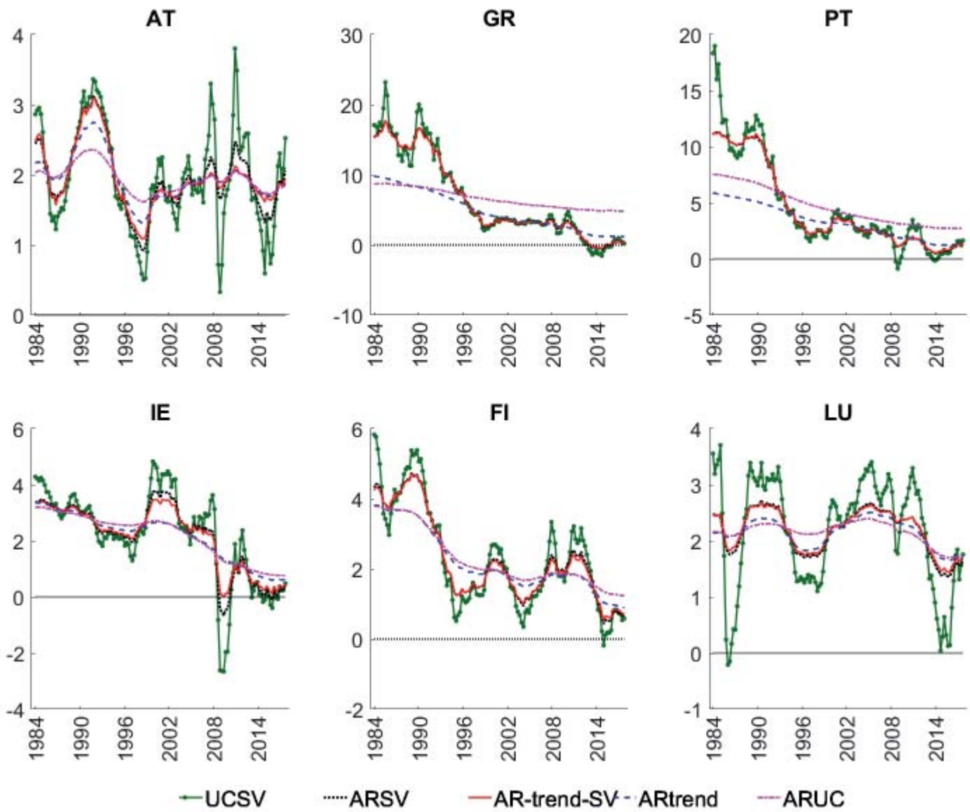


Figure A.2: Estimated trend inflation across models (Core)

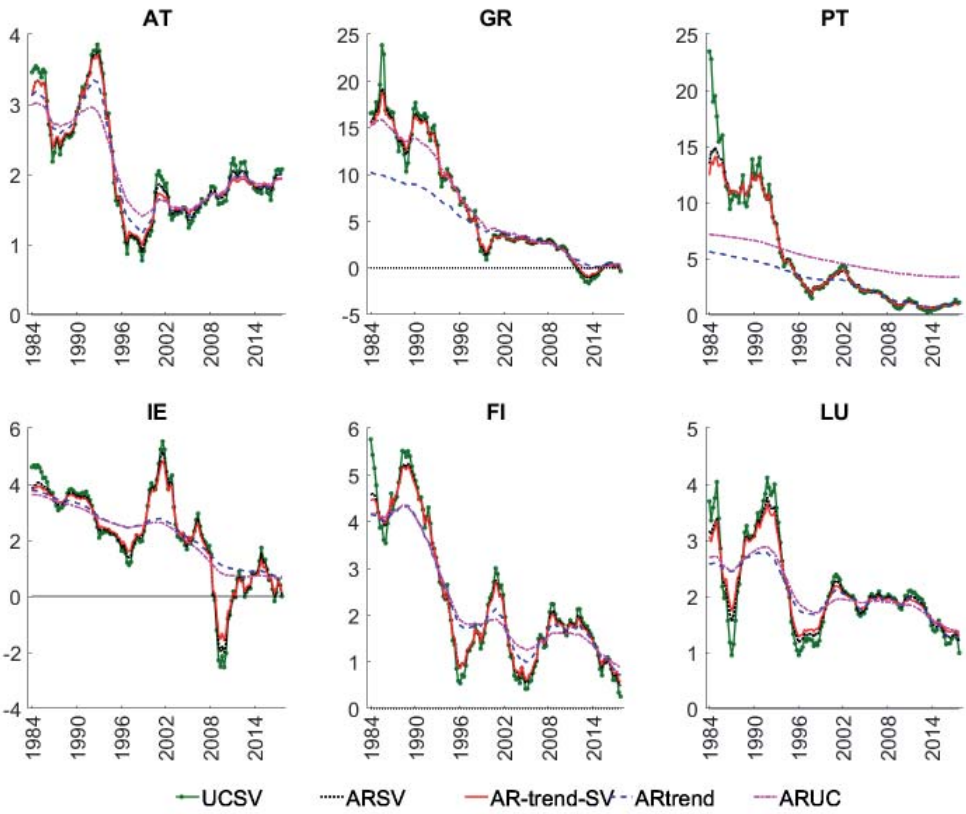
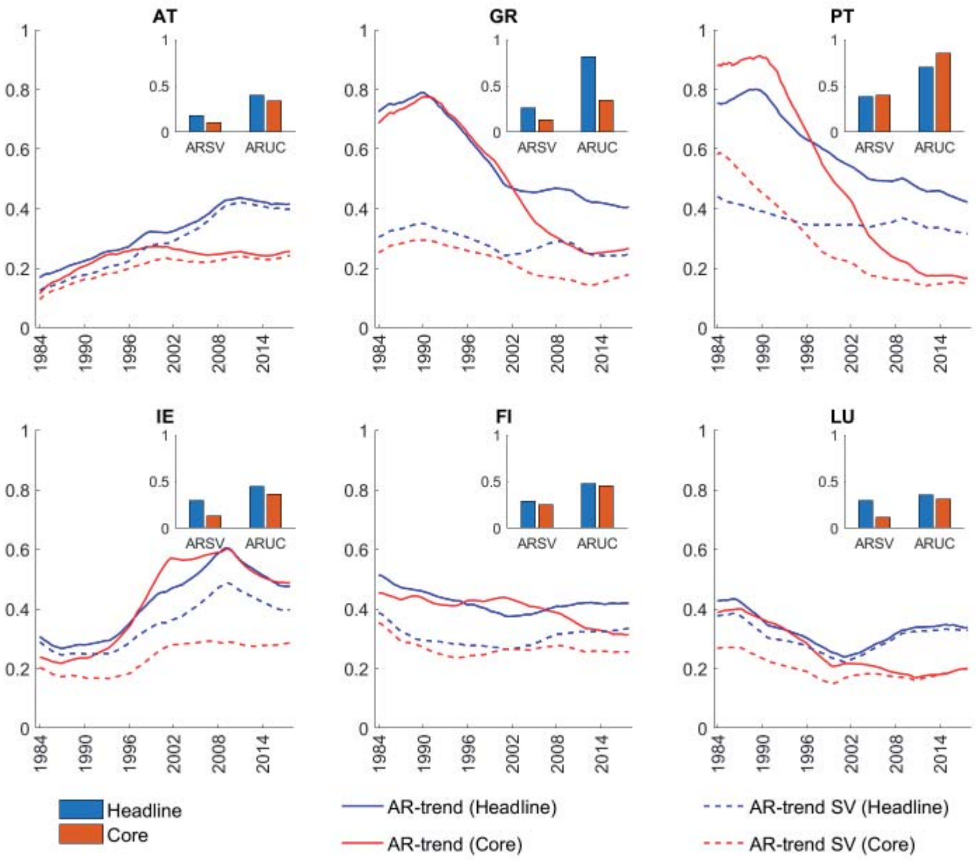


Figure A.3: Estimated inflation gap persistence parameter across models



Note: in the case of the ARUC and the AR-trend models the estimated parameter is fixed over time.

Figure A.4: Estimated trend stochastic volatility across models

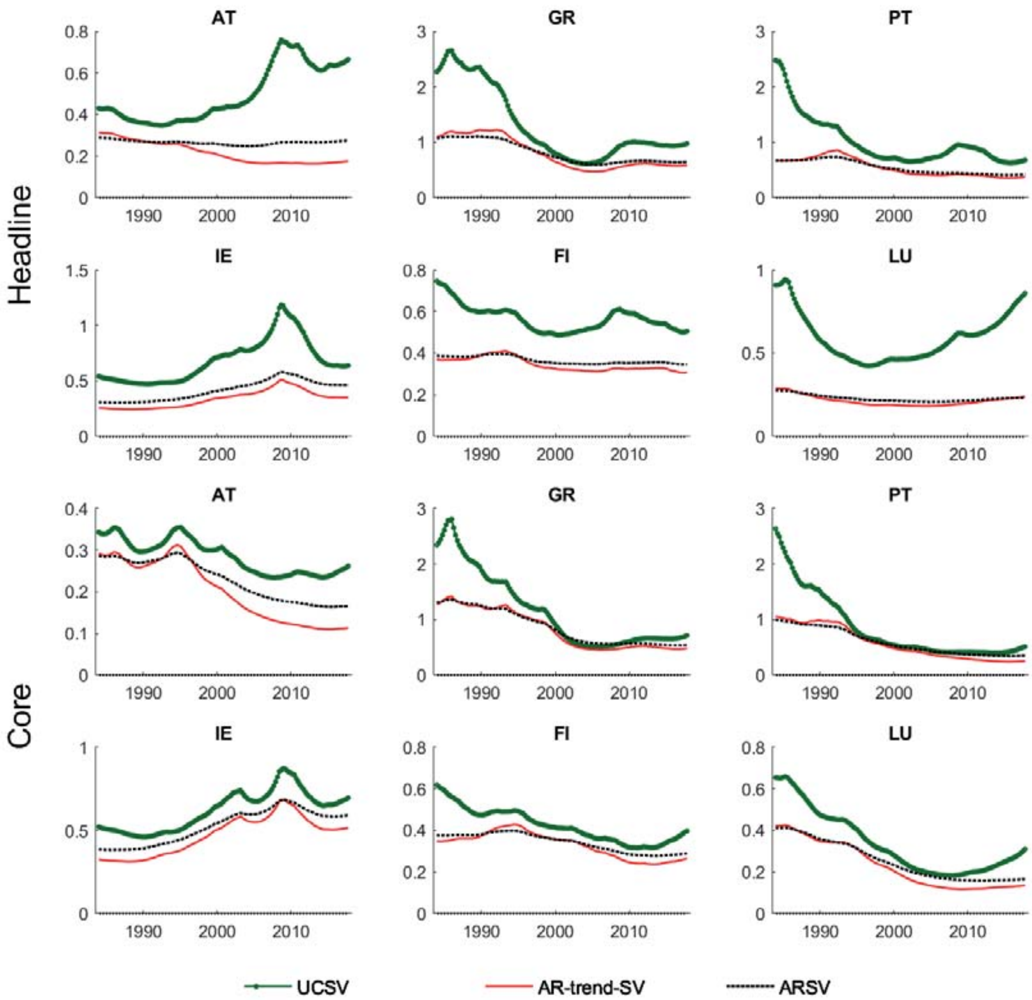


Figure A.5: Estimated inflation gap stochastic volatility (headline) across models

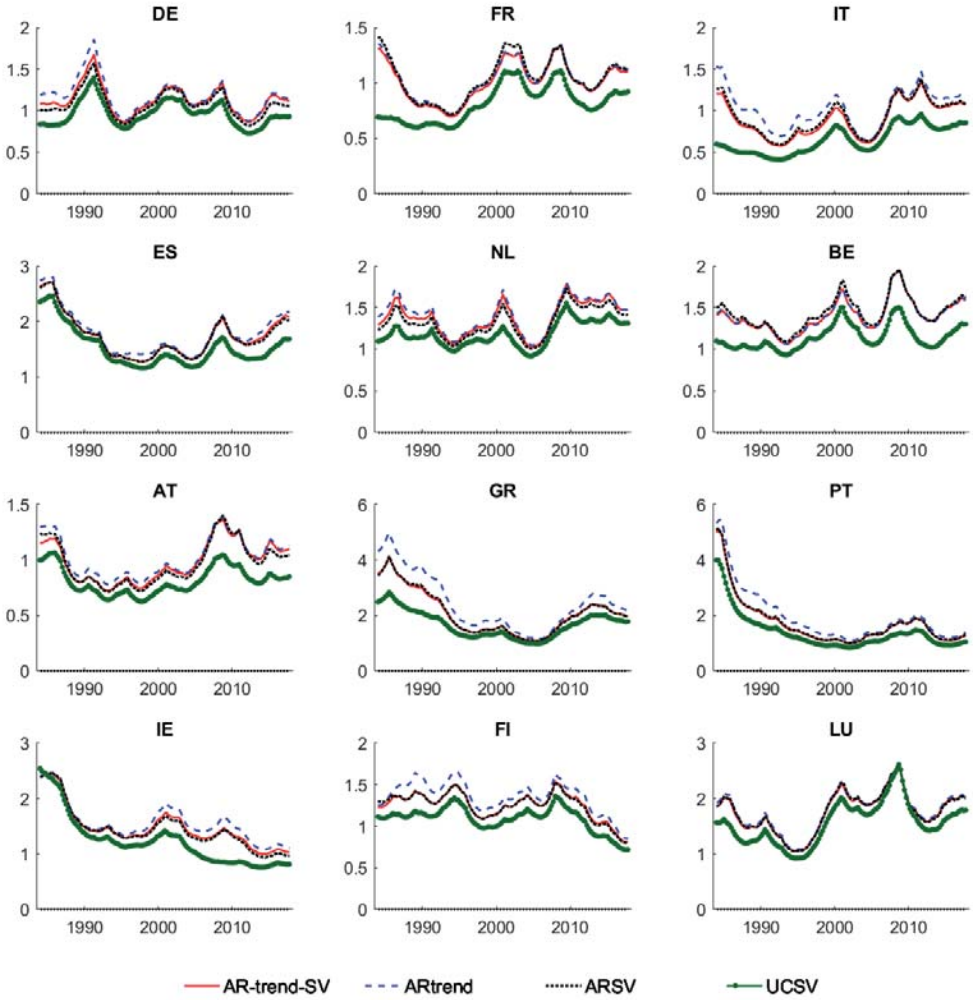


Figure A.6: Estimated inflation gap stochastic volatility (core) across models

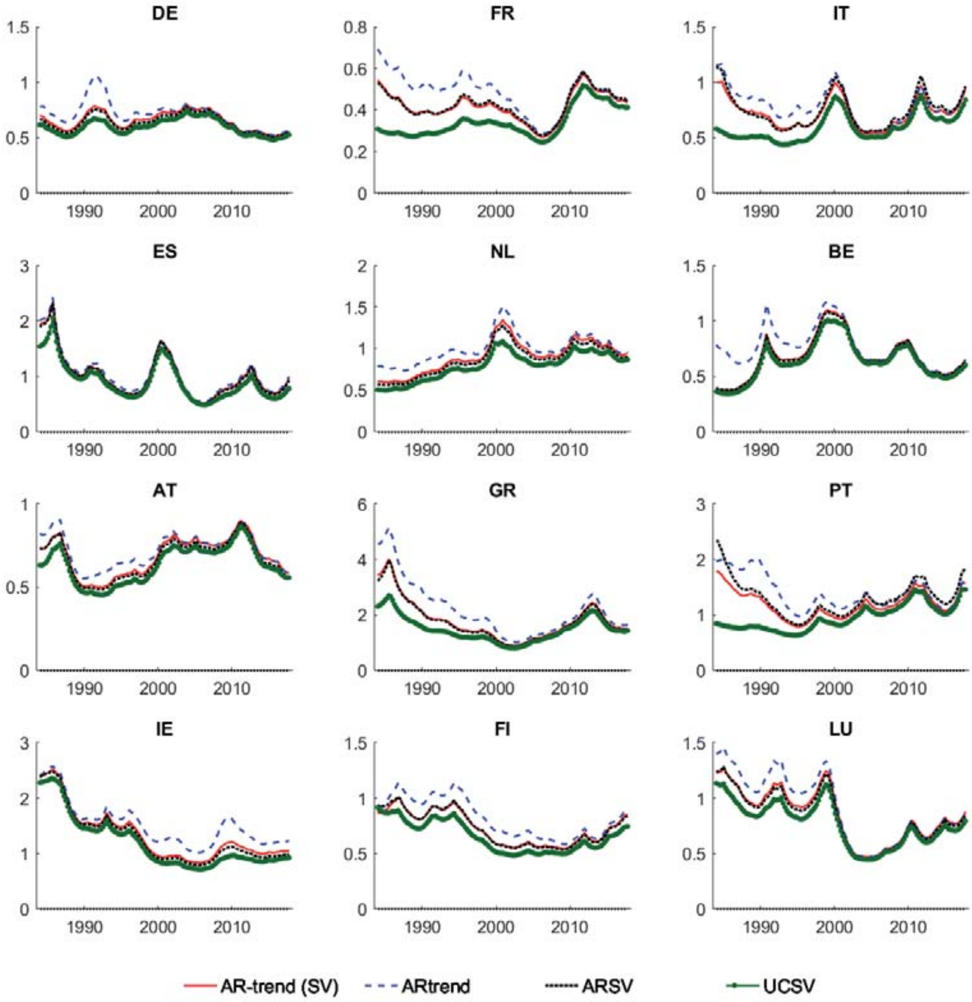
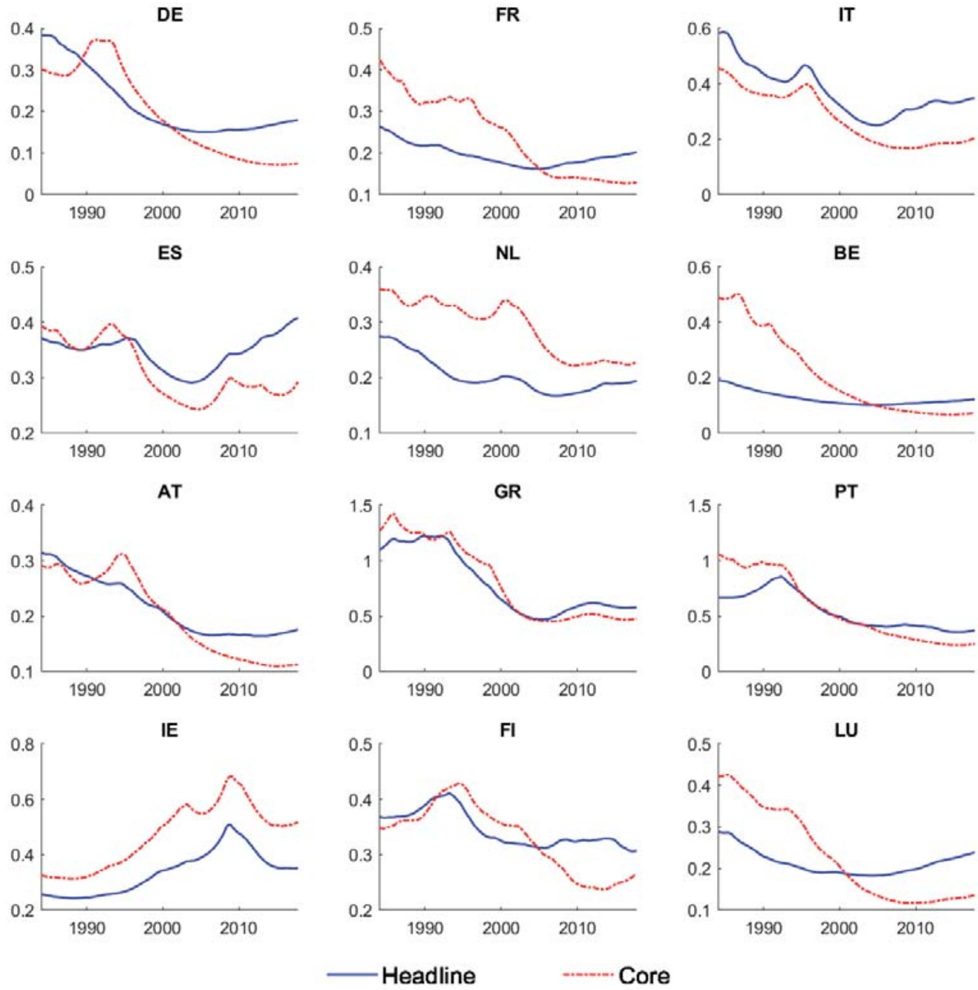


Figure A.7: Trend stochastic volatility (AR-trend-SV model): Headline vs Core



Appendix B Data definitions and sources

The database contains quarterly information of 12 EA countries. Most of the variables are availabe from 1995:q1 until 2017:q4. We work with HICP data to produce inflation series for the period 1984:q1-2017:q4.

Inflation measures are computed from the Harmonized Index of Consumer Prices (Headline HICP) and the HICP excluding food and energy (Core HICP). The inflation rate is calculated as the annualized quarter-on-quarter growth rate of the respective index, in percentages. Inflation series are seasonally adjusted. Source: OECD.

Inflation expectations are based on consumer survey data that capture the price trends of the respective country over the next twelve months. The original monthly series is aggregated to the quarterly frequency and standardized. The data available on the OECD-website are the numerical time series after the transformation of the qualitative survey responses. Source: OECD.

Economic slack measures are estimated following the three-equation model in Benes et al. (2010), except for Ireland where the output gap is calculated by applying the HP filter to the GDP series and the unemployment gap is taken from the ECB. The output gap is expressed in percentage log deviations from trend. The unemployment gap is the percentage difference between the unemployment rate and the NAIRU. Sources: Eurostat, ECB.

Earnings correspond to average hourly earnings computed as the ratio of wages divided by hours worked. The variable is expressed as annualized quarter-on-quarter growth rates, in percentages. Source: ECB.

Unit labor costs data is expressed as annualized quarter-on-quarter growth rates, in percentages. Sources: Datastream, ECB.

Import price inflation is computed from the import price deflator index, adjusted by openness (the sum of exports and imports divided by GDP, all nominal). The variable is expressed as annualized quarter-on-quarter growth rates, in percentages. Source: Datastream, ECB.

World export price inflation is computed from an aggregate global export price deflator, adjusted by openness at the country level (the sum of exports and imports divided by GDP, all nominal). The variable is expressed as annualized quarter-on-quarter growth rates, in percentages. Source: Datastream, ECB.

REER is the real effective exchange rate based on the price deflator of exports of goods and services. The variable is expressed as annualized quarter-on-quarter growth rates, in percentages. Source: European Commission.

Brent oil price inflation is computed from the $ price of the most important type of crude oil used in Europe, which serves as a major benchmark price for purchases of oil worldwide. The variable is expressed as quarter-on-quarter growth rates, in percentages. Source: ECB.

Commodity price index is the S&P GSCI, which is a broad-based commodity price index developed by Goldman Sachs containing 24 commodities from all commodity sectors: six energy products, five industrial metals, eight agricultural products, three livestock products and two precious metals. The variable is expressed as quarter-on-quarter growth rates, in percentages. Source: Datastream.

Money supply (M3) includes currency, deposits with an agreed maturity of up to two years, deposits redeemable at notice of up to three months and repurchase agreements, money market fund shares/units and debt securities up to two years. The variable is expressed as annualized quarter-on-quarter growth rates, in percentages. Source: ECB.

Private non-financial debt is the outstanding debt to the private sector (excl. financial institutions) in euro currency. The variable is expressed as annualized quarter-on-quarter growth rates, in percentages. Source: BIS.

Yields refers to the 10-year government bond yield. It is given as annualized yield-to-maturity, in percentages. Source: Datastream.

Stock index represents the country-specific leading stock market index. The variable is expressed as quarter-on-quarter growth rates, in percentages. Source: Datastream.

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