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Abstract

Although there is a vast literature on GDP comovement across countries, there is scant evidence on inflation interdependence. We analyze inflation comovements across a wide set of advanced economies and across the subset of euro area countries. Some of our findings are expected, such as the fact that inflation interdependence among advanced economies is quite relevant, but is higher among euro area countries, which show strong trade links and a share common monetary policy, or the fact that inflation synchronization among countries is highest for energy prices, reflecting common oil shocks. We also find a robust puzzle: core inflation interdependence is fairly low and this result holds for both core goods and services. Inflation synchronization seems to be particularly linked to comovements in driving variables of open economy new Keynesian Phillips curve and mark-up pricing models.

Keywords: inflation, synchronization, filtering, price heterogeneity, trend inflation.

JEL classification: E31, E32, C50.

Resumen

Aunque la literatura sobre el grado de comovimiento del PIB entre países es prolífica, existe poca evidencia sobre la interdependencia de la inflación. En este trabajo, se analizan los comovimientos de la inflación en un amplio conjunto de economías avanzadas, prestando especial atención a los países del área del euro. Los resultados confirman que el grado de interdependencia de la inflación entre las economías avanzadas es bastante elevado, pero es todavía mayor entre los países de la zona del euro, que tienen fuertes vínculos comerciales y comparten una política monetaria común. Asimismo, el componente energético muestra el mayor grado de sincronización, lo que puede reflejar la existencia de *shocks* comunes en el precio del petróleo. Un resultado inesperado, que se mantiene robusto frente a distintas especificaciones empíricas, es que el grado de interdependencia de la inflación subyacente en su conjunto es muy reducido. Este resultado se mantiene tanto para los bienes industriales no energéticos como para los servicios. Por último, identificamos que la sincronización de la inflación parece estar ligada a las variables recogidas en los modelos nekeynesianos de curva de Phillips de economía abierta y en los modelos de *mark-up* de precios.

Palabras clave: inflación, sincronización, filtrado, heterogeneidad de precios, inflación tendencial.

Códigos JEL: E31, E32, C50.

1 Introduction

Recent decades have witnessed an increase in the degree of interconnectedness among global economies associated with the growing economic and financial integration among countries. This globalization process is having an impact not only on real macroeconomic variables, but also on nominal ones, such as inflation. The aim of this paper is twofold. On the one hand, to derive a set of stylized facts on the degree of inflation comovement across countries. On the other hand, to shed some light on the macroeconomic drivers of inflation interdependence.

The open economy New Keynesian Phillips curve model provides a conceptual framework that suggests a variety of channels that potentially link inflation developments across countries. According to this model, inflation in a given country is driven by developments in external prices, including those of commodities, business cycles and inflation expectations, so that comovements in these drivers may lead to interdependence in inflation rates of different countries. For instance, commodity prices are largely determined in global markets, so that consumer price fluctuations can be experienced in many countries at the same time. This is particularly the case for oil prices, given that their transmission to domestic retail prices is typically fairly quick. A second natural explanation for the comovement of national inflation rates is that real activity is also correlated across countries. That is, business cycle comovement could lead to inflation comovement, via a Phillips Curve mechanism, as domestic inflation responds to changes in domestic demand.¹ For instance, the global financial crisis of 2007-2008 was followed by a prolonged period of low inflation worldwide. A third reason to explain inflation synchronization across countries rests on comovements in inflation expectations. These, in turn, may be affected by similar monetary policies and similar reactions by central banks or private agents to common shocks.

Open economy models also suggest that increases in the degree of openness, such as those brought about by globalization, may lead to higher inflation synchronization. In this regard, the growing importance of global value chains -i.e. cross-border trade in intermediate goods and services-, which also increase international competitive pressures on domestic price setting (Auer et al. (2017b)), would reinforce the degree of inflation interconnectedness.

Alternatively, mark-up pricing models suggest a highly relevant role of productivity developments in inflation dynamics. Indeed, in the presence of technological spillovers, productivity growth can generate movements in inflation which are synchronized across countries (Henriksen et al. (2013)) and common sector-specific technology shocks are amplified due to input-output linkages (Auer et al. (2017a)). Finally, inflation synchronization may be explained by relative purchasing power parity theories (Taylor and Taylor (2004)).

Even though, as discussed above, there are many theoretical channels that explain inflation interdependence, the evidence on the synchronization of inflation dynamics is very limited, in

¹An alternative theoretical reason behind inflation comovements is that domestic inflation is affected by world output to the extent that it has an impact on real marginal costs (e.g. Gali and Monacelli (2005)). From an empirical standpoint, Borio and Filardo (2007) show that measures of global slack have explanatory power into standard Phillips curve type equations of domestic consumer price inflation, but this finding has not been found to be robust. See e.g. Mikolajun and Lodge (2016).

contrast with that on business cycle comovement, the well-known fact that fluctuations in real economic activity tend to coincide across countries.² Early attempts at documenting inflation comovements, such as in Wang and Wen (2007) or Henriksen et al. (2013), have relied on Pearson correlation coefficients between country pairs and clearly show that headline inflation rates between any country pairs are positively correlated. A related strand of literature, following the seminal work by Cicarelli and Mojon (2010), estimates common/latent factor models³ and uses variance decompositions to measure the extent to which world and country-specific components explain the variation in national inflation rates.

Against this background, our contribution to the literature can be summarized as follows: First, we consider to which extent inflation interdependence is affected by heterogeneity in price dynamics. i.e. are inflation comovements mostly due to synchronization of sectoral shocks (e.g. energy) or are they broad-based? Heterogeneity in price dynamics has been documented along a number of dimensions,⁴ such as the degree of price stickiness (Álvarez et al. (2006)), the size of price adjustments (Dhyne et al. (2006)), the degree of inflation persistence (Lünnemann and Mathä (2004)), or demand elasticities, to name but a few, and it is standard in the inflation forecasting literature to consider different consumer price components (e.g. ECB (2016)) to capture heterogeneity in their response for different shocks. Moreover, optimal monetary policy is different when there is heterogeneity in price setting (Aoki (2001) and Carvalho (2006)). Second, we systematically study to which extent the degree of inflation interdependence is different for trends, business cycle fluctuations or short-term movements in inflation.⁵ For instance, comovement of trend inflation is likely to be due to similarities in central banks' inflation targets.⁶ In contrast, idiosyncratic shocks, such as those related to changes in indirect taxes, to weather conditions, and differences in transmission mechanisms, such as those due to differences in the degree of nominal stickiness, are likely to result in a low degree of inflation synchronization over the short run. Finally, inflation comovement is expected to be strongest at business cycle frequencies, reflecting the interdependence of international business cycles and its impact on national inflation via Phillips curve mechanisms. Third, we present evidence on inflation synchronization covering the period after the global financial crisis, which is characterized by low inflation levels.⁷ Fourth, we focus not only on advanced economies, but also on the subset of euro area countries, which have strong trade links and share a common monetary policy, that is a source of common demand shocks. Furthermore, euro area countries are also split into original euro area countries and newer ones. Fifth, we consider summary measures

²See, for instance, Kose et al. (2008) or de Haan et al. (2008).

³Other contributions include Neely and Rapach (2011), Mumtaz and Surico (2012) or Forster and Tillmann (2014). Carriero et al. (2018) analyze the global component of inflation volatility.

⁴The scant evidence on heterogeneity in inflation synchronization is limited to CPI stripped off energy and food prices. See e.g. Henriksen et al. (2013).

⁵Some papers present results on inflation interdependence over business cycle frequencies, e.g. Henriksen et al. (2013).

⁶Monetarist models of trend inflation (e.g. McCallum and Nelson (2011)) suggest, on average a one-for-one relation between long-run money growth, adjusted for trend output growth, and long-run inflation.

⁷Inflation in advanced economies has experienced long-term swings. Inflation progressively rose in the 1960s and 1970s before it declined in the 1980s and 1990s. Inflation in this Century has been fairly low, particularly since the global financial crisis.

of inflation interdependence which allow us to carry out statistical inference rather than using pairwise country correlations that are difficult to summarize.⁸ These summary measures can also be used to analyze changes in inflation synchronization over time. Indeed, the degree of inflation interdependence is not stable over time, reflecting the time-varying importance of the different types of shocks.⁹ Sixth, we analyze possible sources of inflation interdependence among the variables included in open economy new Keynesian Phillips curve and mark-up pricing models.

Our main results can be summarized as follows. First, we find that inflation interdependence among advanced economies is quite relevant. Second, inflation synchronization is not broad-based and there is marked heterogeneity in the degree of interdependence across sectors. Unexpectedly, inflation comovement is fairly low for core goods and services. Third, medium run fluctuations in inflation are synchronized to a large extent, when the Phillips curve mechanism is strongest. Comovement is also substantial for trend inflation. Fourth, the degree of comovement in headline inflation has increased over our sample period, possibly reflecting the role of growing trade integration and the impact of the common euro area monetary policy. Fifth, inflation synchronization among original euro area countries is higher than for all euro area countries, given that some of the newer members could not be characterized as having price stability prior to joining the euro, which in turn is higher than for advanced economies as a whole, partly due to the existence of different central banks with different reaction functions. Sixth, inflation interdependence seems to be particularly linked to comovements in driving variables of open economy new Keynesian Phillips curve and mark-up pricing models. Specifically, inflation expectations, business cycles, external prices, unit labour costs and mark-ups.

After this introduction, the rest of the paper is organized as follows. Section 2 describes the data, whereas section 3 is devoted to presenting results on inflation interdependence along several dimensions, such as country groups, types of products or frequency bands. Section 4 presents some robustness exercises. Section 5 analyses different sources of inflation interdependence and section 6 concludes.

2 The data

We focus on analyzing inflation developments in a wide set of advanced economies. Specifically, we consider a sample of 24 countries: Austria, Belgium, Canada, Cyprus, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Japan, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Slovakia, Spain, Sweden, United Kingdom and United States. In our analysis, we pay particular attention to euro area countries (EAC) as they show a high degree of trade linkages and share a common monetary policy that could lead to a high degree of inflation interdependence. Among EAC, we distinguish between original euro area countries (OEA) and

⁸Specifically, we consider the Stock and Watson (2008) modification of the Moran statistic used in the spatial correlation literature.

⁹For instance, evidence in Cicarelli and Mojon (2010) or Mumtaz and Surico (2012) suggest a lower degree of inflation synchronization early this Century than during the latest decades of the 20th Century.

newer euro area countries (NEA) to take into account that the latter only recently met the criteria needed to join this monetary union, including price convergence, and generally show a lower degree of trade interconnection with the rest of countries. Finally, the rest of advanced economies have country-specific monetary policies and are grouped as other advanced countries (OAC). See Table 1 for details.

To carefully assess the degree of heterogeneity in price setting, we have put together a database harmonizing, to the extent possible, country definitions. Specifically, we consider, besides the headline index, the following breakdown: (i) energy prices, which are typically quite volatile and subject to supply shocks (see Figure A1 and Table A1 in the appendix), (ii) food prices, which are also volatile and subject to sizable transitory shocks and (iii) core inflation, defined as the headline index excluding food and energy. We further decompose this core measure into (iv) non-energy industrial goods and (v) services, which are less exposed to external competition than manufactured goods.

We employ consumer price indexes for the period from January 1996 to April 2018. The series are seasonally adjusted. Data for the European countries come from Eurostat, US data from the Bureau of Labor Statistics, Canadian data from Statistics Canada and data for Japan from the Statistics Bureau of Japan.

3 Interdependence among advanced economies

A natural way to analyze inflation comovements is to consider the Pearson correlation coefficient for all country pairs. However, in our setting we would have 276 measures of synchronization for each inflation measure, which is not very practical. In order to solve this dimensionality problem, we take two different approaches. First, for each country, we simply compute the mean of its bivariate Pearson correlation coefficients with the rest of countries. Second, we use the Moran-Stock-Watson index of comovement (Stock and Watson, 2008). This measure, based on the spatial correlation literature, summarizes in a single number the degree of comovement in inflation across different countries. Furthermore, the distribution of this statistic is known, so that statistical inference can be carried out.

3.1 A first look at the data: Pearson correlation measures

Figure 1 shows the mean correlation of a specific country with all the other countries for each of the six inflation measures considered. The original members of the euro are depicted in red, those of more recent incorporation in blue, whereas countries in green correspond to the rest of advanced economies.

For headline inflation, we show that inflation comovements among euro area countries are higher than for advanced economies as a whole, possibly reflecting the fact that these countries show a high degree of trade linkages and share a currency. Among non-euro area countries, the

Japanese economy stands out for its very low degree of comovement with the rest of countries. In contrast, the high mean correlation of Denmark with respect to the rest of countries could be due to the fact that the Danish krone has been linked to the euro since the beginning of our sample. We also observe a higher degree of synchronization among original euro area countries than among those euro area countries of more recent incorporation (see Figure 2).

To assess whether inflation comovements are broad-based we have also computed mean correlations by type of product. Our main findings are as follows: First, core inflation measures generally show a low degree of comovement, a result also found in Carney (2017). This is particularly so for non-energy industrial goods, which may be affected by some country-specific factors, such as the timing of sales and promotions or the use of different quality adjustment procedures. Second, comovement is very high for energy prices, reflecting the role of common oil price shocks. Finally, there is a substantial degree of synchronization in food prices, probably reflecting high trade linkages.

3.2 Moran-Stock-Watson index of comovement

A more sophisticated measure of interdependence than the use of average correlations is given by the Moran-Stock-Watson (MSW) index of comovement (Stock and Watson, 2008), which summarizes in a single number the degree of synchronization in inflation developments across different countries. Specifically, the modification by Stock and Watson (2008) of Moran's I_t statistic is given by:

$$\widehat{MSW}_t = \frac{\sum_{i=1}^N \sum_{j=1}^{i-1} \widehat{cov}(\pi_{it}, \pi_{jt}) / N(N-1)/2}{\sum_{i=1}^N \widehat{var}(\pi_{it}) / N} \quad (1)$$

where

$$\widehat{cov}(\pi_{it}, \pi_{jt}) = \frac{1}{k} \sum_{s=t-int(k/2)}^{t+int(k/2)} (\pi_{is} - \overline{\pi_{it}})(\pi_{js} - \overline{\pi_{jt}}) \quad (2)$$

$$\widehat{var}(\pi_{it}) = \frac{1}{k} \sum_{s=t-int(k/2)}^{t+int(k/2)} (\pi_{is} - \overline{\pi_{it}})^2 \quad (3)$$

$$\overline{\pi_{it}} = \frac{1}{k} \sum_{s=t-int(k/2)}^{t+int(k/2)} \pi_{is} \quad (4)$$

where π_{it} is the inflation of country i in time t , $k = 61$ is the rolling window, which equals to 5 years working with monthly data, and $N=24$, the number of countries equals 24 and int refers to the integer part. It would be possible to build a spatial weights matrix $W(w_{ij})$ to weigh the different spatial units. Following Stock and Watson (2008), we have assumed that all countries behave like neighbors and, therefore, $w_{ij} = 1$ if $i \neq j$ and 0 if $i = j$.¹⁰

¹⁰The calculation of the MSW indexes using a spatial contiguity matrix does not change the results.

This index is bounded between 1 and -1, and the higher (lower) is its absolute value the higher is the degree of comovement. Positive values mean that inflation rates in different countries tend to go up (down) in tandem. An advantage of this index is that its distribution is known, so that we can carry out statistical inference and compute confidence intervals. Indeed, its mean and variance are given by:

$$E[MSW_t] = -1/(N-1) \quad (5)$$

$$Var_t[MSW_t] = \frac{NS_4 - S_{3t}S_5}{(N-1)(N-2)(N-3)S_0^2} \quad (6)$$

where

$$S_0 = \sum_i \sum_j w_{ij}$$

$$S_1 = \frac{1}{2} \sum_i \sum_j (w_{ij} + w_{ji})^2$$

$$S_2 = \sum_i (\sum_j w_{ij} + \sum_j w_{ji})^2$$

$$S_{3t} = \frac{N^{-1} \sum_i \frac{1}{k} \sum_{s=t-int(k/2)}^{t+int(k/2)} (\pi_{is} - \bar{\pi})^4}{(N^{-1} \sum_i \pi_i - \bar{\pi})^2}$$

$$S_4 = (N^2 - 3N + 3)S_1 - NS_2 + S_0^2$$

$$S_5 = S_1 - 2NS_1 + 6S_0^2$$

and the z-score for the MSW statistic is computed as:

$$z_t(MSW_t) = \frac{MSW_t - E(MSW_t)}{\sqrt{Var_t(MSW_t)}} \quad (7)$$

Before exploring the time series dimension of the Moran-Stock-Watson index of comovements we have computed a scalar version by considering the whole sample. The results for advanced economies and the euro area ones are presented in Table 2. We observe that inflation comovements are important and significant for all areas. Furthermore, interdependence is higher for original euro area countries than for all euro area countries which, in turn, is higher than for advanced economies as a whole. We interpret these results as reflecting the role of high trade linkages, which are particularly high among original euro area countries, and common monetary policy in the euro area.

We also analyze the role of heterogeneity across goods and services in the degree of synchronization. As expected, we find a high degree of heterogeneity in the degree of comovement of price change measures of the different types of goods and services. First, interdependence of

core inflation measures is significantly lower than for headline inflation ones, in line with Carney (2017).¹¹ This synchronization is particularly low for non-energy industrial goods. This low degree of comovement, which is somewhat puzzling, is in line with simple average correlation measures and suggests that more permanent fluctuations of inflation are not heavily synchronized across countries. Our explanation is that this low degree of synchronization reflects factors such as differences across countries in sales and promotion practices, which are particularly relevant for some goods, such as clothing, footwear or electrical appliances, and which have sizable impacts on retail prices.¹² Notice also that we use final consumer goods prices, which have a sizable non-tradable component linked to factors, such as retailers' labour costs such as rentals and, whose developments will generally vary across countries. We would expect export prices of these type of goods to display a higher degree of comovement. Second, the highest degree of comovement corresponds to energy prices. This is consistent with the relevance of common oil price shocks and the low degree of stickiness of these prices. Third, we find that food prices are also quite synchronized, probably due to globalization of food commodity markets and the increasing existence of multinational companies. Third, regarding the geographical breakdown, the highest degree of comovement for all categories of goods and services corresponds to original euro area countries, which is higher than for the whole set of euro area countries, which, in turn is higher than for advanced economies as a whole. As mentioned above, the high degree of trade linkages and the common monetary policy in the euro area may be behind these results.

3.2.1 Interdependence over time

To analyze changes over time in the degree of inflation synchronization we have used two complementary approaches. The first one refers to the examination of interdependence measures for two different subsamples and the second one to the use of rolling windows in the computation of measures. Notice that the subsample analysis considers a higher number of observations, so that inference is more precise than for rolling windows. This comes at the cost of subsample analysis being less accurate in the timing of changes than the one with rolling windows.

In the subsample analysis, we consider two different subsamples: the first subsample spans the period prior to the global financial crisis (that is, it goes from 1996 to 2007) and the second one covers the period after it (from 2008 to 2018).

Results are presented in Tables 3 and 4. Overall, inflation interdependence has increased after the global financial crisis, with the only exception of core inflation among the original euro area countries. This most likely reflects the fact that different countries increased indirect taxes and administered prices in a non-synchronized fashion after the crisis and, as a result, consumer prices tended to show a lower degree of interdependence.¹³

¹¹Similarly, Carriero et al. (2018) find that the global component of the volatility of headline inflation is considerably higher than that of core measures.

¹²Moreover, it has also to be borne in mind that, some countries make quality adjustments in some articles, while others do not.

¹³Core measures, non-energy industrial goods and services, also present different patterns across subsamples and geographical areas.

Some interesting information can also be obtained by analyzing developments over time of the Moran-Stock-Watson measures (see Figures 3 and 4), as some of the underlying factors, such as globalization are more relevant in the more recent period than in the past. Indeed, computing this statistic for centered rolling windows of 5 years, we find that inflation interdependence has not remained stable, but rather has tended to increase over time among advanced economies and also among euro area countries. This possibly reflects the role of growing trade integration and the role of a common euro area monetary policy in the latter group of countries.

Considering the different components for the whole sample of countries, the comovement is quite low for core inflation and the upward trend that was observed up to 2011 seems to be reversing, probably reflecting the fact that different euro area countries passed indirect tax increases in a non-synchronized manner. In contrast, the highest degree of synchronization corresponds to energy, where a mild upward trend over time is also observed. Patterns for euro area countries as a whole are broadly similar to those of advanced economies.

As the statistical distribution of the Moran-Stock-Watson index of comovement is known, we have calculated confidence intervals for advanced economies (Figure 5) and euro area ones (Figure 6) for each of the 6 types of products.¹⁴ The blue dotted lines show the confidence intervals for each of the 6 inflation measures. We find that the increase in synchronization trend is statistically significant for headline inflation and the most volatile components, energy and food. For core inflation, comovement is significant only around the years of the global financial crisis.¹⁵

Finally, given the well documented comovement in GDP, we compare it with inflation synchronization. We have computed the Moran-Stock-Watson index of comovements using GDP data. We find that inflation interdependence among advanced economies is quite relevant, but it is smaller than GDP interdependence (Table 2), a result that is also found for euro area countries. Moreover, developments over time in the degree of synchronization are different for inflation and activity. For instance, whereas headline inflation interdependence has remained quite high in recent years, GDP synchronization, which peaked at the time of the global financial crisis, decreased after the two latest European recessions (see Figures A3 and A4 in the appendix).¹⁶

3.3 Interdependence across frequency bands

The analysis above has not considered possible differences in the degree of inflation interdependence regarding developments in trend inflation, business cycle fluctuations in inflation or short-term movements in inflation, despite the fact that there are theoretical reasons for expecting differences in the degree of comovement depending on the more permanent or transitory nature of the forces driving inflation. For instance, country-specific shocks, such as those stemming from changes in indirect taxes or regulated prices, are likely to result in a low degree of inflation syn-

¹⁴For a comparison of developments over time of each inflation measure for each of the two groups of countries, see Figure A2 in the appendix.

¹⁵Considering windows of 10 years, comovement in core is significant.

¹⁶Moran-Stock-Watson indexes using quarter-on-quarter GDP growth rates have also been computed. Developments are similar, although the degree of interdependence is lower. These results are available upon request.

chronization over the short run, since they typically come into force in different countries at different times. In turn, synchronization of trend inflation may be due to similarities in central banks' inflation targets. Finally, inflation interdependence is expected to be strongest at business cycle frequencies, reflecting the synchronization of international business cycles and its impact on national inflation rates via Phillips curve mechanisms.

To decompose inflation into its trend, business cycle and short-term movements we use a band-pass filter.¹⁷ Different band-pass filters can be used to carry out this decomposition. For instance, Christiano and Fitzgerald (2003) or Baxter and King (1999) filters. In this paper, given that the Baxter and King filter involves losing observations at the start and end of the sample, we follow Henriksen et al. (2013) and use the Christiano and Fitzgerald filter. Specifically, we decompose inflation as:

$$\pi_t = \pi_t^T + \pi_t^{BC} + \pi_t^{SR} \quad (8)$$

where π_t^T captures movements in trend inflation, defined as cycles over 5 years, π_t^{BC} captures business cycle fluctuations between 2 and 5 years and π_t^{SR} captures short-run fluctuations, that is cyclical movements below 2 years.

Decomposition of inflation into its trend, business cycle and short-run components are displayed in the appendix for advanced economies (Figure A5) and euro area countries (Figure A6). To determine the source of comovements, we compute the Moran-Stock-Watson-based synchronization measures separately for π_t^T , π_t^{BC} and π_t^{SR} . Results of this interdependence measure for advanced economies, euro area countries and original euro area countries are displayed in Table 5 for the six products and the three frequency bands considered.¹⁸

Regarding headline inflation, we find that the degree of comovement is fairly low for high frequencies, reflecting the relevance of country-specific transitory shocks. In contrast, it is highest for the medium run, when the Phillips curve mechanism is expected to be strongest. In turn, trend inflation also shows a sizable degree of comovement, although it is lower than for long-run GDP fluctuations. Interestingly, for every frequency band, the degree of interdependence is higher for original euro area countries than for all euro area countries than for all advanced economies, suggesting a relevant role of (original) euro area-specific shocks. A similar pattern applies to GDP growth.

Regarding the product breakdown, we find that short-run interdependence of core inflation is close to zero, in sharp contrast with the energy component, which is heavily affected by common oil shocks. Core inflation synchronization for business cycle frequencies is significantly higher than for the short run, but still quite limited. Again, the highest degree of comovement in the medium run is found for the energy component. Finally, synchronization is limited for trend movements in

¹⁷Band-pass filters are explicit about frequency bands considered, in contrast with unobserved components models. Note that trend, cycle and irregular decompositions in unobserved component models implicitly consider different frequency bands, so some care is needed when comparing across countries or type of products. See Álvarez and Gómez-Loscos (2018).

¹⁸We have also computed mean Pearson correlation coefficients and results are broadly the same.

core inflation, in contrast with energy prices. For all frequency bands, food prices comove more than core ones, but less than energy ones.¹⁹

4 Robustness analysis

4.1 Leading/lagging countries

The analysis above exploits contemporaneous comovement among inflation rates, that is, the interrelationships of inflation across countries at the same moment of time. Here, as a robustness check, we analyze whether some countries could be leading/lagging the rest. To that end, we have computed cross-correlation coefficients of inflation in advanced economies/euro area ones with national inflation series for up to 12 leads and up to 12 lags. To save space, in Table 6 we report the highest correlation coefficient for lags 1 to 12, the contemporaneous one, and the highest correlation coefficient for leads 1 to 12, both for advanced economies as a whole and for euro area ones. This exercise is useful for determining whether inflation in some of the countries tends to lag or lead inflation in advanced economies or the euro area. Results show no clear evidence that any country is markedly leading or lagging advanced economies/euro area inflation developments. This allows us to discard the possibility that inflation in a particular country (for example, the United States) has been systematically leading that of the rest of the advanced economies. This supports the use of contemporaneous spatial correlation indexes.

4.2 Alternative measures of inflation interdependence

An alternative measure of comovement across countries is given by Pesaran's cross dependence test (Pesaran, 2004), which measures interdependence as a function of simple correlation coefficients across variables. Specifically, the measure is given by:

$$CD = \sqrt{\frac{2T}{N(N-1)}} \left(\sum_{i=1}^{N-1} \sum_{j=i+1}^N \hat{\rho}_{ij} \right) \quad (9)$$

where T is the total number of observations, N refers to the number of countries and ρ_{ij} to Pearson correlation coefficients. This statistic, under the null hypothesis of no cross-sectional dependence, follows a standard Gaussian distribution for $N \rightarrow \infty$ and T sufficiently large.

Results on Pesaran's cross-dependance test are displayed in Table 7. We find that results found using the Moran-Stock Watson measure are confirmed by using Pesaran's measure. That is, the lowest degree of synchronization is found for core prices and particularly so for those of non-energy industrial goods. In contrast, energy prices show the highest degree of comovement.²⁰

¹⁹For a comparison of developments over time of each inflation measure across frequency bands, see Figures A7 and A8 in the appendix.

²⁰Notice that Pesaran's statistic depends on the number of countries considered, so, on the basis of it, no claims can be made on the relative degree of interdependence for groups of countries of different sizes.

We have also applied the Peña-Rodriguez measure of cross-sectional dependence (Peña and Rodriguez, 2003). Similarly to the previous measures, we find that for all types of products and groups of countries, we reject the null hypothesis of no cross-sectional dependence.

5 Sources of inflation interdependence

To shed some light on the macroeconomic drivers of the degree of inflation interdependence, we consider a number of variables suggested by open economy new keynesian Phillips curve and mark-up pricing models. Then, we assess to which extent the interconnectedness of potential driving variables of inflation, in terms of their correlation matrix, mimics that of inflation interdependence. To that end, we assess the distance between correlation matrices using a matrix norm.²¹

Specifically, to compute the degree of similarity between two correlation matrices we use the Frobenius norm.²² This matrix norm is given by

$$\|P_{\pi} - P_{x^i}\|_F = \sqrt{\text{Tr}[(P_{\pi} - P_{x^i})(P_{\pi} - P_{x^i})']} \quad (10)$$

where P_{π} is the correlation matrix of inflation across countries, P_{x^i} is the correlation matrix of a potential driving variable and Tr is the trace operator.

The lower (higher) is the value of this norm, the closer (farther) are the two matrices. In the extreme case in which the two matrices are identical, the Frobenius distance between them is equal to zero.

As potential driving variables of inflation interdependence, we consider standard variables in new Keynesian Phillips curve and mark-up pricing models. An open economy new Keynesian Phillips curve models explains inflation developments (π_t) in terms of inflation expectations ($E_t\pi_{t+1}$), business cycles ($y_t - y_t^*$) and external prices (p_t^m). In stylized form:

$$\pi_t = \alpha E_t\pi_{t+1} + \beta(y_t - y_t^*) + \gamma p_t^m \quad (11)$$

To proxy these variables, we use a measure of inflation expectations based on consumer surveys, business cycles are measured using GDP growth, whereas external prices are proxied using the import deflator.

Alternatively, mark-up pricing models explain inflation dynamics in terms of the growth rate of unit labour costs (ulc_t) - which can be decomposed into its compensation per employee and productivity components-, mark-ups (μ_t) and external prices (p_t^m)

$$\pi_t = \alpha ulc_t + \beta \mu_t + \gamma p_t^m \quad (12)$$

²¹For a discussion on matrix norms, see e. g. Horn and Johnson (2012).

²²Note that a Frobenius norm is entry-wise, so that the similarity of matrices is done on an "element-by-element basis".

In this case, we use unit labour costs data from the national accounts, whereas mark-ups are proxied by the difference between the growth rate of the GDP deflator and the growth rate of unit labour costs.

The statistical distribution of the Frobenius norm between two correlation matrices is unknown, so we resort to Monte Carlo techniques to estimate it. Specifically, to test for the significance of each driver, we have designed an exercise in which we compute the empirical distribution with 10,000 replications of two random correlations matrices with a dimension equal to the number of involved countries. Figure 7 shows the kernel of the density obtained from which the p-values are calculated.

Results of the Frobenius norm, along with the p-values, are presented in Table 8.²³ Our results support both Phillips curve and mark-up pricing theories, given the similarity of interrelations of inflation drivers across countries (expectations, business cycles, external prices, unit labour costs and mark-ups) to interrelations of inflation across countries.

We also note that inflation interdependence between countries is similar to that of unit labor costs reflects similar synchronization patterns in wages (compensation per employee) developments rather than those of productivity.

In order to compare the sources of inflation interdependence in the three geographical areas, we focus on the significant variables (expectations, business cycles, external prices, unit labour costs and mark-ups) and we use the normalized inverse of the Frobenius norm, so that the measure does not depend on the number of countries. A higher (lower) value of this measure means that the interdependence of the explanatory variable is more (less) close to that of inflation (Figure 8).²⁴ We show that the most related variables to inflation interdependence are, in this order, business cycles, inflation expectations and external prices. We find that the relationship between these variables and inflation interdependence is closer among the euro area, and even more, among the original euro area countries. This holds for all variables, except unit labour costs, for which the values are similar in the three areas.

6 Concluding remarks

This paper has documented that inflation tends to move together in advanced economies. This is particularly so for euro area countries, which have substantial trade linkages and share a common monetary policy. Moreover, there is important heterogeneity in the degree of interconnectedness

²³GDP, employment, GDP deflator and import deflator (as a proxy for external prices) data are from Eurostat for the European countries, Statistics Canada for Canada, Cabinet office for Japan and Bureau of Economic Analysis for the US. Inflation expectations have been computed using the methodology of Buchmann (2009) for the European countries (see the Appendix B for details). For Japan, we apply the Carlson and Parkin (1975) methodology to Bank of Japan data. For Canada, data refer to firms and come from the Bank of Canada. For the US, they come from the St. Louis Fed FRED database. Compensation per employee data are from the OECD for all the countries, but Cyprus and Malta, for which we use Eurostat data. Unit labour costs (ULC) are computed as compensation per employee divided by productivity. The mark-up proxy is computed as the growth rate of the consumption deflator minus the growth rate of unit labour costs. Results are robust to using the GDP deflator instead of that of consumption.

²⁴It is divided by the number of observations within each group.

by type of product. Surprisingly, core inflation synchronization is fairly low, in clear contrast with energy prices, which are heavily dependent on oil global markets. Comovement across countries is higher when removing short-run fluctuations, which are typically quite country-specific, so that inflation interdependence is a medium to long run phenomenon. Furthermore, inflation synchronization has increased in recent years, against a background of globalization. However, the recent surge of protectionism points that this process may not necessarily deepen in the future.

Regarding the sources of inflation interdependence, we find that comovements in driving variables of open economy new Keynesian Phillips curve and mark-up pricing models help explain it.

On further work, one interesting line of research that this paper does not address is the role of trade intensity in explaining comovements in inflation. We expect that countries with closer trade links will tend to have more tightly correlated inflation rates. Another element well worth exploring is analyzing the sources of inflation interdependence in a multivariate setting. Finally, an issue that we also leave for further research is the study of the implications for monetary policy of the low degree of core inflation interdependence.

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Tables

Table 1: Geographical and product breakdown

Geographical breakdown			
Country aggregates	Euro Area countries		Other advanced countries (OAC)
	Original EA countries (OEA)	Newer EA countries (NEA)	
Advanced economies	Austria	Cyprus	Canada
European Union (EU)	Belgium	Greece	Denmark
Euro Area (EA)	Finland	Latvia	Japan
	France	Lithuania	Poland
	Germany	Malta	Sweden
	Ireland	Slovakia	United Kingdom
	Italy		United states
	Luxembourg		
	Netherlands		
	Portugal		
	Spain		
Product breakdown			
Headline inflation			
1. Energy			
2. Food			
3. Core inflation (Headline ex food and energy)			
3.1 Non-energy industrial goods			
3.2 Services			

Table 2: Moran-Stock-Watson measures of comovements

Countries	Headline	Energy	Food	Core	Non-energy	Services	GDP
Advanced economies	0.30 (0.00)	0.60 (0.00)	0.32 (0.00)	0.15 (0.01)	0.09 (0.07)	0.19 (0.00)	0.42 (0.00)
Euro area (EA)	0.36 (0.00)	0.65 (0.00)	0.36 (0.00)	0.20 (0.02)	0.14 (0.06)	0.22 (0.01)	0.42 (0.01)
Original EA countries (OEA)	0.59 (0.00)	0.84 (0.00)	0.51 (0.00)	0.29 (0.04)	0.18 (0.14)	0.31 (0.03)	0.55 (0.00)

Note. p-values in parentheses.

Table 3: Moran-Stock-Watson measures of comovements (1996M1-2007M12)

Countries	HICP	Energy	Food	Core	Non-energy	Services
Advanced economies	0.05 (0.24)	0.50 (0.00)	0.18 (0.00)	0.07 (0.13)	0.10 (0.06)	0.06 (0.16)
Euro area (EA)	0.03 (0.39)	0.55 (0.00)	0.22 (0.01)	0.04 (0.34)	0.08 (0.20)	0.02 (0.43)
Original EA countries (OEA)	0.40 (0.01)	0.81 (0.00)	0.43 (0.00)	0.41 (0.01)	0.32 (0.02)	0.31 (0.03)

Note. p-values in parentheses.

Table 4: Moran-Stock-Watson measures of comovements (2008M1-2018M4)

Countries	HICP	Energy	Food	Core	Non-energy	Services
Advanced economies	0.50 (0.00)	0.67 (0.00)	0.47 (0.00)	0.19 (0.00)	0.03 (0.33)	0.19 (0.00)
Euro area (EA)	0.55 (0.00)	0.74 (0.00)	0.51 (0.00)	0.23 (0.01)	0.12 (0.10)	0.25 (0.00)
Original EA countries (OEA)	0.77 (0.00)	0.86 (0.00)	0.65 (0.00)	0.22 (0.09)	0.11 (0.25)	0.25 (0.06)

Note. p-values in parentheses.

Table 5: Moran-Stock-Watson measures of comovements across frequency bands

Countries	Headline	Energy	Food	Core	Non-energy	Services	GDP
TREND INFLATION							
Advanced economies	0.26 (0.00)	0.63 (0.00)	0.29 (0.00)	0.15 (0.01)	0.10 (0.06)	0.20 (0.00)	0.40 (0.00)
Euro area (EA)	0.33 (0.00)	0.69 (0.00)	0.31 (0.00)	0.20 (0.02)	0.15 (0.06)	0.24 (0.01)	0.40 (0.00)
Original EA countries (OEA)	0.58 (0.00)	0.89 (0.00)	0.47 (0.00)	0.30 (0.03)	0.20 (0.10)	0.34 (0.02)	0.58 (0.00)
BUSINESS CYCLE FLUCTUATIONS							
Advanced economies	0.40 (0.00)	0.61 (0.00)	0.42 (0.00)	0.20 (0.00)	0.07 (0.13)	0.18 (0.00)	0.58 (0.00)
Euro area (EA)	0.45 (0.00)	0.67 (0.00)	0.48 (0.00)	0.23 (0.01)	0.14 (0.07)	0.22 (0.01)	0.57 (0.00)
Original EA countries (OEA)	0.65 (0.00)	0.83 (0.00)	0.62 (0.00)	0.33 (0.02)	0.16 (0.16)	0.36 (0.01)	0.65 (0.00)
SHORT-RUN FLUCTUATIONS							
Advanced economies	0.28 (0.00)	0.50 (0.00)	0.12 (0.03)	0.03 (0.34)	0.00 (0.55)	0.02 (0.38)	0.15 (0.01)
Euro area (EA)	0.26 (0.00)	0.51 (0.00)	0.14 (0.06)	0.03 (0.38)	0.01 (0.53)	0.03 (0.42)	0.14 (0.07)
Original EA countries (OEA)	0.45 (0.00)	0.72 (0.00)	0.20 (0.11)	-0.01 (0.61)	-0.03 (0.71)	0.02 (0.52)	0.14 (0.19)

Note. p-values in parentheses.

Table 6: Cross-correlations of inflation of each country with Advanced economies and the Euro Area

Countries	Advanced economies			Euro Area		
	lags	comtemp.	leads	lags	comtemp.	leads
Austria	0.69	0.73	0.71	0.77	0.80	0.78
Belgium	0.71	0.76	0.75	0.79	0.82	0.79
Finland	0.39	0.45	0.51	0.60	0.64	0.66
France	0.77	0.82	0.79	0.92	0.95	0.91
Germany	0.79	0.83	0.79	0.87	0.90	0.86
Ireland	0.53	0.56	0.57	0.62	0.64	0.63
Italy	0.66	0.70	0.72	0.88	0.92	0.92
Luxembourg	0.83	0.86	0.81	0.88	0.89	0.84
Netherlands	0.34	0.39	0.50	0.61	0.64	0.66
Portugal	0.63	0.65	0.65	0.79	0.79	0.77
Spain	0.79	0.80	0.78	0.91	0.92	0.89
Cyprus	0.62	0.67	0.69	0.75	0.78	0.77
Greece	0.49	0.51	0.49	0.62	0.62	0.59
Latvia	0.53	0.57	0.61	0.55	0.58	0.60
Lithuania	0.34	0.39	0.47	0.34	0.38	0.42
Malta	0.30	0.38	0.53	0.47	0.52	0.57
Slovakia	0.38	0.40	0.40	0.39	0.40	0.39
Canada	0.68	0.73	0.66	0.59	0.61	0.56
Denmark	0.62	0.67	0.66	0.78	0.80	0.78
Japan	0.15	0.20	0.22	-0.13	-0.10	-0.05
Poland	0.23	0.25	0.24	0.16	0.17	0.17
Sweden	0.31	0.36	0.35	0.48	0.49	0.47
United Kingdom	0.37	0.42	0.44	0.47	0.51	0.53
United States	0.94	0.99	0.92	0.77	0.78	0.73

Note. We report the highest correlation coefficient for lags 1 to 12, the contemporaneous one, and the highest correlation coefficient for leads 1 to 12.

Table 7: Pesaran's cross-dependence test (CD)

Countries	HICP	Energy	Food	Core	Non-energy	Services
Advanced economies	116.20	176.28	103.94	47.46	17.10	70.40
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Euro area (EA)	98.29	133.35	86.78	44.36	21.98	56.43
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)
Original EA countries (OEA)	76.71	102.54	66.29	37.07	23.09	37.63
	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)	(0.00)

Note. p-values in parentheses.

Table 8: Inflation sources (Frobenius norm)

Variables	AE	EA	OEA
Inflation expectations	8.50 (0.00)	5.01 (0.00)	2.04 (0.00)
Business cycles	7.78 (0.00)	4.34 (0.00)	1.92 (0.00)
External prices	8.52 (0.00)	4.74 (0.00)	2.67 (0.00)
Unit labour costs	8.18 (0.00)	5.60 (0.00)	4.06 (0.00)
Compensation per employee	9.16 (0.04)	7.44 (1.00)	5.92 (1.00)
Productivity	10.21 (1.00)	7.73 (1.00)	5.56 (0.97)
Mark-up	9.04 (0.01)	6.27 (0.03)	3.30 (0.00)

Note. p-values in parentheses.

Figures

Figure 1: Mean correlation coefficients of each country with the rest by group

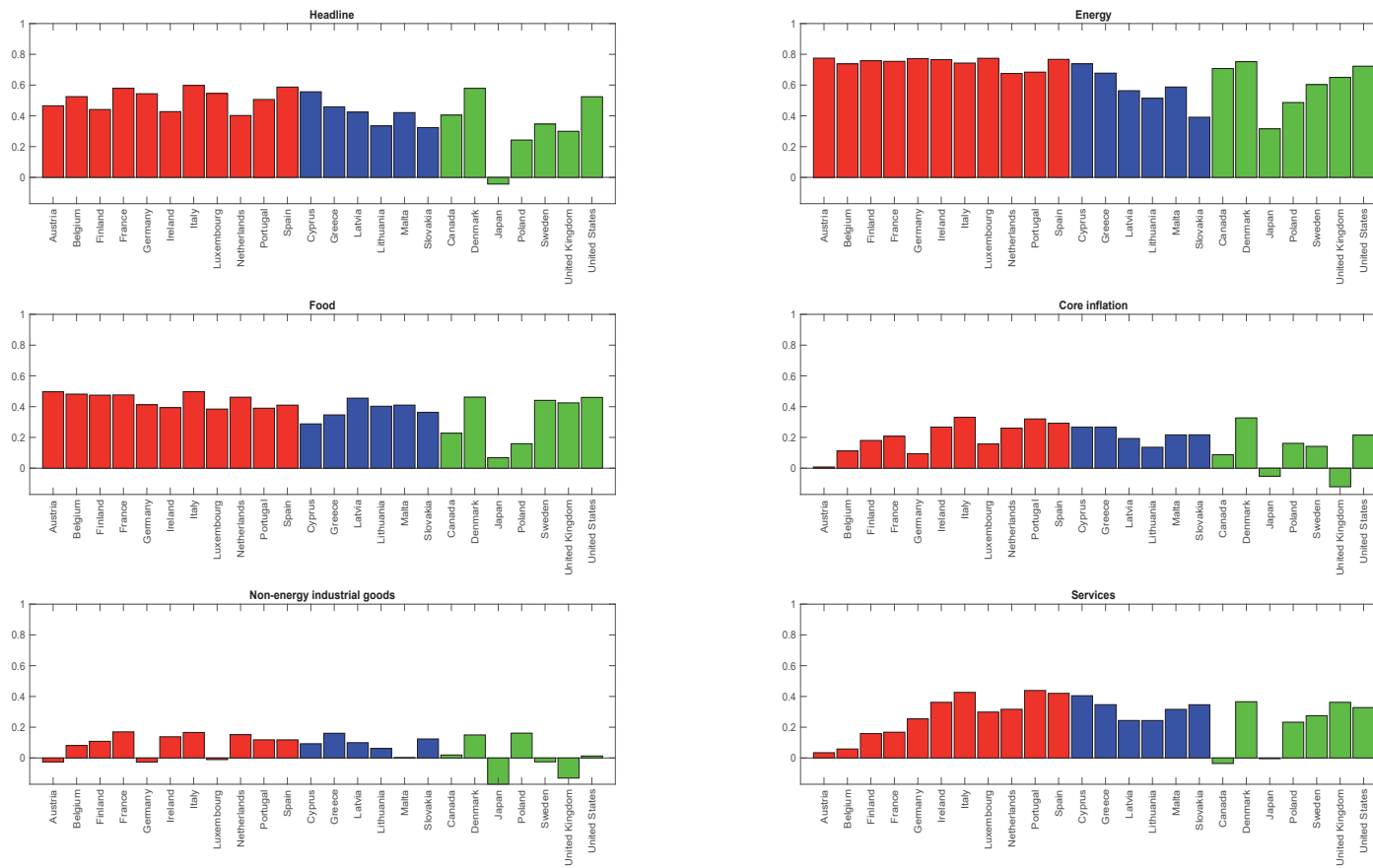


Figure 2: Mean correlation coefficients of each EA country with the rest by group

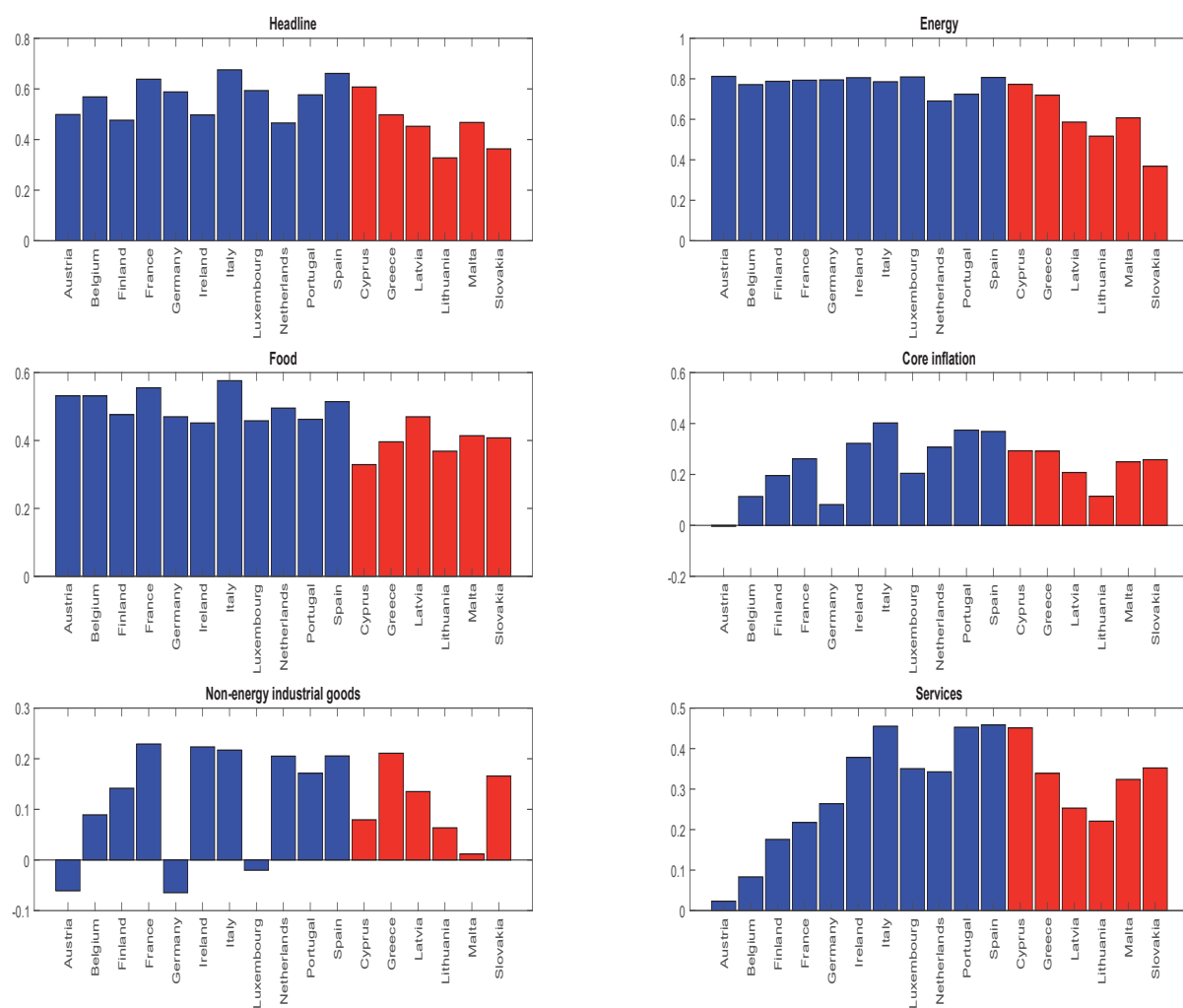


Figure 3: Moran-Stock-Watson measure of comovements. Advanced countries (window=5 years)

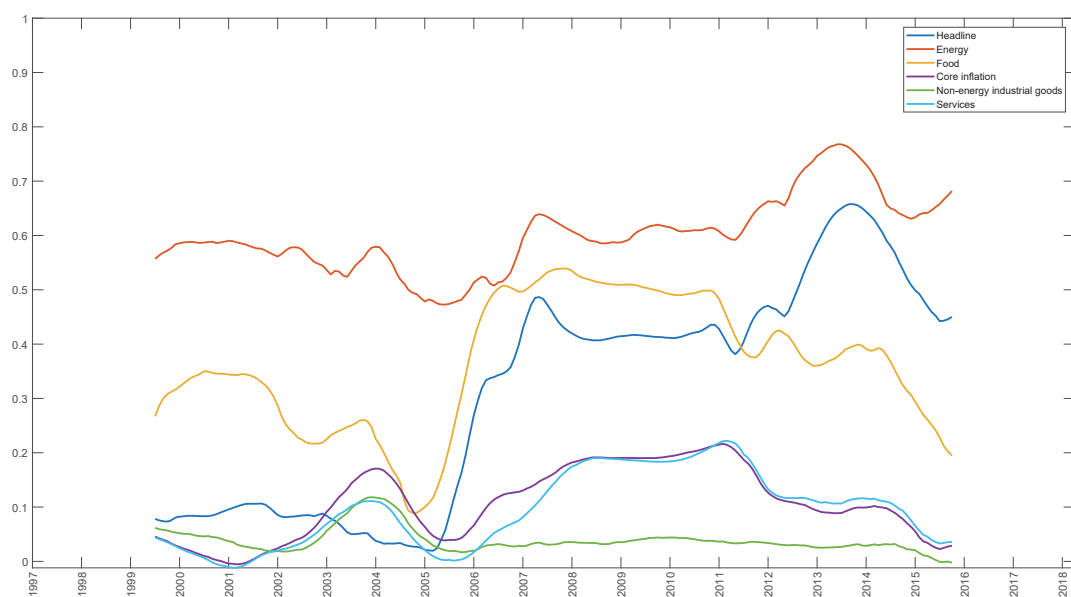


Figure 4: Moran-Stock-Watson measure of comovements. Euro area countries (window=5 years)

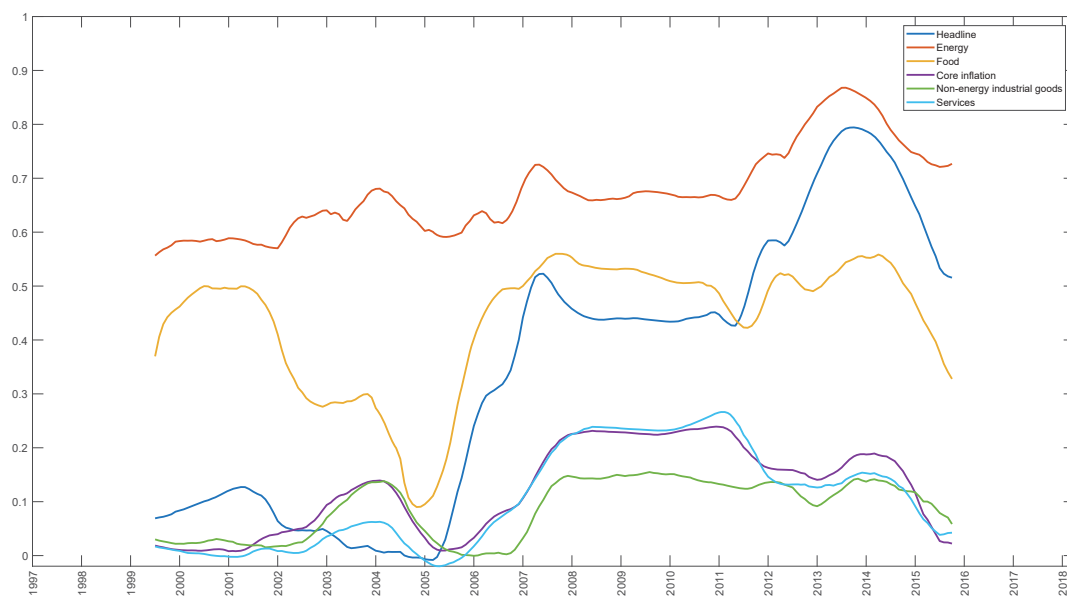


Figure 5: Moran-Stock-Watson measure of comovements. Advanced economies (window=5 years, along with 0.95 confidence intervals)



Figure 6: Moran-Stock-Watson measure of comovements. Euro area countries (window=5 years, along with 0.95 confidence intervals)



Figure 7: Empirical distribution of the Frobenius norm test

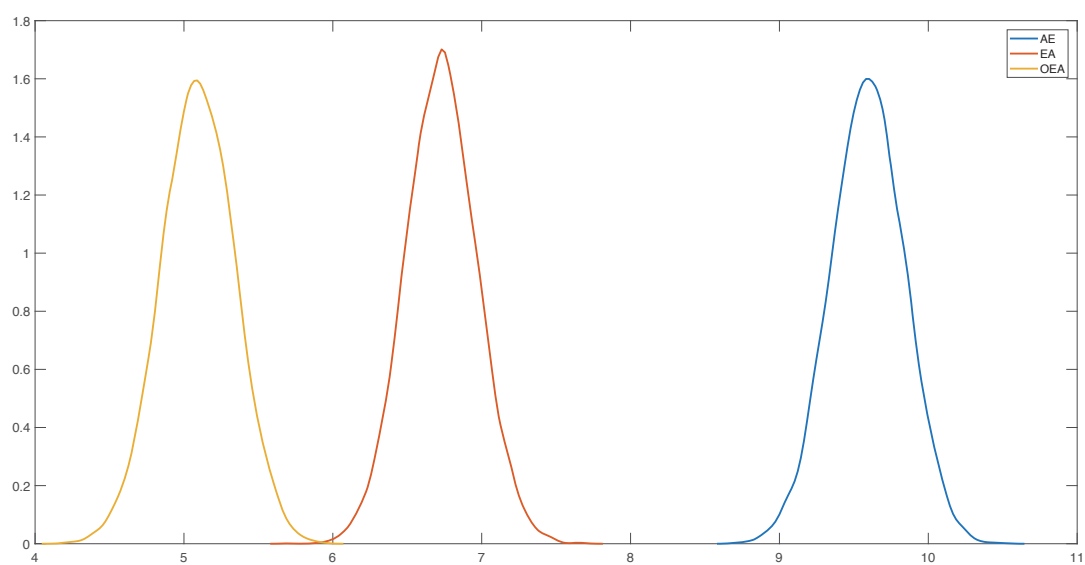
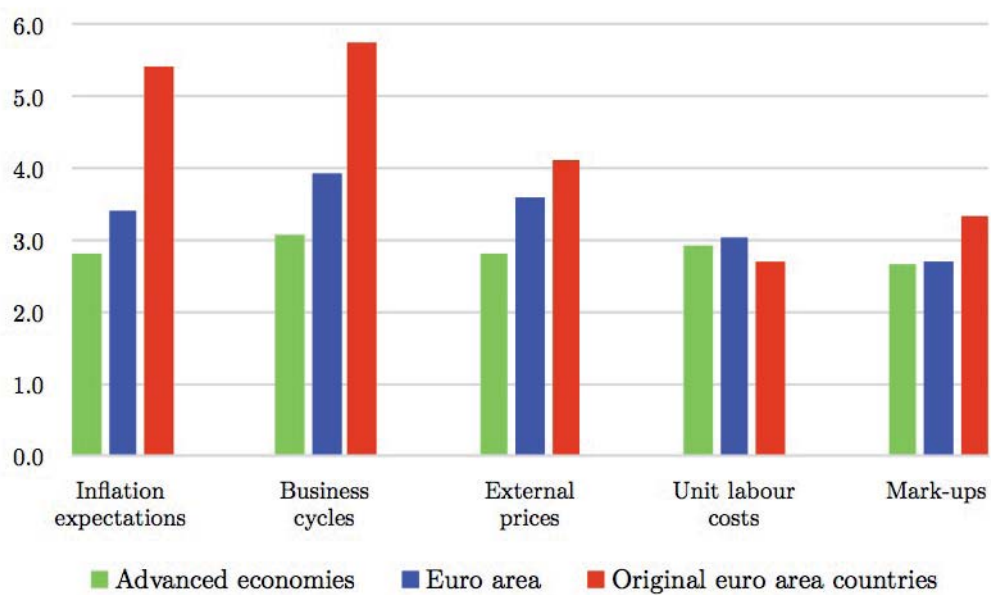


Figure 8: Sources of inflation interdependence



Note. Computed as the inverse of the Frobenius norm standardized

Appendix A

Table A1. Descriptive statistics

Countries	Headline			Energy			Food			Core inflation			non-energy industrial goods			Services		
	Mean	Median	St.dev.	Mean	Median	St.dev.	Mean	Median	St.dev.	Mean	Median	St.dev.	Mean	Median	St.dev.	Mean	Median	St.dev.
Advanced economies	1.87	1.83	0.96	3.12	3.77	9.64	2.12	1.96	1.16	1.74	1.76	0.36	0.13	0.09	0.53	2.41	2.45	0.54
European Union	1.76	1.85	0.89	3.10	2.81	5.81	2.28	2.04	1.44	1.42	1.47	0.39	0.36	0.38	0.36	2.21	2.25	0.58
Euro area	1.65	1.84	0.89	2.92	2.52	6.40	2.06	1.94	1.33	1.37	1.36	0.42	0.64	0.60	0.35	1.90	1.87	0.57
Austria	1.73	1.72	0.85	2.13	1.63	6.89	2.13	2.05	1.60	1.62	1.61	0.52	0.68	0.63	0.70	2.26	2.25	0.65
Belgium	1.85	1.78	1.09	3.01	2.38	9.38	2.29	2.16	1.51	1.50	1.46	0.42	0.83	0.86	0.61	2.03	2.04	0.48
Finland	1.63	1.43	1.04	2.92	2.26	6.78	1.74	1.38	2.69	1.45	1.50	0.67	0.01	0.00	0.79	2.51	2.56	0.83
France	1.45	1.51	0.87	2.66	1.83	6.61	1.96	1.65	1.60	1.14	1.04	0.50	0.19	0.14	0.50	1.77	1.65	0.72
Germany	1.39	1.41	0.80	3.01	2.74	6.06	1.88	1.86	1.46	1.06	1.14	0.41	0.57	0.66	0.56	1.41	1.38	0.49
Ireland	1.74	1.92	1.89	3.37	3.25	6.95	1.73	1.53	2.67	1.50	1.65	1.81	-1.89	-1.54	2.19	3.20	3.07	1.89
Italy	1.85	2.04	0.99	2.44	2.51	6.46	2.01	1.78	1.42	1.73	1.87	0.66	1.28	1.37	0.60	2.09	2.24	0.85
Luxembourg	2.09	2.17	1.40	2.57	2.44	10.41	3.04	2.97	1.22	1.73	1.88	0.53	1.09	1.12	0.55	2.36	2.49	0.71
Netherlands	1.83	1.70	1.18	3.54	4.17	5.66	2.05	1.82	1.95	1.56	1.29	0.98	0.56	0.41	1.22	2.32	2.17	1.10
Portugal	2.00	2.19	1.36	3.29	3.02	5.72	1.93	2.26	2.12	1.79	1.84	1.21	0.42	0.34	1.48	2.82	2.79	1.36
Spain	2.12	2.39	1.45	2.97	2.57	8.14	2.54	2.52	1.75	1.84	2.25	1.03	0.90	0.96	0.95	2.60	3.21	1.36
Cyprus	1.85	2.07	1.84	4.75	5.34	11.68	3.22	3.40	3.08	0.97	1.00	1.08	-0.43	-0.59	1.42	2.08	2.32	1.57
Greece	2.35	2.96	1.97	4.16	3.10	10.98	2.78	2.74	2.20	2.01	2.54	2.12	1.02	1.60	2.12	2.66	3.19	2.55
Latvia	3.74	2.98	3.79	5.60	5.01	7.60	4.44	2.52	5.11	3.11	1.93	3.58	1.61	1.30	2.95	4.54	3.00	4.82
Lithuania	2.83	2.31	3.17	5.40	5.73	7.87	3.06	2.58	4.39	2.20	1.61	2.97	0.43	0.08	2.55	4.45	3.45	4.03
Malta	2.24	2.29	1.24	4.16	3.02	8.36	3.24	2.90	2.00	1.81	1.70	1.11	0.72	0.76	1.01	2.64	2.36	1.79
Slovakia	3.94	3.51	3.50	7.16	4.16	11.93	3.20	3.72	2.83	3.51	2.51	2.77	1.63	0.85	2.55	5.32	4.21	3.74
Canada	1.83	1.83	0.86	3.00	4.07	8.44	2.29	1.99	1.53	1.66	1.61	0.56	2.28	2.18	0.62	0.41	0.38	1.20
Denmark	1.63	1.69	0.97	2.61	1.75	5.12	1.83	1.48	2.08	1.42	1.40	0.63	0.01	0.05	0.90	2.50	2.50	0.74
Japan	0.14	-0.10	1.07	4.14	1.89	10.70	0.37	-0.00	1.65	0.37	-0.00	1.65	-1.06	-1.23	1.69	0.32	0.16	0.89
Poland	3.71	2.76	3.82	5.43	5.53	5.55	3.77	3.41	3.63	3.38	1.78	4.22	1.98	0.35	4.03	4.84	2.69	4.70
Sweden	1.44	1.35	0.84	2.97	3.16	4.45	1.89	1.60	1.80	1.04	0.93	0.58	-0.08	-0.18	0.93	1.86	1.83	0.64
United Kingdom	1.95	1.81	1.06	4.07	3.63	6.15	2.57	2.44	2.26	1.53	1.47	0.67	-0.83	-1.05	1.64	3.26	3.33	0.62
United States	2.13	2.09	1.19	3.01	4.11	12.17	2.32	2.21	1.31	2.00	2.08	0.43	0.09	0.12	0.97	2.74	2.83	0.66

Figure A1. Boxplot of different inflation measures

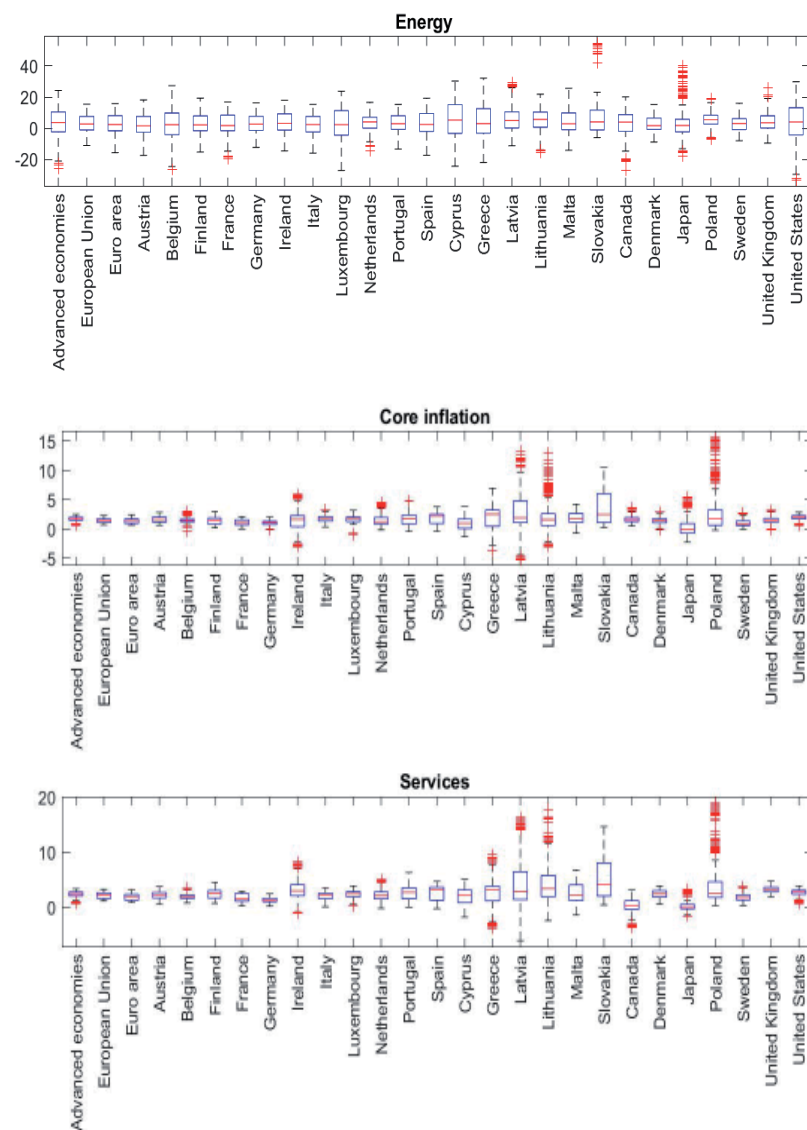
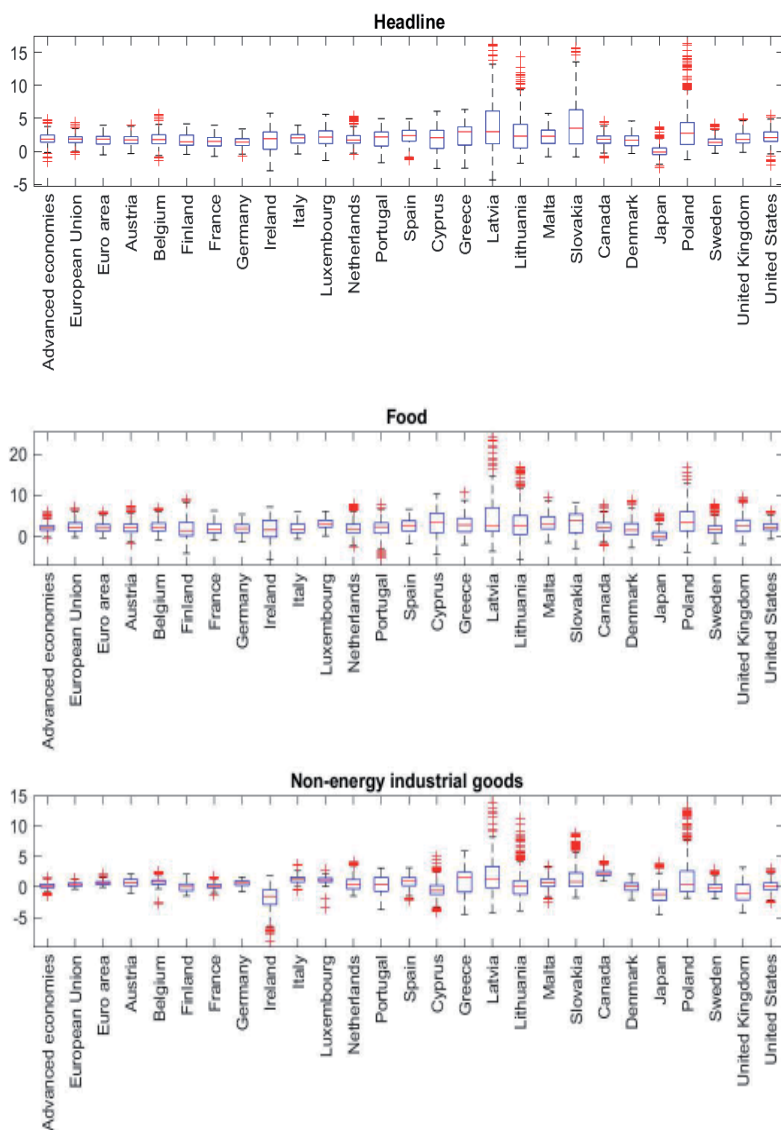
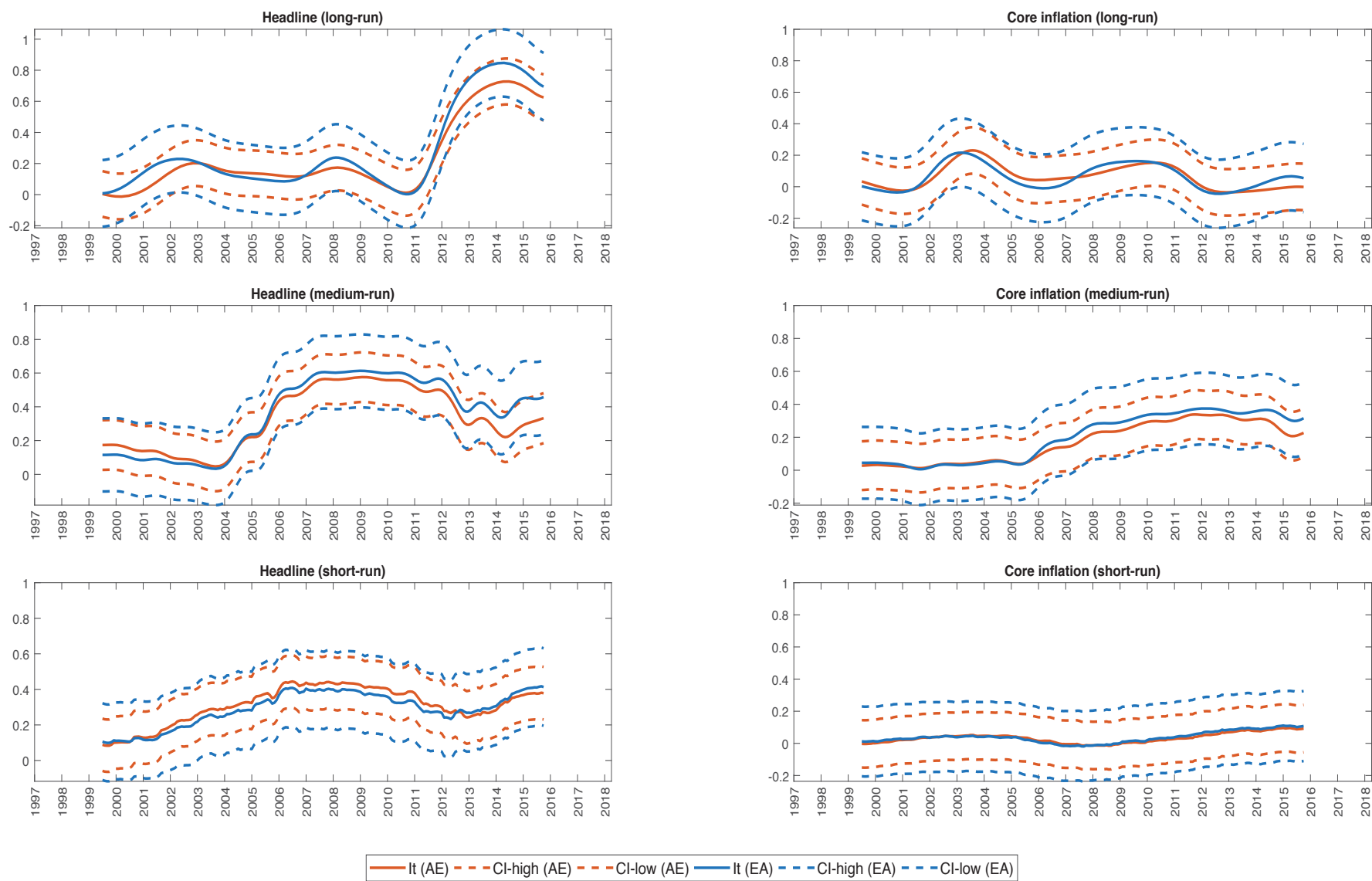
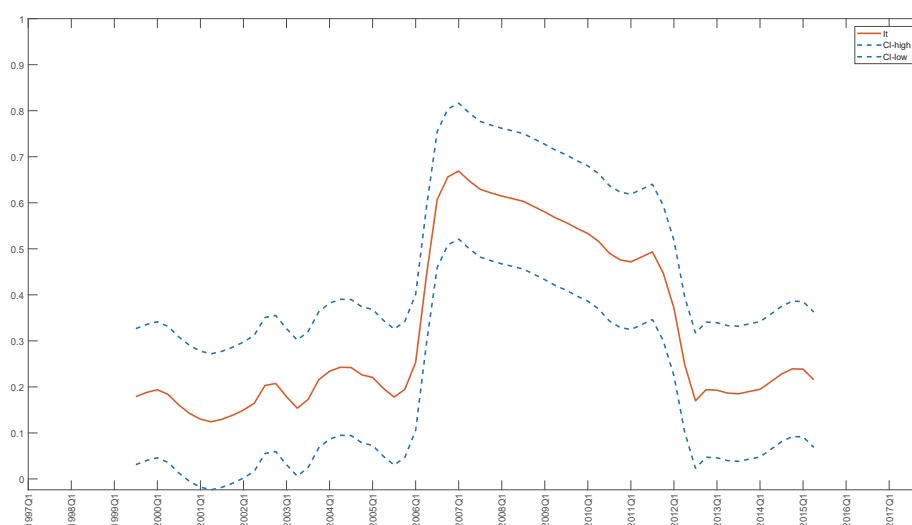


Figure A2. Moran-Stock-Watson measure of comovements of inflation (window=5 years)



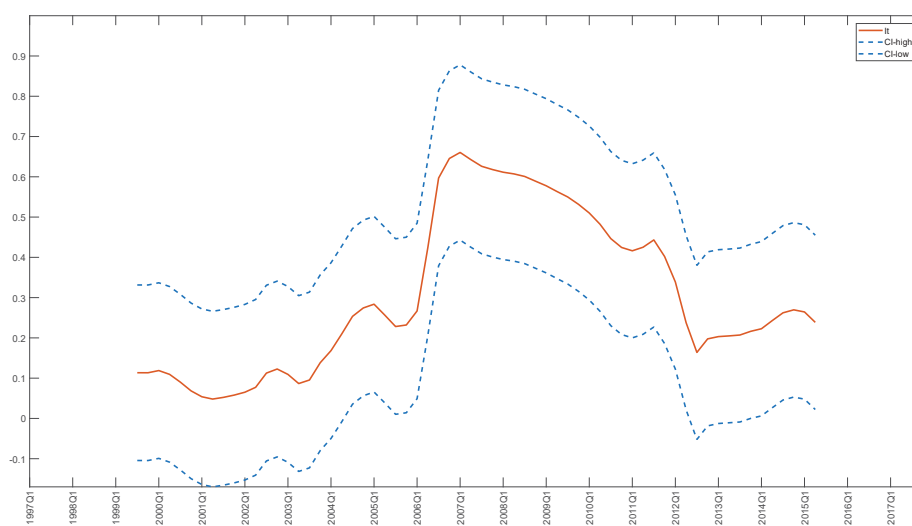
Note. Confidence intervals at 5%.

Figure A3. Moran-Stock-Watson measure of comovements of GDP. Advanced economies (window=5 years)



Note. Confidence intervals at 5%.

Figure A4. Moran-Stock-Watson measure of comovements of GDP. Euro area countries (window=5 years)



Note. Confidence intervals at 5%.

Figure A5. Decomposition of inflation rates into frequency bands (Christiano and Fitzgerald filter). Advanced economies

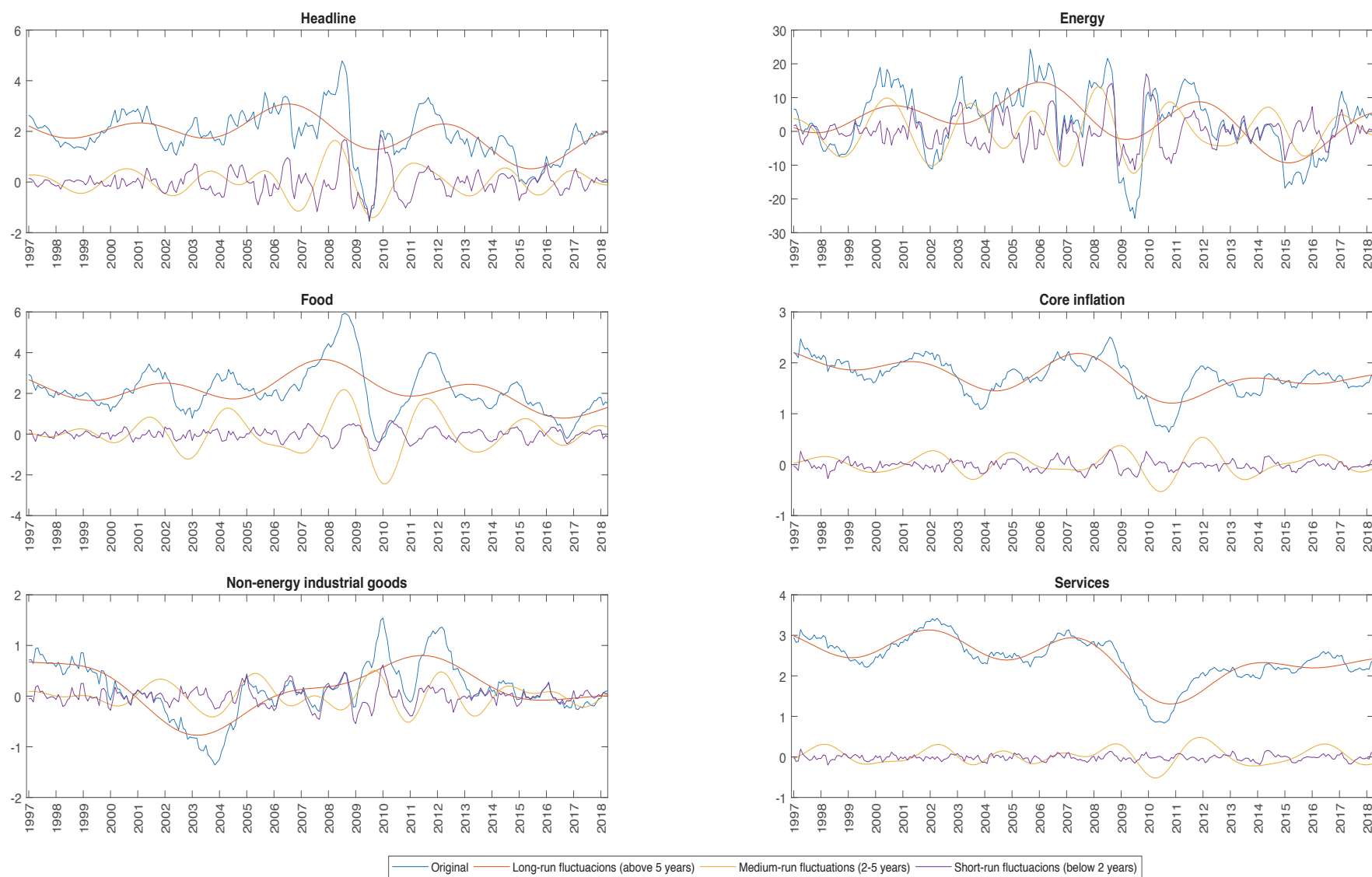


Figure A6. Decomposition of inflation rates into frequency bands (Christiano and Fitzgerald filter). Euro area

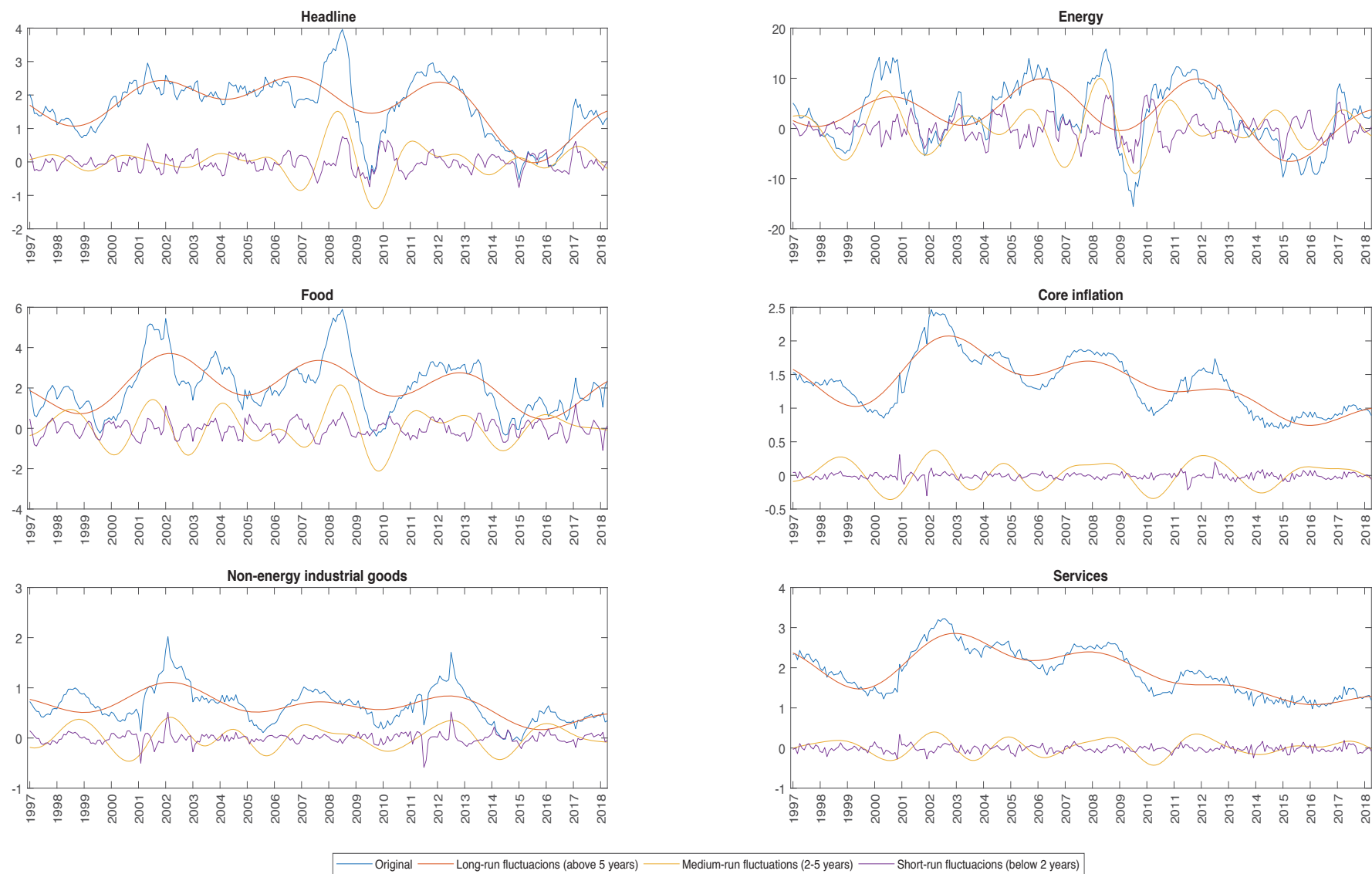
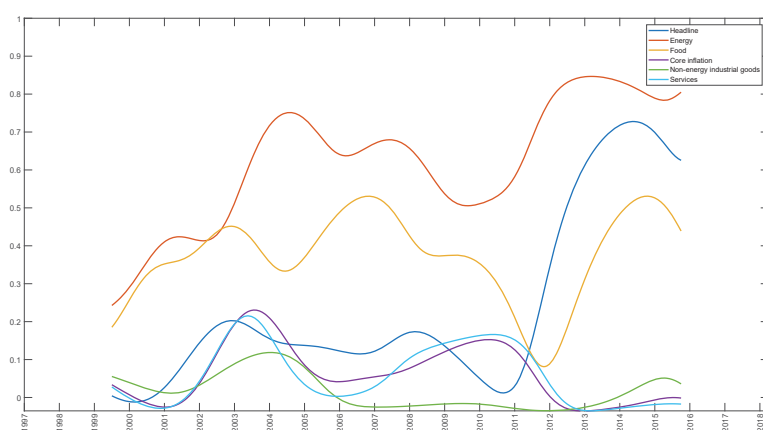
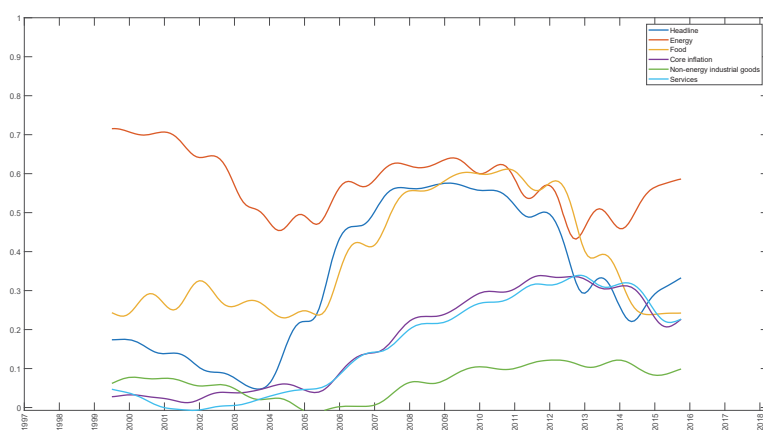


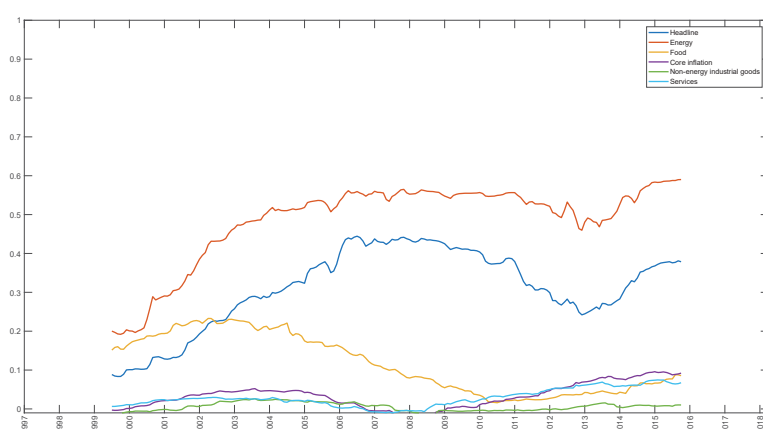
Figure A7. Moran-Stock-Watson measure of comovements. Advanced economies (window=5 years)



(a) Long-run fluctuations

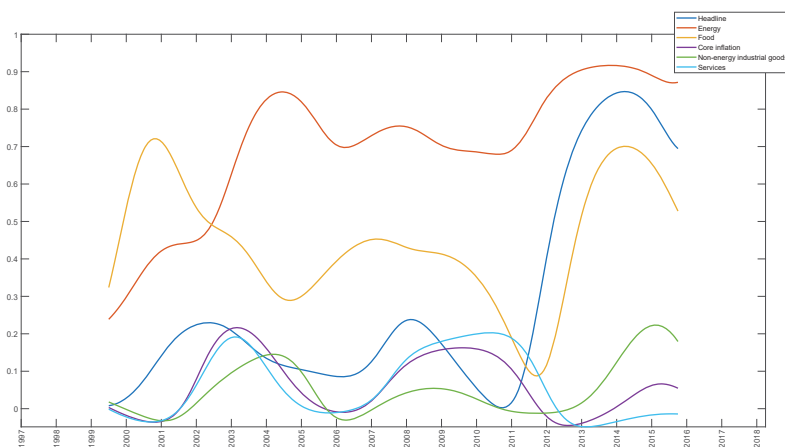


(b) Medium-run fluctuations

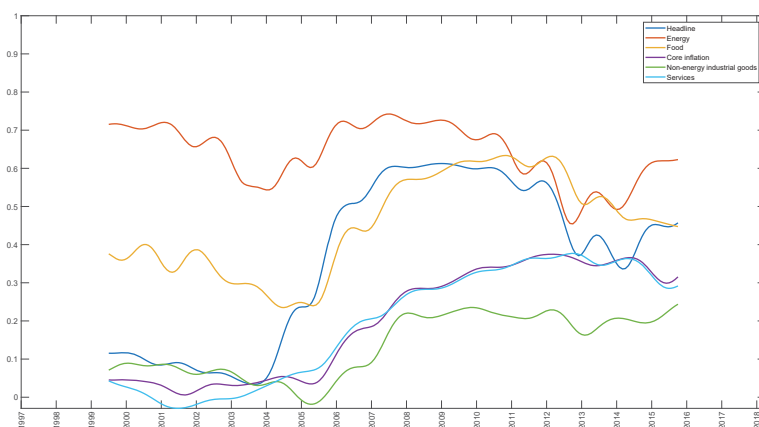


(c) Short-run fluctuations

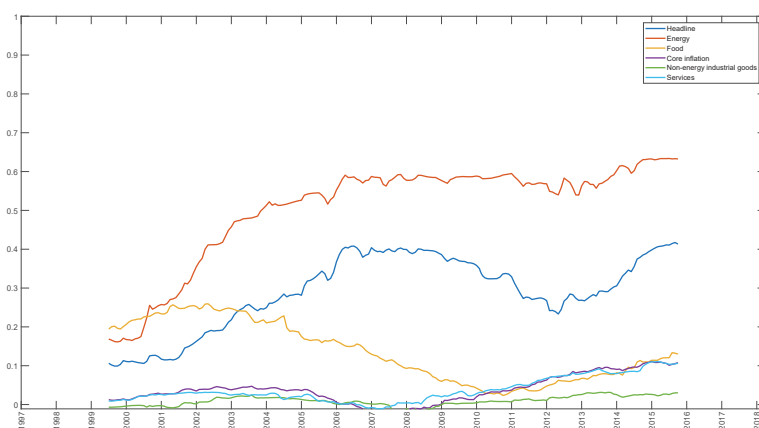
Figure A8. Moran-Stock-Watson measure of comovements. Euro area countries (window=5 years)



(a) Long-run fluctuations



(b) Medium-run fluctuations



(c) Short-run fluctuations

Appendix B. Quantitative measures of inflation expectations

Quantitative measures of inflation expectations for European Union countries are derived on the basis of the European Commission (EC) Consumer Survey. This survey asks consumers quantitative assessments on both past and expected price changes.²⁵ From their responses, weighted measures²⁶ are computed that allow one to get qualitative perceived inflation (π_t^p) and expected inflation (π_t^e) measures. In order to derive quantitative estimates of perceived and expected inflation, the modification by Buchmann (2009) of the Carlson and Parkin (1975) method is used.

Specifically, denoting by π_t the observed inflation rate, a linear relationship is assumed between observed inflation and perceived inflation

$$\pi_t = \alpha + \beta \pi_t^p + \varepsilon_t$$

To allow for possible time variation in the relationship between both variables, the equation is estimated using a rolling window of 36 months and fitted values are computed

$$\hat{\pi}_t^p = \hat{\alpha}_t + \hat{\beta}_t \pi_t^p$$

The resulting time series of fitted values gives a quantitative measure of perceived inflation ($\hat{\pi}_t$).

To obtain a quantitative measure of inflation expectations the conventional Carlson and Parkin (1975) approach is used. Let $\{s_t^{e1}, s_t^{e2}, s_t^{e3}, s_t^{e4}, s_t^{e5}\}$ denote the shares in each of the five response categories in the question on expectations.²⁷ Then, the conditional expectation of inflation can be computed on the basis of these shares and the measure of perceived inflation

$$\pi_{t+12|t}^e = -\hat{\pi}_t^p \left[\frac{Z_t^3 + Z_t^4}{Z_t^1 + Z_t^2 - Z_t^3 - Z_t^4} \right]$$

where

$$Z_t^1 = \phi^{-1}(1 - s_t^{e1})$$

$$Z_t^2 = \phi^{-1}(1 - s_t^{e1} - s_t^{e2})$$

$$Z_t^3 = \phi^{-1}(1 - s_t^{e1} - s_t^{e2} - s_t^{e3})$$

$$Z_t^4 = \phi^{-1}(s_t^{e5})$$

so that expected inflation one year ahead depends on the distribution of the strength of expected inflation and on perceived inflation.

²⁵Specifically, the following question is asked: How do you think that consumer prices have developed over the past 12 months? They have... risen a lot (RL), risen moderately (RM), risen slightly (RS), stayed about the same (S), fallen (F) and don't know.

²⁶ $\pi_t^p = RL + 0.5RM - 0.5S - F$, where all variables are percentages excluding don't know answers.

²⁷Specifically, the following question is asked: By comparison with the past 12 months, how do you expect that consumer prices will develop in the next 12 months? They will... increase more rapidly (IM), increase at the same rate (IE), increase at a slower rate (IS), stay about the same (S), fall (F) and don't know. Categories considered correspond to IM, IE, IS, S and F.

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