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Inflation synchronisation strengthening in Europe in post-quantitative easing and post-pandemic high inflation times: consequences for single monetary policy management

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1. Introduction

Inflation refers to the rate of price increases over a period of time and has an impact on the economy and economic policy of any country, especially as a result of globalization and international trade relations (Öner, 2012). According to Eurostat (2023), inflation rates in the European Union and euro area were at unusually high levels in 2022, indicating that inflation is an important phenomenon in the current period and has been addressed by a significant number of authors. Inflation is a key macroeconomic fundamental whose fluctuations have a major impact on the global economic system and according to some policymakers, the high inflation rate will be permanent, not temporary (Aharon et al., 2023).

When different countries have similar inflation rates over a period of time, this phenomenon is called inflation synchronization, which can

potentially have an impact on international trade but also on monetary policy, i.e., through international trade in goods and various assets, as macroeconomic shocks originating from one country are transmitted to the inflation rate of the other country (Tiwari et al., 2015). Synchronised inflation between countries means that their economies are closely interlinked. Moreover, inflation synchronisation may have the ability to influence monetary authorities to maintain price stability. According to Tiwari et al. (2015), it is crucial to assess inflation synchronisation for proper monetary policy formulation and understanding inflationary behaviour. Szafranek (2021) argues that high inflation synchronisation suggests that inflation behaves similarly across countries due to the use of similar policies applied by central banks, for example, after the outbreak of a crisis. Given the increasingly interconnected world, this topic is expected to remain an essential area of interest for economists and policymakers in the future. The impact of globalisation on inflation was already discussed by Badinger in 2009 and by Schnabel, a member of the Executive Board of the ECB, in 2022. In times of a globalised world, it is becoming increasingly important to understand the factors that lead to convergence or divergence of inflation rates.

As the EU continues to strive for greater integration, an understanding of how inflation interacts among EA member countries can have a significant impact on the achievement of the European Central Bank's objectives, such as price stability or even the promotion of sustainable economic growth. Understanding the mutual influence of inflation is also important for financial market participants, as inflation can affect investments through interest rates. The relationship between inflation and interest rates has been discussed, for example, by Butt et al. (2010), Anari and Colary (2016), Karahan and Yilgör (2017), and Özen et al. (2020).

Disruptions to supply chains and demand during some events such as Brexit, the pandemic crisis or war could have had a significant impact on inflation rates or inflation interactions (Breinlich et al., 2021; Bonam and Smădu, 2021). The study of this topic requires constant attention and scrutiny as the EU also seeks to address challenges such as climate change or even digital transformation (ECB, 2023).

The paper focuses on research on inflation synchronisation and inflation interactions across EU countries and thus provides an overview of the latest research findings in this field. There are many studies that look at the determinants of inflation, or the relationship between inflation and any particular macroeconomic fundamentals, but we fill the gap in this literature by providing evidence on the relationships between individual inflations that may affect a particular country's economy, while also pointing out that the European

Central Bank's single monetary policy may not be appropriate for all countries in the EA, precisely because of the unsynchronised inflation of a particular member country with the average inflation in the EA.

2. Literature review

Recently, a small number of papers have explored the implications of inflation synchronization for monetary policy. The academic literature on this topic is not extensive and contains few studies that examine the causes and effects of inflation synchronisation. In this review, we will discuss some of the key findings from recent research on this topic as well as some points on the topic of inflation interactions.

High inflation synchronization was identified by Ha et. al. (2019) and Auer et al. (2019). Subsequently, this topic was also addressed by Szafranek (2021), who, like us, also used monthly data in his analysis. According to its results, inflation in emerging countries is catching up with inflation in advanced economies. According to this author, oil is a key determinant that can influence or increase the synchronisation of inflation.

Kang et al. (2020) analysed inflation cycle synchronization in ASEAN countries (Indonesia, Malaysia, Philippines, Singapore, and Thailand) using the wavelet coherence method. The authors suggest that a similar inflation path over time, or synchronisation, may have been influenced by central bank quantitative easing. Inflation synchronization between the G7 and China has been discussed by Elsayed et al. (2021), who find that oil is the variable that influences inflation spillovers.

Inflation synchronisation is closely related to inflation convergence. Higher inflation convergence can lead to higher inflation synchronisation. Inflation convergence has been addressed by several authors, for example, Lopez and Papell (2012). These authors studied the behaviour of inflation among the 12 original EA member states, over the period from 1979 to 2010. The convergence of inflation in EU countries has been analysed by Brož and Kočenda (2018) and inflation persistence in the EA countries by Batini (2006), Benigno and Lopez-Salido (2006), Kanellopoulos and Koutroulis (2016), Vyrostková and Mirdala (2022). According to these authors, the convergence of inflation has not weakened after the crisis and does not constitute an obstacle to further enlargement of the EA. The convergence of inflation in East African countries was analysed by Dridi and Nguyen (2018), who concluded that inflation rates are converging in these countries. Stylianou (2022) looked at the period from 1999 to 2018 and argues

that inflation rates among EA members diverged over time more than expected. The author reaches this conclusion using two methods, namely OLS and GMM, based on which he argues that inflation differentials do not tend to fall.

Giovane and Bini-Smashi (1996) already argued that in the absence of convergence, the transition to EMU would lead to spillovers from countries with high inflation to countries with low inflation. Consequently, Thanh Trung (2022) warns against the worsening of the monetary conditions index.

Several studies have shown that inflation in one country can be transmitted to other countries. This issue was addressed by Istiak et al. (2021), who covered a long time period from June 1956 to December 2020. They looked at the spillovers of inflation between the G7 countries and found that the US and Japan are the main inflation transmitters. The same sample of countries was also used by Yang et al. (2006), who identified the transmission of inflation between these countries using a widely used econometric method - the Vector Autoregression (VAR) model. The authors argue that US inflation affects inflation in other countries but also vice versa.

The analysis of inflation spillovers within selected EA countries (France, Spain, Italy, and Germany) was the focus of a study by Tiwari et al. (2019), who also covered a very long time period and used newly developed methods to achieve their objectives. The aim of Liu's (2015) paper was to analyse the international transmission of inflation among a sample of 14 countries before the economic crisis. The study concluded that US inflation had a limited impact on developing countries between 1990 and 2008. Tiwari et al. (2015) looked at the co-movement of inflation rates among G7 countries, using wavelet transform. They attributed the long-run co-movements in inflation to the theory of purchasing power parity. The authors also provide evidence of breaks in common movements in inflation rates, and also show that inflation rates in four European countries are synchronised (France, Germany, Spain, and Italy). Cheung and Yuen (2002) examined whether US inflation affects Hong Kong and Singapore inflation. The spillovers of inflation between the regions of Turkey have been discussed by Cakir (2022), who finds that Istanbul and the western regions of Turkey are the main transmitters of inflation, while the eastern regions receive more inflationary shocks.

3. Data and Research Methodology

The main objectives of this study are to analyse the mutual relationship of inflation between the countries of the European Union and to find out the

synchronisation of inflation of a particular country that is a member of the European Union or the euro area with the average of the euro area, and the European Union. We achieve the objectives using a less traditional method - the Minimum Spanning Tree, as well as more traditional cross-correlations.

3.1. Data

The data included into the calculation of the selected methods took the form of a time series starting in January 2001 and ending in April 2023. We divided this time series into four shorter periods. The Bai and Perron test identified a structural break in December 2008. The second structural break was set for March 2015, in order to determine the behaviour of inflation after the application of the European Central Bank's non-standard monetary policy, i.e. after the implementation of quantitative easing, which was introduced by the ECB in the euro area on 9 March 2015. We have chosen July 2021 as the third breakpoint, because there has been a significant increase in inflation in euro-area countries since August 2021. Thus, the whole time period is divided into these four sub-periods: January 2001 - December 2008, January 2009 - March 2015, April 2015 - July 2021, and August 2021 – April 2023. The monthly inflation rate was expressed as the harmonised index of consumer prices.

As the European Central Bank (2016) states that monthly data related to inflation should be seasonally adjusted, we have followed this statement and thus proceeded to their seasonal adjustment. The cross-correlation method requires the data entering the analysis to be stationary. We tested this assumption using the Zivot-Andrews test, which assumes a structural break in the period under analysis (Výrost et al., 2013).

3.2. Cross-correlation

Cross-correlations (C-C) represent the correlation between two variables with a certain time lag or a lead. This approach was also used in a study by Benčík (2012) and Jakubíková et al. (2014). Authors such as Shen (2015), Rodriguez and Ramirez (2021), and Contreras-Reyes and Indrovo-Aguirre (2020) have used detrended C-C in their study, that is, two time series are initially nonstationary and then stationary.

Since monthly data were used in our analysis, we used lags or a lead over a twelve-month period. Inflation in a particular European Union country was denoted as x_{t+h} at time *t*, and inflation in the euro area, and the European Union

as a whole was denoted as y_t. In this way, we were able to determine whether a country's inflation was catching up with or overtaking inflation in the EA and the EU.

The synchronisation between the inflation of a particular country and the average of the EA and EU was assessed based on the correlation coefficient. If the correlation coefficient was greater than 0.7, the inflation was synchronized. If the correlation coefficient was > 0.7 between $t - 1$ and $t - 12$, then inflation in a particular country is outpacing inflation in the EA and the EU. If the correlation coefficient was > 0.7 between $t + 1$ and $t + 12$, then the country's inflation is lagged compared to inflation in the EA and the EU. Simultaneous development of inflations (i.e. "perfect" inflation synchronisation without lag or lead) was demonstrated if the value of the correlation coefficient reached the highest value at time t.

3.3. Minimum Spanning Tree

A Minimum Spanning Tree method is based on the work of Otakar Borůvka (1926). This diagram is useful for identifying correlations within a group of commodities or other assets (Filip et al., 2018).

The MST represents a diagram that is composed of n nodes and $n - 1$ edges. In our case, the nodes represent inflation in a particular country that is a member of the European Union and the edges represent the relationship between inflations. The thickness of the edge in this diagram depends on the strength of the correlation that exists between the inflations. This approach was used by Mantegna (1999), Rešovský (2013), Limas (2019) and Memon et al. (2019) in their research.

The MST construction uses Pearson's correlation coefficient (Filip et al., 2018). Since the correlation coefficient can take negative values and thus cannot be used as a distance metric, we used the Mantegna (1999) transformation of the original correlation matrix to obtain a distance matrix d_{ij} of the following form:

$$d_{ij} = \sqrt{2(1 - \rho_{ij})} \tag{1}$$

where is the Pearson correlation coefficient between the inflation rates of country i and j over the time period.

4. Results and Discussion

The European Central Bank's main objective is to maintain price stability, or inflation, at 2%. This objective is pursued through various monetary policy tools, both standard and non-standard in the form of, for example, quantitative easing, which was first implemented by the Bank of Japan in 2001.

Our results showed what were, or are, the patterns of inflation behaviour in the countries of the EU before, during and after the quantitative easing application. We also examined the behaviour of price increases in the recent 'high inflation' post-pandemic period. Since the European Central Bank uses a single monetary policy within the EA countries, we assumed that within this integration the inflation of a particular EA country should be synchronised with the inflation in the EA, so that this policy, whether standard or non-standard, has the same positive effect on each EA member. We also expected inflation to be more synchronised after post-pandemic times during the 'high inflation' period; this assumption has been confirmed.

4.1. Synchronisation of inflation in individual EU Member States with inflation in the euro area and the impact of these inflations on each other in four different periods

4.1.1. Cross-correlation

During several years prior to the financial and economic crisis, from January 2001 to December 2008, inflation rates in EU countries were highly synchronised with those in the euro area, with only a few exceptions. Inflation rates in Luxembourg, Greece, Cyprus, Lithuania, and Latvia are slightly synchronised with the average euro area inflation. The Netherlands, Ireland, Portugal, Slovenia, Slovakia, Hungary, Poland, and Romania are the countries whose inflation is not synchronised with the euro area average. Before the economic crisis, inflation in Belgium, France, Italy, Denmark, and Sweden developed in parallel with inflation in the EA. However, inflation in Malta and Spain lags behind the euro area average by one month and in Finland by one to two months. In Germany, Austria and the Czech Republic, inflation is leading by one to two months with reference to the EA; by one, two and three months in Croatia and Estonia; and by one, two, three and four months in Bulgaria.

The inflation rates of individual EU countries were not synchronised with those of the EA in the post-crisis period, and also before the quantitative

easing implementation, with a few exceptions for which a moderate inflation synchronisation was confirmed, i.e. Belgium, Germany, France, Spain, Austria, and Croatia.

In the period from the start of the European Central Bank's quantitative easing until July 2021 (a period marked by a slight increase in the euro area inflation), Belgium, Germany, France, Spain, Austria, and Croatia had their inflation slightly synchronised with the average euro area inflation. In the rest EU countries, there was not a high correlation between country-specific inflation and the euro area average.

During the high inflation period, i.e. from August 2021 to April 2023, results conclude for a parallel evolution of EA inflation with that of Belgium, Germany, Austria, Slovenia, and Finland (see table 1). In most EU countries, inflation was shown to be moderately synchronised with EA inflation; and there was no correlation in nine countries.

Table 1. Cross-correlation of individual EU Member States with the euro area average, August 2021-April 2023

	t-11	t-9	t-7	t-5	t-3	t-1	t	t+1	t+3	t+5	t+7	t+9	t+11
BE	-0.097	0.078	-0.060	-0.073	0.216	0.573	**0.771**	0.562	-0.063	-0.196	0.157	0.287	-0.269
DE	-0.076	0.094	-0.034	-0.195	0.020	0.673	**0.879**	0.618	0.016	-0.222	0.024	0.247	-0.195
FR	0.043	-0.098	-0.027	0.055	-0.041	0.080	-0.164	-0.048	-0.388	0.230	0.107	-0.226	-0.023
IT	-0.063	0.475	-0.037	-0.274	-0.245	0.398	0.434	0.175	-0.531	-0.227	0.079	0.027	0.044
LU	0.038	0.090	0.051	0.113	0.396	0.538	0.607	0.380	-0.186	-0.358	-0.156	0.067	-0.194
NL	-0.100	-0.100	-0.150	-0.021	0.267	0.575	0.549	0.358	0.252	0.095	0.120	0.084	-0.310
EE	-0.097	-0.011	0.048	0.052	0.245	0.519	0.641	0.596	0.220	-0.184	-0.233	0.131	-0.079
IE	0.137	0.220	0.038	-0.429	-0.387	-0.002	0.152	-0.054	-0.390	-0.407	0.258	0.557	0.296
GR	0.059	0.023	0.000	0.141	-0.088	0.065	-0.163	-0.124	0.057	0.061	-0.015	-0.124	0.017
ES	0.194	0.368	0.056	-0.259	-0.069	0.205	0.261	-0.033	-0.649	-0.358	-0.038	0.109	0.255
CY	0.186	-0.031	0.142	-0.055	0.071	-0.257	-0.271	-0.317	-0.362	0.116	0.036	-0.187	-0.051
LV	-0.231	-0.056	-0.040	-0.353	-0.470	0.092	0.428	0.495	0.299	0.072	0.245	0.371	-0.047
LT	-0.143	-0.069	-0.135	-0.285	-0.251	0.247	0.466	0.385	0.275	0.115	0.235	0.432	-0.165
MT	-0.133	0.036	-0.117	-0.461	-0.584	0.074	0.229	0.159	0.144	0.100	0.419	0.303	-0.140

AT	-0.279	0.074	0.039	0.017	0.059	0.450	**0.703**	0.603	0.253	-0.039	-0.093	-0.184	-0.268
PT	0.037	-0.103	-0.031	0.213	0.692	0.484	0.331	0.145	0.014	0.019	-0.041	-0.311	-0.299
SI	-0.064	0.091	0.068	-0.046	0.269	0.568	**0.803**	0.568	0.036	-0.371	-0.121	0.144	-0.103
SK	-0.191	-0.128	-0.069	0.095	0.296	0.405	0.457	0.405	0.329	0.115	0.103	-0.079	-0.349
FI	-0.096	0.023	-0.038	-0.039	0.169	0.492	**0.718**	0.466	0.105	-0.164	0.085	0.284	-0.183
BG	0.057	0.164	0.027	-0.096	0.237	0.473	0.572	0.429	-0.233	-0.498	-0.057	0.489	0.152
CZ	-0.171	-0.097	-0.047	0.006	0.159	0.426	0.557	0.562	0.323	-0.030	0.043	0.165	-0.185
DK	-0.042	0.281	0.101	-0.042	-0.161	0.525	0.694	0.431	-0.230	-0.516	-0.170	0.277	-0.002
HR	0.004	0.010	-0.033	0.235	0.458	0.555	0.552	0.326	-0.018	-0.102	-0.161	0.017	-0.247
HU	-0.059	-0.048	-0.005	0.152	0.481	0.537	0.522	0.431	0.142	-0.125	-0.111	-0.015	-0.194
PL	-0.032	-0.026	-0.049	0.167	0.483	0.541	0.538	0.394	0.017	-0.150	-0.011	0.100	-0.215
RO	-0.004	-0.119	-0.062	0.243	0.607	0.441	0.348	0.245	0.111	0.019	-0.049	-0.039	-0.253
SE	-0.185	0.021	-0.160	-0.295	-0.339	0.383	0.583	0.469	0.244	0.189	0.146	0.205	-0.140

Note: t corresponds to the years 2021 August to 2023 April; the highest value of the correlation coefficient at time t is shown in thick; if the correlation coefficient is in the interval <0.7 ; 1>, it is shown in dark grey; if the correlation coefficient is in the interval from (0.5 ; 0.7), it is shown in light grey.

Source: own processing based on Eurostat data (2023)

4.1.2. Minimum Spanning Tree

The relative impact of inflation among the countries of the European Union is shown in Figure 1. In this diagram, nodes and edges are shown, and the thickness of the edge indicates the strength of the correlation between inflations. The central inflation position of a country is denoted by a node that has more than two edges (Rešovský et al., 2013). This implies that Belgian, Austrian, Estonian, Czech, Danish, Slovenian, and Dutch inflation is a central one (figure 1a.). Before the financial crisis, Slovak inflation was influenced by Romanian inflation, which in turn was directly affected by the inflation of the Netherlands. The MST also uncovers that the inflation rates in Lithuania and the Czech Republic are directly influenced by the inflation rates in Estonia. Before the crisis, French inflation had a direct impact on the Spanish one. During the whole

period under review, inflation in Germany had no impact on inflation in any of the countries; on the other hand, Austrian inflation had an impact on German inflation. Inflation from the Czech Republic is transmitted to Poland, which in turn affected inflation in Hungary. According to the MST chart (see Figure 1a.), inflation in Estonia, Latvia, and Lithuania (the Baltic countries) followed the following path: as mentioned above, Austrian inflation directly influenced Estonian inflation, which in turn affected the Lithuanian one, which is in turn transmitted to the Latvian one. The direction of the chain can be explained by the international trade between the Baltic countries. During the period January 2001 – December 2008, we conclude a strong lagged/lead correlation between the EA average inflation and inflation in the EA member states. Inflation in EA core countries, such as Belgium, Germany, France, Italy, Austria, and Spain is mainly leading in relation with the EA inflation.

According to the MST diagram shown in Figure 1b., after the economic crisis until the introduction of quantitative easing in the EA, German inflation is a central one; the central position is confirmed also for Italian, French, Danish, and Bulgarian inflation. Slovak inflation is directly influenced by Italian inflation, which also affects inflation in the Czech Republic, while Austrian inflation is influenced by German inflation. The Baltic States are not influenced in the same direction as they were before the economic crisis; Lithuanian inflation is not influenced by Estonian inflation but by the Bulgarian one.

The inflations of Estonia, Croatia, Italy, Spain, Latvia, Slovakia, and Luxembourg have a central position (figure 1c). German and French inflation is not central, German inflation does not affect any inflation in EU countries, and French inflation directly affects the Bulgarian one. In the period under study, Greek inflation has an impact on Malta's inflation. In the V4 countries, inflation followed the following path: Slovak inflation was directly influenced by Bulgarian inflation, and then Slovak inflation had an impact on the Hungarian one, which in turn influenced inflation in Poland, which thereafter directly influenced the inflation in the Czech Republic.

Figure 1d shows that the synchronisation of inflation between the V4 countries and Austria stems from geographical proximity and trade relations. Inflation spills over from Poland to Slovakia and Austria, from Slovakia to the Czech Republic and France, and from Austria to Hungary. The Slovak Republic exports in large quantities toward to France and the Czech Republic, which may explain the transmission of inflation to these countries. In times of high inflation, we observe inflation spillovers between the Benelux countries. Spillovers of inflation are evident between other geographically related countries such as Bulgaria, Croatia, and Romania.. Slovenia's inflation does not affect the inflation of any EU

country and, as it has been shown before; Slovenia has an inflation synchronized with the average euro area inflation.

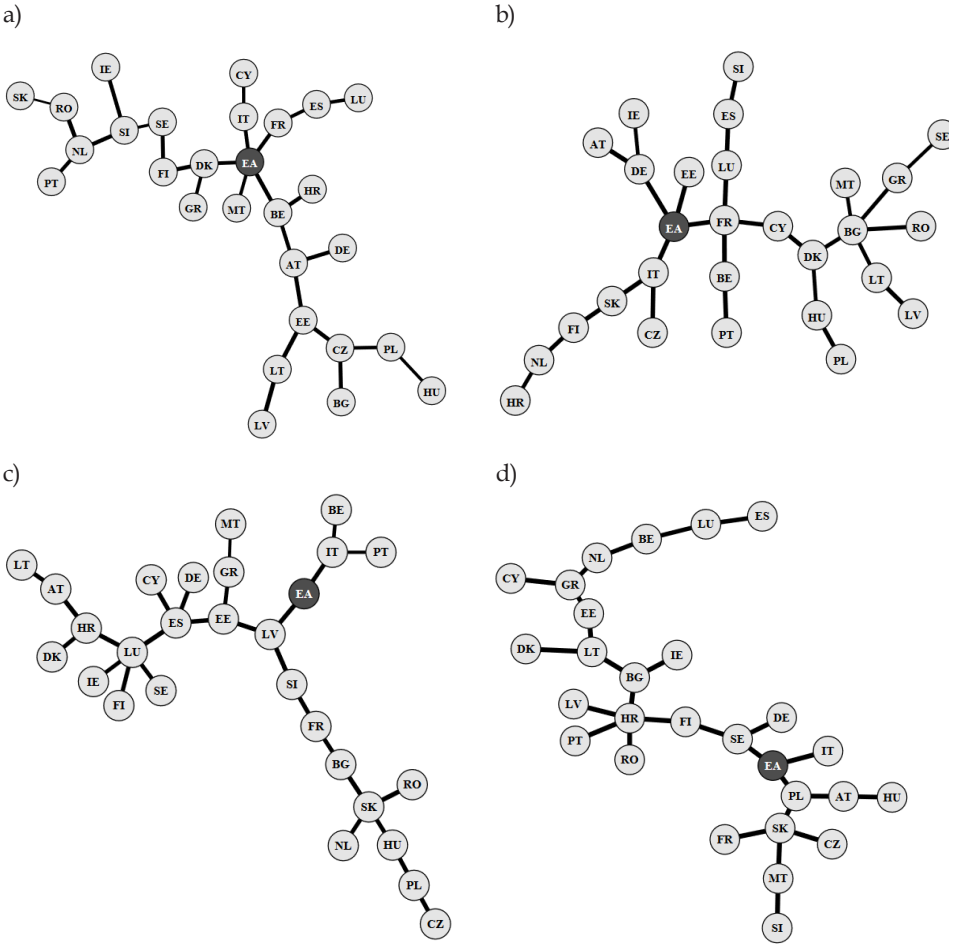


Figure 1. Inflation peer effects in European Union countries: a) January 2001 - December 2008, b) January 2009 - March 2015, c) April 2009 - July 2021, d) August 2021 – April 2023

Note: The euro area average is shown in a black circle, the thickness of the lines is proportional to the correlation between inflation rates.

Source: own processing based on Eurostat data (2023)

The V4 countries, having stronger international trade connections and near geographical position are connected and nearly situated in MST. Moreover, MST uncovers that Slovakia has always had a more central position than the Czech Republic, Hungary and Poland. Therefore, we can conclude for inflation transmission from Slovakia (the EA member) to the rest V4 countries. This fact is in accordance with the central position of the EA and shows that countries having common monetary policy have a stronger position, they are more resistant from external inflation shocks and rather influence the inflation of other countries.

The difference in how inflation in the Czech Republic affects Polish inflation, compared to the less pronounced effect of German inflation on Poland, can be attributed to various factors. Inflation in the Czech Republic impacted inflation in Poland relatively more than German inflation due to similar catching-up, transition and post-transition situation in the Czech Republic and Poland. The Czech Republic and Poland, which are part of Central and Eastern Europe, have closely interconnected economies thanks to similar economic structures (e.g., both economies have significant industrial sectors and agriculture) and levels of development. This similarity, as well as geographical proximity, likely facilitated the transmission of inflation between them from January 2001 to December 2008. Although Germany is one of Poland's main trading partners, its inflation impacted Polish inflation relatively less. The structure of trade between these two countries may influence how inflationary pressures are transmitted. If Polish imports from Germany are not dominant in critical sectors that could significantly affect overall inflation in Poland, the impact of German inflation may be limited. Another reason could be that the period after 2008 was marked by the global financial crisis, and Germany, with its strong industrial base and export-oriented economy, may have experienced different inflationary pressures compared to Poland, whose economy might have been more influenced by regional recovery efforts. German inflation did not impact Polish inflation, for example, because Germany is a member of the eurozone and therefore is directly influenced by ECB policy, unlike Poland, whose monetary authority is not the ECB. This means that since Poland does not use the euro but has its currency, Polish monetary policy is independent of the eurozone. This allows Poland to adapt its monetary policy to its specific economic needs, which can mitigate the direct impact of inflationary pressures from the eurozone. The reason why German inflation might not affect Polish inflation could also be based on supply chain disruptions during the COVID-19 pandemic and different political responses.

From the above, we conclude that trade relationships between partners are an important factor that can influence the transmission of inflation between countries. For a comprehensive understanding, more detailed econometric examination would be needed, including specific economic indicators, trade data (volume and structure of trade), and changes in policies during the examined periods.

Figure 2 shows the mutual influence (i.e. correlation) of inflation in the EU countries in the studied periods (the euro area average inflation is also included in the matrix). The box is darker if there is a greater correlation between inflations in EU countries. The highest number of inflation synchronisation of individual EU countries was observed in the period from August 2021 to April 2023, i.e. in the high inflation post-pandemic period.

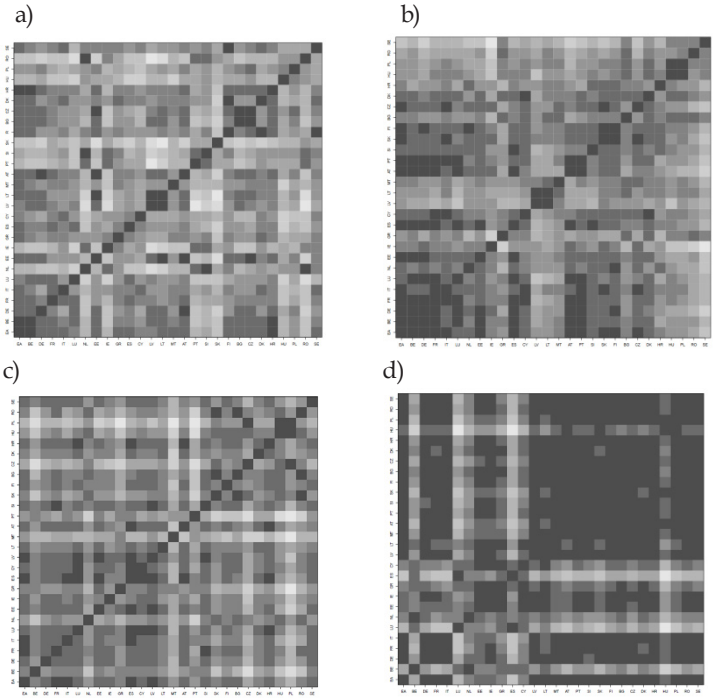


Figure 2. Inflation peer effects between European Union countries over the period (average euro area inflation included): a) January 2001 - December 2008, b) January 2009 - March 2015, c) April 2009 – July 2021, d) August 2021 – April 2023

Source: own processing based on Eurostat data (2023)

Generally, in the last 4th analysed period (post-pandemic times: August 2021 – April 2023), the C-C matrix concludes for stronger inflation correlations. The graphical representation of correlations shows the inflation synchronisation between countries in "the right-up" quadrant (see correlation matrix for the EA as well as the EU in the 4th period).

4.2. Synchronisation of inflation in individual EU Member States with inflation in the European Union and the impact of these inflations on each other in four different periods

4.2.1. Cross-correlation

Before the economic crisis, inflation in the ten EU Member States was synchronised with the EU average. It was the inflation of the following countries: Belgium, Estonia, Austria, Finland, Bulgaria, the Czech Republic, Denmark, Croatia, Poland, and Sweden. Inflation in Belgium, Finland, Denmark, Poland, and Sweden paralleled that in the EU.

Since January 2009, and before the application of the ECB's non-standard monetary policy, Dutch, Slovenian, Finnish, Czech, Polish, and Romanian inflation has followed a parallel path to the EU average. Inflation in Slovakia was not synchronised with the inflation in the EU during the period considered. Two Baltic countries, Latvia and Lithuania, also did not have inflation in synchronisation with the EU average. Estonian inflation has been only slightly synchronised with average inflation in the EU.

After the quantitative easing application and prior to the sharp increase in inflation, we observed a simultaneous development of inflation in the Netherlands, Portugal, Slovenia, Finland, the Czech Republic, Poland, and Romania, with the average inflation of the EU. In other countries, there was only mild synchronization or none at all.

In the high inflation period (i.e. August 2021-April 2023), we observe a parallel development of inflation with the average inflation of the EU in several countries (see table 2). Portuguese inflation trails EU inflation by 1 to 3 months. Price increases in countries such as France, Italy, Ireland, Greece, Spain, Cyprus, Latvia, and Malta have not been synchronised with the increase in prices in the EU at times of high inflation. In the rest countries, only a slight synchronisation of inflation was confirmed.

Table 2. Cross-correlations of individual EU Member States with the EU-27 average: August 2021–April 2023

	t-11	t-9	t-7	t-5	t-3	t-1	t	t+1	t+3	t+5	t+7	t+9	t+11
BE	-0.199	0.011	-0.067	-0.023	0.366	0.758	**0.949**	0.771	0.351	0.071	0.106	0.138	-0.213
DE	-0.234	0.003	-0.060	-0.111	0.204	0.720	**0.932**	0.798	0.409	0.057	0.043	0.077	-0.181
FR	0.012	-0.102	0.033	0.087	-0.112	0.009	-0.127	-0.022	-0.214	0.056	0.107	-0.168	-0.028
IT	0.057	0.351	0.070	-0.153	-0.222	0.169	0.100	-0.074	-0.321	-0.248	-0.117	-0.016	0.046
LU	-0.067	0.185	0.193	0.283	0.609	0.701	**0.767**	0.546	0.089	-0.223	-0.254	-0.159	-0.276
NL	-0.283	-0.237	-0.187	0.005	0.402	0.776	**0.846**	0.741	0.573	0.312	0.208	0.039	-0.265
EE	-0.277	-0.057	0.098	0.185	0.408	0.742	**0.913**	0.871	0.537	0.098	-0.118	-0.054	-0.185
IE	0.280	0.335	-0.023	-0.503	-0.584	-0.309	-0.237	-0.266	-0.423	-0.353	0.077	0.417	0.439
GR	0.069	-0.033	0.085	0.082	-0.040	0.036	-0.059	-0.068	0.029	-0.014	0.047	-0.130	0.060
ES	0.301	0.471	0.201	-0.109	-0.157	-0.081	-0.094	-0.235	-0.566	-0.453	-0.277	-0.001	0.218
CY	0.212	0.107	0.112	0.002	0.021	-0.415	-0.512	-0.467	-0.522	-0.096	-0.080	-0.108	0.005
LV	-0.291	-0.259	-0.312	-0.492	-0.444	0.065	0.350	0.454	0.447	0.351	0.382	0.379	0.080
LT	-0.233	-0.234	-0.372	-0.409	-0.221	0.243	0.501	0.501	0.494	0.362	0.379	0.403	0.004
MT	-0.117	-0.162	-0.407	-0.607	-0.608	-0.147	-0.015	0.046	0.203	0.255	0.460	0.367	0.099
AT	-0.436	-0.105	0.044	0.154	0.316	0.629	**0.795**	0.718	0.530	0.204	-0.035	-0.214	-0.343
PT	-0.123	-0.085	0.095	0.408	0.845	0.771	0.698	0.543	0.234	0.076	-0.099	-0.324	-0.399
SI	-0.210	0.099	0.127	0.121	0.450	0.723	**0.929**	0.769	0.346	-0.074	-0.160	-0.061	-0.180
SK	-0.346	-0.277	-0.122	0.146	0.465	0.718	**0.804**	0.729	0.590	0.343	0.184	-0.073	-0.345
FI	-0.206	-0.030	-0.054	-0.026	0.326	0.643	**0.909**	0.717	0.435	0.108	0.100	0.131	-0.133
BG	0.032	0.255	0.157	-0.023	0.251	0.566	**0.701**	0.576	0.069	-0.260	-0.161	0.205	0.097
CZ	-0.331	-0.227	-0.106	0.020	0.300	0.686	**0.861**	0.844	0.626	0.276	0.158	0.086	-0.198
DK	-0.080	0.328	0.241	0.012	0.054	0.475	0.529	0.342	-0.017	-0.363	-0.234	-0.023	-0.049
HR	-0.144	0.024	0.112	0.348	0.664	0.810	**0.866**	0.642	0.307	0.008	-0.133	-0.151	-0.318
HU	-0.223	-0.077	0.087	0.295	0.647	0.841	**0.895**	0.789	0.448	0.093	-0.079	-0.140	-0.292

PL	-0.158	-0.030	0.055	0.257	0.644	0.838	**0.908**	0.732	0.353	0.039	-0.028	-0.049	-0.263
RO	-0.145	-0.117	0.027	0.359	0.726	0.774	**0.803**	0.666	0.389	0.143	-0.020	-0.118	-0.307
SE	-0.311	-0.243	-0.322	-0.363	-0.253	0.319	0.547	0.553	0.533	0.389	0.310	0.228	-0.052

Note: t corresponds to the years 2021 August to 2023 April; the highest value of the correlation coefficient at time t is shown in thick; if the correlation coefficient is in the interval <0.7 ; 1>, it is shown in dark grey; if the correlation coefficient is in the interval from (0.5 ; 0.7), it is shown in light grey.

Source: own elaboration based on Eurostat data (2023)

4.2.2. Minimum Spanning Tree

Before the economic crisis, several inflations were central, namely Slovenian, Dutch, Finnish, Danish, Italian, Belgian, Austrian, Estonian, and Czech inflation (see Figure 3a). The diagram differs from Figure 1a in that, for example, in this case, Belgian inflation affects inflation in Malta but not in Croatia, and also Italian inflation directly affects inflation in France.
Figure 3b shows that Slovak inflation was not directly affected by Italian inflation as suggested by Figure 1b. Estonian inflation is already directly influenced by Belgian inflation, which at the same time influences inflation in Portugal. Also, in this case, French inflation has had a significant impact on the Belgian one.

Figure 3c shows that the V4 inflation followed the same direction as in figure 1c, i.e. inflation spills over from Slovakia, which is part of the EA, to the other V4 countries, i.e. Slovakia has a stronger inflation impact on the other V4 countries. Spanish inflation influences inflation in a large number of economies, e.g. it directly influences Italian inflation, which in turn influences inflation in Portugal.

Over the time of August 2021-April 2023, we observe that Benelux inflation is interlinked, i.e. spills over from the Netherlands to Belgium, and then to Luxembourg (see figure 3d). This was not the case before the high inflation period (see figure 3c). MST also concludes that Slovak inflation no longer directly affected Hungarian inflation (nor Romanian and Dutch inflation), but had an impact on price increases in Malta, France, and the Czech Republic.

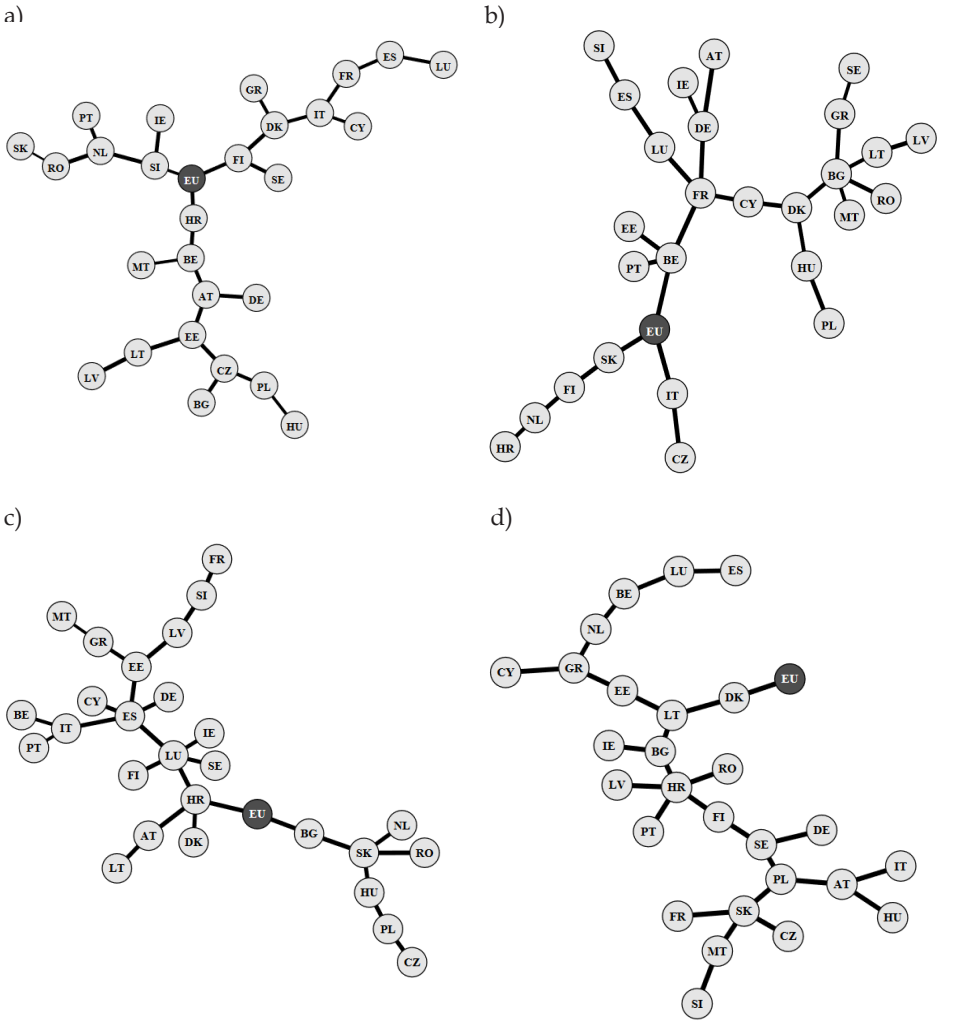


Figure 3. Inflation peer effects in European Union countries: a) January 2001 – December 2008, b) January 2009 - March 2015, c) April 2009 - July 2021, d) August 2021 – April 2023

Note: The European Union average is shown in a black circle, the thickness of the lines is proportional to the correlation between inflation rates

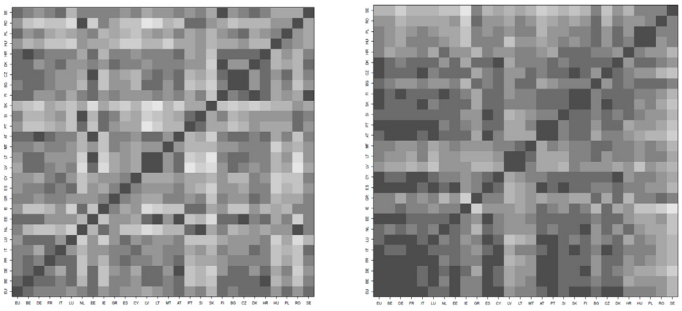
Source: own processing based on Eurostat data (2023)

MST graphs uncover the effect of the central position of the EA, while the position of the EU is mainly in the periphery. This fact leads to the conclusion, that inflation is transmitted mainly from the EA countries, having a more central position in the MST.

Furthermore, MST graphs (see e.g. MST for the EA in the 3rd and 4th analysed period) show the near and connected position of geographically near countries, which are also connected by international trade. Firstly, the position of Poland, Hungary, the Czech Republic, Slovakia, and Austria uncovers the inflation transmission and its synchronisation between the countries. Secondly, we can state inflation synchronisation between Netherlands, Belgium, and Luxembourg. Thirdly, looking at the 4th analysed period (the euro area MST), Hungary, Romania, and Bulgaria with the connection to Estonia, Latvia, and Lithuania uncover stronger inflation synchronisation between two groups of geographically near countries, having together position of newer members of the EU. Then, MST uncover near position and inflation synchronisation between Greece and Malta, furthermore between Luxembourg, Finland, Sweden, and Ireland (see MST for the EA, 3rd analysed period). Similar results are uncovered for MST graphics with the reference to the whole EU in the 3rd and 4th analysed periods.

Figure 4 shows the mutual influence (i.e. correlations) of inflation in the EU countries in the studied periods (the matrix also includes the average inflation in the EU). The box is darker if there is a greater correlation between cowuntries' inflations. Again, the matrix confirms stronger correlations between inflations in the 4th 'high inflation' period.

a) b)



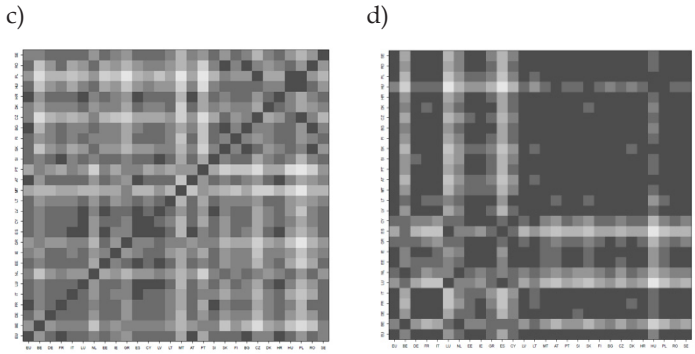


Figure 4. Inflation peer effects between European Union countries over the period (EU average inflation included): a) January 2001 - December 2008, b) January 2009 - March 2015, c) April 2009 - July 2021, d) August 2021 – April 2023

Source: own processing based on Eurostat data (2023)

In table 3, we present the results of C-C, based on which we were able to determine whether a particular country's inflation is lagged in comparison to the EU/EA average, consequently whether a particular country's inflation is leading the EU/EA inflation and whether the inflations have a synchronous development (i.e. with no lag or lead in the correlation). Based on the correlation coefficient, we were also able to determine whether the inflations are slightly or more strongly synchronised. Further, in table 3, countries, whose inflation is a central one in MST, are highlighted in bold.

Table 3. Cross-correlations of EU countries with EA and EU in four different periods

January 2001 – December 2008		Average inflation	
		EA	**EU**
Synchronised inflations	leading countries	DE, **EE**, ES, **AT**, BG, **CZ**, HR	**EE, AT,** BG, **CZ**, HR
	synchronous countries	**BE,** FR, IT, **DK**, SE	**BE, FI**, **DK,** PL, SE
	lagging countries	MT, FI	

Slightly synchronised inflations		LU, GR, CY, LV, LT	DE, FR, **IT, NL,** GR, ES, LT, MT, **SI**
Unsynchronised inflations		**NL,** IE, PT, **SI,** SK, HU, PL, RO	LU, IE, CY, LV, PT, SK, HU, RO
January 2009 – March 2015		**Average inflation**	
		EA	**EU**
Synchronised inflations	leading countries		
	synchronous countries		NL, SI, FI, CZ, PL, RO
	lagging countries		
Slightly synchronised inflations		BE, **DE, FR,** ES, AT, HR	EE, AT, PT, HR, HU, SE, IE
Unsynchronised inflations		**IT**, LU, NL, EE, IE, GR, CY, LV, LT, MT, PT, SI, SK, FI, **BG,** CZ, **DK**, HU, PL, RO, SE	**BE**, **DE, FR**, IT, LU, GR, ES, CY, LV, LT, MT, SK, **BG, DK**
April 2015 – July 2021		**Average inflation**	
		EA	**EU**
Synchronised inflations	leading countries		
	synchronous countries		NL, PT, SI, FI, CZ, PL, RO
	lagging countries		
Slightly synchronised inflations		BE, DE, FR, **ES,** AT, **HR**	**EE,** AT, **HR,** HU, SE, IE
Unsynchronised inflations		**IT**, **LU,** NL, **EE,** IE, GR, CY, **LV,** LT, MT, PT, SI, **SK,** FI, BG, CZ, DK, HU, PL, RO, SE	BE, DE, FR, **IT**, **LU,** GR, **ES**, CY, LV, LT, MT, **SK**, BG, DK

August 2021 – April 2023		Average inflation	
		EA	**EU**
Synchronised inflations	leading countries		PT
	synchronous countries	BE, DE, AT, SI, FI	BE, DE, LU, NL, EE, **AT**, SI, **SK**, FI, **BG,** CZ, **HR**, HU, **PL,** RO
	lagging countries		
Slightly synchronised inflation		LU, NL, EE, PT, **BG,** CZ, DK, **HR**, HU, **PL,** RO, **SE,** IE	**LT**, DK, **SE**
Unsynchronised inflations		FR, IT, **GR,** ES, CY, LV, **LT,** MT, **SK**	FR, IT, IE, **GR,** ES, CY, LV, MT

Note: Bold = countries that had a central position in MST graphs.

Source: own elaboration

Based on our results (table 3), we conclude that during the pre-economic crisis period (i.e., January 2001 - December 2008) and the 'high inflation' period (i.e., August 2021 - April 2023), synchronized/slightly synchronised inflation developments with the EA and EU averages were observed in the largest number of countries. Before the financial and economic crisis of 2008, global economic conditions were characterised by interconnectedness and financial integration, which could have led to a synchronisation of inflation rates. The post-crisis period is marked by various external shocks (e.g. fluctuations in world commodity prices, trade disruptions). These shocks can affect inflation rates differently in individual countries, leading to a reduction in synchronisation. During the COVID-19 pandemic, many countries implemented similar measures to control the spread of the virus, with significant economic consequences. Governments and central banks not only in the EU but also worldwide introduced unprecedented fiscal and monetary (i.e. quantitative easing measures) stimulus to mitigate the impact of the crisis. The harmonisation of these macroeconomic policies could have contributed to similar inflation trends in countries and their synchronisation of inflation with the EA/EU average.

5. Conclusion

In the euro area, the main task of the European Central Bank is to control and manage inflation and maintain price stability (ECB, 2023). Price synchronisation, i.e. inflation synchronisation, is the situation when the prices of products and services in different markets or locations converge over time, which leads to synchronised price level movements. This process can significantly affect the efficiency and stability of the international economy and integration procedures in monetary unions. Inflation synchronisation and its international transmission can also make it difficult for central banks to conduct efficient monetary policy.

The effectiveness of monetary policy in managing inflation can be different in various EU countries, because of unique economic conditions. At the same time, inflation in one country can significantly affect other countries. To ensure macroeconomic stability, reduce inflationary pressures, and understand the causes of consumer price volatility, EU Member States need to coordinate their actions through effective communication, and cooperation between policymakers on issues related to monetary policy, fiscal policy, and labour market regulation (as stated also by Szafranek, 2021).

Our research aimed to find out whether the inflation rates of individual EU countries are synchronised with those of the EU and the euro area average and to investigate the mutual influence and transmission of the inflation rates of individual countries. To meet the predetermined goals, cross-correlations, and MST were applied in this study. We have analysed the behaviour and synchronisation of inflation in four different periods, i.e. (1) before the economic crisis that occurred in 2008; (2) subsequently after it and also before the introduction of the ECB's non-standard monetary policy; (3) the third period starting after the introduction of the quantitative easing measures, lasting until July 2021; and (4) the last period started in August 2021, when a significant increase in inflation was recorded, and lasted until April 2023. Further, the Bai and Perron test also helped us to divide the whole period into these parts. We intended to find out the international behaviour and co-movement of inflation, as inflation topic is very often mentioned and discussed nowadays so that the ECB could be cautious in implementing its monetary policy on this basis.

Based on our results, we can argue that since inflation in some EU member states was not synchronised with the average inflation in the EA, the ECB's single monetary policy may not have been appropriate to implement for each individual member country. Our findings suggest that the European Central

Bank should exercise caution when determining the course of its monetary policy to avoid having a significant adverse effect on any EA member.

This study attempts to contribute to the literature that deals with international inflation transmission and inflation synchronization or its convergence. The results of our study can help policymakers devise methods to mitigate the impact of inflation on the world economy by providing them with valuable information. Despite unprecedently high inflation in the EU countries in the post-pandemic period, the strengthening of inflation synchronisation is a good sign that simplifies the management of the single ECB monetary policy and potentially enables easier monetary integration of new member EA countries.

Our results and inflation interconnections between geographically near countries open the following questions for future research: Are countries with higher trade openness more sensible to external inflation shocks? Is inflation of more open countries more synchronised? Does openness or international (inter-country) trade volume influence international inflation transmission and its synchronisation? Further research could also focus on the possible determinants of the transmission of inflation between countries in order to predict the effects on a particular country's economy and consequently take macroeconomic policy measures to influence it.

Abstract

This paper aims to find out whether the inflation rates of individual European Union (EU) countries are synchronised with those of the EU as a whole and with the euro area (EA). Another objective is to examine the mutual inflation interconnections and its synchronisation across countries. We use the Minimum Spanning Tree (MST) and cross-correlations (C-C). Based on structural break tests, the period is divided into four periods: January 2001 - December 2008, January 2009 - March 2015, April 2015 - July 2021, August 2021 - April 2023. The results showed that the direction of the inflation transmission is not the same across the periods under study. Before the financial and economic crisis, Estonian inflation influenced Lithuanian inflation, which in turn influenced the Latvian one; while after the crisis (but just before the application of the ECB's quantitative easing) Latvian inflation is already influenced by Bulgarian inflation. Once quantitative easing had already been applied but in times before the 'high

inflation' period, the inflation in Lithuania has no impact on the Latvian one. During the 'high inflation' period, results conclude the impact of Latvian inflation on the Estonian one. We also point out that inflation rates in some states are not always aligned with average inflation in the EU, the EA. Although, MST results showed that inflation is transmitted mainly from the EA average or the EA countries, having a more central position (e.g. Slovakia has generally a more central position than the Czech Republic, Hungary, or Poland). Therefore, countries having common monetary policy are more resistant to external inflation shocks and rather influence the inflation of other countries. Finally, even if inflation rates are synchronised, inflation may be outpaced or lagged by one to several months, which may present policymakers with the question of the appropriate monetary policy stance.

Keywords: *inflation transmission, inflation synchronisation, quantitative easing, Minimum Spanning Tree, cross-correlation.*

JEL Classification: E31, E52, F65

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