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INFLATION AND GLOBAL SUPPLY CHAIN PRESSURE IN EUROZONE: A TIME-VARYING CAUSAL ANALYSIS

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Abstract. The aim of this paper is to analyze the causal relationship between inflation and global supply chain pressure in the Eurozone. In contrast to the full-sample causality method, this paper utilizes the bootstrap subsample rolling window causality method to account for structural changes. Initially, the computed vector autoregressive models demonstrate that the short-term relationship between inflation and global supply chain pressure is unstable. The dynamic causal relationship is reexamined in the subsample rolling window causality test using a time-varying method (RB bootstrap-based modified-LR causality test). The results indicate that inflation is influenced by the expansion of global supply chain pressure in a variety of sub-periods, with both positive and negative effects. Conversely, inflation fluctuations increase the uncertainty of the Global Supply Chain Pressure Index. The novelty of the findings is that they illustrate bidirectional causal relationships between the two variables, which is in contrast to the existing body of empirical research that does not support the direction of causality. The implications of these findings emphasize the need to implement appropriate monetary policy measures in order to mitigate the inflationary consequences of disruptions in the global supply chain and to ensure a more stable supply chain network.

Keywords: causal analysis, inflation, global supply chain pressure.

JEL Classification: E31, C32, F15.

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1. Introduction

The global supply chain pressure (GSCP) and its effects on the global economy have recently attracted widespread public interest. In particular, ever since the COVID-19 pandemic began, supply chain disruptions have emerged as a prominent topic of discussion, posing a considerable obstacle to economic growth. In the last 20 years, various events and factors have influenced inflation and supply chains in the Eurozone. For instance, the Global Financial Crisis (2007–2008) resulted in increased consumer prices, particularly for goods rather than services, with energy and food being the primary contributors (di Giovanni et al., 2022). The disruption of international supply chains played a crucial role in driving up consumer prices, highlighting the significance of supply-side factors. The finding that supply challenges were responsible for at least 80% of the increase in producer prices in the manufacturing and industrial sectors lends more credence to this (Shteynberg et al., 2022). The crisis also caused supply chain disruptions, leading to higher prices and shortages of basic commodities (Pasimeni, 2022). These disruptions were caused by a halt in production and worker layoffs, which affected global trade and resulted in ships being stranded at sea and a shortage of truck drivers (Gechev, 2019).

The Eurozone Sovereign Debt Crisis (2010–2012) was a significant event that affected several Eurozone countries, leading to severe debt problems and austerity measures. This crisis had widespread implications for inflation rates and supply chains, as countries implemented fiscal and monetary policies to address the situation. As a result, there were diverging dynamics in the cost of loans and credit developments among Eurozone countries, leading to heterogeneous credit conditions and diverging trends in economic activity and employment (di Giovanni et al., 2022). Supply-side disruptions were the main cause of the increase in inflation, with sectors such as energy and food accounting for a significant portion of the increase in consumer prices (Shteynberg et al., 2022). Global input-output links intensified these disruptions, impacting trade and inflation (Neri & Ropele, 2015).

The European Central Bank (ECB) launched quantitative easing (QE) in the Eurozone in 2015. This had various impacts on inflation and supply chains. The ECB's QE program mostly benefited the financial sector, with limited evidence of significant macroeconomic effects, as per Roderweis et al. (2023). Although the central bank's money was supposed to stimulate economic activity by promoting lending, it had the opposite effect, discouraging lending to productive sectors. Nonetheless, QE did result in a general rise in investment and a decline in the marginal costs of businesses, resulting in disinflationary supply-side repercussions that offset the inflationary impacts of the aggregate demand stimulus, as shown by Boehl et al. (2021).

The Brexit had substantial consequences for inflation and supply chains in the Eurozone. The decision by the British people to exit the European Union raised significant questions about the UK's future relationship with the EU and the potential for unconventional monetary policy, such as QE, to mitigate the impending crisis. The impact of the Brexit on the EU and the Eurozone was investigated (Kyriazis & Economou, 2019) and it was concluded that new rounds of non-conventional monetary policy were required to sustain the weaker southern European economies. Furthermore, the shift from services to goods consumption and global supply chain constraints contributed significantly to the explanation of Eurozone inflation in 2020–2021.

The Eurozone experienced substantial consequences from the COVID-19 pandemic, including those related to inflation and supply chains. The pandemic caused recessionary pressures, leading governments to enact expansionary policies to stimulate economic growth (Li et al., 2023). Additionally, the pandemic had sweeping economic, social and environmental consequences on supply chains (Aljuneidi et al., 2023). These disruptions in supply chain management resulted in temporary bottlenecks and hindrances to the smooth flow of goods. Furthermore, the pandemic emphasized the risks associated with concentrating businesses in specific regions and underscored the need for shorter supply chains for essential products (Santos & Donato, 2023).

Energy price volatility in the Eurozone had considerable consequences on inflation and supply chains. Global events like the pandemic and the war in Ukraine caused disruptions and crises that caused difficulties in international supply chains and a reduction in demand and prices for raw materials and energy resources. The European energy crisis, which was influenced by these international shocks, caused an increase in energy prices and significantly inflacted inflation, impacted businesses and households in Europe (Min, 2022). In particular, inflation in the Eurozone was greatly affected by energy price disruptions, particularly in the natural gas sector (Casoli et al., 2022). Demand shocks related to gas consumption and oil and gas supply shocks were linked to the high levels of inflation in the Eurozone. Energy price shocks also had long-lasting effects on global inflation, lasting approximately 2.5 years (Škare et al., 2023).

The ongoing trade disputes and tensions between major economies like the US and China can have significant consequences for international trade patterns. These conflicts can lead to disruptions in supply chains and ultimately influence inflation in the Euro area. Research has demonstrated that the US-Sino trade war has resulted in alterations to the circumstances around US-China trade, which in turn affected the contributions made by different countries in global value chains (Fusacchia, 2020).

Technological advancements have had a noteworthy influence on inflation and supply chains in the Eurozone. The shift in consumption from services to goods, brought about by compositional effects, has impacted both trade and inflation, exacerbating the consequences of supply chain disruptions (di Giovanni et al., 2022). Disturbances along international supply chains have been a major factor in inflation, particularly in sectors of the economy that heavily rely on imports (Pasimeni, 2022). The interconnectivity of global manufacturing and how it affects inflation rates are now crucial issues, with supply chain disruptions being linked to inflation levels in significant trading partners (Ekici, 2022). Global shocks, such as worldwide supply chain breakdowns have led to price volatility and affected energy prices, resulting in inflationary pressures in the Eurozone. The high rates of inflation in the Eurozone are mostly the result of aggregate demand and supply dynamics, especially supply chain disruptions (Gordon & Clark, 2023).

Based on these events, which have had an impact on both inflation and supply chains, this article aims to contribute significantly to the study of the time variation in the causal relationships between inflation and the Supply Chain Pressure Index within a complex and highly integrated economic region, with a focus on the Eurozone. Within the Eurozone, the ECB administers a single monetary policy. This uniform policy environment offers a distinctive context for investigating the impact of GSCP on inflation and the response of the ECB's policy measures to these pressures. The Eurozone has undergone a variety of inflationary trends, such as periods of low inflation and deflation concerns, as well as recent inflationary pressures. Understanding how pressures from the global supply chain affect these changes is crucial in order to develop effective monetary policies.

This study contributes to the body of knowledge in several significant ways. First, investigating the causal connections between two variables is essential because it enables us to comprehend the nature and direction of their interaction. By determining causality, it is possible to determine which variable influences the other and to what amount. Having this knowledge is important for making prudent choices and building effective strategies in a variety of sectors, including economics, finance and healthcare. Overall, causality study provides greater understanding of the intricate interrelationships among variables and the consequences they have on a variety of phenomena, as well as to construct cause-and-effect relationships and validate hypotheses. The majority of studies on causal relationship analysis has been concentrated on full-sample Granger causality tests, which operate under the presumption that the VAR model's parameters remain constant across time. This assumption might be violated, though, if full-sample data exhibit structural changes. This would invalidate full-sample causality tests and cause variable causal links to fluctuate. This research uses an approach based on the bootstrap sub-sample rolling window causality test to fill this gap in the empirical literature, which is more reliable than the full-sample causality test and may detect time-varying causal links when assessing the relationship between variables.

Second, the direction of the causal relationship between inflation and the GSCP is not supported by the amount of empirical research that has been done thus far. This study investigates and demonstrates bidirectional causal relationships between inflation and GSCP. The results indicate that the GSCP effects inflation both positively and negatively in a number of subperiods and that inflation has a negative effect on the GSCP.

The study's findings are significant because they demonstrate causal relationships between the two variables, implying that monetary policy must take adequate measures to mitigate the inflationary impact of disruptions in the global supply chain. By analyzing this study's time-varying causal analysis and econometric models' implications, policy makers can gain valuable insights into potential challenges as well as opportunities stemming from inflation dynamics and GSCP in the Eurozone.

The structure of this document is as follows. The theory and literature review is presented in Section 2. The methods and explanation of the theoretical models are provided in Section 3. The description of the corresponding data ends the empirical results are provided in Section 4. The study is concluded in final Section.

2. Theory and literature review

Global supply chain pressure describes the challenges and strains faced by supply chains on a global scale. These pressures can arise from various factors, such as disruptions in production and trade, changes in demand patterns, bottlenecks in supply chain networks due to events like COVID-19 pandemic, geopolitical conflicts and resource dependencies. Geopolitical conflicts have disrupted supply chains for key inputs such as neon, palladium and semiconductors (Warin, 2022). Resource dependencies in supply chains, particularly in water, energy and land use, are poorly understood but have significant consequences for global resource management (Taherzadeh, 2021). These forces have been seen to convey shocks to commodity markets throughout all time horizons, with a more noticeable influence over a longer length of time (Gozgor et al., 2023). These pressures have, however, forced businesses to reconsider their business strategies. As a result, they have revised debt ratios, raising the value of short-term debt while decreasing long-term debt in times of turmoil (Hupka, 2022). The GSCP was analysed by researchers in association even with bitcoin price: Qin et al. (2024) investigated the relationship between the GSCP and the price of bitcoin over time using full-sample and subsample bootstrap techniques, suggesting that "digital gold" can, in theory, resist these tensions to some degree, but not consistently.

The Global Supply Chain Pressure Index (GSCPI) is a novel indicator, proposed by the Federal Reserve Bank of New York (n.d.-b), that captures pressures at the global supply chain level. It serves as a monitoring tool to gauge global supply chain conditions. The GSCPI helps explain how demands on natural resources are distributed throughout national and sector supply networks within the global water, energy, and land (WEL) system. It reveals that these pressures are mostly caused by the reliance of the nation and sector's resources on immediate and upstream producers within their supply network (Taherzadeh, 2021).

The expansion of global supply networks has facilitated economic growth and enhanced competitiveness among trading partners. However, reliance on global supply chains also brings challenges (Zavala et al., 2019). The Logistics Performance Index, developed by the World Bank, is a benchmarking instrument utilized to assess the efficiency of the logistics supply chain within a given nation. It assists nations in identifying opportunities and constraints to enhance their logistics performance (Balan et al., 2006).

Inflation is a significant factor in determining economic policies. Significant fluctuations in its value can significantly influence household savings and consumption decisions as well as company investment and production decisions. Inflation has long been a subject of dispute in the field of macroeconomics and has also emerged as a concern for political and social stability. Therefore, a large volume of literature (e.g., Arrazola & Hevia, 2008; Cristadoro et al., 2005) has been directed towards the need to improve the accuracy of inflation forecasts and provide useful tools for policy monitoring and implementation using different approaches and models: ordered multinomial models augmented with macroeconomic variables (Miccoli et al., 2017); a flexible inflation target index that incorporates house prices and stock prices (Brugnolini & Ragusa, 2022); index that extracts the common component of national inflation and ignores idiosyncratic shocks (Shah & Sosvilla-Rivero, 2021). The connection between financial development and inflation has also been studied in scientific literature. For example, Sanusi et al. (2017) challenge the general consensus that inflation is detrimental to financial systems and does not necessarily have a negative impact on financial development. Given the significant, long-term correlation between inflation and credit extended to the private sector, their findings show that inflation can be a driver of financial development.

The theoretical model supporting this research is based on the interplay between supply disruptions and inflation dynamics. The research incorporates theories that pertain to the behavior of price setting in the occurence of supply limitations. Classical economics is the foundation of the economic theory of price. It is primarily concerned with the work of Adam Smith, who established the foundation with his concept of the 'invisible hand', which governs supply and demand to determine prices in a market economy. Alfred Marshall formalized price theory in his 1890 work, "Principles of Economics", by introducing the concepts of supply and demand curves intersecting to evaluate equilibrium prices (Egle, 1961). The economic theory of price setting under supply constraints investigates the manner in which businesses modify their pricing strategies in response to fluctuations in production costs and disruptions in the supply chain. The theory also takes into account the potential for inflation to be caused by GSCP, which can result in increased costs for businesses due to the creation of bottlenecks and delays. This inflationary impact is especially significant in interconnected and globalized markets, where supply chain disruptions can have a cumulative impact on the entire economy.

Demand-pull and cost-push inflation are frequently distinguished in theoretical models. The cost-push inflation is a result of the increasing costs of production inputs, whereas demand-pull inflation is driven by an rise in aggregate demand. In practice, the policy response can be complicated by the simultaneous occurrence of both categories of inflation (Takami, 2015). Although both types of inflation result in increased prices, their underlying causes and policy responses are distinct. Although monetary tightening may be employed to address demand-pull inflation, cost-push inflation necessitates more complex strategies, such as subsidies, tax relief, or measures to stabilize supply chains.

Post-Keynesian economists were particularly influential in the development of the concept of cost-push inflation, which posits that as production costs increase, prices also increase. The development of cost-push inflation theory is frequently attributed to Weintraub (1959). His research underscored the primary role of wage increases and other cost factors in the development of inflation. The concept of cost-push inflation acquired prominence following World War II, particularly throughout the 1970s oil price shocks. Significant price increases across a variety of sectors were the result of substantial increases in wages and the cost of critical commodities during these periods. Recently, the pandemic has caused supply chain disruptions that have resulted in cost-push inflation in a variety of sectors.

A variant known as profit-led inflation has been emphasized in the literature (e.g., Harding et al., 2023), in which firms increase their profit margins in response to supply disruptions. This has been observed in the post-pandemic period, when corporate profit shares increased in tandem with general price levels. This implies that companies not only passed on the increased costs but also capitalized on the situation to increase their profitability. For example, firms have been observed to establish prices at levels that are considerably higher than their costs in order to achieve the desired profit margins. This trend has been exacerbated by inflationary pressures and supply chain disruptions.

Cost-push factors, including increases in global commodity prices and disruptions in supply chains, have been substantial contributors to recent inflationary trends, as demonstrated by empirical analyses. For example, research has shown that the pandemic has exacerbated transportation costs and supply chain delays, resulting in increased costs for products that have been subsequently applied to consumer prices (Atigala et al., 2022).

Cost-push inflation emphasizes the necessity of targeted interventions that address supply-side constraints, such as managing commodity price volatility and enhancing supply chain resilience, to alleviate inflationary pressures without stifling economic growth. The ECB may raise or reduce interest rates in response to inflation-causing supply chain disruptions. The ECB has the capacity to implement unconventional monetary policy measures, such as Quantitative Easing QE, by purchasing substantial quantities of financial assets, including government and corporate bonds, in order to reduce long-term interest rates and expand the money supply. This has the potential to boost economic activity during periods of severe supply chain disruptions and associated deflationary risks. The ECB has the capacity to influence market expectations and behavior by communicating its future policy intentions through forward guidance. Despite its primary focus on fiscal policy, the ECB has the power to promote structural reforms in order to enhance the resilience of the supply chain. This encompasses the investment in infrastructure, the improvement of logistics efficiency, and the encouragement of innovation in the field of supply chain management to reduce the effects of future disruptions. In order to guarantee a thorough response to supply chain disruptions, the ECB may collaborate with fiscal authorities. Monetary policy initiatives may be supplemented by fiscal measures, including subsidies or tax incentives for industries that are impacted.

Recent research (Benigno et al., 2022) demonstrates that inflationary pressures, notably in producer price inflation in the Eurozone and the US, are highly tied to the behavior of GSCP. Therefore, the purpose of this study is to explore the causal link between Index Inflation Eurozone (IIEZ) and Global Supply Chain Pressure Index (GSCPI) using empirical application of the bootstrap sub-sample rolling window causality approach.

Various empirical studies on the connection between GSCP and inflation confirm the causality between the two, but there is no agreement on the direction of causality. For instance, according to Ye et al. (2023), pressures from the global supply chain have an unequal influence on inflation rates, having a greater effect in advanced economies as the supply chain develops and vice versa in emerging markets. Benigno et al. (2022) analyze the relationship between the Global Supply Chain Pressure Index (GSCPI) and inflation outcomes and show that the GSCPI's behavior is closely correlated with recent inflationary pressures, specifically with regard to the inflation of producer prices in the Eurozone and the United States. Di Giovanni et al. (2022) show that global supply bottlenecks have significantly driven the inflation that has affected all nations, but the inflation in the Euro area has been comparatively more significantly impacted by negative supply shocks (both domestic and foreign) than in the United States, where aggregate demand shocks have had a relatively less effect.

In terms of methodology, previous literature investigating the causal relationship between two variables has typically used the full-sample causality test, which requires that the parameters of the VAR model being tested remain constant over time, implying that a single causality exists throughout the period. Nonetheless, structural changes in the underlying full-sample data are willing to break this assumption (Balcilar & Ozdemir, 2013). To cover these previous literature gaps, this paper tests for causality on a rolling sub-sample with a fixed-size window in addition to the full sample. The rolling window method yields more precise causality results than the full-sample causality test because it accounts for the model's structural alterations as well as the progression of causality over different subperiods.

3. Methodology

To model the causal relationship between IIEZ and GSCPI, this study first adopts a bootstrap full-sample Granger causality test, based on a residual bootstrap process with a modified-LR test in the context of a bivariate VAR(*p*) model proposed by Balcilar et al. (2010). The presence of structural alterations is then verified using the parameter stability test. The causal relationship is investigated once more by applying the bootstrap subsample causality test. A description of the fundamental principles behind the parameter stability test, the subsample rolling window test, and the bootstrap full-sample causality test is given in the next section.

3.1. Bootstrap full-sample Granger causality test

This study examines the causal relationship between IIEZ and GSCPI using the Granger causality test, which is based on the bivariate VAR model. Considering the sensitivity of Granger causality test results to the selection of the sample period (Ghysels et al., 2016), we cannot assume that IIEZ and GSCPI are permanently correlated. In contrast, the present study employs the notion of "temporary" Granger causality, which suggests that the causal relationship is only valid for certain periods of time, consistent with Balcilar and Ozdemir (2013).

Standard asymptotic properties become problematic when non-stationary variables are included in the VAR model because of possible structural alterations in both the VAR model and the time series (Sims et al., 1990). Also, it is essential for both the variables and the VAR process to follow normal distribution principles (Sims, 1980, 2003). However, if this distribution cannot be replicated in certain situations, the robustness of the traditional VAR method may consequently decrease (Qin et al., 2022).

In order to tackle these issues, Shukur and Mantalos (2000) introduce the technique known as residual-based bootstrap (RB), which may be implemented on Granger causality statistics whose distributions deviate from the expected normality assumption. The so-called 'bootstrap' is a method to guarantee the precision of the test findings by multiple sampling (generally more than 1000 times, allowing repeated sampling) and it can greatly improve the accuracy of the findings, particularly in the test of small samples (Su et al., 2022). Also, the RB method can increase the power and size of the critical values when assessing the Granger causality between nonstationary variables, demonstrating its validity. Balcilar et al. (2010), Hacker and Hatemi-J (2006) demonstrate that when examining Granger causality tests to determine causal relationships between two variables, the bootstrap approach may be used for both cointegrated and noncointegrated data.

Based on the elements discussed above, this article uses a RB approach in conjunction with a modified-Likelihood Ratio (LR) test to investigate the Granger causality relationship between Index Inflation Eurozone (IIEZ) and Global Supply Chain Pressure Index (GSCPI). The following bivariate VAR(p) process is applied to illustrate the RB-based modified-LR causality test:

$$y_t = \varphi_0 + \varphi_1 y_{t-1} + \ldots + \varphi_p y_{t-p} + \varepsilon_t,\ t = 1,2,\ldots,T, \tag{1}$$

where $\varepsilon_t = \left(\varepsilon_{1t}, \varepsilon_{2t}\right)'$ is a zero-mean, independent, white noise process with non-singular covariance matrix. In this instance, the Schwarz Information Criteria (SIC) determine the ideal lag duration, p (as in Qin et al., 2024). To analyse the causal relationship between IIEZ and GSCPI, we divide y_t into two sub-vectors $(y_{1,t}, y_{2,t})'$. The following is a representation of Equation (1):

$$\begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} = \begin{bmatrix} \varphi_{10} \\ \varphi_{20} \end{bmatrix} + \begin{bmatrix} \varphi_{11}(L) & \varphi_{12}(L) \\ \varphi_{21}(L) & \varphi_{22}(L) \end{bmatrix} \begin{bmatrix} y_{1,t} \\ y_{2,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{1,t} \\ \varepsilon_{2,t} \end{bmatrix}, \tag{2}$$

where $\varphi_{ij}(L) = \sum_{k=1}^{p+1} \varphi_{ij,k} L^k$, i, j = 1, 2 and L is the lag operator $\left(L^k x_t = x_{t-k}\right)$.

By applying the restriction that $\varphi_{12,k} = 0$ for k = 1, 2, 3, …, p, based on the above VAR(p) process, the null hypothesis that GSCPI does not Granger cause IIEZ is examined. In the event that the null hypothesis proves false, GSCPI Granger will substantially contribute to IIEZ. Thus, GSCPI is able to forecast IIEZ movements. Analogously, by setting the restriction $\varphi_{21,k} = 0$ for k = 1, 2, 3, ..., p, the null hypothesis that IIEZ does not Granger induce GSCPI can also be tested. If the second null hypothesis is disproved, there is a statistically significant causal association between the IIEZ and the GSCPI.

3.2. Parameter stability test

It is assumed in the full-sample causality tests that the parameters of the VAR model remain constant over time. Additionally, previous studies have operated under the assumption of no structural changes in the variables and have solely investigated the causal relationship within the full sample (Balcilar & Ozdemir, 2013). Consequently, the full-sample causality tests that rely on the assumption of constant parameters become inaccurate if the variables experience structural changes and the causal linkages between two variables are unstable (Zeileis et al., 2005). As Ding and Granger (1996) emphasized, structural instability may be one of the most difficult issues confronted by empirical investigations in recent years. Consequently, the full-sample approach is not relevant and more advanced techniques are required to capture this dynamic correlation.

To find out whether the studied series shows significant structural changes, this article assesses the parameter stability. The short-term parameters' stability are evaluated with the help of the Sup-F, Mean-F and Exp-F tests. Although the null hypothesis is the same for these tests, their alternative hypotheses are distinct (Andrews & Ploberger, 1994). Mean-F and Exp-F assume that the parameters follow a martingale process and assess the model's stability over time, whereas Sup-F checks if a regime shift occurs and captures structural mutations in each sequence and the VAR(p) system. We also apply the Lc test, which was created by Nyblom (1989) and Hansen (1992), to ascertain the stability of parameters over time. The series of LR statistics is used to calculate the tests, which assess the stability of parameters against the potential for a single structural break at any moment.

In this study, the critical values and p-values are establish based on a parametric bootstrap process using an asymptotic distribution obtained through Monte Carlo simulations involving 2,000 samples from a VAR model with constant parameters, in line with the approach suggested by Andrews (1993), Andrews and Ploberger (1994). In consideration of the 15 percent trimming requirement from both ends of the sample for the Sup-F, Mean-F and Exp-F tests, the tests employed in this paper utilize samples in the fractions (0.15, 0.85).

3.3. Sub-sample rolling-window causality estimation

As discussed previously, the examined series display substantial structural changes, rendering the full-sample results invalid (Balcilar & Ozdemir, 2013). To study the causal relationship between GSCPI and IIEZ, we employ the rolling-window bootstrap method (Balcilar et al., 2010). Rolling-window estimation accommodates variations in the causal relationship between variables and is effective at capturing the instability among subsamples produced by structural change. Rolling window techniques make use of fixed-size subsamples that roll consecutively from the start of the sample to its end (Balcilar et al., 2010).

This paper assumes that the size of the total sample is T and sets a fixed-size rolling window including i observations. According to this width, the full-sample is separated into T-i sub-samples and the end of each small section is i, i + 1, ……, T. The potential time-varying causality between the GSCPI and IIEZ might be determined by computing the bootstrap p-values of observed LR-statistics rolling through T-i sub-samples. To acquire a large number of estimations, this research used the bootstrap method. The effect of GSCPI on IIEZ is defined as the average of the bootstrap estimates of $N_b^{-1}\sum_{k=1}^{p}\widehat{\varphi_{12,k}^{*}}$, where N_b^{-1} represents the number of bootstrap repetitions. The GSCPI's response to the IIEZ is determined by $N_b^{-1}\sum_{k=1}^{p}\widehat{\varphi_{21,k}^{*}}$. Both $\widehat{\varphi_{12,k}^{*}}$ and $\widehat{\varphi_{21,k}^{*}}$ are VAR model bootstrap estimates found in Equation (2). Grounded on Balcilar et al. (2010), this analysis performs the 90% confidence interval with lower (the 5th quantile of $\widehat{\varphi_{12,k}^{*}}$ and $\widehat{\varphi_{21,k}^{*}}$) and upper (the 95th quantile of $\widehat{\varphi_{12,k}^{*}}$ and $\widehat{\varphi_{21,k}^{*}}$) bounds (Su et al., 2020, 2022).

The two competing objectives in the rolling-window estimation implementation are the representativeness of the method over the subsample period and the accuracy of the model estimations. The number of observations, or window size, controls the estimate's precision and has an anti-correlated relationship with the magnitude that measures the representativeness of the model. The estimation becomes more accurate as the window size increases. However, representativeness is weakened if the window size is too big and many shifts may be included in the same window sample. Pesaran and Timmermann (2007) state that the size and persistence of the break determine the proper window size, as represented by the square root mean square error. The Monte Carlo simulations show that the window size should not be less than 20 when there are several breaks. Considering this requirement, this paper uses the 24-month size to ensure representativeness and accuracy.

4. Empirical data and analysis

4.1. Data sets and sources

This article uses the Global Supply Chain Pressure Index (GSCPI), which is a monthly indicator proposed by the Federal Reserve Bank of New York (n.d.-b), to measure supply chain pressure, in line with Gozgor et al. (2023) and Qin et al. (2024). This choice is based on two key factors. Firstly, the GSCPI provides a long panel of monthly data from 1997 to 2023, allowing for a thorough examination of the relationship between inflation and GSCP. Secondly, the GSCPI incorporates crucial aspects of potential supply chain disruptions, such as information on the costs of cross-border transportation and survey results from manufacturing purchasing managers. Using data from the Baltic Dry Index (BDI) for bulk shipping, the Harpex index for container shipping and airfreight cost indices from the U.S. Bureau of Labor Statistics, the index accounts for the cost of transportation worldwide. Additionally, the GSCPI includes various supply chain-related components from Purchasing Managers' Index (PMI) surveys, such as delivery times, backlogs and inventories, concentrating on manufacturing companies in the seven interrelated economies of the US, UK, China, Japan, South Korea, Taiwan and the Euro region.

Since the beginning of the pandemic, the GSCPI has shown two notable increases (as displayed in Figure 1). The first wave of lockdowns in the spring of 2020 caused a surge that resulted in production problems like longer delivery delays and lower inventory. It appeared that supply chain difficulties subsided in the autumn of 2020. A second, concurrent increase occurred in the spring of 2021, which was accompanied by an escalation in shipping expenses. Comparatively, bulk and container shipping costs have increased by a factor of four and seven since the beginning of the epidemic, respectively, in 2021 (Andriantomanga et al., 2023).

Our inflation measure come from the historical inflation rates for the Euro area published by the RI (https://www.rateinflation.com/) on a monthly basis, starting with 01.1999 and consist of the Index inflation Eurozone. This index is used to assess and monitor price dynamics in the area. It provides a summary measure of inflationary pressure, considering different indicators of price dynamics.

As illustrated in the Figure 1, inflation in the Euro area exhibited a downward trend from the Great Financial Crisis of 2007–2008 to 2020. This decrease in inflation has been caused by a number of causes, including a drop in inflation expectations, the ongoing effects of globalization, a decrease in labor bargaining power, technological advancements, the growth of e-commerce, demographic shifts and financial factors.

On the other hand, significant pressures have been created on the supply and demand sides of inflation in the Eurozone as a result of the COVID-19 outbreak. Rising energy prices played a key role in driving up inflation on the supply side (Krompas, 2022). Additionally, inefficiencies in natural gas pricing within the EU contributed to inflationary pressure. On the demand side, fiscal and monetary expansionary measures implemented during and after the pandemic have been strongly linked to high inflation across countries (Andersson, 2023).

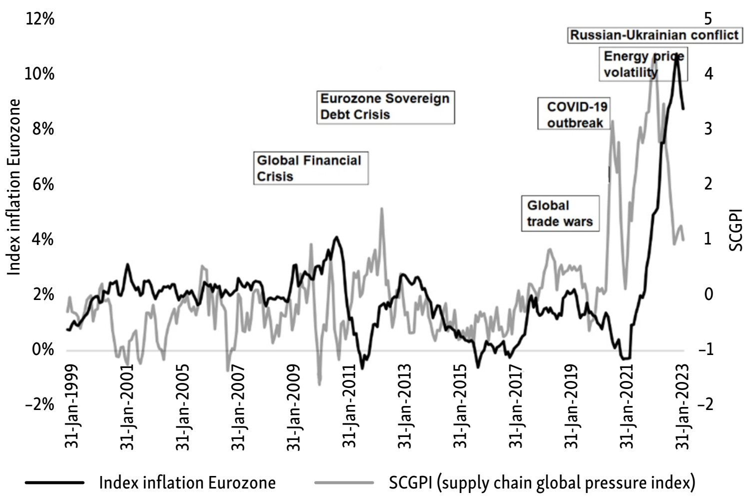

Figure 1. The trends of Index Inflation Eurozone and Global Supply Chain Pressure Index (GSCPI) (source: authors' representation, using data from Federal Reserve Bank of New York, n.d.-a, n.d.-b and https://www.rateinflation.com/)

In particular, the Eurozone's inflationary pressures were exacerbated by the extremely expansionary monetary policy that was undertaken throughout the pandemic (Nickel et al., 2022).

This study covers the following timeframe for the data series: 1999 M1–2023 M1 (monthly data). We chose this timeframe because it covers the most important events in the Euro area that affected inflation and supply chain pressure, like the Global Financial Crisis, Eurozone Sovereign Debt Crisis, Brexit, COVID-19 pandemic and others. The study is carried out utilizing the E-Views 10 and R programming language (for parameter stability test).

4.2. Empirical results

Stationarity test

Sims et al. (1990) point out that utilizing non-stationary series variables when evaluating real-world problems with VAR models might offer statistical inference issues because standard statistical tests and statistical inference require all series to be stationary. As a consequence, to evaluate data using the Vector Autoregression (VAR) technique, analyzing the data's stationarity is the first step. If a variable exhibits non-stationarity, exemplified by a unit root process (meaning it has a stochastic trend), this can result in spurious regression, in which two independent non-stationary variables show considerable evidence when none exists. In order to use the causality test, the data must be stable and if they are not stable, they must first be differentiated and transformed into a stable series.

To evaluate the whole-sample Granger causality test and parameter stability tests' reliability using the VAR system, we initiate our investigation by examining the unit root of each sampled variable. In this case, we employ ADF and PP unit root tests. These tests work based on the premise that the series is non-stationary because of a unit root under the null hypothesis. The lag length in ADF is set to zero, thereby determining automatically via Schwarz Information Criterion (SIC) up to a maximum of 10 lags. The PP test statistic is computed using differences between time series data and their lagged values.

The results of the stationarity tests are shown in Table 1. Both tests results at level for GSCPI are significant at the 5% (ADF) and 1% (PP) level. Because the p-value in this instance is less than 0.05 (0.01), the series is stationary at level and the null hypothesis of a unit root can be rejected at the 5% (1%) level of significance. For the time series IIEZ, the null hypothesis that IIEZ has a unit root cannot be rejected, according to the findings, indicating that the data are non-stationary and show a level trend. Following the analysis, in the first difference, the null hypothesis regarding the presence of a unit root for IIEZ is rejected. Table 1 presents clear evidence that the ADF and PP tests effectively indicate the rejection of the null hypothesis of non-stationarity for GSCPI at level, but fail to do so for IIEZ. However, in the case of first differences of IIEZ series, these tests reject the null hypothesis.

Table 1. Unit root tests (source: authors' calculation)

Series	Levels		First differences	
	ADF	PP	ADF	PP
	t-Statistic	*t*-Statistic	*t*-Statistic	*t*-Statistic
GSCPI	–3.009**	–2.827*	–16.085***	–17.763***
IIEZ	–2.325	–0.563	–12.482***	–12.856***

Note: ***significant at the 1% level. MacKinnon (1996) one-sided p-values.

The findings imply that either the level or first difference stationary time series are present. In other words, it appears that GSCPI and IIEZ follow a stationary process, which validates the use of the VAR system. Consequently, the full-sample Granger causality and rolling window Bootstrap Granger causality tests can be used to further this investigation.

It is necessary to determine if the sampled variables are integrated or cointegrated in order to test the vector autoregression model's parameters for long-term stability (see Balcilar et al., 2010). As a preliminary step, it is essential to test for at least one cointegrating relation. The next step involves using Johansen's linear cointegration method (Johansen, 1991, 1995) to determine if a cointegration relationship exists. Table 2 shows the results of the Johansen cointegration test, which includes conducting both Trace and Maximum Eigenvalue tests. At the significance level of 0.05, both tests reveal the presence of two cointegrating Equations. The Unrestricted Cointegrating Coefficients demonstrate a positive association between GSCPI and IIEZ in the long term. These findings lead us to reject the null hypothesis that there are no cointegration vectors and favorably accept an alternative hypothesis suggesting there is at least one vector present.

Table 2. Results of the Johansen cointegration test (source: authors' calculation)

Unrestricted Cointegration Rank Test (*Trace*)				
Hypothesized		Trace	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.089	32.155	15.495	0.000
At most 1 *	0.019	5.453	3.841	0.020
Notes: Trace test indicates 2 cointegrating eqn(s) at the 0.05 level; * denotes rejection of the hypothesis at the 0.05 level; ** MacKinnon-Haug-Michelis (1999) *p*-values				
Unrestricted Cointegration Rank Test (*Maximum Eigenvalue*)				
Hypothesized		Max-Eigen	0.05	
No. of CE(s)	Eigenvalue	Statistic	Critical Value	Prob.**
None *	0.089	26.702	14.265	0.000
At most 1 *	0.019	5.453	3.841	0.020
Notes: Max-eigenvalue test indicates 2 cointegrating eqn (s) at the 0.05 level; * denotes rejection of the hypothesis at the 0.05 level; ** MacKinnon-Haug-Michelis (1999) *p*-values				

Then, bivariate VAR models are built using the first-differenced log-levels of the GSCPI and IIEZ since we are interested in investigating the causal link between the two variables, as shown in Equation (3). Equation (2) can be expressed as follows by dividing y_t into two sub-vectors $(y_{GDP,t}, y_{GAS,t})'$:

$$\begin{bmatrix} y_{GDP,t} \\ y_{GAS,t} \end{bmatrix} = \begin{bmatrix} \varphi_{10} \\ \varphi_{20} \end{bmatrix} + \begin{bmatrix} \varphi_{GDP,GDP}(L) & \varphi_{GDP,GAS}(L) \\ \varphi_{GAS,GDP}(L) & \varphi_{GAS,GAS}(L) \end{bmatrix} \begin{bmatrix} y_{GDP,t} \\ y_{GAS,t} \end{bmatrix} + \begin{bmatrix} \varepsilon_{GDP,t} \\ \varepsilon_{GAS,t} \end{bmatrix}, \quad (3)$$

where $y_{GDP,t}$ is GSCPI and $y_{GAS,t}$ is IIEZ.

Given that GSCPI and IIEZ demonstrate non-stationary behavior, we analyze the full-sample causal connection between them. To establish the optimal lag length, we employ the Vector Autoregression technique. The findings of the Lag Length test indicate that based on both the Hannan-Quinn and Schwarz criterion, an optimal lag length of 1 is determined.

By utilizing RB-based modified-LR causality tests, the Table 3 presents the full-sample causality outcomes of Bootstrap LR tests. The table provides the statistics and *p*-values for each test. In the first test, a statistic of 1.12 and a *p*-value of 0.3 are observed, indicating insufficient evidence to refute the null hypothesis that GSCPI does not Granger cause IIEZ. Similarly, in the second test, a statistic of 1.47 and a *p*-value of 0.31 show weak support for rejecting the null hypothesis that IIEZ does not Granger cause GSCPI. The results suggest no causal link between these two variables.

These findings contradict some previous research. Gordon and Clark (2023), for instance, discovered that excessive inflation has been mostly caused by supply chain disruptions as well as aggregate demand and supply variables. Moreover, Pasimeni (2022) showed that disruptions in global supply chains can be crucial in driving inflation in the Euro area, indicating a potential causal relationship between inflation and supply chain disruptions.

Table 3. Full-Sample Granger causality tests (source: authors' calculation)

Tests	H0: GSCPI does not granger cause IIEZ		H0: IIEZ does not granger cause GSCPI	
	statistics	*p*-values	statistics	*p*-values
Bootstrap LR test	1.127	0.300	1.479	0.310

Notes: Causality tests are based on a VAR model, with the lag-length being determined by the Schwarz information criterion and the Hannan-Quinn information criterion. The null hypothesis is: no-causal relationship exists between the variables.

Parameter stability test

Since full-sample estimation assumes constant parameters over the course of the sample period, it is not always correct (Zeileis et al., 2005). Moreover, in this instance, the structural shift in the economy that was disregarded by the full-sample test may have an impact on the variables.

This study investigates the stability of parameters and detects potential structural changes in the full-sample time series. As mentioned earlier, three statistical tests – Sup-F, Ave-F and Exp-F – are employed to assess short-term parameter stability in the GSCPI and IIEZ-formed VAR models. Furthermore, the Lc test is applied to evaluate long-term parameter stability across all variables in the entire VAR system. The detailed results of parameter stability analysis are presented in Tables 4 and 5.

First row in Table 5 displays the Sup-F tests for assessing whether parameters remain constant or undergo a one-time sharp shift. The findings reveal that both the GSCPI and IIEZ equations exhibit a sudden structural shift at significance levels of 1% and 5%. This suggests rejection of the hypothesis that model parameters are stable over time, indicating instead a sudden structural change at these specific levels. Furthermore, the Ave-F test indicates potential gradual alterations in GSCPI, IIEZ and VAR(*p*) processes at respective significance levels of 1% and 5%. Similarly, the Exp-F test shows possible rejection of the null hypothesis regarding parameter adherence to a martingale process at both 1% and 5% significance levels within GSCPI, IIEZ and VAR(*p*). Additionally, according to Lc statistics, it can be inferred that null hypotheses concerning conformity with random walk for VAR(*p*) process are rejected at a level of significance of 1%, indicative of inconsistencies in calculated VAR model parameters. To examine the stability of the long-run relationship parameter, Table 5 presents bootstrap *p*-values indicating that Sup-F, Ave-F, Exp-F and Lc statistics reject the null hypothesis of a stable relationship between variables at a significance level of 1%.

Table 4. Short-run parameter stability tests (source: authors' calculation)

Tests	GSCPI Equation		IIEZ Equation		VAR process	
	Statistics	Bootstrap *p*-value	Statistics	Bootstrap *p*-value	Statistics	Bootstrap *p*-value
Sup-F	20.613***	0.002	16.610**	0.016	29.048***	0.001
Ave-F	14.842***	0.000	7.271**	0.021	16.964***	0.000
Exp-F	8.952***	0.001	5.618**	0.015	11.073***	0.001
Lc					6.814***	0.005

Notes: This investigation calculates *p*-values through employing 2,000 bootstrap repetitions;
*, **, *** denote significance at 10, 5 and 1 percent, respectively. Hansen-Nyblom (L_C) parameter stability test for testing all parameters in the VAR jointly.

Table 5. Long-run parameter stability tests (source: authors' calculation)

	Sup-F	Ave-F	Exp-F	L_C
GSCPI = α + β*IIEZ	50.526***	22.579***	22.317***	7.948***
Bootstrap *p*-value	0.000	0.000	0.000	0.005

Notes: This investigation calculates *p*-values through employing 2,000 bootstrap repetitions;
*** denote significance at 1%.

Consequently, these findings provide compelling evidence that the presence of structural alterations causes short-run instability in the predicted parameters of the VAR model based on the full sample. It indicates that the results indicating a lack of full-sample causality between GSCPI and IIEZ are inaccurate. Furthermore, parameter stability tests reveal that there is no valid cointegration between the GSCPI and IIEZ. The results show that there is no evidence for full-sample non-causality between the variables.

The causal relationship between GSCPI and IIEZ is examined in this article using rolling window estimates, which take structural changes into account. Because it takes into consideration the time-varying character of subsamples, this method accounts for the causal relationship between two variables more effectively than a full-sample causality test.

Sub-sample rolling window causality test

The tests' null hypothesis is that IIEZ does not cause Granger and vice versa. By using 24-month observations in rolling subsample data, one can calculate bootstrap *p*-values for LR-statistics using the VAR models from Equation (3). After removing 24-month observations from the start of the entire sample, the estimates shift from Q1 2001 to Q1 2023.

Panel A of Figures 2 and 4 depicts the rolling bootstrap *p*-values for LR-statistics with GSCPI and IIEZ as dependent variables. The null hypothesis – the assertion that one variable does not impact the other via Granger causality – can be rejected at a significance level of 10%. In order to mitigate the risk of obtaining results with inadequate descriptive power, *p*-values exceeding 10% (located above the red horizontal line) are ignored.

Panel B in Figure 3 and Figure 5 illustrate the magnitudes of the influence, with the dependent variables GSCPI and IIEZ, respectively. Strong rejection of null hypotheses is possible in Panels A of Figure 2 and Figure 4, provided that the rolling bootstrap of *p*-values do not exceed 10%.

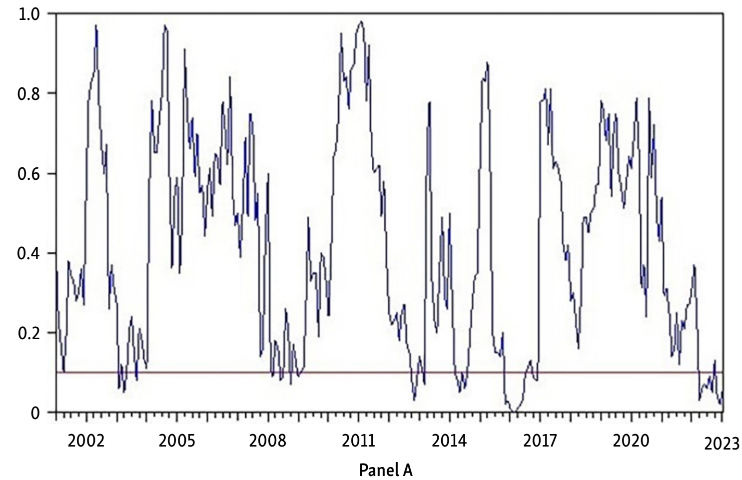

Figure 2. Bootstrap *p*-values for rolling tests of the null hypothesis that GSCPI does not Granger cause IIEZ (source: authors' calculation)

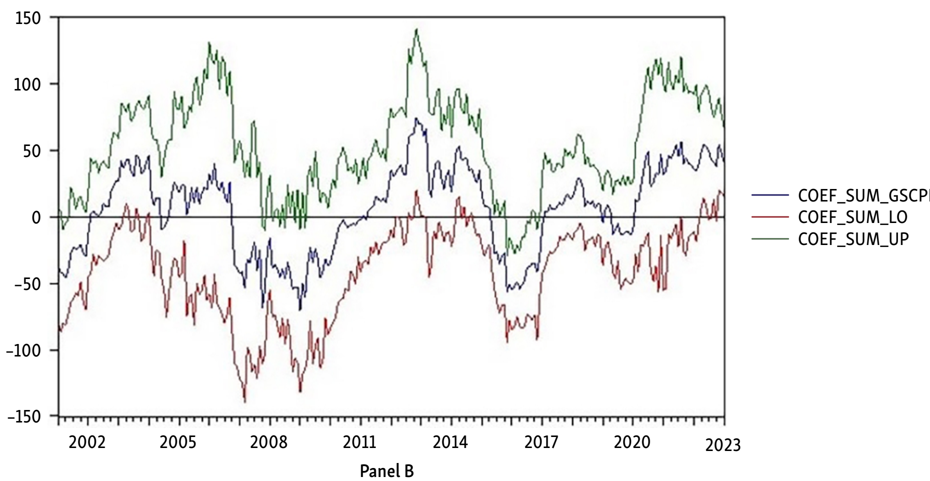

Figure 3. Bootstrap estimates of the sum of rolling window coefficients for the influence of GSCPI on IIEZ (source: authors' calculation)

Figure 2's Panel A shows that the null hypothesis is substantially rejected during a number of sub-periods (2003.01–2003.04, 2008.04–2008.06, 2012.08–2012.11, 2014.02–2014.07, 2015.09–2016.12, 2022.03–2023.01). That is, GSCPI has effect on inflation. The findings suggest that the direction of IIEZ is only partially guided by the GSCPI during some sub-periods. The Figure 3, Panel B displays the bootstrap calculations of the overall rolling window coefficients for the impact of GSCPI on IIEZ. In most cases where the impact is deemed statistically significant, influence from the GSCP has a positive effect on inflation in the Eurozone (2003.01–2003.04, 2012.08–2012.11, 2014.02–2014.07, 2022.03–2023.01), except for 2008.04–2008.06 and 2015.09–2016.12, during which the effect is negative.

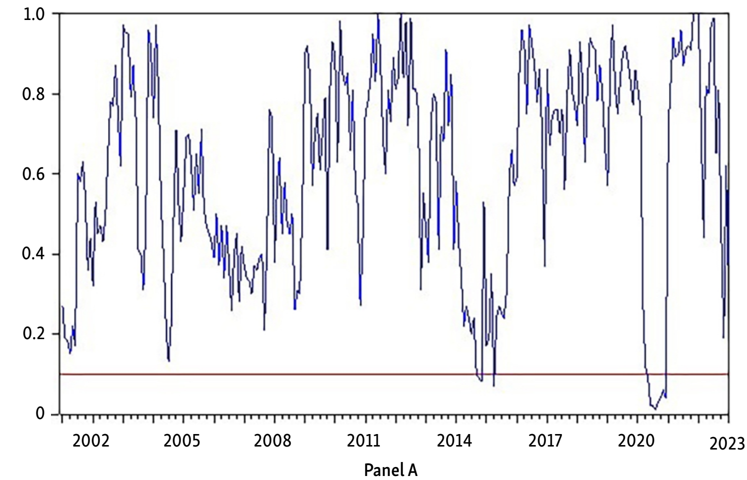

Figure 4. Bootstrap *p*-values of rolling test statistic testing the null that the IIEZ does not Granger cause the GSCPI (source: authors' calculation)

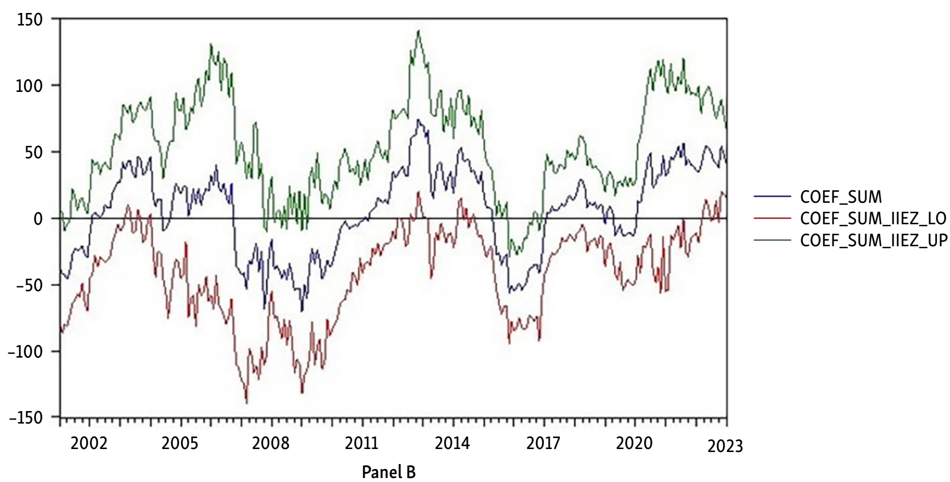

Figure 5. Bootstrap estimates of the sum of the rolling window coefficients for the impact of IIEZ on GSCPI (source: authors' calculation)

As we can see from Panel A of Figure 4 (and also in Figure 1), the annual inflation rate in 2022 reached a record high of 10.62 percent since the Eurozone's founding in 1999, primarily as a result of supply chain disruptions worldwide and the energy crisis sparked by the conflict in Ukraine.

With respect to the causal relationship between inflation and the Global Supply Chain Pressure Index, the null hypothesis is significantly rejected in Panel A of Figure 4 for several sub-periods (2014.08–2014.10 and 2020.03–2020.12). That is, IIEZ has effect on GSCPI. The findings suggest that the influence of inflation on the GSCPI is limited to specific time periods, suggesting that the causal relationships between IIEZ and GSCPI are time-varying. Panel B of Figure 5 shows that the inflation has a negative effect on the GSCPI for these periods. In other words, fluctuations in inflation enhance the uncertainty of GSCPI in some periods.

Figures 2–5 depict the emergence of structural changes in relationships. In contrast to the causality test, the result is significantly different due to its disclosure of the time-varying nature of the full sample. The presence of causality is restricted to specific sub-periods, suggesting that changes in one variable are insufficient to completely account for variations in the other.

5. Conclusions

This study offers a greater understanding of the intricate relationship between inflation and GSCP within the Eurozone through the use of time-varying causal analysis. The time-varying causal link between IIEZ and GSCPI was examined in this study using a bootstrap subsample rolling window causality technique.

Several events affecting inflation and the supply chain occurred in the Eurozone over the time period covered by this study. Chronologically, the findings of this study, surprisingly, revealed no connection between the two variables during the Global Financial Crisis (2007–2008), despite the fact that the crisis created supply chain disruptions, resulting in higher prices and shortages of basic commodities. In contrast, during the Eurozone Sovereign Debt Crisis (2010–2012), the results indicated a positive causation between GSCP and inflation, which is consistent with the findings of Pasimeni (2022) and Shteynberg et al. (2022).

The pandemic crisis, the military conflict in Ukraine and the volatility of energy prices have all maintained a significant positive correlation between the pressure on the global supply chain and inflation. This suggests that disruptions in the supply chain have played a role in the recent rise in inflation around the world (in line with Andriantomanga et al., 2023; Santacreu & Labelle, 2022). These results, which suggest a positive causation between inflation and GSCP, are in accordance with recent literature. For instance, the causation identified in this study is supported by the research conducted by Pasimeni (2022), which analyzed the most recent trends in Eurozone inflation and underscored the substantial influence of supply-side factors, such as global supply chain disruptions, on inflationary pressures. Santacreu and Labelle (2021) investigated the direct effects of disruptions in global supply chains on inflationary pressures. The mechanisms identified in their study during the Eurozone crisis are still pertinent today, according to the findings in this study. These are further supported by Shapiro's (2022) paper, which underscored the substantial and enduring impact of supply chain disruptions on inflation. Ha et al. (2023) examined the impact of external shocks, such as global supply chain disruptions, on inflation dynamics in the Eurozone, particularly during periods of economic pressure. This is consistent with the period examined in this study and confirms the existence of causality between inflation and supply chain pressures.

A negative supply shock occurred early in the pandemic's course, causing the initial supply chain disruption. When this disruption was combined with uncertainty, it resulted in insufficient demand and a large GDP contraction. Pent-up demand throughout the recovery period added pressure on supply chains, resulting in inflation. Supply chain bottlenecks in the Eurozone have been driven by various factors, including shortages of critical manufacturing components, like semiconductors. The most important elements are as follows: i) challenges facing the logistics and transportation industry; ii) shortages of semiconductors; iii) limitations on economic activity due to pandemics; and iv) a scarcity of labor. The Eurozone's inflationary pressures have been exacerbated by these supply chain disruptions.

The results imply that there is a temporal variation in the causal link between GSCPI and IIEZ. While GSCP mostly has a positive impact on inflation in the Eurozone, it shows a negative effect towards the end of 2015 and 2016, contrary to the predominant recent literature, which generally emphasizes the inflationary pressures resulting from global supply chain disruptions. One possible reason for this change could be attributed to the ECB Quantitative easing (QE) program, which led to an overall uptick in investment and reduced marginal costs for firms. This resulted in deflationary effects from the supply side outweighing the inflationary impacts caused by stimulating aggregate demand (Boehl et al., 2021).

The study's empirical findings point to the need for monetary policy to take adequate action in response to the inflationary effects of interruptions in the global supply chain. This can be accomplished through various methods, including implementing strategies to diversify suppliers and regions, creating plans to swiftly adjust and address disruptions, investing in technology that improves visibility and strength of the supply chain, encouraging cooperation and sharing of information among stakeholders, as well as promoting sustainable practices that decrease susceptibility to disruptions. These actions combined with proactive monetary policies responsive to changing patterns of inflation and global pressures on the supply chain can help reduce negative effects on the economy while ensuring a more stable and robust supply chain network within the Eurozone. For example, a step in this way was accomplished by Andriantomanga et al. (2023), whose empirical evidence and model simulations showed that central banks can more effectively stabilize production and inflation by taking a proactive approach to addressing disruptions in the global supply chain.

A potential limitation of this study refers to data, which can impair the accuracy of the causal analysis because supply chain disruptions can happen abruptly, making it difficult to assess their immediate impact on inflation. The econometric modeling constraints of this study may not fully capture the complexities of global supply chains and their myriad interactions with the economy, because over-simplification can lead to incomplete conclusions. Also, the causal relationship may not account for all external factors like geopolitical tensions, policy changes, or unexpected global economic shifts, which can also influence inflation. The specifics of supply chain pressures and their impacts on inflation can vary by sector and over different time periods, making it challenging to generalize findings across the whole Eurozone economy. Each of these limitations would need to be addressed or acknowledged to enhance the reliability of conclusions drawn from the causal analysis.

Future studies on inflation and the challenges faced by global supply chains should concentrate on a number of key areas to advance our comprehension and capability to effectively address these issues. There is a necessity for more extensive and current data concerning global supply chains, encompassing information about supplier networks, transportation routes and inventory levels. Such data will enable researchers and decision-makers to gain improved insight into the vulnerabilities and interconnections within supply chains, as well as to create more precise models for anticipating and alleviating disruptions. Moreover, future research should investigate how new technologies including artificial intelligence can improve supply chain resilience while lessening inflationary pressures. Through the utilization of these technologies, stakeholders in supply chains can enhance transparency, traceability and real-time monitoring of inventory levels; thus enabling them to respond more efficiently to disturbances and manage inflation dynamics. In addition, future research ought to explore the effects that geopolitical factors have on global supply chains and inflations. It is crucial to understand how geopolitical tensions and trade policies can disrupt supply chains and support inflationary pressures. By analyzing the interactions between inflation dynamics, GSCP and geopolitical factors, researchers can craft strategies that reduce negative impacts and support global stability in the supply chain ecosystem.

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Author contributions

S-ES: conceptualization, formal analysis, investigation, methodology, visualization, supervision. CO-S: conceptualization, formal analysis, investigation, methodology, visualization, writing – original draft, writing – review & editing. CB: conceptualization, formal analysis, investigation, methodology. BM: conceptualization, writing – original draft, writing – review & editing. RB: conceptualization, writing – original draft, writing – review & editing.

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The authors declare that they have not any competing financial, professional, or personal interests from other parties.

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