COLLEGIUM OF ECONOMIC ANALYSIS
WORKING PAPER SERIES

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SGH KAE Working Papers Series Number: 2023/094 September 2023

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September 28, 2023

Abstract

This article quantifies the effects of supply chains disruptions on inflation in European economies. We apply the local projections method in a panel framework and estimate responses of nine measures of consumer and producer inflation to shortages in materials and equipment reported by enterprises in the business surveys conducted by the European Commission. We find that supply chains disruptions are proinflationary for all considered measures of inflation, and a larger effect can be observed for inflation of prices of goods rather than services. The peak of impulse responses can be observed 4-6 quarters after shock, while the effect usually dies out after 8-12 quarters. The forecast error variance decomposition (FEVD) suggests that supply chain disruptions are much more important in explaining inflation changes at medium- rather than short-run forecast horizon. Moreover, supply chain shocks seem to matter relatively more for the variance of inflation of consumer prices of goods than for other measures of inflation. Interestingly, the positive estimates of the impact of supply chains disruptions on inflation can be related mainly to the period corresponding with the COVID-19 pandemics as well as the full-scale invasion of Ukraine and may exhibit asymmetric or regime-switching nature.

Keywords: supply chains shock, inflation, local projections, panel data
JEL Classification Numbers: E31, E32, F41, C33

*The views expressed herein belong to the authors and have not been endorsed by Narodowy Bank Polski. We would like to thank Michał Gradzewicz, Jacek Kotłowski and Oleksiy Kryvtsov, as well as conference participants at the NBU-NBP 2023 Annual Research Conference and the 29th Computing in Economics and Finance Conference for helpful comments and discussions.

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1 Introduction

In the 1990s and early 2000s globalization was usually perceived as a process providing a favorable environment for low global inflation. Some early papers on the relation between globalization and inflation (e.g. Romer, 1993; Lane, 1997) abstracted from the role of structural integration of goods, capital and labor markets being the essence of globalization but rather focused on the exchange rate channel. They suggested that increased trade openness reduces the inflation bias in the spirit of Kydland and Prescott (1977) and Barro and Gordon (1983) because expansionary monetary policy leads to real depreciation that additionally raises inflation via the import prices. Therefore the positive output effects of expansionary monetary policy come at the cost of higher inflation than in a closed economy. In other words, the Phillips curve should become steeper as an economy gets more open. This effect should be even strengthened by the positive effect of trade openness on competition since higher competition leads to more flexible prices and wages, which steepens the Phillips curve as well (Rogoff, 2003, 2007). However, as pointed by Ball (2006), there had been robust empirical evidence that the Phillips curve had become flatter rather than steeper.

The empirical pattern of the flattening of the Phillips curve turned the economists' attention into more detailed modelling of the market structure and markups in an open economy setting. Chen et al. (2004) found that lower markups are potent in reducing the inflation bias in the Kydland-Prescott Barro-Gordon model for a given slope of the Phillips curve. Daniels and VanHoose (2006, 2009) proposed new Keynesian multi-sector open economy models which are potent to deliver both flattening of the Phillips curve and lowering of the inflation bias as a result of goods and capital mobility. Binyamini and Razin (2008) used a new Keynesian open economy model to show that increased mobility of goods, capital and labor lowers the responsiveness of inflation to domestic demands shocks because all dimensions of openness and mobility make domestic household less dependent on domestic firms, and vice versa. The latter finding was accompanied by empirical research on the growing role of global factors in shaping domestic inflation (e.g. Ciccarelli and Mojon, 2010) and a debate on whether the inflation paradigm should be updated from country-centric to globe-centric (e.g. Borio and Filardo, 2007), or not (e.g. Ball, 2006; Woodford, 2007). As a result, since the late 2000s, the focal point of the literature on the subject has been gradually changing from accounting for the role of globalization in low global inflation into explaining the phenomenon of the comovement of domestic inflation rates across countries. Szafranek (2021a,b) provides an extensive literature overview on that subject, documents time-varying inflation synchronization among countries and disentangles its sources.

According to the proponents of the globalization of inflation hypothesis the co-movement of domestic inflation rates across countries cannot be fully enough attributed to common developments in economic policies or their institutional framework but, above all, reflects the structural integration of goods, capital and labor markets. It was probably a widely cited paper by Auer et al. (2017) that unveiled a key role of global value chains (GVC) and internationalization of the production process in shaping the relationship between global factors and domestic inflation. Moreover, Auer et al. (2019) documented that international input-output linkages indeed synchronize (producer price) inflation across countries (even in the presence of imperfect exchange rate pass-through and demand complementarities) and account for half of the global producer price inflation. In addition, input-output networks preserve a fat-tailed nature of cost shocks and therefore may create periods of not only disinflation but also high inflation.

The outbreak of the COVID-19 pandemic has very evocatively supported the latter concerns. The administrative anti-COVID measures (including various forms of lockdowns, quarantines, teleworking solutions, and gathering and traveling restrictions, etc.) seriously impaired the functioning and capacity of many branches. At the same time, demand for some commodities, intermediates, electronics, and logistical services increased rapidly, resulting in bottlenecks, delivery delays, and higher costs and prices (Rees and Rungcharoenkitkul, 2021). It is believed that the semiconductor (Dunn and Leibovici, 2021; Celasun et al., 2022) and shipping industries (Carrière-Swallow et al., 2023), in particular, were among the worst hit due to their geographic concentration, an essential role in the production process of many upstream goods, lack of substitutes and short-run supply rigidities. The adverse effects of bottlenecks were further aggravated by the so-called bullwhip effect i.e. a situation when anticipation of shortages creates incentives for precautionary hoarding of inventories along the supply chain (Rees and Rungcharoenkitkul, 2021). As highlighted by Auer et al. (2019) input-output linkages within the global value chains created large international spillovers and resulted in the global rise of inflation.

Initially the inflationary effects of disruptions in global value chains seemed to be rather limited and temporary (see e.g. Budianto et al., 2021; Rees and Rungcharoenkitkul, 2021) but very soon the resurge of inflation in developed countries turned close to zero headline CPI and below zero PPI inflation rates (in 2020Q2) into 30-year peaks (in 2021Q4).[1][2] Such dramatic changes in inflation rates motivated growing research interest. Some authors analyzed the relative importance of various demand and supply shocks in shaping the post-pandemic inflation within the New Keynesian framework (e.g. Baqaee and Farhi, 2022; di Giovanni et al., 2022) or Bayesian VAR models (e.g. Szafranek et al., 2023; Kabaca and Tuzcuoglu, 2023), Alessandria et al. (2023) offered a formal general equilibrium approach for modelling the aggregate effects of supply-chain disruptions while others focused rather on estimating the impact of supply chains disruptions on inflation more directly. Carrière-Swallow et al. (2023) applied the local projections method on a sample of 46 countries (1992-2021) and found a positive and significant relation between Baltic Dry Index and import prices, PPI, headline, and core inflation, as well as inflation expectations. Celasun et al. (2022) used sign restricted VAR and estimated that supply bottlenecks are responsible for half of the rise of the manufacturing producer price inflation in the euro area in 2021. LaBelle and Santacreu (2022) combined industry-level measures of GVC participation with country-level information on bottlenecks and delivery times to proxy the exposure of the U.S industries to foreign and domestic bottlenecks. The counterfac-

[1]see https://www.dallasfed.org/research/international/dgei/cpi and https://www.dallasfed.org/research/international/dgei/ppi for CPI and PPI figures, respectively, in a worldwide context.

[2]After the Russia's invasion of Ukraine the inflation rates went even higher, into 40-year peaks in 2022Q2-2022Q3.

tual analysis based on these measures and panel model estimates showed that the impact of bottlenecks on PPI inflation in the U.S. manufacturing sector could reach even 20 pp at the end of 2021.

This article follows the recent strand of the literature aimed at quantifying the effects of supply chains disruptions on inflation and it is focused on the European countries. Similarly as Carrière-Swallow et al. (2023) we apply the local projections method to panel data i.e. a method which is believed to provide impulse response estimates that are more robust to model misspecification than e.g. VAR models. The measure of disruptions in supply chains utilized in this paper is built on industry- and country-specific share of enterprises reporting (in business surveys conducted by the European Commission) shortages in materials and equipment as a factor limiting production. Therefore the path of the adopted measure of supply chains disruptions is slightly different for every country and reflects factual rather than potential problems with supply chains in the enterprise sector. We argue that such an approach allows for more precise identification of supply chains disruptions than, e.g. relying on global or common indices (Carrière-Swallow et al., 2023) or retrieving supply shocks from a sign-restricted VAR (Celasun et al., 2022). Moreover, we analyze responses of nine measures of inflation (four HIPC-based and five PPI-based), what allows us to not only verify the robustness of the results with respect to different measures of inflation but also offer an economic story while interpreting the results and provide some policy implications. We also perform several robustness checks and additional estimates to corroborate and enrich our baseline results.

Previewing the results, we document the proinflationary effects of supply chains disruptions on all considered measures of inflation, including headline and core inflation. We also find that larger effect can be observed for inflation of prices of goods rather than services. The estimated proinflationary effects of supply chains disruptions build up gradually and are quite persistent – the impulse responses reach their peaks 4-6 quarters after shock and die out 8-12 quarters after shock. Such a pattern of impulse responses gives monetary policy both room and incentives to counteract the inflation pressure despite its supply-side origin. We also contribute to the literature by showing that the positive estimates of the impact of supply chains disruptions on inflation come mainly from the period corresponding with the COVID-19 pandemic as well as the full-scale invasion of Ukraine. Moreover, we show that the effects of supply chains disruptions on inflation may exhibit asymmetric or regime-switching nature.

The structure of the remainder part of article is as follows. Sections 2 and 3 provide information on the method and data, respectively. Section 4 presents and discusses baseline results while section 5 performs robustness checks and discusses additional results. The final section concludes with the key findings of the study.

2 Methodology

To scrutinize the effect of the supply chains disruptions on inflation, we employ panel local projections method. One might expect that the overall effect of supply chain bottleneck is distributed over time. Therefore, our key interest is related to dynamic effect which can be captured by the impulse response function (IRF). Hence, a natural environment to study empirically macroeconomic effect supply chains shocks are the VAR (vector autoregression) models. However, given the data limitation, i.e. moderate time dimension, and uncertainty about specification of VAR models, we incorporate the local projections method, which was proposed by Jordà (2005). As shown by Plagborg-Møller and Wolf (2021) LPs and VARs estimate the same impulse responses but have different finite-sample properties. A practical difference between these methods is that VAR models require more explicit assumptions about specification, while the local projections consist of a sequence of regressions of outcome variable on a variable of interest (possibly a structural shock) for different horizons. In addition, this method can be easily accommodated in the panel data context.

In the context of the current study, the response of inflation to the supply chain disruptions can be described with the following local projections:

$$y_{it+h} = \alpha_h + \beta_h shortages_{it} + x'_{it}\gamma_h + \varepsilon_{ith}, \tag{1}$$

where y_{it} is the measure of inflation, $shortages_{it}$ denotes the key variable of interest, x'_{it} is the set of control variables and ε_{ith} is the error term. The key parameter β_h allows to identify the response of outcome variable (y_{it}) for the horizon h. Thus, the parameters of equation (1) are estimated separately for each horizon, i.e., $h \in \{0, 1, 2, \ldots, H\}$. In other words, estimated impulse responses consist of a set of β_h that are independently estimated.

It is a common expectation that a variable of interest in the local projections framework should be a "shock" variable or, put differently, that the local projections method requires exogeneous variation of a variable of interest (see e.g. Ramey, 2016). This is because local projections are claimed to be only a reduced form of a structural impulse response function and equivalence between the two calls for the appropriate form of exogeneity. However, extending the point made by Plagborg-Møller and Wolf (2021) who showed that LPs and VARs estimate the same impulse responses, one should differentiate among the closely related problems of (i) measuring a shock itself, (ii) shock identification, and (iii) estimation of the coefficient on the variable of interest. If a shock is directly measured, plugged as an explanatory variable into a regression and claimed to be strictly exogeneous, it is (by definition) identified and the econometrics behind is usually straightforward. Otherwise an empirical strategy for estimating LPs usually relies on some combination of transforming or prefiltering the variable of interest, controlling for confounding variables, and applying an estimator which could address or be robust to potential econometric challenges (e.g. serial correlation or cross-section dependence). In this article we follow this eclectic strategy of estimating LPs followed by a number of robustness checks.

In our baseline specification we do not transform or prefilter the variable of interest (but we do so in one of our robustness checks). By doing so we implicitly assume that shortages of intermediates may impact inflation immediately while inflation may influence shortages of intermediates only with some lag. This is conceptually equivalent to ordering shortages of intermediates higher than inflation in a corresponding structural VAR model with A-type of short-run restrictions.[3] We argue that such an ordering is plausible because

[3] see e.g. Lütkepohl (2017) for a systematic overview of structural VARs.

inflation refers to the prices of output goods and its impact on shortages of intermediates is indirect and operates mainly via the (aggregate) demand channel. This impact is even more prolonged in time and less important if shortages of intermediates originates mainly from global rather than local market. As mentioned before, we relax this debatable assumption in one of our robustness checks.

In all of our LPs we include a rich set of control variables. We discuss them in a greater detail in Section 3, where we present data. Following Olea and Plagborg-Møller (2021) the set of explanatory variables x'_{it} is extended by lags of the variables in the regression. Such extension allows to account for persistence as well as to improve estimation precision at long horizon. Since our data are available at quarterly frequency the local projections are augmented by four lags of the variables.

As far as as the econometric framework is concerned, it is important to address some issues related to the macroeconomic panel. In order to control for possible differences between countries (1) is extended by an individual fixed effect. Although we deal with a dynamic model (due to the extensions of LPs by lags of all variables in the regression), the LPs are estimated with the use of the standard FE (within) estimator. This is because inconsistency and bias of the standard FE estimator resulting from the lack of strict exogeneity of the explanatory variables, including the bias of Nickell (1981), are in our case negligible. If ε_{ith} is only weakly dependent, they are both of order $O(T^{-1})$ (see e.g. Wooldridge, 2010), while the average time dimension of the analyzed panel is above 70. At the same time, the estimates of impulse responses obtained with the standard FE estimator are much more stable when compared to the ones obtained with the IV/GMM estimator in the spirit of Anderson and Hsiao (1981). Apart from that, to account for possible heteroskedasticity, serial correlation as well as cross-section dependence, we use robust variance-covariance estimator proposed by Driscoll and Kraay (1998).

For illustrative purpose we present the quarterly estimated responses as effect on annual inflation. Namely, the estimated dynamic multipliers are cumulated over the horizon of response. Next, the effect of interest is calculated as annual change.

To assess an importance of supply chains disruptions in variability of the inflation measures the FEVD (forecast error variance decomposition) estimator proposed by Gorodnichenko and Lee (2020) is applied. In general, this approach focuses mainly on residuals obtained from (1) which represent the estimated forecast error for the horizon h:

$$\hat{\varepsilon}_{ith} = \alpha_0 shortages_{it+h} + \alpha_1 shortages_{it+h-1} + \ldots + \alpha_h shortages_{it} + \nu_{ith}, \qquad (2)$$

where $\alpha_0, \alpha_1, \ldots, \alpha_h$ is the set of parameter describing the impulse response and ν_{ith} is the remaining error component. Gorodnichenko and Lee (2020) postulate to use the R^2 from (2) as the estimated share of error variance that can be attributed to the shock of interest, i.e. $shortages_{it}$.

3 Data

In this section we discuss our measurement strategy and data used.

To study the macroeconomic effect of supply chains disruptions on inflation we consider nine measures of inflation. First, we focus on measures of consumer inflation by using the harmonized index of consumer prices (HICP). Apart from the overall HICP, we analyze the HICP for goods, services and HICP for all items excluding energy, food, alcohol and tobacco (hereinafter called "core inflation"). All HICP series are at constant tax rates. Second, various measures of producer inflation (PPI) in manufacturing are investigated. This includes overall index for manufacturing and its main subcomponents, i.e., producer price indexes for intermediates, capital goods, durable and nondurable consumer goods. This conceptually broad set of inflation measures allows us to study how supply disruptions are propagated on aggregate consumer inflation. Since we employ measures of inflation at quarterly frequency all price indexes are seasonally adjusted using the X-13 ARIMA-SEATS method.

Our principal source of data describing supply chains disruptions is the Business and Consumer Surveys carried out by the European Commission. This survey is conducted at quarterly frequency while data are available at the two-digit industry level. One part of the questionnaire is related to factors that limit the production of manufacturers. In particular, to identify the effect of supply chains disruptions, we use shares of enterprises reporting shortages in materials and equipment at the industry level. This measure is related to actual supply shortages faced by actual enterprises rather than global tensions as in the case of Global Supply Chains Pressure (GSCP) Index, which we discuss later.

To aggregate these shares at the country level we use the weighted average of the industry-specific shortages of intermediates:

$$shortages_{it} = \sum_{j \in J} w_{ijt} shortages_{ijt}, \tag{3}$$

where $shortages_{it}$ is the country-specific measures of shortages, $shortages_{ijt}$ is its counterpart observed for the j-th industry in the i-th country at time t and the w_{ijt} represents the share of the j-the industry in the i-th country production.

To measure the time-varying role of each industry (captured by w_{ijt}), we estimate its share in the country's gross output. The detailed data on gross output and value added for the two-digits industries from National Accounts are not available at the quarterly frequency while the annual data are significantly delayed and, more importantly, not available for all two-digit industries. Therefore, the Structural Business Statistics, which is provided by Eurostat, is exploited to get more detailed information about gross output at two-digits industries level. More precisely, we use the data for 2015 as a reference period[4] and we extrapolate gross output with quarterly industrial production data in order to gather estimates of share of each industry in total manufacturing.

We observe substantial industry and country heterogeneity of share of firms reporting shortages in intermediates (see figure 1). For instance, the long-run weighted average of this variable varies from 2.6% for Italy to 23.5% for the United Kingdom. In addition, the variation of variability is also substantial as various industries have different ability to absorb shocks related to the shortage of intermediates. At the aggregate level, the standard deviation of weighted average of this variable range from 3.1 pp for Bulgaria

[4] We also experimented with other reference periods, i.e., referring to other years or consisting of a longer time period. However, the implied estimates of weights (w_{ijt}) were very close to our choice.

to 17.5 pp for Germany. Thus, in our measurement strategy, we account for differences in both the long-run level and the variance, and standardize the industry-specific time series describing proxies of tensions in supply chains. This strategy limits the role of cross-sectional heterogeneity and heteroscedasticity in the estimation of local projections and helps us to obtain narrower confidence intervals when compared to the results based on non-standardized series.[5]

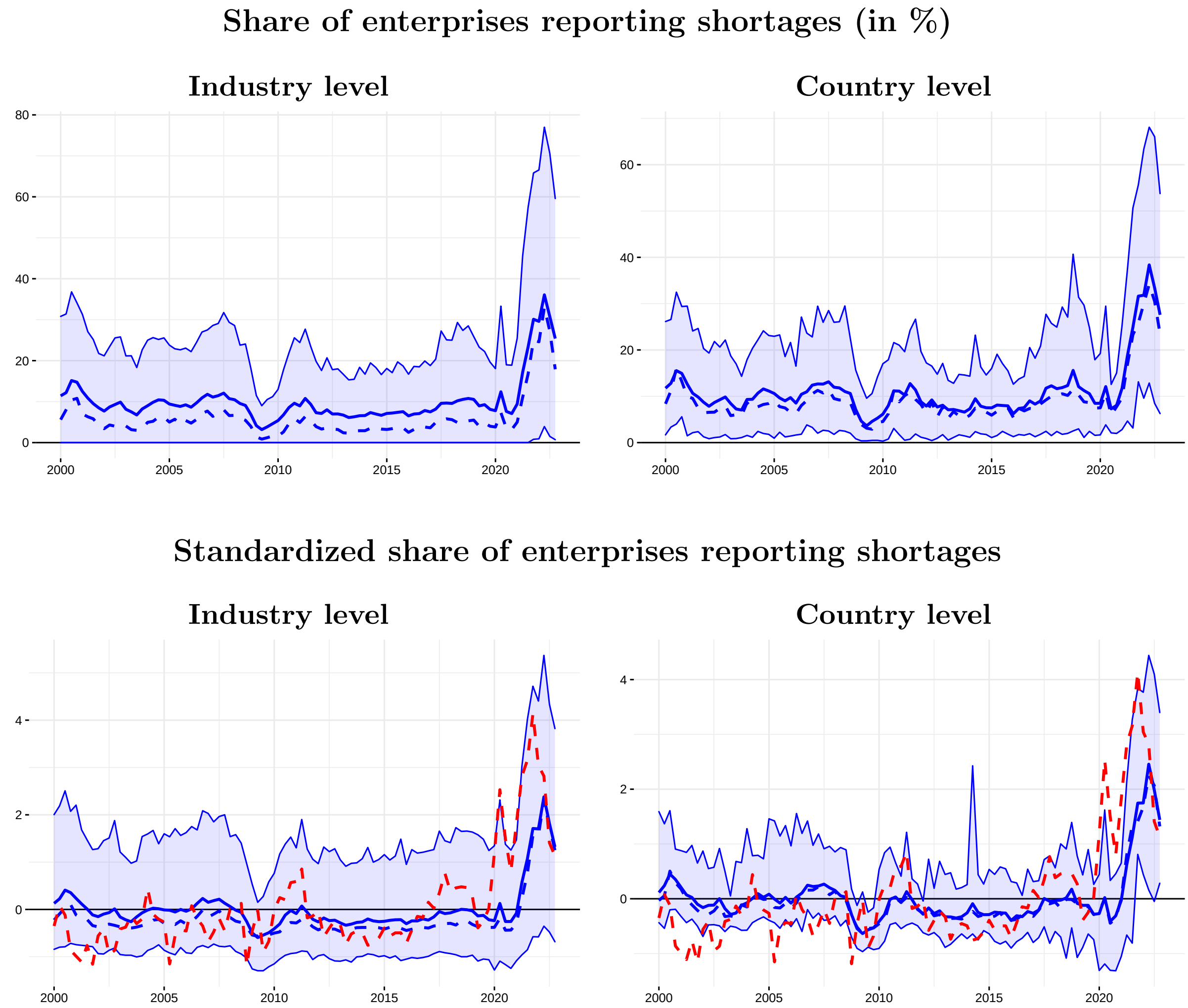
Inspecting the constructed series confirms the conventional wisdom that the most spectacular disruptions in supply chains could be observed after the outburst of the COVID-19 pandemic (see the bottom panel of figure 1). Both mean and median from the country and industry distribution reached their historical maximum values in 2022. The same applies to the marginal quantiles. Interestingly, since the interquantile range is broader after 2020 than before, the period of COVID-19 pandemic also corresponds with the increased heterogeneity of problems with supply shortages at both the industry and the country level.

In addition, we also compare series with the Global Supply Chains Pressure index (GSCP, see Benigno et al., 2022). Importantly, like the GSCP index, our series also suggest the most pronounced disruptions in supply chains during the recovery after the period of most severe COVID-19 lockdowns. However, there are several differences between the global indicator and our variable. Focusing on the period of the COVID-19 pandemic, the GSCP index predicts a substantial disruptions already in 2020 while our preferable proxy variable indicates that tensions in supply chains started several quarters later.[6] There are two possible reasons explaining this difference. First, the conceptual discrepancies. The GSCP index measures overall cost pressure, and it synthesizes information from shipping and air transportation costs as well as some PMI components which exhibit leading properties to overall business fluctuations. At the same time, the $shortage_{it}$ contains information about intensity of actual shortages in intermediates, which are consequences of either local or global tensions in supply chains. Second, the coverage is different. The GSCPI combines information about 7 major economies with relatively low weight of European economies while our constructed series refers only to individual European countries. There could be several structural differences that can be responsible for a lack of exact comovement during recovery after the COVID-19 pandemics, for example the structure of imports or resilience of specific transportation linkages to excess demand. In addition, the Russian invasion of Ukraine could limit availability of intermediates in Europe but its effects on supply chains in other regions seem to be not sizable.

[5] Otherwise the patterns of the estimated impulse responses for standardized and non-standardized series are virtually the same.

[6] At the country level, the comovement with the GSCP index is quite heterogeneous. For the full sample, pairwise correlation varies from 0.07 for Bulgaria and Romania to almost 0.84 for Germany. More striking differences can be observed before 2020. In this case, only for Germany the correlation between $shortage_{it}$ and the GSCP index exceeds 0.5 while for Bulgaria, Spain and Portugal it is below -0.2.

Figure 1: Shortages of intermediates



Note: the blue solid and dashed lines denote (unweighted) average and median measures of the shortages. The shaded areas capture variation in distribution of shortages of intermediates. For the country-level data the illustrated range of empirical values is constrained between the 5th and 95th quantiles while in the case of the industry variation the underlying limits are narrowed, i.e., the 10th and 90th quantiles. The country-specific measures of shortages are weighted by gross output. The red dashed lines in the bottom panel represent the Global Supply Chains Pressure Index. All presented moments of distribution are limited to sample that is used in the baseline estimation.

In addition to the key variable of interest, several control variables are included in (1) to reduce the risk of the omitted variable bias. First, we use the labor cost index for business sector. Since shortages of intermediates could potentially increase the average cost of production one should control for any movement in other sources of overall costs of production. Second, the same reason applies to energy prices. Here, we use producer prices index for energy commodities. Instead of using global measures of energy prices (e.g. WTO oil prices, indexes provided by World Bank) we prefer to use the prices that are faced on domestic market since the pass through effect of changes in global market could affect the country-specific energy prices in a heterogenous way due to, for instance, introduced regulations on domestic market or unpredictable policy actions. Third, we control for global prices of non-energy commodities (using the World Bank Commodities Price Data), which exhibited an upward trend during the COVID-19 pandemic period and were additionally hit by the Russian invasion of Ukraine. Fourth, the nominal effective exchange rates from the BIS are included in (1) to account for exchange rate pass-through effect. Fifth, as to control for fluctuations in aggregate activity, we include the GDP series detrended with the standard HP-filter procedure. This variable not only reflects the standard business cycle position but also captures the effects of lockdowns on aggregate activity (recall that the HP-filter is a high-pass filter). Sixth, information about other factors limiting production is also used as control variables in (1). This broad set includes constraints affecting production that are related to (i) labor, (ii) demand, and (iii) financial factors. These variables are taken from the Business and Consumer Surveys conducted by the European Commission and are transformed analogously as our key variables of interest, i.e., industry and country specific times series are standardized and further weighted by our quarterly estimates of gross output. We argue that these variables help to control for the effects of quarantines and medical leaves, shifts in relative demand, and changes in both the financial situation of enterprises and financial markets that coincided with the supply chains tensions during the pandemic period.

In our baseline estimates, except for the EC survey data, all control variables are included as first differences of logs.

With all above choices, our panel consists of 19 European economies.[7] The panel is unbalanced, while the number of available observations ranges among concerned measures of inflation from 1331 to 1577. All series are available till the last quarter of 2022 but beginning of the time span is varying among both inflation measures and countries (e.g. the longest time series for producer prices start in 1998 while in the case of consumer inflation estimation is performed on the data that begin mostly after 2003).

4 Baseline results

In this section, we discuss baseline results of the estimated effect of supply chains disruptions on inflation.

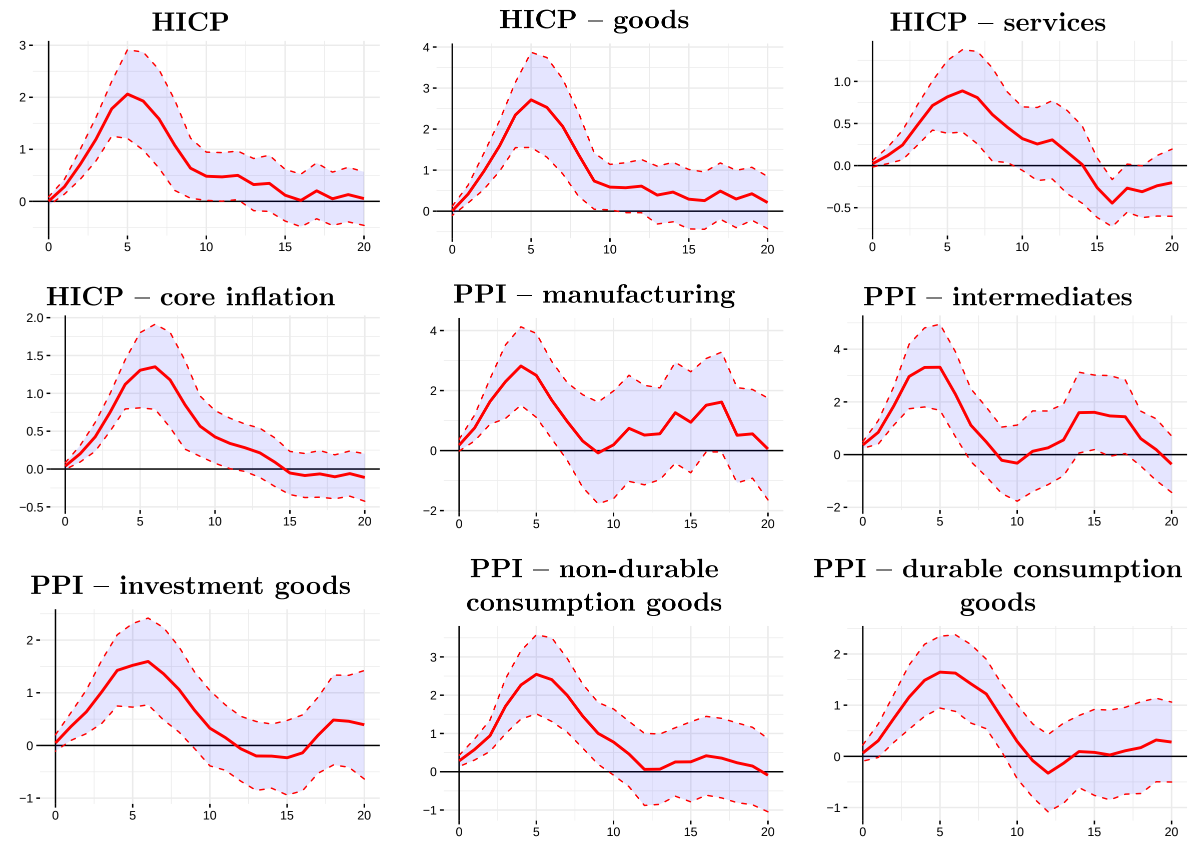
Figure 2 portrays the estimated impulse responses with corresponding confidence intervals while Table 3 contains the relative importance of supply chain disruptions according to the forecast error variance decomposition (FEVD) i.e. the local projections counterpart of variance decomposition in VAR models. These results allow us to offer some stylized facts regarding the impact of supply chains disruptions on inflation.

First, supply chains disruptions are proinflationary for all considered measures of inflation but a larger effect can be observed for the inflation of prices of goods rather than services. This results from the fact that producing goods is generally much more sensitive to supply chains disruptions than offering services, since the former usually requires physical transportation of inputs and outputs. The impulse responses for HICP-goods

[7] More specifically, the sample includes: Belgium, Bulgaria, Czechia, Germany, Denmark, Estonia, Greece, Spain, France, Hungary, Italy, Lithuania, Latvia, Netherlands, Poland, Portugal Romania, Sweden and the United Kingdom.

and PPI-manufacturing are very similar, both in shape and magnitude, within 10 quarter horizon after shock, while the peak of impulse response for HICP-services is ca. 3 times lower than for HICP-goods. Therefore the difference between the impulse responses for HICP and PPI-manufacturing stems mainly from the service component in consumer prices. For the same reason, the magnitude of impulse response for core inflation resembles the one for HICP-services rather than HICP-goods (recall that the basket for core inflation excludes mainly non-durable consumption goods).

Figure 2: An estimated effect of the supply chains disruptions on various annual inflation measures



Note: the red solid lines denote the estimated impulse responses while the shaded areas refer to the 90% confidence intervals. The estimated effects correspond to one standard deviation shock in shortages of intermediates.

Second, the effect of supply chains disruptions on inflation builds up gradually at a moderate pace and is quite persistent – the peak of impulse responses can be observed 4-6 quarters after shock (i.e. similarly as Carrière-Swallow et al. (2023) report for shipping cost shocks), while the effect usually dies out and becomes statistically insignificant (at 10% significance level) after 8-12 quarters. Such a pattern resembles the impulse response to a negative productivity shock, but not the impulse response to a "cost-push" shock in the goods market, obtained by Smets and Wouters (2003) in their estimated DSGE model for the Euro area. Indeed, an unexpected supply chains disruption does not simply change the relative price of some goods (eg. due to the markup shock in the goods market as in Smets and Wouters (2003)) but rather limits their availability. Since materials and intermediates that are necessary for a production process in many branches were historically among the worst hit during these type of turmoils, a supply chains shock may be perceived as a type of productivity shock that lowers either the total factor productivity (TFP) in a canonical production function with stocks of labor and capital as inputs, or the capacity utilization if the inputs are measured in terms of flow of services rather than level of stocks. The patterns of our impulse responses contrast with the ones provided by Cavallo and Kryvtsov (2023), since in the latter case the proinflationary effects of supply disruptions are much faster but smaller and short-lived. However, Cavallo and Kryvtsov (2023) analyzed the impact of stockouts on inflation of online prices of selected consumption goods in online shops rather than the impact of shortages on official inflation of various types of goods in the whole economy. Therefore the results should not be compared one-to-one.

Third, we do not observe that inflation for intermediates reacts any quicker after shock than inflation for (both durable and non-durable) consumption goods. This is probably because: (i) we analyze quarterly rather than monthly data[8], (ii) our measure of supply chains disruptions is built on industry- and country-specific declarations of shortages in materials and equipment being a factor limiting production[9], (iii) production of consumption goods is generally less time-consuming and less dependent on semiconductors than production of investment goods for which we do observe a phase shift in impulse response of 1-2 quarters when compared to intermediates. The delayed response of inflation for investment goods to supply chains shocks when compared to inflation for intermediates is very consistent with the "chronology" of supply chains of investment goods, since the production of investment goods requires loads of intermediates. However, the observed pattern may, at least partially, result from the fact that the pandemic supply chains shocks originated from the semiconductor industry, which may be particularly important for investment goods.

Fourth, the forecast error variance decomposition (FEVD) suggests that supply chain disruptions are much more important in explaining inflation changes at medium rather than short (forecast) horizon. Moreover, supply chain disruptions seem to be a distinctively more important source of variance of changes in inflation of consumer prices of goods than in other measures of inflation.[10] More precisely, supply chain shocks play relatively little role for changes in inflation of consumer prices of services, producer prices of capital and – surprisingly – durable consumption goods, but contribute remarkably to the variance of inflation of producer prices of intermediate goods and consumer prices of goods. The difference between the results for HICP for goods and PPI for durable consumption goods seems to be a puzzle – it cannot be attributed to the role of non-durable consumption goods since the relative importance of supply chains disruptions for core

[8]We do observe more differences among the estimated peak effects when we analyze monthly data in section 5 Robustness checks (see Figure A.4)

[9]Therefore, according to the "chronology" of the supply chains, the problems with shortages in materials and equipment should be earlier reported by upstream rather than downstream industries.

[10]Recall that, in the context of local projections, the forecast error variance decomposition (FEVD) informs about the relative, not the absolute, importance of supply chains shocks in the variance of changes in a particular measure of inflation. Therefore the share of variance that can be attributed to supply chains shocks depends on both the overall variance of changes in the selected measure of inflation and the role of other shocks.

inflation (e.g., excluding most important nondurables) is still two times larger than for PPI for durable consumption goods. One may suspect that the discovered wedge has its source in the mechanism of transmission of producer prices into consumer prices and the nature of supply chains shocks. In general, consumer prices exhibit lower variance than producer prices as retailers usually aggregate idiosyncratic risks of producer price shocks and may have some room and incentives for smoothing prices. However, this may not be exactly the case of the pandemic supply chains disruptions, which eventually turned out to be global (nondiversifiable) rather than idiosyncratic (diversifiable). If retailers are able to smooth out some idiosyncratic producer prices shocks more easily than supply chains shocks (since the latter sometimes happen to be global), supply chains shocks are relatively more important in shaping inflation of consumer rather than producer prices. This effect may be even strengthened by the bullwhip effect (see Rees and Rungcharoenkitkul, 2021) as retailers are located at the very end of the supply chains of consumption goods.

Fifth, it seems that the effects of supply chains disruptions on inflation may not necessarily die out asymptotically in a simple exponent way. Although the confidence intervals for impulse responses are generally quite wide for a horizon over 10 quarter after shock, it seems that supply chains disruptions may add some cyclical frictions, of frequency similar to business-cycle, into the behavior of inflation of intermediate and capital goods. In other words, a single supply chains shock may potentially result in a more than just one episode of elevated inflation. We argue that this may be a plausible scenario when a shock is large (as in the case of the pandemic supply chains disruptions) and interferes with real and nominal rigidities. Such a pattern is also consistent with the aforementioned bullwhip effect.

The presented stylized facts regarding the impact of supply chain disruptions on inflation have important policy implications. Since the proinflationary effects of these disruptions build up gradually at a moderate pace and are quite persistent, there may be room for both fiscal and monetary policy, even if we take into account a delayed response of the economy particularly to the latter one. In other words, the patterns of impulse responses suggest enough time for authorities (including central bankers) to analyze the situation, make an action and observe the response of the economy before the effects of a supply chain shock on inflation naturally die out. All the more so, since supply chains disruptions seem to be persistent themselves and we observe periods of supply chain tensions rather than one-off shocks. The proinflationary effects of supply chains disruptions are persistent for all considered measures of inflation, including headline consumer inflation and core inflation, which are crucial for the credibility of a central bank and the formation of the inflation expectations. Therefore monetary authorities do have some incentives to counteract the inflationary pressure created by supply chain disruptions despite the supply nature of these shocks.

Table 3: The role of supply chains shocks – FEVD (in %)

	horizon (in quarters)				
	4	8	12	16	20
HICP					
overall	9.3	12.2	19.6	19.4	27.9
goods	10.4	13.1	20.1	20.4	28.1
services	1.8	4.0	9.6	8.2	11.5
core inflation	4.7	8.2	16.7	15.3	22.7
PPI					
manufacturing	4.2	5.8	9.3	12.7	18.4
intermediates	8.7	10.3	14.3	19.2	23.7
capital goods	2.3	3.5	5.0	5.8	9.6
non-durable consumption goods	6.6	8.9	14.4	14.8	20.6
durable consumption goods	2.7	4.6	6.5	7.4	10.9

5 Robustness checks

In this section, we provide robustness checks of the estimated effect of supply chains shock on inflation. In particular, we focus on the sensitivity of main results to: (i) aggregation strategy of industry-specific shocks, (ii) transformations of variable measuring shortages, (iii) alternative measurement of supply chains shock, (iv) the effect of supply chains on the level of prices, (v) time variation in estimates and, (vi) non-linearities.

Our first robustness check is related to the strategy of aggregation of industry-specific shortages at the country level. To cross-check our strategy of aggregating industry-specific information of shortages, we compare estimates with unweighted averages as well as the aggregate published by the European Commission.[11]

Figure A.1 portrays all the estimated responses functions. It turns out that our baseline estimates are between the two considered variants. In particular the estimates based on the unweighted measure of shortages predict the responses around 50% higher while results for the EC aggregates are around 30% below our baseline estimates. The above discrepancies could be related to the granularity of the shocks. For instance, larger estimates basing on unweighted series can be linked to higher short-run variability that comes from relatively smaller industries. The same applies for the EC aggregates that are based on smoothed weights. Nevertheless, the relative sizes of the estimated effect among considered measures of inflation, as well as the shapes of impulse (including the peak effect), are very similar.

Second, additional transformations of the measure of supply chains disruptions are considered. The baseline results suggests that the estimated effect dies out gradually. It could be related to the persistence of our preferable measure of shortages. Another intuitive explanation is a potential comovement between shortages faced by firms and

[11]for technical details see: https://economy-finance.ec.europa.eu/system/files/2023-02/bcs_user_guide.pdf

other macroeconomic shocks (e.g., aggregate demand, oil price shock) which could bias our estimates. To cross-check the baseline results we employ the strategy which is very close to the approach proposed by Canova and Pappa (2022). In particular, we redefine the shock variable by running the following regression:

$$shortages_{it} = z_{it}'\psi + \xi_{it}, \tag{4}$$

where z_{it} is a set of variables which potentially affects the $shortages_{it}$. The residuals from (4), i.e. $\hat{\xi}_{it}$, could represent variation that abstracts from the co-movement between shortages and other key drivers of inflation.

Figure A.2 illustrates the estimated reactions of the inflation measures to changes in filtered proxy of shortages, i.e, $\hat{\xi}_{it}$. Two variants of $\hat{\xi}_{it}$ are presented, i.e, (i) residuals from country-specific AR(4) models for shortages,[12] and (ii) residuals from the fixed effects estimation of (4) in which z_{it} contains explanatory variables from the baseline local projections, their lags and lagged dependent variable.[13] In the latter case, z_{it} consists of x_{it} in order to eliminate the effect of potential comovement between changes in shortages and other shocks. In both cases the estimated impulse responses are very close to the baseline results (see figure A.2) which implies that the persistently proinflationary nature of the shortages is rather not related to other macroeconomic shocks.

Third, we replace our preferable measure of disruptions in supply chains by the GSCP index. Figure A.3 presents the estimated responses to changes in the GSCP index which have been aggregated to a quarterly frequency. Importantly, the average effect is almost similar-sized, both in absolute and relative (between various measures of inflation) terms. However, two striking differences can be observed.

In comparison to the baseline, the estimated peak effect is lagged by 4-6 quarters which implies that it can be observed around 8-12 (rather than 4-6) quarters after shock. This implies extremely high persistence of the supply-chains bottlenecks. A potential explanation can be here related to discrepancies in conceptual definition. As regards, our baseline shock measure is based on the industry-specific information about the shortages of intermediates that limits production. Therefore our preferable measure of shocks abstracts from disruptions in logistic chain that can be managed quickly without any effect on the shortages of intermediates. In addition, our baseline measure could account for some regional tensions that seems to be negligible at the global level, while the GSCP index covers information on shipping and air transportation costs that could be of secondary importance for some economies or translate into regional tensions with some delay. More importantly, the GSCP index extracts information from PMI subindices which exhibit leading properties with respect to the overall business condition. The leading properties of the GSCP index could be responsible for the delayed peak effect.

Moreover, we also observe that confidence intervals for IRFs based on GSCP index are much broader (particularly at long horizons) than in the case of our baseline estimates.

[12] Given limited time dimension we only consider heterogenous AR(4) models because country-specific estimation of (4), that includes all explanatory variables from baseline local projections, would be inefficient.

[13] The discussed strategies provides the most visible differences in the estimated IRFs. We also experimented with other specifications and these results are available upon request.

This is a consequence of heterogeneous correlation between the GSCP index and our measure at the country level and higher cross-sectional heterogeneity of responses to a global rather than local shock of the same nature.

Fourth, the local projections are estimated on monthly data since all measures of inflation are available at monthly frequency. The same applies to some part of control variables, i.e., nominal effective exchange rates, energy prices and non-energy commodity prices. However, the variable measuring the shortages is available at quarterly frequency. We estimate its monthly proxy with the GSCP index using the Denton-Cholotte method. A similar strategy is employed for the proxy of output gap. Here, the monthly estimates of GDP are obtained by using industrial production and retail sales series at the country level. These estimates are further HP-filtered to detrend series.

The estimated monthly impulse responses to supply chains shocks confirm our main finding about the proinflationary effect of these disruptions (see figure A.4). In addition, the relative size of the effect is quite similar as in the baseline case, i.e. it is the lowest for the consumer prices in services while the largest for the producer prices of intermediates. Interestingly, when compared to results for quarterly data we can distinguish some differences in the peaks effects. Namely, the producer inflation for intermediates and non-durable consumer goods reacts quicker after the shock of interest. In comparison to the baseline results, the mean estimated IRFs are now slightly above the quarterly counterparts. However, one should keep in mind that the corresponding confidence intervals are broader, which results mostly from the chosen strategy of measuring monthly proxy of disruptions.[14]

Fifth, we consider estimation of (1) using (logged) levels of non-stationary variables rather than first-differenced series. First-differencing of series could lead to reduction in the long-run variation of series. This long-run variability could contain information about key reaction at long horizon. At the same time, first-differencing increases the role of the short-run variation which can deteriorate the efficiency of estimation. Therefore, we consider local projections that exploit all potentially non-stationary series, i.e., energy prices, labor cost, nominal effective exchange rate and non-energy commodity prices, which are now taken in the logged form.

Focusing on non-stationary series in the considered local projections does not change our main findings (see A.5). The supply chain shocks have a positive effect and the peak effect can be observed after 4-6 quarters. In relative terms, one may observe the same responsiveness among considered measures of prices, i.e. the same supply chain shock to a lesser extent moves prices of consumer services while the corresponding effect for the prices of intermediates is the highest one.

Sixth, we investigate time stability of estimates. As it has been discussed the COVID-19 pandemic led to unprecedented tensions in global value chains. At the same time, various measures of inflation have reached their historical peaks in many countries. Therefore, it is important to analyze how this effect is stable over time. To challenge this issue, we

[14] In particular, using the GSCP index to interpolate the industry-specific series of shortages leads to substantial cross-sectional dependence. Since we are using the robust variance estimator postulated by Driscoll and Kraay (1998) this feature of panel is taken into account in the estimation of confidence intervals.

limit the sample to observations before 2020.

It seems that the COVID-19 pandemic probably increased the macroeconomic effect of the supply chains shocks (see figure A.6). It is straightforward to observe that before 2020 the overall effects are 2-3 times lower in comparison to the estimates obtained for full sample. In addition, for some measures of inflation they become mostly insignificant. Another difference is persistence, which for many measures is higher. These differences might be crucially related to previous globalization processes. In our sample, there was a lack of extraordinary supply chains shocks before 2020. Given fat-tailed nature of cost, which resulted from international vertical specialization (Auer et al., 2019), one might suppose that the supply chains shocks were more easily accommodated by firms before 2020 as the shocks exhibited lower variability. In consequence, the estimated impulse to these shocks is less pronounced. However, the outburst of the COVID-19 pandemic led to extraordinary supply chain shocks which, due to their size, were strongly transmitted through input-output linkages.

Seventh, we consider a non-linear effect that is related to global factors. Previous results show relative robustness of our key finding, but also time variation in the overall response to supply chains disruptions. As discussed, sensitivity of inflation to these shocks can potentially depend on the level of tensions in global value chains. Intuitively, in the period of substantial disruptions in the GVC one might expect that it is relatively more difficult to cope with shortages of intermediates. For that reason, we additionally consider the nonlinear local projections. In particular, we differentiated two regimes characterized by low and high pressure within the global supply chains. To identify these time periods, the GSCP index is categorized as binary value with the corresponding value threshold set at the pre-pandemic average. Then the estimated local projections take the form:

$$y_{it+h} = \alpha_h + \beta_{low,h} shortages_{low,it} + \beta_{high,h} shortages_{high,it} + x'_{it}\gamma_h + \varepsilon_{ith}, \qquad (5)$$

where $\beta_{low,h}$ and $\beta_{high,h}$ are the key parameters for low and high pressure regimes, respectively while $shortages_{low,it}$ and $shortages_{high,it}$ are equal to $shortages_{it}$ for the corresponding low/high pressure regime and 0 otherwise. The responses of inflation measures varies remarkably between regimes determined by high and low global supply chains pressure (see figure A.7). In a situation when the global supply chains face large pressure the effect of country-specific shortages is strongly pro-inflationary. This could be explained by the fact that under high global pressure it could be relatively difficult to find suppliers. Contrary to this case, when pressure within global supply chains is moderate, the shortages of intermediates can be relatively easily resolved which does not require adjustment in prices.

6 Concluding remarks

In this paper we study macroeconomic effect of supply chains shock on inflation in European economies. By applying the panel local projections method and using the business surveys conducted by the European Commission we document that these shocks have positive impact on both producer and consumer inflation. Although the largest effect can be found for producer prices of intermediates these shocks also positively affect core inflation and inflation of services. For all nine measures of inflation considered the estimated effect of supply chains shock reaches its peak at the 4-6 quarter horizon and further dies out after 8-12 quarters. Importantly, our main findings are confirmed by numerous robustness checks.

Our empirical evidence contributes to the debate about the role of globalization in inflation. As input-output networks have become quite complex, one might expect that international vertical specialization preserved a fat-tailed nature of cost shocks. As a result, extraordinary shocks that are propagated in global value chains may prolong the periods of high inflation. In this context, our results are consistent with this hypothesis because the positive estimates of the impact of supply chains disruptions on inflation can be related to a large extent to the period corresponding with the COVID-19 pandemic and the full-scale invasion of Ukraine. Moreover, this impact may additionally exhibit asymmetric or regime-switching nature.

We argue that our findings have important policy implications. Given the delayed and persistent effects of supply chains disruptions on all considered measures of inflation, including headline and core inflation, monetary policy may have both room and incentives to curb inflation pressure despite its supply-side origin.

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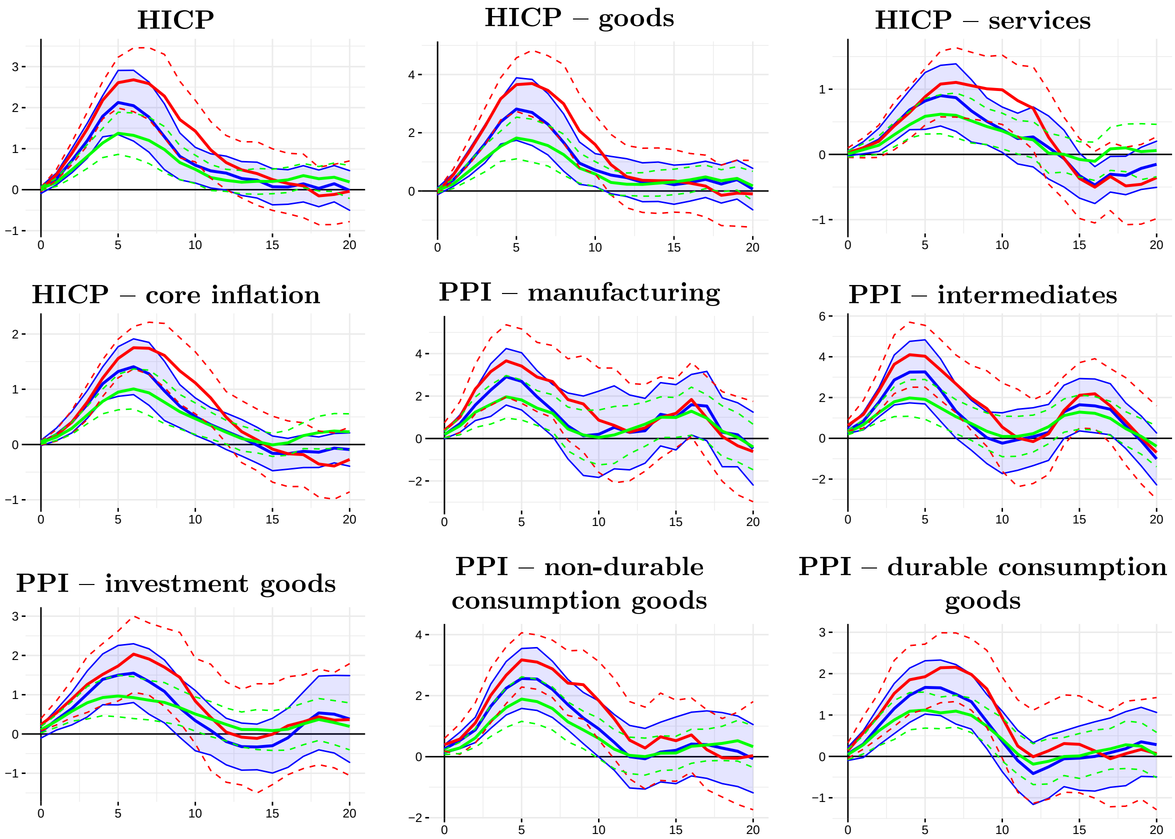
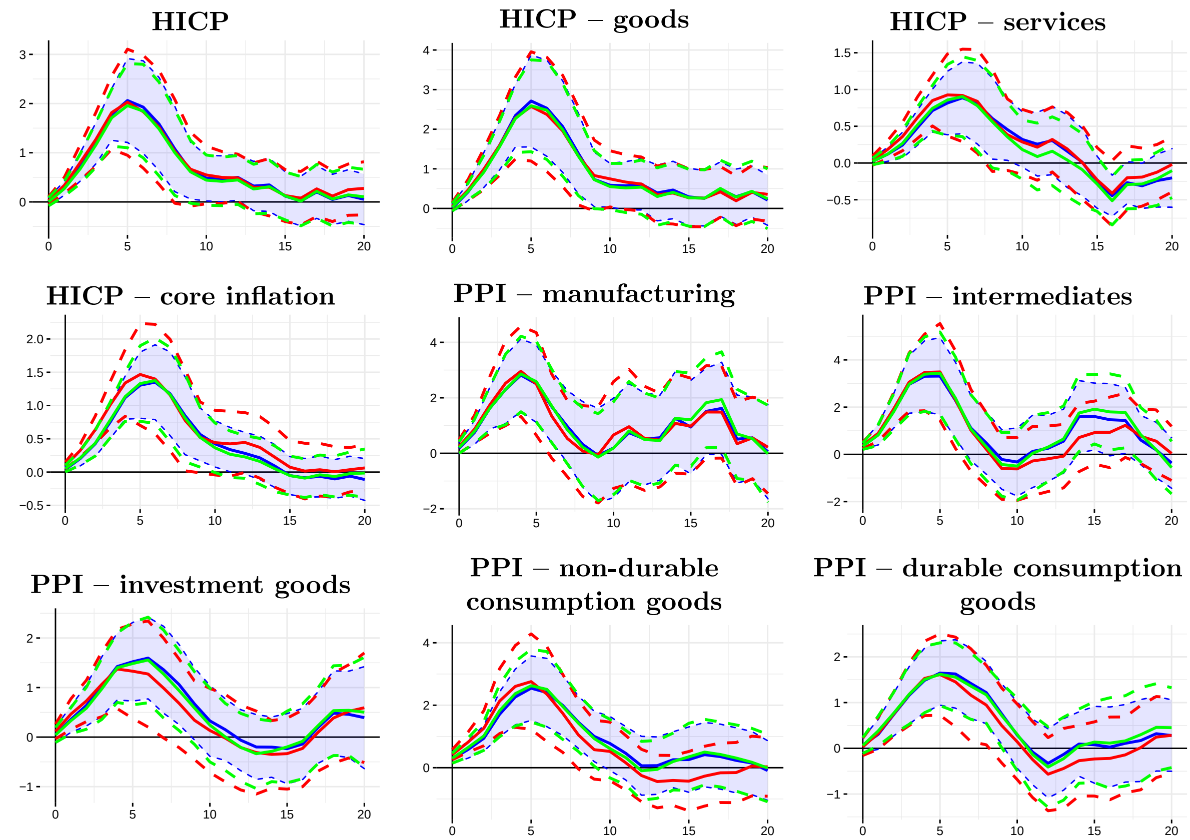
A Additional figures

Figure A.1: An estimated effect of the supply chains disruptions on various annual inflation measures – comparison of different strategies of aggregating industry-specific tensions' measures



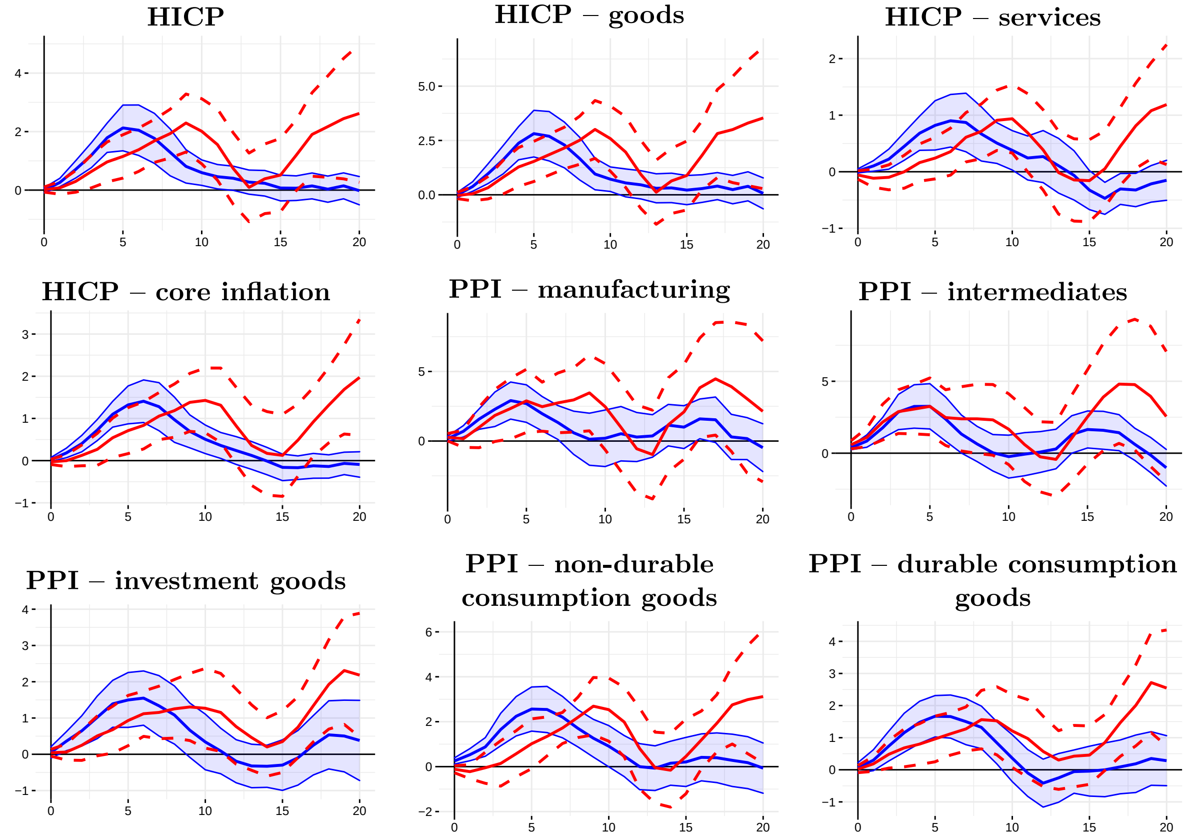
Note: the solid and dashed lines denote the mean estimated impulse responses with the corresponding 90% confidence intervals, respectively. The blue color refers to baseline results. The estimates obtained by using (unweighted) averages of unweighted industry-specific shortages are colored with red while green color captures the estimated IRFs that are based on the EC aggregates of variable of interest.

Figure A.2: An estimated effect of the supply chains disruptions on various annual inflation measures – comparison of different transformations of baseline measure of shortages



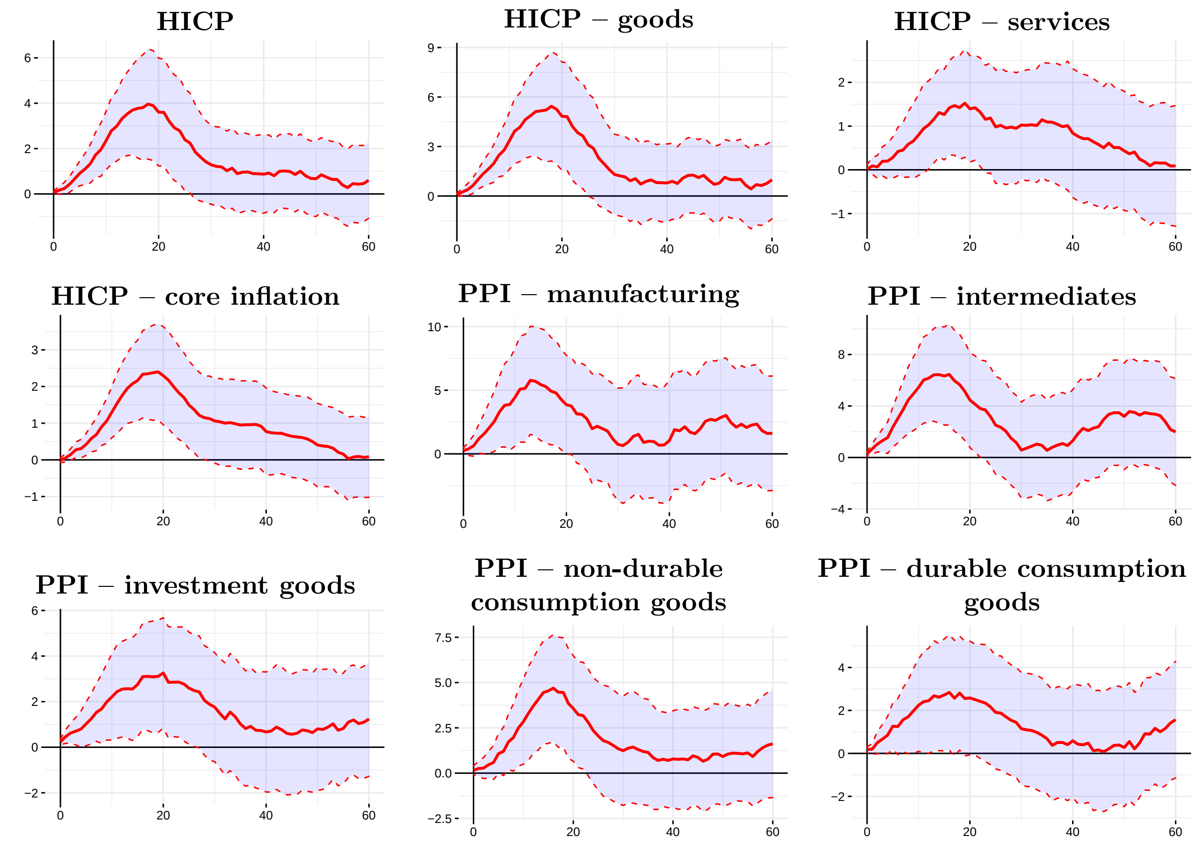
Note: the solid and dashed lines denote the mean estimated impulse responses with the corresponding 90% confidence intervals, respectively. The blue color refers to baseline results. The red color is related to the proxy that is obtained as residuals from the country-specific AR(4) models for shortages. The green color refers to estimation results in which the residuals from the fixed effects regression of the baseline measure (on control variables as well lags of variables of regression) are taken as the shock variable.

Figure A.3: An estimated effect of the supply chains disruptions on various annual inflation measures – the GSCP index as a proxy of global supply chains shock



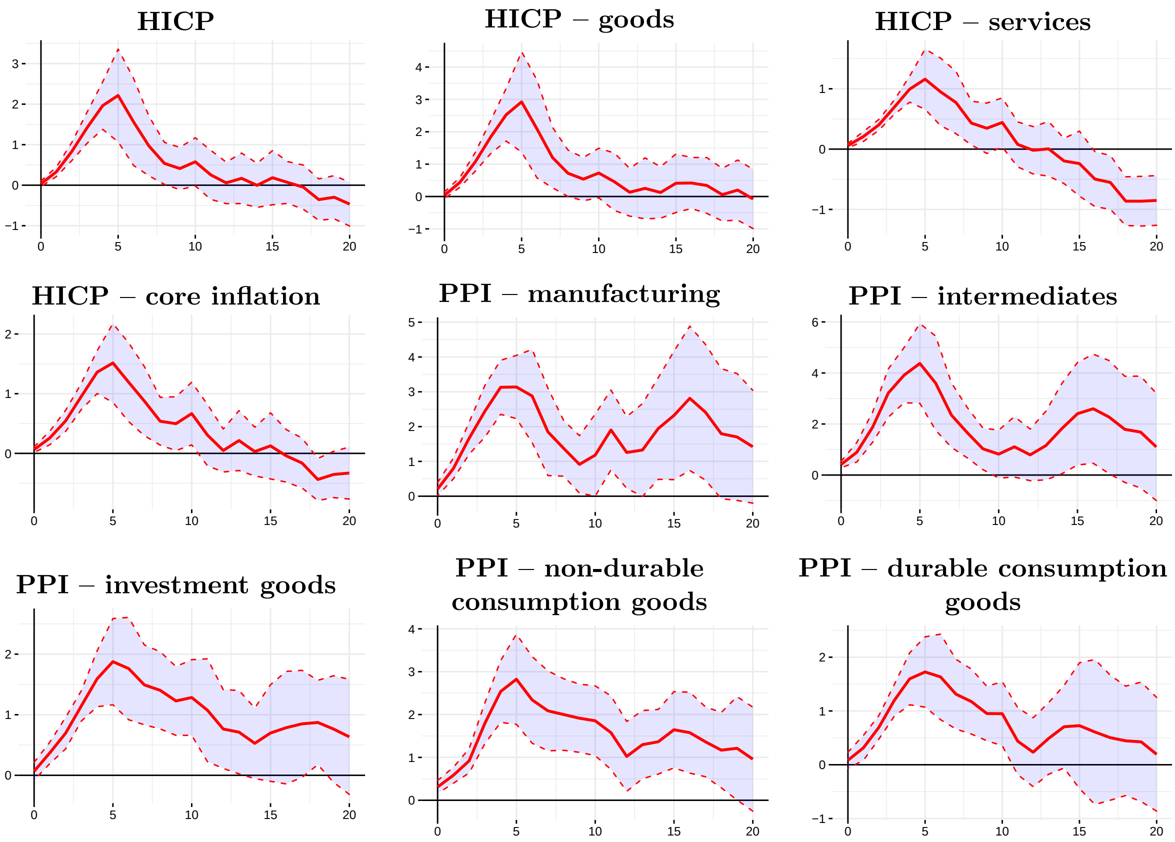
Note: the red colored IRFs denote the estimates that are based on the GSCP index while the blue responses are the baseline results. The estimated effects correspond to one standard deviation shock in shortages of intermediates.

Figure A.4: An estimated effect of the supply chains disruptions on various annual inflation measures (monthly data)



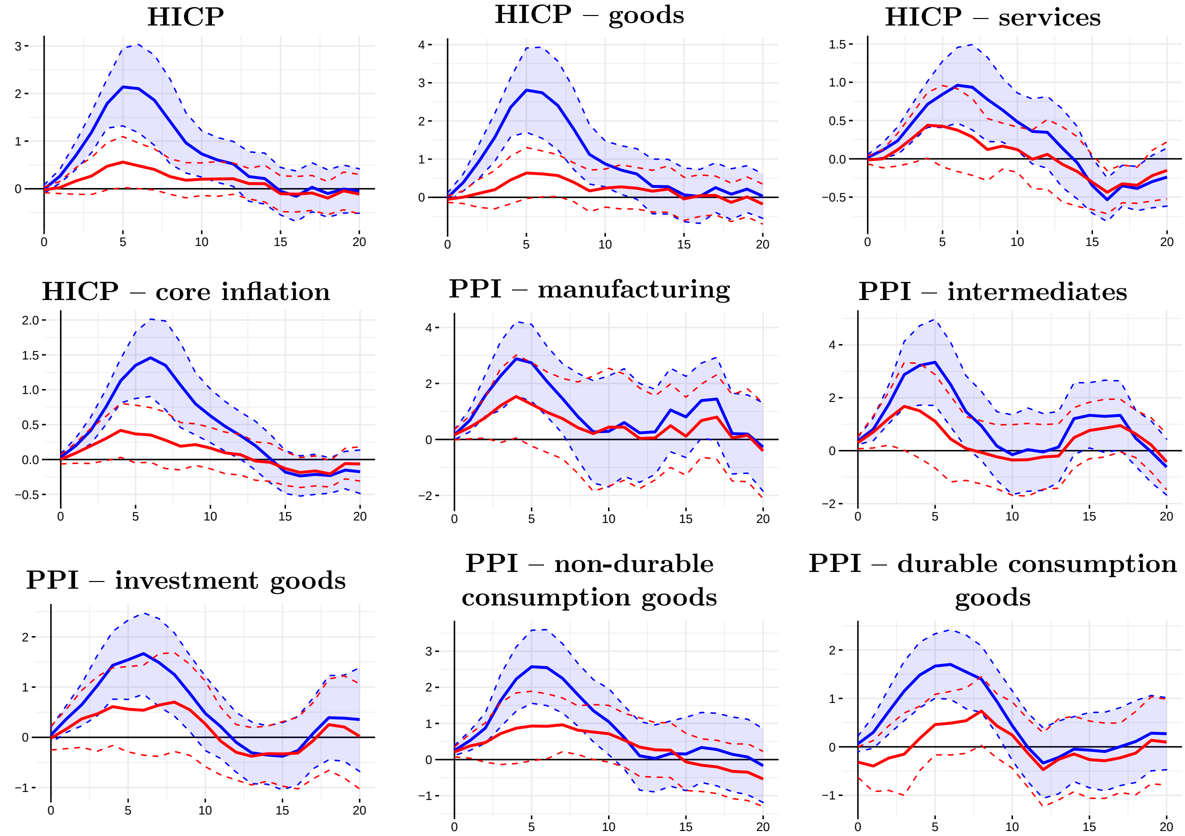
Note: the red solid lines denote the estimated impulse responses while the shaded areas refer to the 90% confidence intervals. The estimated effects correspond to one standard deviation shock in shortages of intermediates.

Figure A.5: An estimated effect of the supply chains disruptions on various annual price levels (in %)



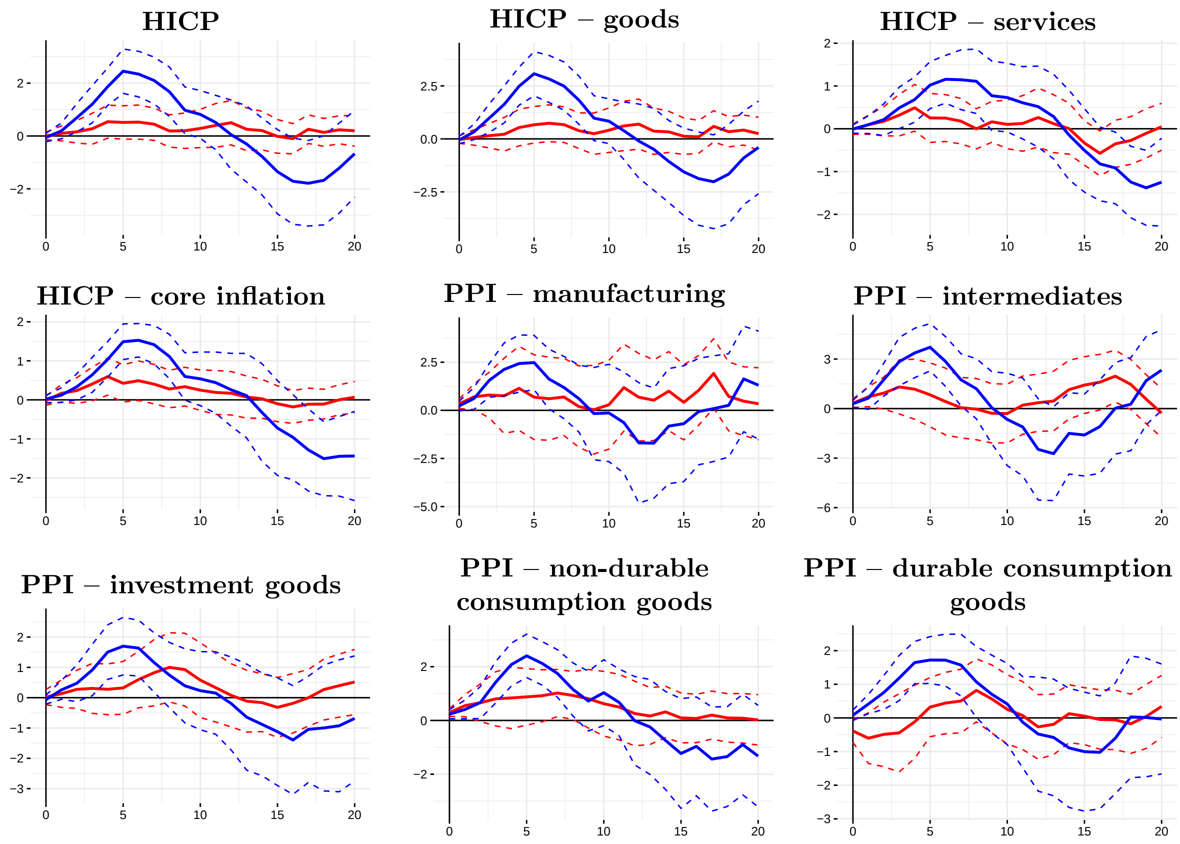
Note: the red solid lines denote the estimated impulse responses while the shaded areas refer to the 90% confidence intervals. The estimated effects correspond to one standard deviation shock in shortages of intermediates.

Figure A.6: Time variation in estimated effect of the supply chains disruptions on various annual inflation measures



Note: the blue lines and shaded areas denote the full-sample estimates of the impulse responses with the corresponding 90% confidence intervals. The estimates for the pre 2020s sample are colored in red, i.e., the solid lines refer to the mean effect while the dashed lines represents the 90% confidence intervals. In all cases, the estimated effects correspond to one standard deviation shock in shortages of intermediates.

Figure A.7: Regime-specific impulse responses of various annual inflation measures to supply chains shock



Note: the blue and red colors refer to regimes characterized with high and low global supply chain pressure, respectively. In both cases, the solid lines denote mean estimates while the dashed lines are the 90% confidence intervals.