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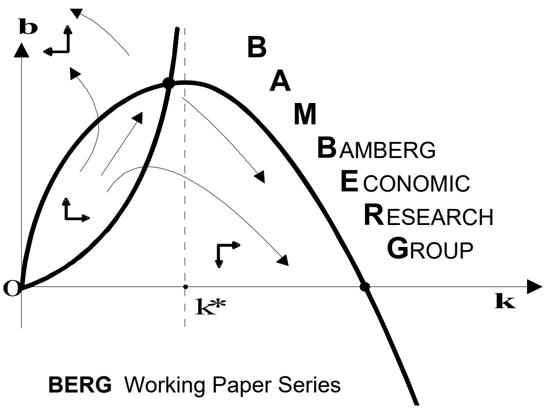

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Stress-testing Inflation Exposure: Systemically Significant Prices and Asymmetric Shock Propagation in the EU28

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Abstract

Building on the seminal paper of Weber et al. (2022), we provide a stress-test framework of inflation exposure and apply it to the EU28. This adds a yet unrecognised dimension to the latest calls for supply chain stress-tests. We address both the ex- and internal dimensions of inflation exposure for the former EU28 countries within global production networks via a Leontief price model. Using data from the World Input Output Database, we confirm the existence of systemically significant sectors for the overall price level in the EU28, EU periphery and core, respectively. We show that while the direct price effects of various sectors on the respective consumption shares are significant, about two-thirds of the overall effects are indirect and thus a result of higher-order propagation within the production network. It crystallizes that two properties (size and centrality) may render a sector systemically significant. Breaking down the geographical component, we show that the indirect effect is even larger for peripheral countries, which points to a higher exposure to world market prices. By tracing individual shock trajectories, we confirm this hypothesis: price volatility originating from the core countries impacts the peripheral countries more than vice versa. In addition to this, our method to recover consumption substitution effects shows that substitution is much more limited in the European periphery. Overall, we show consumers in peripheral countries are relatively more exposed to price volatility.

Keywords: inflation, stress-test, input-output analysis, Europe

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1. Introduction

Times are constantly changing. The great moderation found its end with the great financial crisis and inflation management had to come up with new approaches to operate on the zero lower bound. Now again, we experience a regime shift. The recent pandemic, geopolitical changes and global warming challenge policymakers in the EU to cope with cost-push inflation and they seem aware that the current economic toolkit needs to be revised. A fundamental prerequisite for this revision is a clear cut understanding of the dynamics at play. In a seminal paper Weber et al. (2022) took a leap in showing that sectoral price shocks can have systemically significant impacts on an economy's aggregate price level. Building on their approach we provide a stress-test framework of inflation exposure and apply it to the EU28. This adds a yet unrecognised dimension to the latest calls for supply chain stress-tests (Baldwin and Freeman, 2022; D'Aguanno et al., 2021; Miroudot, 2020; Simchi-Levi and Simchi-Levi, 2020).

We address both the ex- and internal dimensions of inflation exposure for the former EU28 countries within global production networks via a Leontief price model. Using data from the World Input Output Database, we confirm the existence of systemically significant sectors for the overall price level in the EU28, EU periphery and core, respectively. We show that while the direct price effects of various sectors on the respective consumption shares are significant, about two-thirds of the overall effects are indirect and thus a result of higher-order propagation within the production network. It crystallizes that two properties (size and centrality) may render a sector systemically significant.

Breaking down the geographical component, we show that the indirect effect is even larger for peripheral countries. By tracing individual shock trajectories, we find that price volatility propagating from the core countries to the periphery manifests more impact than vice versa. We also find periphery countries to import more price volatility from outside the EU28, which points to a higher exposure to world market prices. In addition to this, our method to recover consumption substitution effects shows that substitution is much more limited in the European periphery. Overall, we show consumers in peripheral countries are relatively more exposed to price volatility.

Finally, a power series approximation allows us to uncover round-to-round effects, which show significant differences both on the geographical as well as the sectoral level. However, it also reveals the bulk of higher-order effects to be already present in the very first rounds. On the one hand, this result suggests that price shocks diffuse along rather short path lengths, on the other hand, it testifies to the robustness of our results against the popular criticism of comparative statics to not incorporate sequential adjustments in historical time. Notably, we are able to derive these results from an in-sample of years with relatively low inflationary pressure and thus overcoming a notorious challenge for stress-tests in the financial realm (Borio et al. 2014).

This work adds to a lively discussion addressing the current period of cost-push shocks and potential policy action. As the sledgehammer of interest rate policy leaves central banks bound to move late and break things when addressing cost-push inflation, they look for a way forward. To push academic work in this direction, the ECB put its annual Forum on Central Banking under the headings "Challenges for monetary policy in a rapidly changing world" in 2022 and "Macroeconomic stabilization in a volatile inflation environment" in 2023. Being part of the latter, Tenreyro et al. (2023) discuss the use of monetary policy to counter cost-push inflation. They note that when shocks risk causing prolonged inflation, central banks must intervene to keep the credibility of the inflation target, albeit with the side effect of reduced output and higher unemployment. However, they stress that since monetary policy primarily influences aggregate demand, it's not well-suited to tackle supply-side issues. Consequently, they argue that it should only be used as a residual tool once more appropriate policies have been implemented.

In the same vein, the EU recently launched initiatives to become more resilient by e.g. monitoring external key dependencies. However, as our work shows, these initiatives fall short in neglecting internal dependencies as well as considering inflation exposure lying dormant in global supply networks.

On the national level, there also have been numerous, diverse response policies to compensate for higher prices across the EU. Sgaravatti et al. (2021) provide an overview of all measures that national governments implemented. The main categories of the list include reduced energy tax, value added tax, retail price regulations, wholesale price regulations, transfers to vulnerable groups, mandates to state-owned firms, and business support. However, enhancing structural resilience is more time-intensive. Weber and Wasner (2023) highlight the inflation-exacerbating problem of market power and, accordingly, the need for sound competition policy. Baldwin and Freeman (2022) discuss supply-side risks and means to address them, such as strategic stockpiling, and making supply chains more diversified, shorter, and more domestic through re- and nearshoring activity. Since these considerations are in the interest of both private enterprises and the public, they also discuss the question of the responsibility to become active. They approach this question by comparing private and public risks and propose, depending on their alignment, to grant private freedom, to create and adapt legal frameworks to incentivize prudent supply chain design or to take public action. Notably, they explicitly recommend stress-tests in their closing comments.

The remainder of this paper is organized as follows: Section 2 contextualizes our work and lays the theoretical groundwork for our stress-test exercise. In Section 3, the methodology of the stress test is elaborated. Section 4 showcases our findings, while Section 5 engages in a discussion of these results and suggests implications for policy-making. Section 6 concludes and discusses some limitations of our empirical approach.

2. Related Literature

Our project relates to several strands of research, some of which sparked (renewed) interest in the wake of the latest disruptions. Namely, our work supports efforts to decipher the underlying dynamics of what is widely considered a cost-push inflation resulting from a mixture of supply-side shocks. Moreover, we add a neglected perspective to the latest calls to stress-test production networks by uncovering the latent inflation exposure lying dormant in the global production network using an input-output stress-test framework. Thirdly, we add to the understanding of vastly differing regional exposures manifested in heterogeneous dependencies between regions. The following section will provide a brief overview on the literature embedding our work in the aforementioned strands of literature.

In the post-Lehman world, stress-tests were soon regarded as a viable tool for authorities to simulate pressure on the financial system. Even though "no matter how hard one shook the box, little would drop out" (Borio et al., 2014), these stress-tests played a crucial role in restoring confidence in the financial system (Herring and Schuermann, 2022). By now, stress-tests are considered an indispensable tool and their much needed improvement[1] is high priority for authorities and researchers alike (Aikmann et al., 2023). Lately, calls to establish

[1] Most stress-tests still shy away from incorporating second-round contagion effects or non-bank financial institutions, which both play a crucial role for financial stability (Aikman et al., 2023; Cont and Schaaning, 2017)

macroprudential stress-tests also for supply-networks became more prominent (Baldwin and Freeman, 2022; D’Aguanno et al., 2021; Miroudot, 2020; Simchi-Levi and Simchi-Levi, 2020). There are several studies that underline this necessity while providing possible concepts to build on.

On a more general, level Input-Output (IO) models are commonly used to conduct disaster impact analysis.[2] Similarly, the study of Inoue and Todo (2019) uses a firm-level agent-based model to assess the rippling effects of the Great East Japan Earthquake 2011. Carvalho et al. (2021) investigate the same research phenomenon and document the relevance of input-output linkages in propagating this shock across Japan.

Closer to an actual stress-test are the works of Diem et al. (2022) and Chakraborty et al. (2021). The former propose a novel measure of economic systemic risk of firms in a production network. Using firm-level data for Hungary, the authors show that systemic risk is distributed highly unequally with only a small fraction of firms affecting close to a quarter of national economic production in case of default. The latter show that richer countries expose poorer countries to significantly more systemic risk than vice versa. This finding is equally true for inflation exposure, as our work will show. Finally, the seminal paper of Weber et al. (2022), showing the systemic importance of individual domestic sectors for the overall price level in the US, unveiled the need to expand the supply-side stress-test call to also assess potential inflation exposure. Our paper aims to answer this call for the EU28.

Following Weber et al. (2022), we utilize the Leontief price model as our framework to identify supply-driven price changes, as has been done in several related studies (see e.g. Valadkhani and Mitchel, 2002). We also follow Weber et al.’s (2022) terminology of “systemically significant prices”, originally brought forward by Hockett and Omarova (2016). We thus define sectors whose price changes have a significant effect on the overall price level i.e. monetary stability as systemically significant prices. This idea is in marked contrast to the conventional wisdom of both the Monetarist and New Keynesian flavors that inflation should be understood as an aggregate phenomenon. Thus, as Weber et al. (2022) showed for the US and our paper confirms for the EU28: Cost-push inflation is a phenomenon with heterogeneous origins, evolving bottom-up from the micro to the macro sphere of the economy.

This insight falls on fertile soil. Famously, Acemoglu et al. (2012) argue that microeconomic

[2] See Galbusera and Giannopoulos (2018) for an overview.

idiosyncratic shocks can lead to aggregate fluctuations in the presence of strongly asymmetric intersectoral input-output linkages that typically characterize empirical production networks. In this context, they highlight the importance of different sectors as suppliers to their immediate customers and as indirect suppliers to downstream sectors in capturing higher-order interconnections and the possibility of "cascade effects" of productivity shocks. Conceptually, Hansen (1941) introduced the phenomenon of bottlenecks and highlighted their inflationary potential. Bottlenecks refer to constraints or limitations in various sectors of the economy that impede the smooth flow of goods, services, or resources. The emergence of scarcities can trigger a chain reaction of inflationary pressures.

Extending Weber et al. (2022) we embed our stress-test exercise for the EU28 in a global context, since naturally, not only the interconnectedness of firms and sectors within a given economy is of relevance to understanding output and inflation dynamics, but also the cross-border linkages to the world economy. Borio and Filardo (2007) for example find that the influence of global factors on inflation in OECD countries has been growing over time, particularly since the 1990s, due to the increased integration of the world economy.

However, it is insufficient to only consider the EU28 in a global context. To comprehensively analyze inflation exposure, we also have to shine a light on internal vulnerabilities that otherwise remain hidden. While this applies to the EU28, it is especially true for the Eurozone as the common currency impedes the room for policy maneuvering and thus results in a heightened vulnerability to asymmetric shock propagation. In his seminal paper, Mundell (1961) elaborates on the perks and perils of common currencies and what an optimum currency area defines. He emphasizes the costs and inconveniences associated with having multiple currencies and argues that a larger number of currencies reduces the effectiveness of money as a unit of account and medium of exchange. At the same time, regions should be economically similar, since, with a currency area, there are no flexible exchange rates that could correct trade imbalances anymore. When regions do exhibit heterogeneity though, he addresses the issue that monetary policy cannot optimally adapt to conditions in each region. Then, he remarks, the willingness of central authorities to allow unemployment in regions with trade deficits, determines the pace of inflation in a currency area. In this respect, Bayoumi and Eichengreen (1993) provided an early cause for concern for the euro area by showing that, on average, the correlation between supply and demand shocks is comparatively lower among the European Union countries than for US states. This, in turn, renders the EU less cohesive while making it harder for a common policy to address those heterogeneous needs simultaneously. Furthermore, they seminally provide evidence for the existence of a core–periphery pattern and find that, while comparable shocks occur in the core, in peripheral countries these are more asymmetric. Hence, they expect the European Monetary Union to be beneficial to the core and be detrimental to the periphery.

Gräbner et al. (2020) confirm the core-periphery structure for the Eurozone, finding profound differences along this fault line. Thus, also confirming the core-periphery pattern for inflation exposure would imply that the EU is likely not an optimum currency area, as a common monetary policy by the ECB is unlikely to simultaneously concord with the needs of both core and peripheral regions. This once again underscores the need to analyze dynamics at the sectoral and regional levels as they react differently to changes in interest rates and prices. While it is intuitive that fiscal policy can have different effects in regard to sectors and regions, think of industrial policy, this is less intuitively also the case for monetary policy, as the interest rate elasticity of demand and investment are strongly heterogeneous. Peersman and Smets (2005) document heterogeneity in the effects of an euro area-wide monetary policy change on output growth in eleven manufacturing industries across seven euro area countries. Carlino and DeFina (1998), using US data, show that monetary policy affects regions differently. They link their findings to a different mix of interest-sensitive industries and firm sizes. Beraja et. al (2018) support the finding of regionally different impacts of monetary policy and document the regional distribution of equity (housing) and its effect on (re)financing to be another key factor.

Motivated by this research showing profound differences in regional exposures and dependencies (see also Chakraborty et al., 2021), we build on the structure of a core-periphery dichotomy. It enables us to trace asymmetric shock-trajectories and contrast heterogeneous vulnerabilities due to regional differences in price volatility and elasticities of substitution. This distinction between core (or center) and periphery first gained recognition through the work of dependency theorists. Kvangraven (2021) argues that dependency theory as a research program provides a deep and broad understanding of the persistence of uneven development, in core and peripheral economies and can help to overcome contemporary development challenges as it accounts for power relations, different production means, and constraints faced by peripheral economies, such as limited access to technology, capital and markets. The key concept of economic dependence following the Prebisch-Singer hypothesis is that one cannot forgo something or substitute it (Harvey et al., 2010). Accordingly, we recognize the substitutability of consumption as another concept of our study.

The classical Keynesian view espoused by Pasinetti (1983, chp. 11) argues that proportional differences in national income between countries manifest themselves into structurally different consumption baskets and thus differences in the composition of aggregate demand, since there exists a hierarchy of needs, with essential goods obviously having priority. This line of argument resembles a major hypothesis of dependency theorists (Harvey et al., 2010) who argue that substitutability is much more limited for these essential goods, rendering consumers in low-income countries more vulnerable to world market prices. In neoclassical jargon, these kinds of preferences are called non-homothetic (Foellmi and Zweimüller, 2008) and can be captured by Stone-Geary preferences that account for subsistence consumption. Its characteristic feature is that not consuming the minimum level of a good negatively affects utility (Stone, 1954). We explore the consequences of this presumed differential substitutability between core and periphery as a central building-block of our stress-test.

A second key hypothesis of dependency theorists relates more directly to the input-output structure on which our stress-test is based. It follows the canonical definition of dos Santos (1970, p. 231) for dependency as "a situation in which the economy of certain countries is conditioned by the development and expansion of another". This definition is focused on the notion of asymmetry - the core affects the periphery much more strongly than the other way round. Indeed, given the fact that the peripheral regions on average rely on imports of complex inputs that the core and the rest of the world provides (Gräbner et al., 2020), we conjecture that inflation spill-overs from the core to the periphery are quantitatively much more relevant than vice versa, in line with this oft-cited definition of dependency.

3. Methodology

Intuitively, in an economy, different sectors are woven into a production network via their input and output linkages in their production processes of complex goods and services (Sraffa, 1960; Pasinetti, 1983). IO models build on these inter-linkages by formulating a system of linear equations that describe the functional dependencies emerging from products flowing between sectors (Leontief, 1986; Miller and Blair, 2009). Again, intuitively, the role of sectors may differ substantially depending on their embedding in the production process. Sectors may differ significantly in sheer size, be more up- or downstream in the production process or display heterogeneous levels of centrality (Joya and Rougier, 2019). An illustrative example are raw material sectors, that are often big in size and particular upstream, as energy is essential for any supply chain, which likely implies that shocks to them can exhibit large ripple effects (Cahen-Fourot et al., 2020). Being such a universal input (Hockett and Omarova, 2016) also makes energy sectors high in centrality. While IO models also contain these network information on different sector-level characteristics of an economy and thus are open for network based analysis (Joya and Rougier, 2019), they are predominantly used to assess the impact and propagation of different shocks in an economy. This is done by fixing the ratios of inputs between sectors, which allows us to simulate shocks to final demand as well as supply side shocks to particular sectors and assess the resulting impact on either prices or quantities produced.

3.1 Input-Output Price Model

To stress-test inflation exposure, we set up such an IO model for simulating the impact of a price shock in a given sector on the overall price level. In the following, we first describe the construction of the IO price model, before mapping out how we measure the impact of price shocks to the overall price level.[3] The value of sector_j output can be understood as the quantity x_j times the price P_j of sector_j output. As seen in (1), $x_j P_j$ can be decomposed into i) a multiplicative combination of x_j, the technical coefficient a_{ij}, which is the ratio of value of

[3] See Valadkhani and Mitchell (2002) and Weber et al. (2022) for a similar setup.

inputs from $sector_i$ to the overall value of of $sector_j$ output, and the price of $sector_i$ output, plus ii) the Value Added of $sector_j$.[4]

$$x_j\,P_j = x_j\,a_{1j}\,P_1 + \ldots + x_j\,a_{ij}\,P_i + \ldots + x_j\,a_{nj}\,P_n + V_j \tag{1}$$

While IO tables do not disentangle quantities and prices but display their product i.e. production values in currency units, IO tables make do by normalizing the output of each sector so that its unit price is equal to one. This allows us to shock one sector and observe the results of the induced price formation process as percentage changes in each sector's prices (Miller and Blair, 2009; Weber et al., 2022).

Introducing n sectors yields a system of linear equations that governs their IO relations. The matrix representation of this system can be expressed as

$$\hat{X}\,P = \hat{X}\,A' + V \tag{2}$$

With $\hat{X}$ as the diagonal matrix of the sector's total output, P as a vector of prices, A as the matrix of technical coefficients and V as the vector of value added. Dividing by the total output matrix $\hat{X}$ yields the price per unit of output

$$P = A'\,P + v \tag{3}$$

and finally solving for P gives

$$P = (I - A')^{-1}\,v \tag{4}$$

with $(I - A')^{-1}$ as the Leontief Price Inverse. Fixing the technical coefficients, that is, the ratio of value of inputs of $sector_j$ to the value of outputs of $sector_i$, allows the model to now determine prices endogenously. This setup allows us to simulate cost-push inflation via price shocks to a given sector.

[4] Note that we neglect imports in this setup, as we are working with global data and thus already cover imports within i).

Note that the fixed technical coefficients imply a full cost pass-through and no possibilities of substitution. Thus, the model overestimates price shock propagation where sectors find ways of substitution or function as a "price sink".[5] The same holds for wages, that, as a consequence of the fixed technical coefficients, also remain constant in nominal terms. In this exercise, we aim isolate the short-term effect of a cost-push channel and therefore do not take the effects on the functional distribution of income and potential feedback mechanisms between price determination and distribution into account.[6] Albeit the issue of substitutability being a well-known limitation of IO models, they do not carry as much weight in our implementation as a stress-test of inflationary exposure, since we are interested in understanding the upper bound of potential adverse shocks. Additionally, recent history has shown illustrative for the cases of semi-conductors and gas, that substitution can prove difficult in the short-run, which is the focus of our stress-testing exercise.

Following Valadkhani and Mitchell (2002) and Weber et al. (2022), we simulate a price shock to a sector by setting the respective sector exogenous which allows us to solve the system of equations for the inflation impact of a specific producer price shock (see also Miller and Blair (2009) for a detailed account on this process). Effectively, this allows us to set the price for a particular sector_j and observe how this price shock propagates to and within the endogenous price formation process of all sectors $i \neq j$. Note that there will be no feedback from the endogenous part of the model to the sector that is set exogenous. If we, for example, shock the real estate sector, there will be no feedback from the consequently rising prices in the construction sectors back to the real estate sector, but only to the other connected endogenous sectors. Ruling out changes in the quantities of inputs for the endogenous sectors, this process transforms (4) to

$$P_E = (I - A'_{EE})^{-1} A'_{XE} P_X \tag{5}$$

with P_E and P_X as the price vectors of the endogenous and exogenous sectors, respectively. Thus, the impact of a price shock is conditional on the level of the shock P_X as well as the

[5] The estimation bias could in principle work also towards underestimation. Imagine for example sectors raising prices disproportionately compared to their risen input costs. However, it is arguably reasonable to assume the overestimation bias dominates these conflicting effects.

[6] See Weber et al. (2022) and Weber and Wasner (2023) for a discussion of these aspects.

nature of the input-output network realized in $(I - A'_{EE})^{-1}$ and A'_{XE}. The latter is an $e \times x$ matrix, containing the direct input requirements of the endogenous industries from the exogenous industries, while A'_{EE} is an $e \times e$ matrix containing the direct input requirements of endogenous industries from endogenous industries.

3.2 Stress-testing Scenario

At this point we have established the endogenous price formation process of the IO price model with respect to the prices of the exogenous sector P_X. The next step will be to define our stress-testing scenario, meaning the price shock we inflict on the respective exogenous sector. As in Weber et al. (2022) we compute the standard deviation of the yearly logarithmic price changes σ for every sector$_j$ in our observation period. We use price volatility since large price fluctuations impede predictability in economic decision-making and thus play a crucial role in the functioning of production networks and for household consumption (Damjanovic and Nolan, 2010).[7]

$$\sigma_x^{P_{t_0,t_1}} = \sqrt{\frac{1}{T}\sum_{t=t_0}^{t_1}(\%\Delta P_t^x - \%\Delta P_{t_0,t_1}^{\bar{x}})^2} \quad (6)$$

Sectors which experience more volatile price fluctuations will accordingly be exposed to a larger shock in our stress-test than relatively less volatile sectors. This approach considers the heterogeneous nature of price formations within different sectors. Inserting these price shocks into (5) gives

$$\sigma_E = (I - A'_{EE})^{-1} A'_{XE}\, \sigma_x \quad (7)$$

where σ_E measures the price volatility in the endogenous sectors induced by the price shock σ_x^P to the exogenous sector.

7 We do check the robustness of our results for stress scenarios based on the mean price growth, as this is a second important aspect of price changes. Our results are not materially sensitive to this alternative specification.

We have now set up the stress-test model and derived the computation of the sector-level stress scenarios. In a next step, following Valadkhani and Mitchell (2002) and Weber et al. (2022), we introduce the shares of personal consumption c_i of each sector to measure the impact of σ_x on the overall price level. With our focus on the EU28 in the global production network, we compute three different consumption shares. One for the EU28 as a whole, one for the EU core countries and one for the EU periphery countries. Our definition of core and periphery follows the standard definition within the literature for other measures (Gräbner et al., 2020). In particular, the GDP per capita of all core countries is higher in all core countries than for the peripheral ones.

c_{core} = {AUT, BEL, DNK, FIN, GER, GBR, FRA, ITA, IRL, LUX, NLD, SWE}
$c_{periphery}$ = {BGR, CYP, CZE, ESP, EST, GRE, HRV, HUN, LVA, LTU, MLT, POL, PRT, ROU, SVK, SVN}[8]

This categorization allows us to not only analyze the inflation exposure of the EU28 in a global context, but also trace shock trajectories within the EU28 and identify asymmetric exposure on a regional basis.[9] Note that the consumption shares are the only variable that is varied for the EU28, core and periphery setup, respectively, since we assume propagation through the full global production network in all cases. The individual technical coefficients governing the input-output ratios and the global production network the countries are embedded in do not change. Per construction, differences in implied CPI can only emerge from variation in consumption behavior between regions, i.e., consumers demanding goods that themselves exhibit different producer price indices (PPI) volatilities or are exposed to the price volatilities of their suppliers to differing extents. In line with the work of Pasinetti, every disparity in the inflation exposure of EU28 core and periphery is to be found in differences in the quantity and quality of their consumption. Our approach can thus be partially understood as an attempt to work out the implications of Pasinetti's argument for inflation exposure.

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[8] See Appendix A for a list with full country names.

[9] This sectioning leaves us with a ratio of core to periphery sectors of 3:4. Where appropriate, we offset this misbalance by a normalization that is detailed in Appendix B to prevent over- or underestimation of effects.

3.3 Direct and Indirect Price Impact

Adding the consumption shares, we are able to decompose (7) into a direct (8) and an indirect effect (9) that add up to the total price impact (10) of the shock to the then exogenous sector.

$$\sigma_x^{direct} = c_x \sigma_x \tag{8}$$

$$\sigma_x^{indirect} = \sum_{i \neq x} c_i \, \sigma_i^E \tag{9}$$

$$\sigma^{total} = c_x \sigma_x + \sum_{i \neq x} c_i \, \sigma_i^E \tag{10}$$

Equation (8) describes the direct effect of a price shock to a given sector on the overall price level, due to the sector's weight in the consumption shares. An illustrative example here would be the real estate sector of any given country that makes up a large share of the representative consumer's expenditures. A price shock to this sector would thus translate into a comparatively large impact on the overall price level due to its direct effect on the consumption shares. Equation (9) captures the higher-order propagation effects of a price shock to the exogenous sector due to its IO linkages to other sectors. Think here of an energy sector that functions as an universal input for various other sectors and thus will feed into the consumption shares via propagating its price shock extensively across the production network.

It becomes clear from this decomposition that the inflation impact depends on the severity of the price shock, the share of the affected sector in final consumption expenditures (direct effect) and its position in the production network (indirect effect). Summing over (10) finally gives us the total price volatility induced by our stress-test.

3.4 Asymmetric Exposure and Volatility

The above outlined IO model provides the main formalism of our stress-test and enables us to identify systemically significant prices for the EU28, EU core and EU periphery, respectively. It also allows us to understand the heterogeneous direct and indirect relevance of sectors and to reveal shock trajectories that demonstrate the asymmetric volatility and exposure within and between different regions. For one, we do this by localizing the shock and the regional propagation of its effects. Additionally, based on Olley and Pakes (1996), we propose the following decomposition of the summed direct effect

$$\sigma^{direct} = \sum_i c_x \sigma_x, \ with \ \sum_i c_x = 1 \tag{11}$$

to

$$\sigma^{direct} = \bar{\sigma} + (N-1) \cdot cov(c_x, \sigma_x) \tag{12}$$

where $\bar{\sigma}$ displays the mean price volatility over all sectors and $(N-1) \cdot cov(c_x, \sigma_x)$ gives the cross-sectional covariance between consumption shares and the volatility of a sector's PPI. A covariance of zero implies that there is no relation between the expenditure shares and the volatility of the price level of a specific good which we interpret as no realized substitution. By contrast, a negative covariance would suggest that consumers substitute away from volatile goods' categories.

As a final robustness check, we address the issue that the Leontief price model implicitly assumes that all price adjustments take place simultaneously or, equivalently, that time does not play a role in the basic model mechanism (for a related criticism of comparative statics and historical time, cf. Robinson, 1980). To account for the sequence of adjustments, we exploit the representation of the Leontief Price Inverse as a power series, i.e.,

$$(I - A')^{-1} = I + A' + A'^2 + A'^3 + \ldots + A'^\infty \tag{13}$$

Each partial sum until A'^i has a direct interpretation as accounting for shocks up to the i-th order. We can thus replace A in our basic model equations to examine the robustness of our results up to the i-th order effect.

3.5 World Input Output Database

For our empirical application, we use the World Input Output Database (WIOD). The WIOD provides annual panel IO data for the years 2000 until 2014, covering 43 countries with 56 sectors each (Timmer et al., 2015). These countries account for more than 85 percent of world GDP and should thus provide an excellent representation of worldwide intermediate goods flows. The remainder of world economic activity is accounted for in a residual fictitious entity called "Rest of the World" (ROW). We construct the technological coefficients matrix and consequently the Leontief inverse from the IO tables for the world economy. The consumption shares are based on the values of final use for individual consumption for the EU28 countries or the subset of core and peripheral countries within the EU28, respectively. We thus allow for shock propagation of producer prices through worldwide supply chains, while focusing only on the implied CPI for European consumers. This is in contrast to the approach within the foundational paper by Weber et al. (2022) who use only national IO tables and thus do not take shock transmission through global supply chains into account. As a direct corollary to that, Weber et al. likely underestimate the total impact of price shocks. As detailed above, we use the volatilities in producer prices for each sector, i.e., we take the standard deviation of the logarithmic differences in annual PPI from the WIOD's Socio-Economic Accounts.

Generally, we aim to exploit our dataset to the fullest extent possible. The PPI volatilities are thus calculated for the whole time period for which we have data. The dataset covers all sectors for all countries except for the ROW sectors. However, we include the ROW sectors for the production network for which we use the most recent data from 2014. Excluding the ROW PPI series will lead to a slight downwards bias in implied CPI volatility; yet, we at least account for ROW sectors in the transmission of shocks by other sectors. Our consumption baskets are calculated for the average EU28 consumer (or the average consumer located in the core or peripheral region of the EU28). Using this construct, we aim to identify differences in vulnerability with respect to cost-push inflation that other studies have already documented for different structural characteristics (Joya and Rougier, 2019). While our methodology can be straightforwardly extended to investigate more granular levels of aggregation, our paper tries to account for the clear regional distinction into a core and periphery of the EU28 that is also visible in Figure 1.

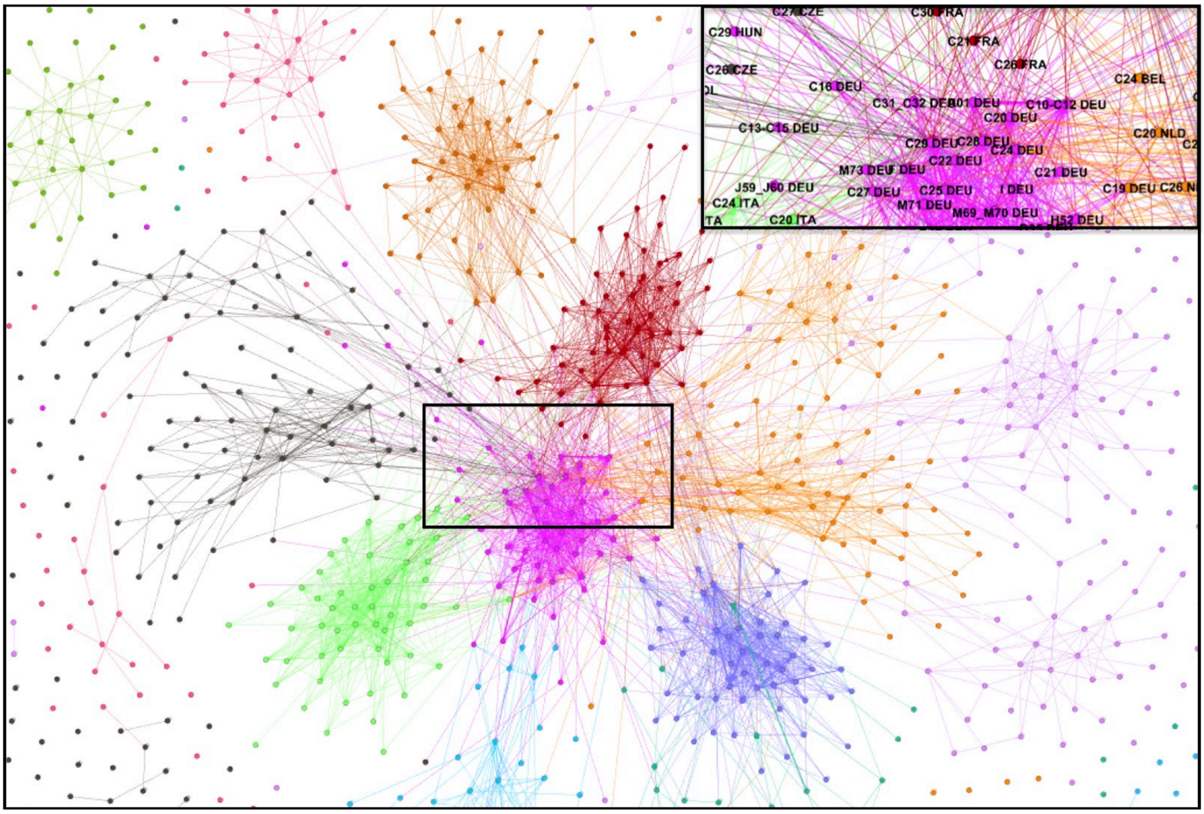

Figure 1: Snapshot of the EU28 production network in 2014 based on World-Input-Output Database. Based on Louvain method for community detection. Upper right panel magnifies the image detail and showing sector specifications according to ISIC Rev. 4.

4. Results

In this section we will go through the different layers of our stress-test results, each tackling a certain aspect of potential inflation exposure on different levels of resolution. First and foremost, we confirm the existence of systemically significant prices for the overall price level in the EU28, EU periphery and EU core, respectively (Weber et al., 2022). We show that while the direct price effects of various sectors on the respective consumption shares are significant, about two-thirds of the overall effects are indirect and thus a result of higher-order propagation within the production network. It crystallizes that two properties (size and centrality) may render a sector systemically significant.

Breaking down the geographical component, we show that the indirect effect is even larger for peripheral countries. By tracing individual shock trajectories, we find that price volatility propagating from the core countries to the periphery manifests more impact than vice versa. We also find periphery countries to import more price volatility from outside the EU28, which points to a higher exposure to world market prices. In addition to this, our method to recover consumption substitution effects shows that substitution is much more limited in the European periphery. Thus and in line with the argumentation of Pasinetti (1983) on hierarchical demand, we show consumers in peripheral countries to be relatively more exposed to price volatility.

Finally, the power series approximation shows significant differences in the round-to-round effects, both on the geographical as well as the sectoral level. However, it reveals the bulk of higher-order effects to be already present in the very first rounds. On the one hand this result suggests that price shocks diffuse along rather short path-lengths, on the other hand, it testifies to the robustness of our results against the popular criticism against comparative statics to not incorporate sequential adjustments in historical time.

4.1 Systemically Significant Prices

Figure 2 - 4 compares the ten most important sectors for the overall price level in the EU28, EU core and EU periphery, respectively. The first bar in Figure 2 can be read as follows: If the French real estate sector is exposed to its average price volatility,[10] it will change the overall price level volatility of the EU28 by more than 0.5 percent. Most of this change (0.45 percent) will be due to its direct impact on consumer prices i.e. its significant share in the EU28 consumption shares. A comparatively small impact (0.1 percent) is due to the price shock propagating to other sectors and thus reaching consumer prices via a detour. The rest of Figures 2 - 4 is to be read accordingly.

[10] Recall that we compute the average price volatility σ as the standard deviation of the logarithmic price changes in this sector from 2000 - 2014.

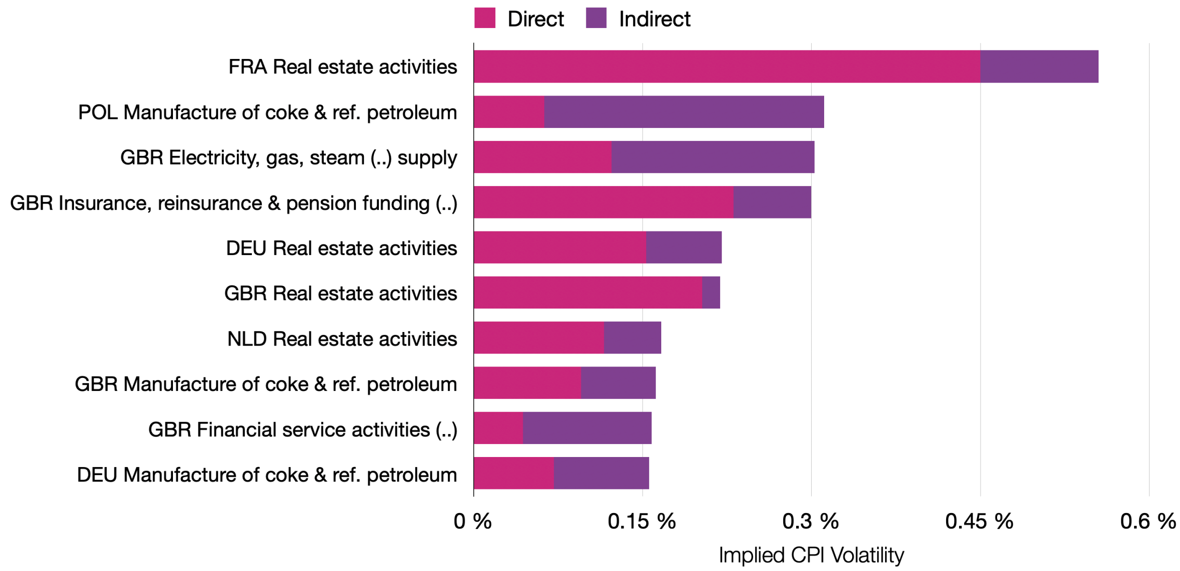

Figure 2: The ten most impactful sectors in decreasing order for the EU28. The total effect can be decomposed into the direct effect (magenta) on the CPI and the indirect effect (purple), i.e. the higher-order propagations.

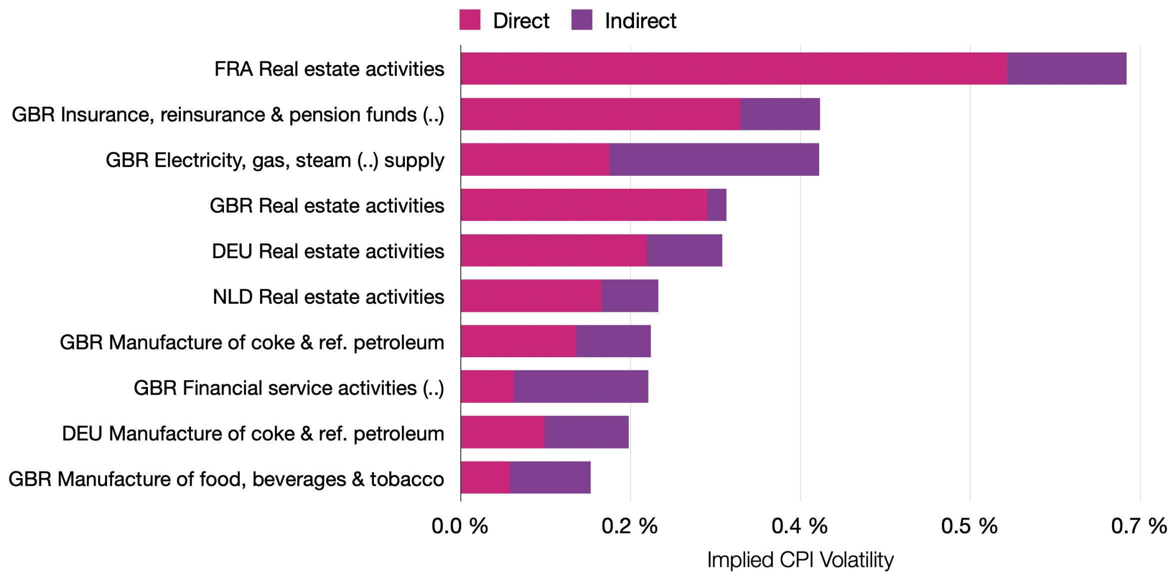

Figure 3: The ten most impactful sectors in decreasing order for the EU core. The total effect can be decomposed into the direct effect (magenta) on the CPI and the indirect effect (purple), i.e. the higher-order propagations.

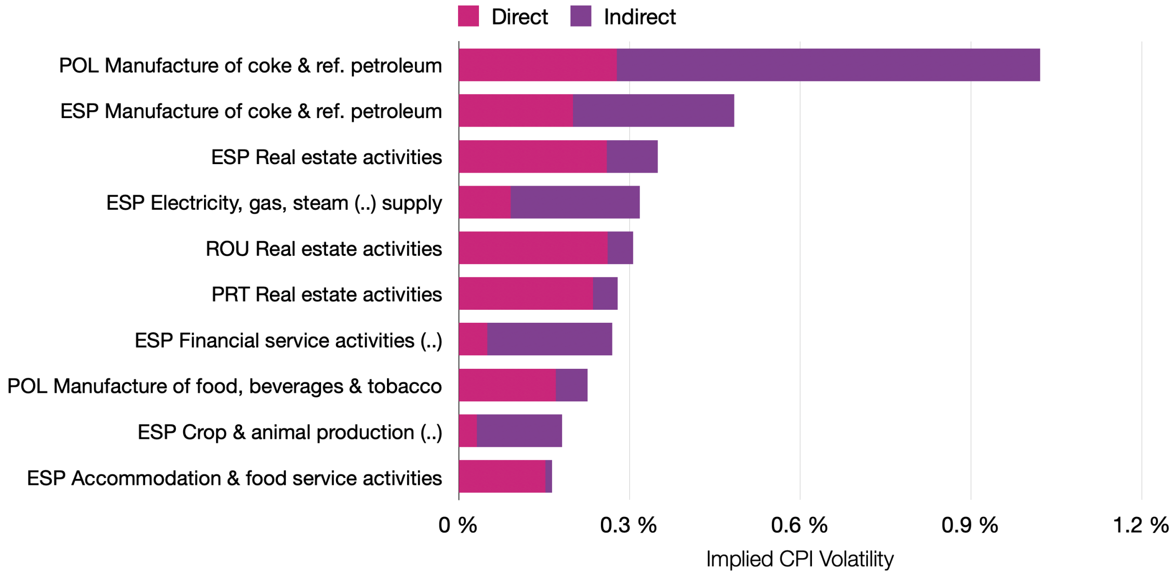

Figure 4: The ten most impactful sectors in decreasing order for the EU periphery. The total effect can be decomposed into the direct effect (magenta) on the CPI and the indirect effect (purple), i.e. the higher-order propagations.

We see that the classes of real estate activities as well as raw materials in the form of energy supply play the lead role for qualifying as systemically significant across all three geographical specifications, however varying in their national localization. We also see that the real estate sectors mostly work through their direct impact, while the sectors qualifying as energy suppliers work through their indirect effect i.e. their pivotal role for other sectors in the production process. This is consistent with our priors that raw materials sectors are important as inputs to other sectors and thus impact CPI volatility primarily through the indirect effect, while the real estate sector delivers comparatively few inputs to other sectors, i.e. generating a very small indirect effect. We can thus conjecture that either size (understood as share in the consumption shares) or centrality (in the form of supplying universal inputs) may render a sector systemically significant.

A more systematic validation of systemically significant prices can be seen in Figure 5. Formally, the existence of systemically significant prices or "granularity" hinges on conditions of the power law distribution of the upper tail, in the case of the foundational paper by Gabaix (2011) of firm sizes and in our case of the sectoral impact on aggregate CPI volatility. If we can establish this power law distribution and if this distribution exhibits a tail exponent smaller than 2, the conditions of the Central Limit Theorem are violated and the idiosyncratic destinies of these very impactful sectors drive aggregate fluctuations of the CPI.

We employ the method of Clauset et al. (2009) to determine the minimal threshold of the power law distribution. Figure 5 shows the rank-size plots of the sectoral ranks with respect to the total impact on aggregate CPI volatility in decreasing order against this total impact. All three regions show approximately linear behavior, indicating power law-like behavior. Estimating their tail exponents via maximum likelihood furthermore shows that all three spatial levels exhibit heavy upper tails with tail exponents below two. Thus, we find that there indeed exist systemically significant prices.[11]

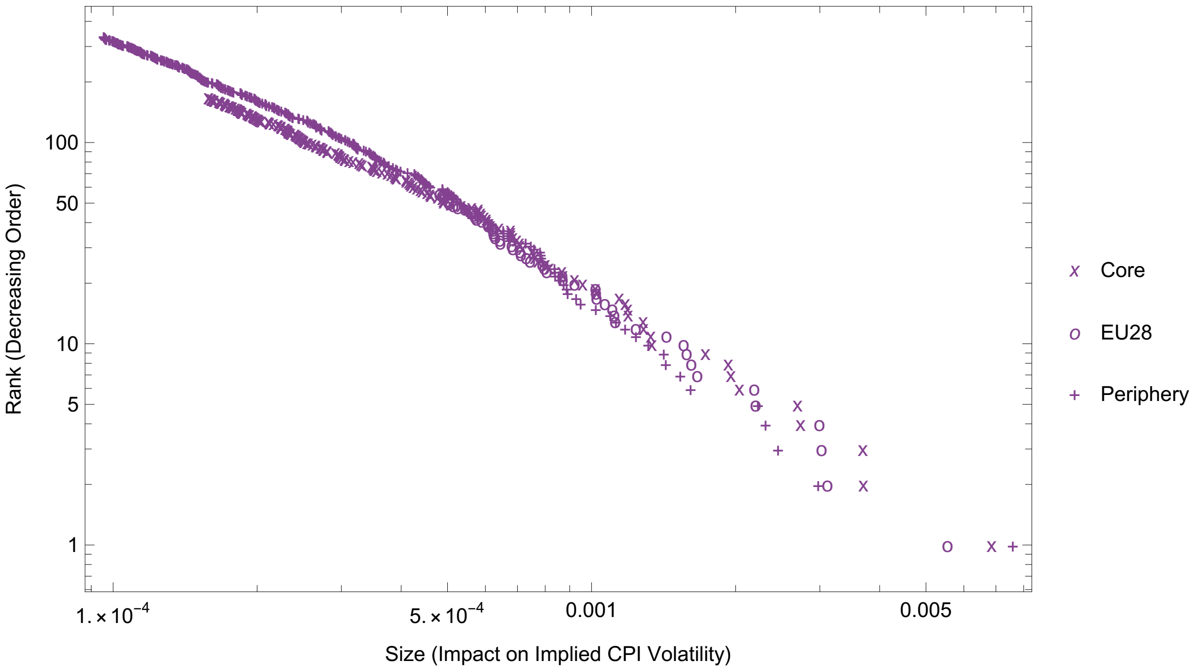

Figure 5: Rank of sectors according to their impact on implied CPI volatility in decreasing order against their impact on a double-logarithmic scale for three different regions. Threshold for the minimum of the power law determined by the method of Clauset et al. (2009). Approximately linear in behavior in all cases indicates power law upper tail.

To gauge the highly asymmetric impact of different sectors apart from this distributional regularity, we plot the cumulative impact of these sectors in Figure 6. It shows the share of industries needed to reach a certain threshold of cumulative impact on the consumer price level. We see that little more than the two percent industries with the highest impact account for 50 percent of the total contribution to consumer price inflation. For the periphery, it is four percent industries accounting for 50% and thus double the share of the core. In the

[11] The origins of this power law are unclear, though. Typically, generating mechanisms build on a variant of stochastically multiplicative growth (Gabaix, 2009) that appears unlikely to be the sole cause here, though. We aim to address this issue in further research.

language of Gabaix (2011), the core is thus more granular with far fewer sectors driving the aggregate volatility of CPI.

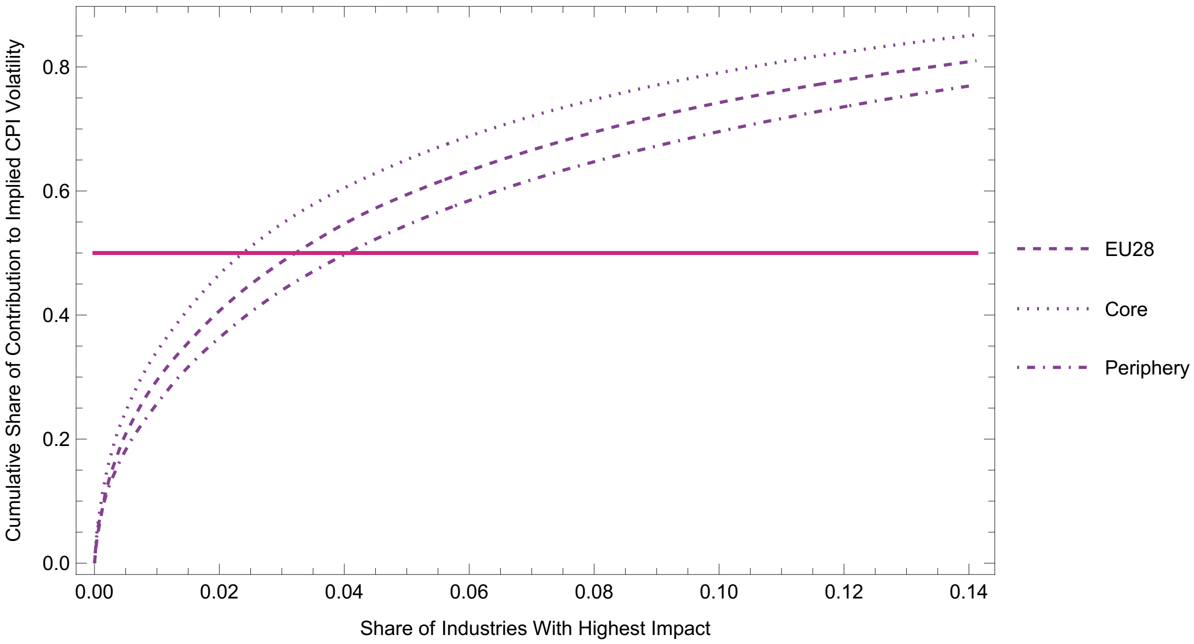

Figure 6: Share of industries needed to reach a certain threshold of cumulative impact on the consumer price level for EU28, periphery and core specification, respectively. Horizontal blue line showing 50 percent threshold.

Having established the existence of systemically significant prices in the EU28, EU core and EU periphery, respectively, we want to now increase the resolution to identify similarities and differences in the inflation exposure of these regions.

4.2 Asymmetric Inflation Exposure Core and Periphery

The scaling of Figure 4 already suggests that the periphery experiences higher volatility. A result that holds when considering the cumulative effects over all sectors: While the EU core experiences 4.44 percent of a direct and 8.43 percent of an indirect effect, accumulating to 12.87 percent in total, the periphery is exposed to 5.35 percent of direct and 11.12 percent of indirect effects, accumulating to 16.47 percent. Note that these numbers deviate from reported numbers of consumer price inflation for the observation period. One reason for this is to be found in the appliance of price volatilities instead of price growth when conjuring up the stress scenarios. Naturally, as we set up our model as a stress-test we are interested in the upper-bound prospects of an adverse scenario. However, when using mean price growth as our input, we will see results closer to reported figures. A second reason is that we use the reported consumption shares as a proxy for the consumer prices. Thus, our results coarsely outline the manifested price volatility consumers actually experienced. Thirdly, we do not consider substitution along the supply chain per the assumptions of the IO model that would tend to decrease CPI volatility. Finally, the IO tables of the WIOD use only one exchange rate per year to construct the table and thus cannot fully account for the potentially compensating effect of exchange rate adjustments. All these factors will likely bias our Implied CPI volatility upwards compared to the volatility of the official CPI. Implicitly assuming the worst case for a stress-testing scenario appears adequate to us, though.

Figure 3 and 4 also suggest a more prominent role of sectors that manufacture "coke and refined petroleum" for peripheral countries, while "real estate activities" dominate the systemically significant prices of the EU core. This again holds when considering the total impact over all sectors of each set. For the core countries the ratio of "coke and refined petroleum manufacturing" to "real estate activities" is 0.857, while it is 1.988 for the periphery.

The significant differences in the importance of raw materials has several consequential implications. For one, the above mentioned size effects seem to dominate in the core, while it is the centrality of sectors providing universal inputs that dominates the price shock propagation in peripheral countries. This is well in line with a higher total indirect effect in the periphery compared to the core (67.52 percent vs. 65.68 percent). Additionally, while monetary policy affects real estate prices srtongly, sectors providing energy and raw materials are less sensitive to changes in interest rates. Indeed, the theoretical and empirical literature has long confirmed that prices are much more sticky for durable consumer goods (e.g., housing) than for non-durables (e.g. energy) (Barsky et al., 2023; Singh et al., 2022). Finally, this difference in the importance of raw materials seems to be a powerful explanatory variable for the greater volatility in the periphery considering the volatile price formation in raw material sectors. This stems from the position of raw materials and energy at the very beginning of the production process, as being positioned in Herman Daly's inverted pyramid (Cahen-Fourot et al., 2020).

A greater dependence on raw materials naturally suggests a more exposed position in world markets. We see this hypothesis confirmed when tracing the price shock trajectories on a geographical level (Table 1-2). The EU periphery imports 3.2 percent of its inflation exposure from sectors located in countries outside the EU28, while it is only 2.5 percent for the EU core. In addition that, peripheral countries also bear a greater inflation exposure vis-à-vis core countries. While core countries face an exposure of only 0.8 percent propagating from peripheral countries, the total effect on the periphery's CPI volatility brought upon by price volatilities diffusing from core sectors approaches four times this size (2.9%). We are thus able to replicate the results of Joya and Rougier (2019) and Chakraborty et al. (2021) that lower-income countries are also exposed to higher supply-chain risk, using a very different dataset. Apart from a higher volatility for peripheral countries, we do not find a sizable difference of direct and indirect shock propagation within the geographical specifications, i.e. from core to core sectors and peripheral to peripheral sectors, respectively.

Effects	Core to Core (%)	Periphery to Core (%)	non-EU28 to Core (%)	Sum (%)
direct	4.13	0.11	0.20	4.44
indirect	5.38	0.71	2.34	8.43
total	9.52	0.82	2.54	12.88

Table 1: Inflation exposure in percentage points for the core vis-à-vis core, periphery and non-EU28 countries. Decomposed into direct, indirect and total effect. Example for first cell, first row: The direct effect of shocks diffusing from core sectors account for 4.13 percent of inflation impact in the core. Ratio of sectors in the core and peripheral countries are normalized to a 1:1 ratio in order to prevent under-/overestimation by differing numbers of sectors.

Effects	Periphery to Periphery (%)	Core to Periphery (%)	non-EU28 to Periphery (%)	Sum (%)
direct	4.80	0.37	0.18	5.35
indirect	5.59	2.52	3.01	11.12
total	10.39	2.88	3.20	16.47

Table 2: Inflation exposure in percentage points for the periphery vis-à-vis core, periphery and non-EU28 countries. Decomposed into direct, indirect and total effect.

Finally, our method of recovering consumption substitution effects (12) unveils that consumers in the peripheral countries are at the mercy of price volatilities, while consumers in the core countries are able to substitute away from increasingly volatile prices. More formally, the cross-sectional covariance between consumption shares and price volatilities is virtually non-existent for the periphery (0.05 percent) while it is significantly negative for the core (-0.86 percent). The mean price volatility $\bar{\sigma}$ is 5.3 percent.

$$\sigma^{direct} = \underbrace{\bar{\sigma}}_{\substack{\text{mean}\\ \text{price}\\ \text{volatility}}} + (N-1) \cdot \underbrace{cov(c_x, \sigma_x)}_{\substack{\text{cross-sectional}\\ \text{covariance between}\\ \text{consumption shares}\\ \text{and price}\\ \text{volatilities}}} \tag{12}$$

4.3 Round-to-round decomposition

Figure 7 show the round-to-round decomposition for the two most relevant cases of the sectors “manufacturing of coke and refined petroleum” and “real estate activities”, respectively. Round 0 marks the direct effect the sector emits, when confronted with our stress scenario. Round 1 to 15 show the cumulative indirect effects adding to round 0. We see that there are sizable differences in the round-to-round effects, both intersectoral as well as geographical. It also shows the bulk of higher-order effects to be limited to the first five to six rounds. This means that price shocks mostly diffuse within the reach of a couple of sectors and thus display rather short path-lengths. These results are valuable in and of itself, however also shield our analysis against the critique of unrealistically considering all round effects in our main stress-test exercise.

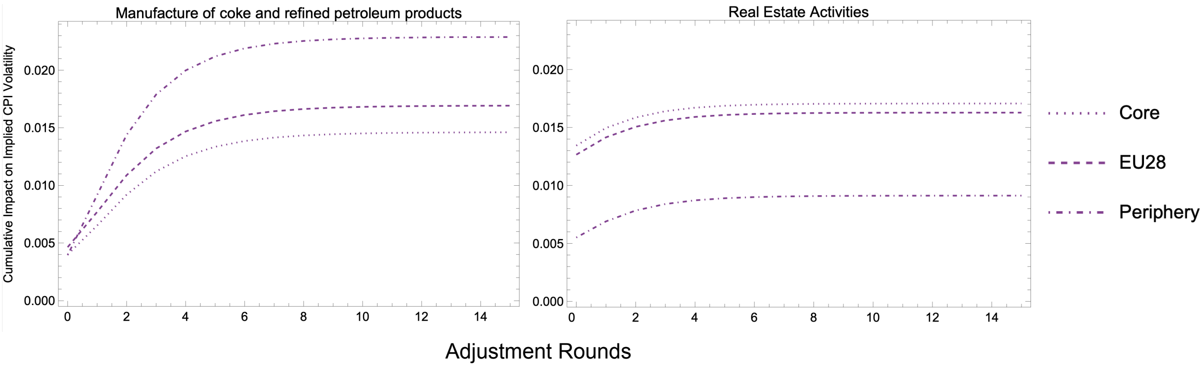

Figure 7: Round-to-round approximation for "Manufacturing of Coke and Refined Petroleum" (left) and "Real Estate Activities (right). Round 0 showing the direct effect, round 1 to 15 showing the cumulative indirect effects adding to round 0.

Overall, peripheral countries seem to be confronted with a significantly greater inflation exposure due to their greater reliance on raw materials and dependence on core and outside-EU sectors. Part of this exposure is attributable to differences in the production regime. However, and in line with the reasoning of Pasinetti (1983), we show that a substantial share of exposure stems from differences in the ability to substitute consumption. Substitutability usually is much more limited for essential goods, which in turn comprises larger shares in the consumption of peripheral countries, confirming a central theoretical tenet of dependency theory applied to the European Union (Kvangraven, 2021).

This increased inflation exposure in peripheral countries is in turn less or arguably insensitive to monetary policy. This presents serious challenges for the stability of the EU and Euro area in times of overlapping crises and mounting supply side shocks. The following section will discuss these challenges and possible policy implications.

5. Discussion

We summarize the hypothesized channels for which we find evidence in our stress-testing exercise in Figure 8 below. Sectoral cost-push shocks affect the costs of final goods producers directly and thus the synthetic CPI via the consumption share vector. Since the PPI also enters as input prices for other sectors, the production network amplifies the cost-effect. In both regards, peripherality crucially mediates the effect: Consumers in the periphery have lower income and thus cannot substitute away from especially volatile goods, and peripheral producers are also relatively more reliant on imports, rendering them more vulnerable to volatility in world markets, i.e., the core and the rest of the world.

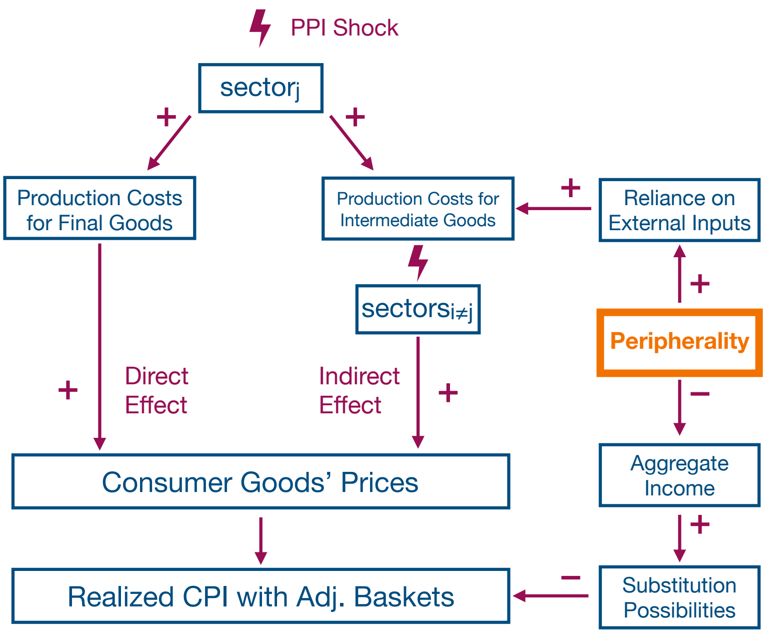

Figure 8: Exposure channels and mechanisms of our stress-testing framework.

5.1 Inflation trajectories

As key inflation propagators, the identified systemically significant prices present risks that need to be addressed by administrations of national and supranational levels. This is evident from our calibration exercise: Only two to four percent of sectors generate more than half of the total inflation exposure. These findings are not driven by the specific functional form of the Leontief inverse (implicitly assuming infinitely many rounds of adjustment). As our power series approximation shows the effect is close to our reported final values even for comparatively few rounds of adjustment.

As previously noted, numerous options exist to mitigate the inflationary effects of cost-push shocks for fiscal measures (Sgaravatti et al., 2021). Due to time lags in the effects of fiscal and especially monetary policy, it is essential to be aware of potential propagation dynamics and systemic significance. Against this background, our results are valuable to assess potential second-round effects and thereby to understand the possibility of "looking-through" a shock or the necessity to counteract.

Effects of supply chain shocks can also be contained in advance by enhancing resilience. Baldwin and Freeman (2022) argue that when private supply chain risk is higher than public risks, it should be left in private responsibility to find appropriate solutions. However, when public risk is higher, promoting private action by public incentives, facilitation, or regulation is necessary. Against this background, the public sphere must have the information available to evaluate risk and, hence, take corresponding action. When found to be appropriate, in analogy to the Basel III framework for banks, we recommend enforcing or incentivizing risk management practices for those sectors identified as bottlenecks and thus systemically important, e.g., by prescribing inventories. Another lever to enhance resilience is competition policy that might reduce the pass-through of shocks (Weber and Wasner, 2023). For both supply chain risk management regulations and competition policy, it would be crucial to have firm-level or even product-level data. However, even our rather aggregate analysis points to a tiny number of sectors driving the aggregate response to cost-push shocks that policy measures can then target.

5.2 Structural asymmetries

In addition, the results of our stress-test exercises point to asymmetries in the EU core and periphery. Building upon dependency theory, we identify several key constraints of peripheral countries for EU cohesion policy to consider. First, as shown in Figure 8, one obvious measure to enhance the resilience of the periphery would be to increase its average income by an appropriate fiscal transfer scheme, thus creating capability for consumption substitution. Second, we find that peripheral price volatility depends strongly on the core and the rest of the world. This means that the peripheral policy is less capable of controlling these largely external sources of disturbances. Building technological capabilities in peripheral regions would thus also decrease inflation exposure, as it would reduce the dependence on imported inputs. This could be achieved e.g. by smart specialization strategies that also take the path-dependent nature of regional development into account (Deegan et al., 2021). A final challenge for policy are differences in the sectoral composition driving the response to cost-push shocks. Quantitatively, only two percent of core sectors generate more than half of the core's inflation exposure, while it is double the amount in the periphery. Thus, policy and costly supervision in the periphery needs to cover more sectors. Qualitatively, the most significant drivers of inflation exposure in the core are the various real estate sectors, while it is sectors related to energy production and raw materials in the periphery. Since monetary policy is empirically far more effective in curbing price increases in the real estate than in other sectors, a common monetary policy as e.g. for the Eurozone might therefore cause divergence of core and periphery. Industrial policy and smart specialization strategies for the periphery to reduce this sectoral dependence might thus be necessary to create the precondition for effective monetary policy without such unintended consequences.

6. Conclusion

Our paper provided a first stress-test regarding inflation exposure explicitly accounting for amplification in production networks. Even though our method relied on highly aggregated data, we nevertheless were able to identify several vulnerabilities in the form of systemically significant prices following Weber et al. (2022). Documenting sectoral and spatial heterogeneity, we hope to aid policy to enhance European inflation resilience, as our analysis highlights potential levers for which policy would disproportionately affect aggregate outcomes. Our findings of structurally asymmetric inflation exposures between core and periphery also highlight that the Eurozone is far from an Optimum Currency Area. Theoretically, our results imply that the notion of inflation as a purely aggregate phenomenon underlying much of orthodox macroeconomics is too simplistic and ignores the role of systemically significant prices and shock propagation within production networks.

Yet, our simulation also has several limitations, essentially due to the lack of more current and granular data: The data does not cover the most recent period of high inflation and is highly aggregated on a country level. In particular, since we do not have consumption microdata, we implicitly employ the fiction of a representative consumer and only consider shares in the total consumption of a region. This prevents us from examining the effects of cost-push shocks along the personal income distribution, which are arguably even more important for policy. Also, as Weber and Schulz (2023) show, core-periphery patterns are more prevalent on the much more granular county level, which, with the appropriate data, would provide an opportunity to study the spatial propagation of cost-push shocks. Finally, the Leontief price model implicitly makes several strong assumptions about substitutability along the supply chain, rendering our simulation results upper-bound estimates. We aim to address these issues in further research, look into country-specifics as a first step, and augment our propagation model with a modified Leontief production function that partially allows for input substitution (Pichler et al., 2020). Notwithstanding these limitations, our paper provides a first stress-test for inflation exposure in supply chains that takes spatial heterogeneities seriously and can be straightforwardly applied and extended to other scenarios.

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Appendix A: Country names

AUT = Austria

BEL = Belgium

BGR = Bulgaria

CYP = Cyprus

CZE = Czech Republic

DNK = Denmark

ESP = Spain

EST = Estonia

FIN = Finland

FRA = France

GBR = Great Britain

GER = Germany

GRE = Greece

HRV = Croatia

HUN = Hungary

ITA = Italy

IRL = Ireland

LTU = Lithuania

LUX = Luxembourg

LVA = Latvia

MLT = Malta

NLD = Netherlands

POL = Poland

PRT = Portugal

ROU = Romania

SVK = Slovakia

SVN = Slovenia

SWE = Sweden

Appendix B: Correction of measured effects for different number of sectors

One issues that arises immediately for comparing the estimates of our model between core and periphery is that there are more core than peripheral sectors and the total effects are thus not directly comparable. To remedy this, we use a simple correction method:

1) Let e_i be the incorrect inflation impact of region$_i$ that is a subset of all regions, i.e., i can refer to the core, periphery or rest of the world. Determine uncorrected share of region$_i$: $s_i \frac{e_i}{\sum_j e_j}$.

2) Determine the share of the amount of sectors in i compared to the whole sample. Divide s_i by this share: $\tilde{s}_i = \frac{s_i}{\#i/\sum_j \#j}$, with # as the number of elements in a set. If $\tilde{s}_i$ is above unity, then the inflation effect of i is higher than would be expected by the number of sectors it entails and vice versa.

3) Correct the share by $\hat{s}_i = \frac{\tilde{s}_i}{\sum_j \tilde{s}_i}$.

4) Multiply by the total effect of all regions to get a corrected estimate while preserving the total inflation impact:$\hat{e}_i = \hat{s}_i \cdot \sum_j e_j$.

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