Financial frictions across the production network and the transmission of monetary policy

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Abstract

We investigate how production network linkages and sector-specific financial frictions influence monetary policy transmission. Using granular country-sector data for the euro area and input-output tables, we develop a novel set of empirical measures of upstream and downstream financial frictions. Our analysis reveals that financial frictions among upstream suppliers and downstream customers significantly impact firms' pricing and production decisions, thus affecting monetary policy transmission. Consistent with a sector-specific "cost channel" of monetary policy, upstream frictions raise sectoral prices, while downstream frictions trigger sectoral demand-channel effects in response to a monetary policy tightening. We develop a multi-sector model incorporating heterogeneity in sectoral financial frictions, deriving theoretical counterparts to our empirical measures. Our model corroborates our empirical findings through both analytical validation and simulation exercises.

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Non-technical summary

Both firms' financial positions and production network linkages have been identified as key determinants of the transmission of macroeconomic shocks. In this paper, we bring together these two dimensions and study how the transmission of monetary policy is affected by their interaction. To this end, we develop a novel set of empirical measures for a sector's exposure to up- and downstream financial frictions, i.e. to the degree of constraints its suppliers and customers face. Equipped with these measures, we investigate the effects of monetary policy in the euro area when explicitly accounting for sector-specific financial conditions and production networks linkages.

Our results show that both direct and indirect financial frictions significantly amplify the effect of a monetary policy shock, with indirect financial frictions accounting for a large share in the overall effect on prices and output. In addition, we find that while downstream financial frictions seem to reinforce the decline in prices and output following a monetary policy tightening shock, upstream frictions tend to partly mitigate these effects. While a tightening shock lowers downstream customers' demand for intermediate goods, we document a novel network-induced cost channel of monetary policy: a monetary policy tightening pushes upstream suppliers to raise prices, possibly to mitigate negative revenue effects stemming from a tightening of financing conditions.

From a policy perspective, these findings underscore the importance of considering both financial frictions and production networks in combination when assessing the potential impacts of monetary policy. For instance, ignoring the possible amplification of dampening demand effects of a monetary policy tightening that can be attributed to downstream customers' financial frictions may result in underestimating its full impact. While a "traditional" balance-sheet channel accounts for a sector's own degree of financial constraints only, we document that "indirect" balance-sheet channels stemming from such downstream exposures need to be adequately accounted for as well. At the same time, the upward effect on sectoral prices stemming from a sector-specific cost channel may dampen the overall efficacy of monetary policy. By understanding these dynamics, central banks can better anticipate the effects of their actions on different sectors and the broader economy.

1 Introduction

The current paper links two key themes in the current macroeconomic debate and studies how they jointly shape the transmission of monetary policy. The first is the role of financial frictions and constraints in amplifying the effects of monetary policy, as formalized in Bernanke and Gertler (1995) and Bernanke et al. (1999) and empirically validated, *e.g.*, in Gilchrist and Zakrajšek (2012) and Ottonello and Winberry (2020). The second is the role of production networks in shaping the transmission of shocks across the economy (Acemoglu et al., 2012, 2016) – an issue that has featured prominently, for instance, in the debate on the supply- versus demand-side origin of the inflation surge following the Covid-19 pandemic.[1]

The specific question we investigate is to what extent the transmission of monetary policy depends on financial frictions across the production network. In doing so, we assess the importance of both direct and indirect channels through which financial frictions across the production network may amplify or dampen the transmission of monetary policy. Financial frictions directly applying to firms in a specific sector may amplify the transmission owing to the traditional balance-sheet channel (Bernanke and Gertler, 1995).[2] Moreover, the balance-sheet channel may also be indirectly amplified via the production network, depending on both the degree of interconnections across sectors and the intensity of their respective financial frictions. For instance, the ability of financially constrained firms in one sector to purchase intermediate inputs from other firms and sectors may be limited once rising interest rates imply a tightening of financial constraints. In turn, this may put downward pressure on prices charged and output provided by upstream suppliers to these firms. At the same time, financially constrained firms may try to raise selling prices, and thereby raise revenue, to alleviate tight financial conditions (Gilchrist

[1]See for instance Bernanke and Blanchard (2025, 2024); Giannone and Primiceri (2024).

[2]In short, this channel prescribes that due to frictions in credit intermediation for instance related to agency costs banks face when monitoring the credit quality of borrowers, the external finance premium, i.e. the firm's cost on externally obtained funding over the cost of internal funds (e.g. retained earnings) is inversely related with the financial position of the firm, i.e. with the amount of collateral the firm holds on its balance sheet. This relationship implies that firms may face binding borrowing constraints once their collateral positions deteriorates, with a monetary policy tightening likely aggravating the issue of binding constraints as both financing costs rise and the value of collateral assets such as government bonds and other fixed-rate assets may fall as interest rates rise. In this way, the balance sheet channel directly amplifies the effect of monetary policy on prices and output, as firms are forced to adjust their production plans in light of their own exposure to financial frictions.

et al., 2017). This channel, in turn, may put upward pressure on prices faced by downstream customers. We show that, failing to account for such indirect financial effects, may lead us to understate the impact of monetary policy shock on the economy. In addition, explicitly accounting for the role of upstream and downstream financial frictions sheds light on the timing of the transmission and on the relative importance of upstream "cost" and a downstream "demand" channels across the production network.

Our empirical analysis proceeds in two steps. First, we develop new measures of financial frictions for suppliers ("upstream financial frictions") and customers ("downstream financial frictions") across the production network. Then, we integrate them into a panel local projections model (Jordà and Taylor, 2016; Jordà, 2005) and study their interaction with monetary policy shocks. The analysis is based on a euro area country-sector panel dataset at monthly frequency including sector-level data on prices, real activity, inter-sectoral linkages as defined by euro area input-output (IO) tables, and sector-specific financial frictions. Financial frictions are measured by sector-specific corporate leverage, a common proxy in the related literature.[3] While an unconditional increase in leverage may, in principle, reflect a sector's growth potential and expected future revenues, rather than a source of financial vulnerability, we control for time-invariant cross-sectoral differences in the "neutral" level of leverage and for its key macroeconomic confounders. This allows us to isolate the *conditional*, marginal tightening or easing of financial frictions – in line with a broad literature that has documented a "financial accelerator" mechanism originating from firms' external financing positions.[4]

[3]In fact, several empirical studies documented the negative impact high debt holdings may have on firms' investment activity and broader economic developments, see e.g.Vermeulen (2002), Jäger (2003), Benito and Hernando (2007), Martinez-Carrascal and Ferrando (2008), Pal and Ferrando (2010), Goretti and Souto (2013), Ferrando et al. (2017), Kalemli-Özcan et al. (2018), Gebauer et al. (2018), or Barbiero et al. (2020).

[4]See, inter alia, Bernanke and Gertler (1989), Bernanke and Gertler (1995), Bernanke et al. (1999), or Kiyotaki and Moore (1997) for early theoretical contributions, and Ottonello and Winberry (2020), Auer et al. (2021) Bahaj et al. (2022), Jeenas (2023), Cloyne et al. (2023), or Anderson and Cesa-Bianchi (2024) for recent empirical evidence on (the heterogeneous effects of) a monetary-policy related financial accelerator. We also point out that the terms "constraints" and "frictions" may bear different connotations, depending on the research question and design at hand. We use these terms interchangeably in this paper to refer to situation of relatively tight sectoral financial positions, and only refer to the possible nature of the underlying frictions explicitly in the theoretical discussions of section 7.

The analysis yields the following key results. First, we show that both direct and indirect financial frictions significantly amplify the contractionary effects of a monetary policy tightening on output and prices, with indirect financial frictions accounting for a significant share of this amplification effect. Second, further disentangling the indirect channel, we find that downstream financial frictions reinforce the monetary policy effect, especially on prices, consistent with a tightening of financial constraints lowering downstream customers' demand for intermediate goods produced by other sectors ("demand channel"). By contrast, upstream financial frictions counteract this effect, in that their tightening fosters incentives for upstream suppliers to raise prices ("cost channel"). The downstream demand channel dominates, however, thus giving rise to the overall amplifying effect of indirect financial frictions in the transmission of monetary policy.

We rationalize our key empirical findings in a canonical multi-sector model allowing for sector-specific constraints and heterogeneity in input-output linkages. By introducing a novel approach to allow for heterogeneity in sectoral financial constraints, the model predicts a heterogeneous impact of changes in the policy interest rate on each sector, with the strength of the idiosyncratic impact determined by the sector's overall financial position. We map our empirical cross-sectoral financial constraints measures into the model economy and use these theoretical measures to assess the importance of sector-specific financial constraints for the transmission of monetary policy.

The remainder of the paper is organized as follows: section 2 reviews the relevant literature, section 3 describes the data, section 4 shows how we construct the sector-specific measures of financial frictions, section 5 outlines the econometric strategy, and section 6 presents the empirical results. We rationalize our empirical financial constraints measures by reporting both analytic derivations and comparative statics analyses based on a theoretical multi-sector economy model in section 7. Section 8 concludes.

2 Literature

Our work intersects with multiple strands of existing theoretical and empirical literature. First, we contribute to the empirical literature on monetary policy shock transmission across production networks by providing new evidence for the euro area and novel insights on the role of sectoral financial frictions. Despite the growing body of theoretical studies assessing the transmission of shocks in production network models, empirical evidence remains relatively scarce and has mainly been obtained for the United States. Ozdagli and Weber (2017) analyze the impact of monetary policy shocks measured via high-frequency changes in financial market data occurring around Federal Reserve press releases. Using stock return data, they find that between 50 and 85 percent of the overall monetary policy effect is attributable to indirect network effects. More recently, Ghassibe (2021) employs monthly data on US sectoral consumption and finds that at least 30 percent of the effect of monetary shocks on aggregate consumption stems from amplification through input-output linkages. At the sectoral level, he finds that the network effect increases with the degree of price stickiness and intermediate input intensity. We expand on this area of research by incorporating the interaction of financial frictions and sectoral linkages in our empirical analysis. From a methodological perspective, our study relates to recent work using disaggregated price data to examine monetary policy transmission to consumer prices (Borağan Aruoba and Drechsel, 2024; Allayioti et al., 2024). In contrast to those studies, we analyze the production side of the economy, and highlight the role of financial frictions within production networks. By accounting for financial variables in the empirical framework, we document a novel cost channel of monetary policy running through the propagation of sectoral financial frictions across the production network, extending earlier findings by BarthIII and Ramey (2002). This cost channel operates both directly through firms' financial frictions, and indirectly through frictions a firm's suppliers and customers face. Moreover, our study complements Demir et al. (2024), who examine the transmission of supply shocks through a production network, and find that the transmission of such shocks is amplified by low liquidity holdings of some firms. We document similar amplification effects for monetary policy shocks, and we show that these shocks propagate both from suppliers to customers via a cost channel, and from customers to suppliers according to a sectoral demand channel.

Second, our work relates to the broader literature on financial frictions in the transmission of monetary policy shocks.[5] The importance of financial frictions has been widely acknowledged since Bernanke and Gertler (1995) and Bernanke et al. (1999) and remains a central theme in macro-financial research. However, the role of financial frictions at the micro-level for the transmission of shocks to the macro economy has only recently been investigated. Ottonello and Winberry (2020) show that financially constrained firms invest significantly less following a monetary pol-

[5]See also references in footnote 4.

icy shock compared to non-constrained firms, rationalizing this finding within a heterogeneous firm New Keynesian DSGE model. Similarly, Jeenas (2023) finds that firms with low liquid asset holdings invest less after unexpected policy rate increases, independent of their leverage or size, highlighting the role of corporate liquidity management in monetary policy transmission. Our study builds on this literature by demonstrating that sectoral financial frictions not only affect individual firms but also propagate through supplier-customer relationships. In this regard, our findings connect with Adelino et al. (2023), who examine the role of trade credit in the transmission of unconventional monetary policy. We broaden this perspective by considering the transmission of interest rate policy through the production network and by disentangling a demand and a cost channel that works through sectoral linkages.

Third, we contribute to the theoretical literature on production networks and shock propagation. Following the seminal work of Acemoglu et al. (2012), research has extensively examined how demand and supply shocks travel through supply chains. Interest in the amplification effects of production networks has grown significantly since the Covid-19 pandemic, particularly concerning supply-side shocks. Our focus on the role of production networks in the transmission of monetary policy relates well to a number of recent theoretical papers that highlight the importance of these network mechanisms. La'O and Tahbaz-Salehi (2022) examine the influence of production networks on optimal monetary policy, finding that optimal stabilization requires a price index that places greater weight on industries that are larger, have higher price stickiness, and are positioned further upstream. Similarly, Rubbo (2023) show that in a multi-sector economy with input-output linkages, the "divine coincidence" – i.e., the simultaneous stabilization of both output and prices via monetary policy – no longer holds. Our theoretical model is an extension of the framework developed in Bigio and La'O (2020), who demonstrate that the US input-output structure amplified financial distortions by a factor of approximately two during the Great Financial Crisis. More recently, Su (2024) highlights how input-output linkages amplify sectoral financial distortions, influencing aggregate total factor productivity (TFP) shocks. Our analysis builds on this work by demonstrating that sectoral financial frictions significantly impact monetary policy transmission through firms, with network effects amplifying or mitigating their impact, depending on the financial conditions of upstream and downstream firms.

3 Data

We construct a country-sector panel at monthly frequency for the 20 euro area countries, with sector-specific information reported at the NACE-2 level.[6] Our dataset is composed of four major building blocks: 1) a set of main macroeconomic indicators reported at the country level, including aggregate monetary policy shocks; 2) a dataset including information on sector-specific producer prices and activity reported at the NACE-2 level; 3) data on input-output linkages for 64 sectors reported at this level capturing bilateral cross-sector flows for all euro area countries; and 4) firm-level balance sheet data obtained from Orbis aggregated at country-sector-year level to obtain information on sector-specific financial frictions. The resulting dataset spans from January 1999 to December 2024. In the following, we describe each of these building blocks in greater detail. Table 1 reports summary statistics for each category.

Country-level macroeconomic data and monetary policy shocks

We collect a set of standard country-level macroeconomic control variables, including data on prices, real economic activity, interest rates and macro-financial variables obtained from Eurostat and the International Monetary Fund (IMF). We identify common euro area monetary policy shocks via high-frequency movements in the 3-month OIS rate over a narrow window (ca. 135 minutes) around the publication of the press release and the press conference following ECB Governing Council meetings. We draw these movements from the euro area monetary policy-event database constructed by Altavilla et al. (2019). In order to isolate monetary policy shocks from information shocks, we use the so-called "poor-man's sign restriction" approach developed in Jarociński and Karadi (2020). We thus identify monetary policy shocks as high-frequency changes in the 3-months OIS rate over the event window coinciding with stock prices movements in the opposite direction.[7]

Country-sector data

We collect data on prices, industrial production, turnover, employment, hours

[6] See Eurostat (2008) for an explanation of the NACE categorization applied to euro area sector-specific data.

[7] Our empirical results in section 6.1 are robust to identifying monetary policy shocks based on the first principal component of high-frequency changes in 1-, 3-, 6-, and 12-month OIS rates, instead of relying on 3-month OIS changes only (Jarociński and Karadi, 2020).

Table 1: Summary statistics of used variables

	Observations	Mean	Standard error	Median
Euro area level				
CISS	312	0.18	0.15	0.12
EUR/USD exchange rate	312	1.18	0.16	1.17
Composite 10y sov. bond yield (%)	312	3.03	1.60	3.41
IMF commodity index	256	134.08	38.25	126.39
3-month OIS (%)	305	1.47	1.75	0.78
Monetary policy shock (bps)	312	0.16	2.67	0.00
Country level				
Real GDP (€bn)	2,380	475.15	894.54	54.49
GDP Deflator	2,266	88.53	15.68	89.25
Unemployment (%)	7,115	8.79	4.14	7.98
Hours worked (bn)	2,338	10.61	19.76	1.67
Employed persons (mil)	1,971	29.97	53.73	2.54
HICP	6,409	95.51	15.81	97.96
QE holdings (€bn)	3,424	100.23	208.25	12.58
10y sov. bond yield (%)	2,974	2.60	1.83	2.85
Sector level				
Producer price index (PPI)	145,986	52.81	48.01	74.04
Industrial production (IP)	197,951	84.83	88.09	92.59
Turnover	220,521	101.23	2533.46	83.60
Employment index	98,710	42.77	53.98	0.00
Hours worked index	87,323	33.06	53.37	0.00
Job Vacancy rate	3,768	1.96	4.12	1.20
Gross wages	96,507	34.09	45.79	0.00

Sources: Eurostat, ECB, Altavilla et al. (2019), IMF.

worked, and wages from the Short-term Business Statistics (STS) dataset of Eurostat.[8] As no information on price indices for the trade sector (NACE codes G00, G45, G46, G47) are reported in the STS, we compute them by dividing nominal turnover by real turnover, consistent with the methodology employed by Eurostat.[9] In addition, we proxy the producer price index (PPI) for the construction sector (NACE code F00) with the PPI for residential buildings construction.[10] Moreover, as STS do not cover the agriculture sector (A01), we complement PPI data for this sector with quarterly information from another Eurostat dataset which we linearly interpolate to obtain monthly observations.[11] We also add industrial production (IP) indices for agriculture from another dataset provided by Eurostat, even if reported data is only available at annual frequency.[12]

In the STS, data on employment, hours worked, and wages are mainly available at quarterly frequency, and only partly provided at monthly frequency on voluntary basis by national statistical offices.[13] Data on prices, industrial production, and turnover are available both at monthly and quarterly frequency, depending on the respective country, sector and time period.[14] To maximize the number of observations while preserving the consistency of the dataset, we linearly interpolate quarterly series to monthly and we either take the original monthly series or the quarterly interpolation, depending on which final series has more observations.

For all available indices, we use seasonally adjusted series and perform a four-step cleaning procedure:[15]

1. We exclude all observations of a specific index variable reported with a value of zero.

[8]The STS can be found here.

[9]More precisely, we divide turnover values by the volume of sales (deflated turnover).

[10]This refers to the statistical classification of products by activity (CPA) code F411X, the main component of sector F41 which covers "new buildings" only.

[11]The "Price indices of agricultural products (apri_pi)" data which can be found here.

[12]The "Economic accounts for agriculture (aact_eaa)" data which can be found here.

[13]See STS regulations here.

[14]This implies that for a given country-sector pair we may be able to retrieve only monthly or only quarterly observations, or both. Moreover, monthly and quarterly observations, if both available, are not perfectly consistent at all times in STS.

[15]We derive seasonally adjusted series in cases for which the seasonal adjustment is not directly carried out by Eurostat by performing a LOESS transformation.

2. We drop all observations of a series with exactly identical data entries for more than six subsequent months (if the series is monthly) or more than four quarters (if the series is quarterly).

3. We drop entirely data series exhibiting an implausibly high level of volatility or poor data quality, i.e. due to implausibly large discrete jumps at random intervals.

Input-output linkages

We derive information on industry-by-industry input-output (IO) linkages from the annual EU inter-country input-output tables in Eurostat's "Full international and global accounts for research in input-output Analysis (FIGARO)" database.[16] These tables are available from 2010 to 2022, and we extrapolate the 2010 figures to preceding years and the 2022 table for the subsequent years. This way, we cover the entire period of interest, and we take comfort in doing so from the fact that IO linkages are changing only very gradually over time. Table 2 provides a schematic example of a multi-country IO matrix with just two countries, A and B, and two industries, 1 and 2, to illustrate the key metrics we derive from IO tables.

Table 2: Simplified Multi-Country Input-Output Table

	A1	**A2**	**B1**	**B2**	**Final Consumption**
A1	$z_{11}^{A,A}$	$z_{12}^{A,A}$	$z_{11}^{A,B}$	$z_{12}^{A,B}$	y_1^A
A2	$z_{21}^{A,A}$	$z_{22}^{A,A}$	$z_{21}^{A,B}$	$z_{22}^{A,B}$	y_2^A
B1	$z_{11}^{B,A}$	$z_{12}^{B,A}$	$z_{11}^{B,B}$	$z_{12}^{B,B}$	y_1^B
B2	$z_{21}^{B,A}$	$z_{22}^{B,A}$	$z_{21}^{B,B}$	$z_{22}^{B,B}$	y_2^B
Labor	L_1^A	L_2^A	L_1^B	L_2^B	L
Value added	VA_1^A	VA_2^A	VA_1^B	VA_2^B	VA
Taxes	T_1^A	T_2^A	T_1^B	T_2^B	T

In this table, $z_{ij}^{A,B}$ is the flow of goods and services from sector i in country A to sector j in country B. Note that part of the sector's output could be used by the same sector for production. By summing all the elements in a certain row, one obtains the total output produced by the corresponding sector. By summing all the elements in a certain column, one obtains the sum of the inputs (including labor, taxes, and value added) used in the production of the corresponding sector.

[16]Further information on FIGARO data can be found here.

First, we calculate the share of each sector's labor expenses, taxes and value added in total input expenses. In our simplified table, this would be given by

$$a_{1A} = \frac{L_1^A + VA_1^A + T_1^A}{z_{11}^{A,A} + z_{21}^{A,A} + z_{11}^{B,A} + z_{21}^{B,A} + VA_1^A + T_1^A} \tag{1}$$

for industry 1 in country A.[17] This represents the share of a sector's inputs other than intermediate input goods acquired from the production network.

Second, we compute the share of output used for final consumption, i.e. the share of a sector's output that is not used as an intermediate input in production by any sector. For sector 1 in country A, this would be given by[18]

$$\tilde{a}_{1A} = \frac{y_1^A}{z_{11}^{A,A} + z_{12}^{A,A} + z_{11}^{A,B} + z_{12}^{A,B} + y_1^A}. \tag{2}$$

We then take the square IO matrix, which reports only the flows of goods and services between sectors:

$$\boldsymbol{A} = \begin{bmatrix} z_{11}^{A,A} & z_{12}^{A,A} & z_{11}^{A,B} & z_{12}^{A,B} \\ z_{21}^{A,A} & z_{22}^{A,A} & z_{21}^{A,B} & z_{22}^{A,B} \\ z_{11}^{B,A} & z_{12}^{B,A} & z_{11}^{B,B} & z_{12}^{B,B} \\ z_{21}^{B,A} & z_{22}^{B,A} & z_{21}^{B,B} & z_{22}^{B,B} \end{bmatrix} \tag{3}$$

and calculate the matrix of technical coefficients $\boldsymbol{B}$ by dividing each element of matrix $\boldsymbol{A}$ by the total of the respective column where the element is located, obtaining

$$\boldsymbol{B} = \begin{bmatrix} \nu_{11}^{A,A} & \nu_{12}^{A,A} & \nu_{11}^{A,B} & \nu_{12}^{A,B} \\ \nu_{21}^{A,A} & \nu_{22}^{A,A} & \nu_{21}^{A,B} & \nu_{22}^{A,B} \\ \nu_{11}^{B,A} & \nu_{12}^{B,A} & \nu_{11}^{B,B} & \nu_{12}^{B,B} \\ \nu_{21}^{B,A} & \nu_{22}^{B,A} & \nu_{21}^{B,B} & \nu_{22}^{B,B} \end{bmatrix}. \tag{4}$$

In this matrix, the element $\nu_{ij}^{A,B}$ represents the relative importance of sector i in country A as a supplier of sector j in country B. In a similar vein, one obtains

[17] In the actual IO tables, we calculate the share of each sector's input coming from outside the production network by dividing all the rows containing W2 (compensation of employees, operating surplus, other gross value added and net taxes) by the total expenses for production.

[18] In the actual IO tables, we calculate the share of each sector's output used for final consumption by dividing the sum of consumption columns ("P3_S" and and P5) by the sum of total output.

the matrix of allocation coefficients $\boldsymbol{C}$ by dividing each element of matrix $\boldsymbol{A}$ by the total of the rows:

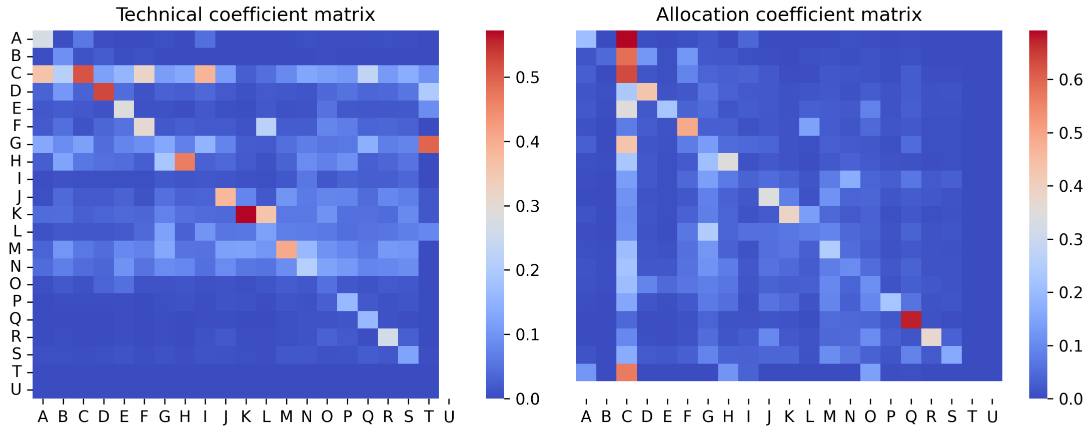
$$\boldsymbol{C} = \begin{bmatrix} \tilde{\nu}_{11}^{A,A} & \tilde{\nu}_{12}^{A,A} & \tilde{\nu}_{11}^{A,B} & \tilde{\nu}_{12}^{A,B} \\ \tilde{\nu}_{21}^{A,A} & \tilde{\nu}_{22}^{A,A} & \tilde{\nu}_{21}^{A,B} & \tilde{\nu}_{22}^{A,B} \\ \tilde{\nu}_{11}^{B,A} & \tilde{\nu}_{12}^{B,A} & \tilde{\nu}_{11}^{B,B} & \tilde{\nu}_{12}^{B,B} \\ \tilde{\nu}_{21}^{B,A} & \tilde{\nu}_{22}^{B,A} & \tilde{\nu}_{21}^{B,B} & \tilde{\nu}_{22}^{B,B} \end{bmatrix}. \tag{5}$$

In this matrix, the element $\tilde{\nu}_{ij}^{A,B}$ represents the relative importance of sector j in country B as a customer of sector i in country A.

Figure 1 presents heatmaps illustrating the technical and allocation coefficients for NACE 1-digit sectors in the euro area. These coefficients quantify inter-sectoral dependencies by mapping the flow of goods and services across sectors. The left heatmap corresponds to the data counterpart to the technical coefficients matrix $\boldsymbol{B}$, given by equation 4, such that any given element gives the share of inputs that the sector in a respective column provides to the buying sector in the respective row. The right heatmap, correspondingly, shows the data counterpart to the allocation coefficient matrix $\boldsymbol{C}$, given by equation 5. Red-shaded cells indicate that the two respective sectors in the corresponding row and column have strong bilateral exposures in the input-output structure. They show that the euro area production network can be broadly characterized as "diagonal", with internal (roundabout) exchange of inputs and outputs in a respective sector being relatively important. However, some sectors such as manufacturing (C) or wholesale/retail trade (G) are important suppliers to and/or customers of other sectors, as indicated by the lighter-blue/red shades of respective cells.

Both the matrix of technical coefficients $\boldsymbol{B}$ and the matrix of allocation coefficients $\boldsymbol{C}$ take only the first-order flows of goods and services between sectors into account. However, multi-layered production chains imply that the impact of a shock transmitting trough the production network will be amplified at each step of the production chain. Following Acemoglu et al. (2016), we account for such higher-order effects by deriving the Leontief and Gosh inverses, given by $\boldsymbol{L} \equiv (\boldsymbol{I} - \boldsymbol{B})^{-1}$ and $\boldsymbol{G} \equiv (\boldsymbol{I} - \boldsymbol{C})^{-1}$, where $\boldsymbol{I}$ is the identity matrix:

Figure 1: Heatmaps of technical and allocation coefficients for NACE 1-digit at euro area level



Notes: The heatmaps show input-output tables as given by 4 and 5 for the euro area (fixed composition), obtained by aggregating across countries and sectors. Sector definitions follow the applied at NACE-1 level categorization: A: Agriculture, B: Mining, C: Manufacturing, D: Electricity/Gas, E: Water/Waste, F: Construction, G: Wholesale/Retail, H: Transport/Storage, I: Accommodation/Food, J: IT/Communication, K: Financial/Insurance, L: Real Estate, M: Professional/Scientific, N: Admin/Support, O: Public Admin, P: Education, Q: Health/Social Work, R: Arts/Entertainment, S: Other Services, T: Household Activities, U: Intl. Organizations. Heatmaps for the year 2015.

$$\boldsymbol{L} = \begin{bmatrix} \omega_{11}^{A,A} & \omega_{12}^{A,A} & \omega_{11}^{A,B} & \omega_{12}^{A,B} \\ \omega_{21}^{A,A} & \omega_{22}^{A,A} & \omega_{21}^{A,B} & \omega_{22}^{A,B} \\ \omega_{11}^{B,A} & \omega_{12}^{B,A} & \omega_{11}^{B,B} & \omega_{12}^{B,B} \\ \omega_{21}^{B,A} & \omega_{22}^{B,A} & \omega_{21}^{B,B} & \omega_{22}^{B,B} \end{bmatrix} \tag{6}$$

$$\boldsymbol{G} = \begin{bmatrix} \tilde{\omega}_{11}^{A,A} & \tilde{\omega}_{12}^{A,A} & \tilde{\omega}_{11}^{A,B} & \tilde{\omega}_{12}^{A,B} \\ \tilde{\omega}_{21}^{A,A} & \tilde{\omega}_{22}^{A,A} & \tilde{\omega}_{21}^{A,B} & \tilde{\omega}_{22}^{A,B} \\ \tilde{\omega}_{11}^{B,A} & \tilde{\omega}_{12}^{B,A} & \tilde{\omega}_{11}^{B,B} & \tilde{\omega}_{12}^{B,B} \\ \tilde{\omega}_{21}^{B,A} & \tilde{\omega}_{22}^{B,A} & \tilde{\omega}_{21}^{B,B} & \tilde{\omega}_{22}^{B,B} \end{bmatrix} \tag{7}$$

In the following, we test both the direct weights from the IO network (matrices 4 and 5) and the Leontief and Gosh matrices (matrices 6 and 7) when deriving the up-and downstream measures for financial frictions in section 4.

Firm-level data and financial frictions measures

We collect firm-level data from Orbis to derive sector-specific financial frictions measures. We follow Gopinath et al. (2017) and Kalemli-Özcan et al. (2015) in cleaning the firm-level data. Table 3 lists the set of financial frictions measures we derive from firm-level data and incorporate in our empirical setup in section 5, and table 4 shows summary statistics for these sector-level measures. We use total sectoral leverage as the default variable for financial frictions, but also asses the working capital share in our empirical setup given its conceptual proximity to the financial frictions approach developed in the theoretical model presented in section 7.

Table 3: Definitions of the financial frictions measures

Measure	Definition
Total leverage	Ratio of total liabilities excluding shareholders funds to total assets.
Working capital share	Ratio of working capital to total assets, with working capital position computed as the sum of stocks plus trade debit minus trade credit.

To ensure that the firm-level financial frictions variables match the level of aggregation of the sectoral price and production data, we compute the financial frictions measures by NACE-2 sector using the sector-specific weighted average of the ratios, with weights derived from firm sales. As a robustness check, we recompute the financial frictions measures by using the sectoral median level of the financial frictions measure in the computations.

Table 4: Financial friction measures: sector level descriptive statistics

	N	Mean	SD	Median
Total leverage	249,144	0.59	0.16	0.60
Working capital share	249,144	0.15	0.15	0.14

Source: Orbis data after the cleaning procedure described in the paper.

4 Up- and downstream financial friction measures

In this section, we derive a set of financial frictions measures indicating how much firms in sector i are exposed to financial frictions their suppliers and customers face.

All measures are derived from the IO and financial frictions measures data reported in section 3. In particular, we define:

$$\Phi_{ic,t_{12}} = (1 - a_{ic,t_{12}}) \sum_{\substack{j \neq i \\ d \neq c}} \nu_{jd,ic,t_{12}} \times \varphi_{jd,t_{12}}$$
$$\tilde{\Phi}_{ic,t_{12}} = (1 - \tilde{a}_{ic,t_{12}}) \sum_{\substack{j \neq i \\ d \neq c}} \tilde{\nu}_{ic,jd,t_{12}} \times \varphi_{jd,t_{12}} \tag{8}$$

$$\Phi_{ic,t_{12}} = (1 - a_{ic,t_{12}}) \sum_{j,d} (\omega_{jd,ic,t_{12}} - 1_{j=i,d=c}) \times \varphi_{jd,t_{12}}$$
$$\tilde{\Phi}'_{ic,t_{12}} = (1 - \tilde{a}_{ic,t_{12}}) \sum_{j,d} (\tilde{\omega}_{ic,jd,t_{12}} - 1_{j=i,d=c}) \times \varphi_{jd,t_{12}} \tag{9}$$

where variables $\Phi_{ic,t_{12}}$ and $\tilde{\Phi}_{ic,t_{12}}$ are annual measures for up- and downstream financial frictions, respectively.[19] They are obtained by summing the products of sector i's exposure to each supplier (customer) sector $j \in J$ in country $d \in D$ as measured by the respective bilateral objects from the input-output tables – the technical and allocation matrices 4 and 5 (equation 8, the baseline case used for results presented in section 6) or the Leontief and Gosh inverse matrices 6 and 7 (equation 9) – and the degree of financial frictions in sector j in country d, $\varphi_{jd,t_{12}}$, given by the respective measure in table 3 under consideration.

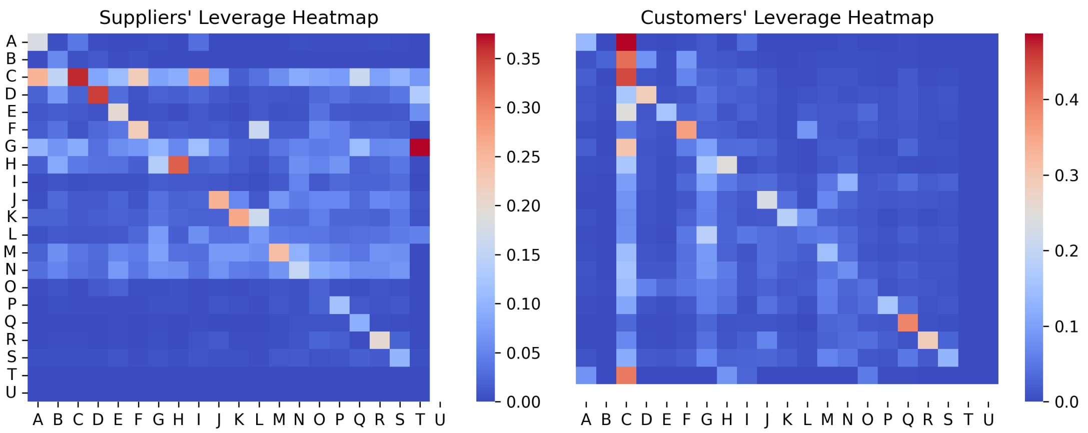
Following Acemoglu et al. (2016), we account for indirect effects stemming from a sector's exposure to its own level of financial frictions by either taking it out (equation 8) or subtracting a value of one from the diagonal elements of matrices 6 and 7 (equation 9) when $j = i$ and $d = c$. This procedure yields a weighted measure of a sector i's exposure to financial frictions accruing to sectors it is interacting with, net of the impact of financial conditions in i itself. As discussed in the previous section, we take sectoral weighted averages of the financial frictions measure $\varphi_{jd,t_{12}}$ in each sector in the interaction with IO table information.

Figure 2 illustrates intersectoral financial dependencies among NACE-1 sectors at the euro area level. Following the specification in equation 8, the respective heatmaps are generated by multiplying the two heatmaps in figure 1 (reflecting $\nu_{jd,ic,t_{12}}$ and $\tilde{\nu}_{ic,jd,t_{12}}$, respectively) with the vector of total leverage, as defined in

[19] To highlight the difference in frequency, we label all variables at annual frequency with the subscript 12.

table 3 (reflecting $\varphi_{jd,t_{12}}$), resulting in the set of bilateral exposures to financial frictions across the 20 NACE-1 sectors in the euro area. Concretely, in the left panel of figure 2, cell values are computed as $\nu^{EA}_{j,i,t_{12}} \times \varphi^{EA}_{j,t_{12}}$. Summing across rows within a given column yields $\sum_{j,d} \nu^{EA}_{j,i,t_{12}} \times \varphi^{EA}_{j,t_{12}}$. Similarly, the right panel shows $\tilde{\nu}^{EA}_{i,j,t_{12}} \times \varphi^{EA}_{j,t_{12}}$, where summing the columns in a specific row results in $\sum_{j,d} \tilde{\nu}^{EA}_{i,j,t_{12}} \times \varphi^{EA}_{j,t_{12}}$.

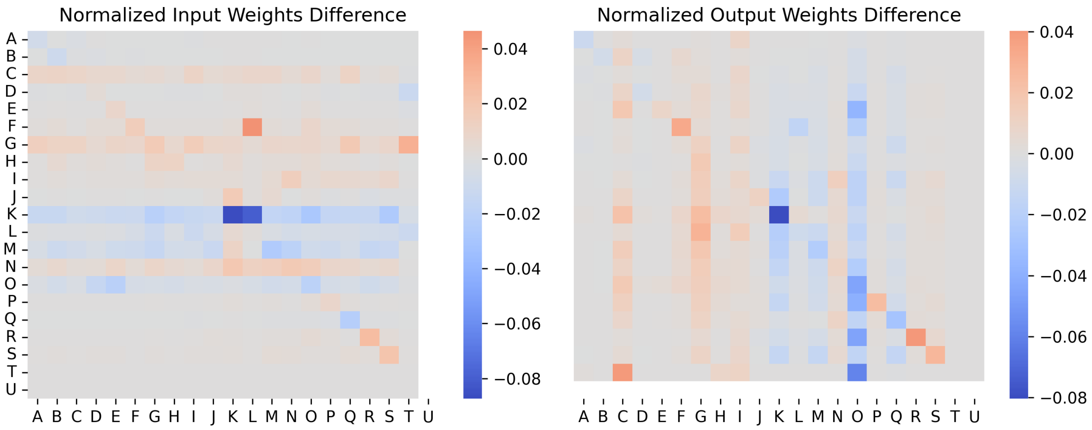
Figure 2: Heatmaps of bilateral leverage exposures for NACE 1-digit sectors at euro area level



Notes: Heatmaps for the interaction of technical (left) and allocation (right) coefficients with the vector of leverages of 1-digit NACE sectors at the euro area level. Sector definitions follow the applied at NACE-1 level categorization: A: Agriculture, B: Mining, C: Manufacturing, D: Electricity/Gas, E: Water/Waste, F: Construction, G: Wholesale/Retail, H: Transport/Storage, I: Accommodation/Food, J: IT/Communication, K: Financial/Insurance, L: Real Estate, M: Professional/Scientific, N: Admin/Support, O: Public Admin, P: Education, Q: Health/Social Work, R: Arts/Entertainment, S: Other Services, T: Household Activities, U: Intl. Organizations. Heatmaps for the year 2015.

Figure 3 illustrates how the relative significance of upstream (suppliers) and downstream (customers) financial frictions across NACE-1 sectors in the euro area changes once IO entries are interacted with total leverage. In the left panel, a blue cell indicates that the corresponding row sector has a lower relative importance as a supplier compared to when only the flow of goods and services is considered. In the right panel, a red cell signifies that the corresponding column sector's relative importance as a buyer of the row sector increases when leverage is taken into account. As the figure illustrates, the relative importance of certain sectors can vary considerably, with some sectors gaining up to 4% in importance as leverage transmitters, while others experience a decline of up to 8% when compared to an analysis based solely on intersectoral flows of goods and services.

Figure 3: Leverage-induced change in relative importance of upstream and downstream exposures for NACE 1-digit sectors at euro area level



Notes: Changes in the relative importance of upstream (suppliers) and downstream (customers) financial frictions across NACE 1-digit sectors in the euro area when leverage is considered. Left panel: change in sectoral exposure to suppliers with leverage relative to standard input-output exposures (figure 1). Right panel: change in sectoral exposure to customers with leverage relative to standard input-output exposures (figure 1). Sector definitions follow the applied at NACE-1 level categorization: A: Agriculture, B: Mining, C: Manufacturing, D: Electricity/Gas, E: Water/Waste, F: Construction, G: Wholesale/Retail, H: Transport/Storage, I: Accommodation/Food, J: IT/Communication, K: Financial/Insurance, L: Real Estate, M: Professional/Scientific, N: Admin/Support, O: Public Admin, P: Education, Q: Health/Social Work, R: Arts/Entertainment, S: Other Services, T: Household Activities, U: Intl. Organizations. Heatmaps for the year 2015.

5 Econometric Strategy

In the following, we integrate our network financial frictions measures in a country-sector panel local projection setup similar to that used in Jordà and Taylor (2016). This framework is particularly suited for studying the transmission of exogenously identified shocks and requires only few assumptions regarding the data generating process.

Our empirical specification explicitly accounts for the role of production networks and financial frictions in the transmission of monetary policy shocks. We estimate the following model:

$$y_{ic,t+h} - y_{ic,t-1} = \underbrace{\beta_1^h \varphi_{ic,t_{12}-1} \times s_t}_{\substack{\text{Direct financial frictions}\\ \text{effect}}} + \underbrace{\overbrace{\beta_2^h \Phi_{ic,t_{12}-1} \times s_t}^{\text{Upstream effect}} + \overbrace{\beta_3^h \tilde{\Phi}_{ic,t_{12}-1} \times s_t}^{\text{Downstream effect}}}_{\substack{\text{Indirect financial frictions}\\ \text{effect}}} + \tag{10}$$

$$\underbrace{\beta_4^h a_{ic,t_{12}-1} \times s_t + \beta_5^h \tilde{a}_{ic,t_{12}-1} \times s_t + \beta_6^h s_t}_{\text{Non-network effect}}$$

$$+ \sum_{l=0}^{L} \boldsymbol{\gamma^h H_{t-l}} + \sum_{l=1}^{L} \boldsymbol{\delta^h K_{t-l}} + \sum_{l=0}^{L} \boldsymbol{\eta^h \Delta X_{t-l}} + \theta_{t_{12}} + \kappa_{t+h} + \epsilon_{ic,t+h}$$

$$\text{with} \qquad h = 1, 2, ..., H$$

$$\boldsymbol{H_t} = \begin{bmatrix} a_{ic,t_{12}-1} \\ \tilde{a}_{ic,t_{12}-1} \\ \varphi_{ic,t_{12}-1} \\ \Phi_{ic,t_{12}-1} \\ \tilde{\Phi}_{ic,t_{12}-1} \end{bmatrix}, \boldsymbol{K_t} = \begin{bmatrix} \Delta y_{ic,t} \\ \varphi_{ic,t_{12}-1} \times s_t \\ a_{ic,t_{12}-1} \times s_t \\ \tilde{a}_{ic,t_{12}-1} \times s_t \\ \Phi_{ic,t_{12}-1} \times s_t \\ \tilde{\Phi}_{ic,t_{12}-1} \times s_t \\ s_t \end{bmatrix}$$

We follow Jordà and Taylor (2024) and estimate the model in long-differences, with $\Delta x_t = x_t - x_{t-1}$.[20] We estimate model 10 to study the importance of nonlinear interactions between production networks and financial frictions for the overall transmission of monetary policy shocks s_t. In our model, the full shock impact is determined by the sum of three separate transmission channels. First, we account for a "direct financial frictions" channel captured by the coefficient β_1^h on the interaction of the monetary policy shock s_t with the respective sector's level of financial frictions as measured by $\varphi_{ic,t}$.[21] This channel can be interpreted as a sector-level representation of the traditional balance sheet channel (Bernanke and Gertler, 1995) affecting a sectors' own borrowing capacities.

We then identify an additional "indirect financial frictions" channel taking into account how a monetary policy tightening may be amplified via balance sheet channel dynamics in other parts of the production network sector i interacts with. To this end, we interact the up- and downstream financial frictions measures $\Phi_{ic,t_{12}}$ and $\tilde{\Phi}_{ic,t_{12}}$ derived in section 4 with the monetary policy shock s_t, and we account

[20] As shown in appendix section B.3, our main results reported in section 6 are robust to estimating the model in levels.

[21] Similarly to the annual notation introduced in section 4, the notation $t_{12} - 1$ refers to the one-year lag of a variable at annual frequency reported for the previous year.

for endogeneity by interacting the shock in period t with the one-year lag of the financial frictions measure. This approach also allows us to disentangle the overall "indirect financial frictions channel" explicitly into downstream (β_2^h) and upstream (β_3^h) financial frictions effects. We also control for the degree to which the transmission of the monetary policy shock to aggregate output and prices depends on a sector i's activity taking place outside the production network. To account for the importance of non-network customers of sector i, we interact the policy shock s_t with $\tilde{a}_{ic,t}$, the share of production sold to final customers outside the network as given by equation 2 (β_4^h). Likewise, we account for the importance of obtaining inputs from outside the network in the transmission of the monetary policy shock by interacting s_t with $a_{ic,t}$, the share of production inputs purchased by sector i from outside the network, as given by equation 1 (β_5^h). Finally, coefficient β_6 account for all other possible channels through which monetary policy shocks may transmit to the real economy, i.e. independent of up- and downstream financial frictions and the broader production network.[22] In the main results presented in section 6, we refer to coefficients β_4^h to β_6^h jointly as "non-network effects".

Finally, matrix $\boldsymbol{H_t}$ contains the remaining single elements in our interaction terms unrelated to the monetary policy shock s_t which are not of first-order interest in our analysis. Matrix $\boldsymbol{K_t}$ collects lags of first-differences of the dependent variable $\Delta y_{ic,t}$ and the shock variables. Matrix $\boldsymbol{X_t}$ contains a set of macro-financial control variables including the euro area OIS3m rate, a GDP-weighted 10y composite euro area sovereign bond yield, the euro-dollar exchange rate, and log-levels of the euro area Composite Indicator of Systemic Stress (CISS), the IMF Commodities Price Index, the euro area harmonized index of consumer prices (HICP) and the euro area unemployment rate, as well as sectoral employment which we add as an additional sector-specific macroeconomic control. θ_i depict month fixed-effects,[23] and we control for the Covid-19 pandemic by adding a forward dummy κ_{t+h} entering the model at the same horizon as the dependent variable.[24]

[22]Such channels may include the interest rate channel, the exchange rate channel, asset price channels, risk-taking and expectation channels. See for instance Beyer et al. (2017) for an overview of traditional transmission channels of monetary policy.

[23]We only account for time fixed-effects as long-differencing eliminates entity fixed effects. As shown in appendix section B.3, we obtain identical results when estimating the model in levels including both month and country-sector fixed-effects.

[24]The forward dummy takes a value of one for the pandemic period being defined as lasting from March 2020 to April 2023, in line with the World Health Organization' declaring the end of Covid-19 as a global health emergency in May 2023.

6 Results

6.1 Main results

In this section, we report our main findings on the role of production networks and financial frictions obtained with the model presented in section 5. We show results using total leverage as our financial friction measure of interest, $\varphi_{ic,t_{12}-1}$, and we ensure consistency in units between $\varphi_{ic,t_{12}-1}$, $\Phi_{ic,t_{12}-1}$, $\tilde{\Phi}_{ic,t_{12}-1}$, $a_{ic,t_{12}-1}$ and $\tilde{a}_{ic,t_{12}-1}$ by scaling the beta coefficients of the interaction terms such that a one-unit change as measured by the coefficients refers to a 10 percent deviation of leverage from the mean. All impulse responses are scaled to the impact of a monetary policy shock that leads to a 25 basis point peak increase of the 3m OIS rate within the first year after the shock.[25] We use cluster-robust standard errors in all specifications by clustering at the country-sector level.[26]

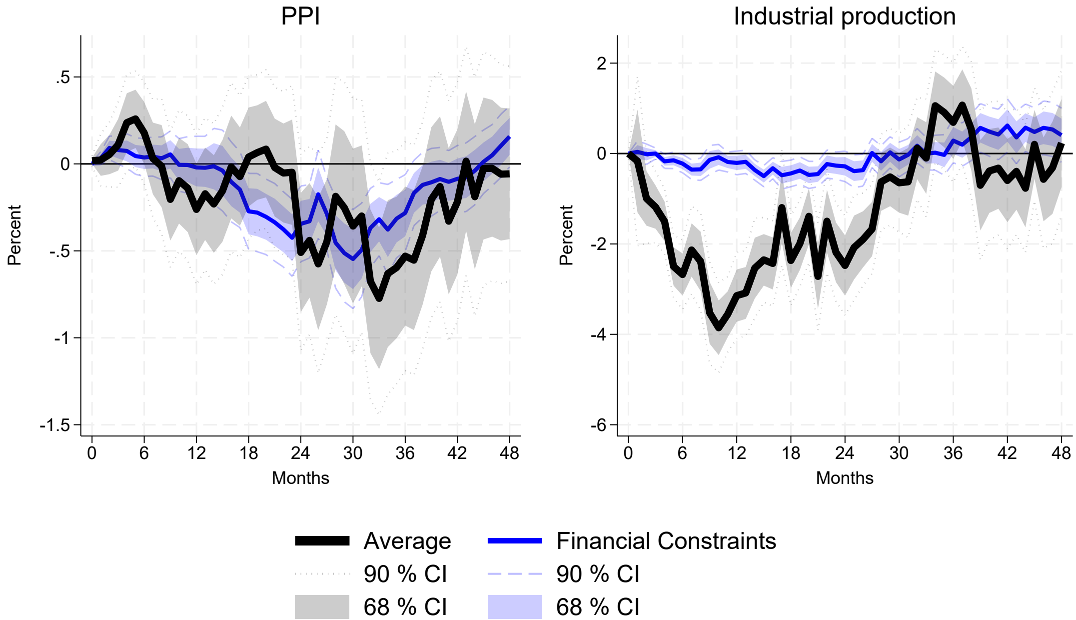
Finding 1. *PPIs and production fall in response to a monetary policy tightening shock, with financial frictions amplifying the contractionary effect.*

As shown in figure 4, both PPIs and production fall in response to a monetary policy tightening shock. For PPIs, the average effect of a monetary policy shock (β_6^h in equation 10), i.e. with all financial frictions measures at the mean (black line in the LHS panel of figure 4), amounts to a trough decline of 0.7 percent between 2.5 and 3 years after the shock. In addition, the blue line in figure 4 reports the *additional* overall effect of an increase in financial frictions using total leverage by 10 percent above the mean, as measured by the linear combination of coefficients β_1^h, β_2^h, and β_3^h. At the trough, the additional disinflationary effect of a monetary policy shock due to a 10 percent increase of network-wide leverage amounts to approximately 0.5 percent. The average decline in production stands at approximately 4 percent 9 months after the shock (black line in the RHS panel of figure 4), with an additional contractionary effect of the monetary policy shock due to financial frictions materializing after approximately 1-2 years (blue line in the RHS panel of figure 4).

[25] See appendix section A for details on the scaling routine.

[26] Following Jordà and Taylor (2024), we use cluster-robust standard errors as the default, as using for instance Driscoll and Kraay (1998) standard errors to account for heteroscedasticity and autocorrelation would require a large time-series dimension T compared to the cross-sectional dimension N, which is not the case in our setup.

Figure 4: Impulse responses to monetary policy tightening shock



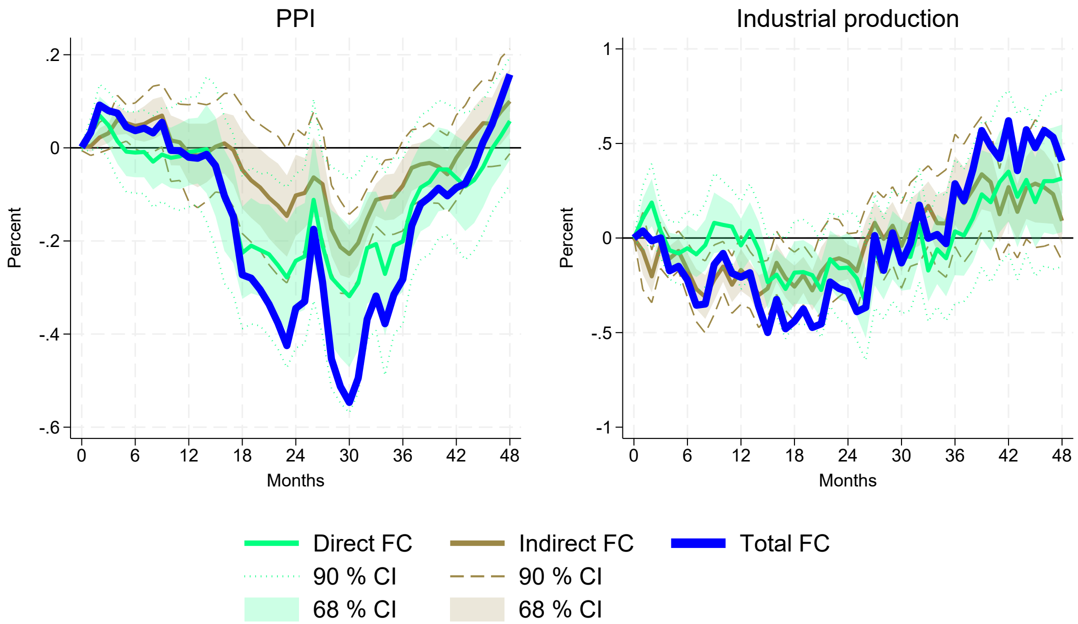
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Finding 2. *Effects stemming from network financial frictions exposure are statistically significant and economically sizable.*

Figure 5 decomposes the overall financial frictions effect reported in blue in figure 4 into the direct financial frictions effect related to the interaction of the monetary policy shock with the respective sector's own level of total leverage (as measured by β_1^h in equation 10), and the indirect effect of financial frictions in the transmission of monetary policy shocks (as measured by the linear combination of β_2^h and β_3^h in equation 10). Figure 5 shows that both direct and indirect financial frictions decrease PPIs, with trough effects reached approximately 2.5 years after the shock (green and brown lines in LHS panel) and direct effects explaining the larger share of overall financial frictions effects. However, the share of indirect effects in total financial frictions effects is only marginally smaller than the direct effect for PPIs, and both effects' shares broadly balance for industrial production (RHS panel in figure 5), where the trough impact of both direct and indirect financial frictions is reached after around 1.5 years.

Finding 3. *Downstream (upstream) frictions reinforce (dampen) the drop in prices, consistent with upstream cost and downstream demand channels.*

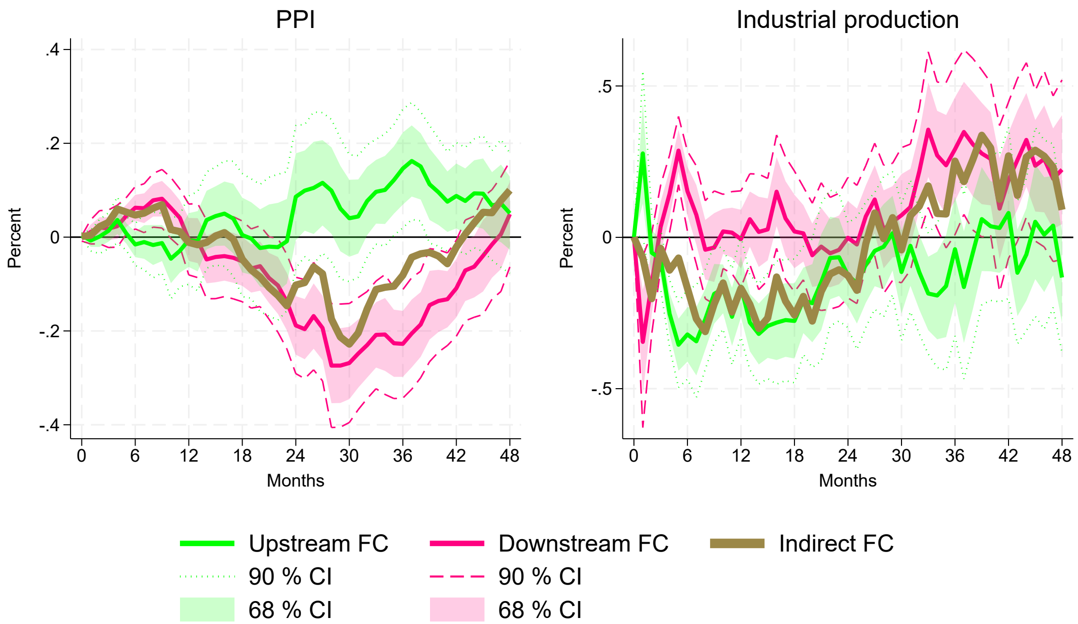
Figure 5: Impulse responses to monetary policy tightening shock - direct vs. indirect financial frictions effects



Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Finally, figure 6 provides a breakdown of the indirect financial frictions effects reported by the brown lines in figure 5 into up- and downstream financial frictions (as measured by β_2^h and β_3^h in equation 10, respectively). While downstream financial frictions seem to reinforce the decline in prices and output following a monetary policy tightening shock (pink lines in figure 6), upstream frictions tend to partly mitigate these effects (green lines in figure 6). In particular, the overall drop in prices associated to the interaction of the monetary policy shock and indirect financial frictions (brown line LHS panel of figure 6) can be largely attributed to downstream financial frictions, while the impulse response function associated to the upstream financial frictions interaction term remains positive for most of the horizon. Similarly, upstream financial frictions seem to amplify the drop in industrial production over the first two years after the shock (green line RHS panel of figure 6), while downstream financial frictions are largely insignificant, and if at all, seem to counteract this additional drop to some extent over the same horizon (pink line RHS panel of figure 6). Taken together, results thus indicate that a tightening of financial conditions seems to lower downstream customers' demand for intermediate goods produced by sector i (in line with a sector-specific "demand channel"), while fostering incentives for upstream suppliers to raise prices to alleviate financial frictions (in line with a sector-specific "cost channel").

Figure 6: Impulse responses to monetary policy tightening shock - direct vs. indirect financial frictions effects



Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

6.2 Robustness

We report a detailed set of robustness checks in appendix section B, and only provide a brief summary of these checks here. Our main interest relates to the robustness of our findings to changing elements specific to our setup. First, we assess robustness when changing from using technical and allocation coefficients (matrices 4 and 5 in equation 8) to using Leontief and Gosh inverses (matrices 6 and 7 in equation 9). Second, we test using the working capital share as reported in table 3 as an alternative candidate for the financial frictions measure $\lambda_{t_{12}}$, in addition to using total leverage as in the baseline results in figures 4 to 6. Third, we assess how differences in aggregating firm-level data on financial frictions measures to the sectoral level affect the result. While main results in figures 4 to 6 where derived using sales-based weighted averages of firm level data to generate sectoral measures, we re-estimate the model with sectoral levels of total leverage being given by the median firm's leverage holdings.

Overall, results presented in appendix section B show that our main findings remain robust when carrying out these tests. In all specifications, prices and output fall in response to a monetary policy tightening shock, with financial frictions adding to the dampening impact. Also, we report robustness regarding the significance of both direct and indirect financial frictions effects, and importantly, the opposing directions in which upstream and downstream financial frictions affect the price impact of a monetary policy tightening.

7 Theoretical model

In this section, we present a multi-sector model with production networks and financial frictions to illustrate the mechanism underlying the propagation of monetary policy shocks and rationalize the empirical findings in section 6 . Our model builds on the framework of Bigio and La'O (2020), which we extend by allowing for a heterogeneous impact of policy rate i on each sector, with the strength of the idiosyncratic impact being determined by the sector's overall financial position. This allows us to derive theoretical counterparts of the empirical measures derived in equations 8 and 9.

We use these theoretical measures to assess the importance of sector-specific financial frictions for the transmission of monetary policy, taking into account potential amplification effects that may unfold as the monetary policy impulse "travels through the production network". Importantly, we model the financial friction such that it introduces a "cost channel" through which monetary policy affects firms' price setting, and we focus on the marginal pricing effect such a sector-specific cost channel may imply. In doing so, the modeling choice regarding the financial frictions parameter allows for a generic interpretation of the underlying source of the friction, and nests the set of different empirical measures reported in table 3.

Our empirical results confirm that the direct effects from financial frictions reinforce the disinflationary effect stemming from a monetary policy tightening surprise (consistent with a traditional balance sheet channel, figure 4). In addition, we present novel findings on the importance of indirect financial frictions. These additional key empirical findings are summarized again in proposition 1. Directly relating to the reporting of our empirical findings, our theoretical model confirms that indirect financial frictions on net aggravate the price impact of a monetary policy tightening (figure 5), and that "zooming" into this net effect by differentiating up- and downstream network effects reveals that upstream financial frictions appear to mitigate this net effect to some degree (figure 6).

Proposition 1. *Key empirical findings on indirect financial frictions effects presented in section 6:*

1. *Indirect financial frictions, i.e. frictions not emanating from sector i's own degree of financial frictions, amplify the transmission of changes in interest rates on sector i's prices (brown line figure 5).*

2. *Downstream financial frictions, i.e. frictions emanating from sector i's customers in sector s amplify demand-channel dynamics, implying downward pressure on sector i's prices (pink line figure 6).*

3. *Upstream financial frictions, i.e. frictions emanating from a sector i's suppliers in sector j amplify cost-channel dynamics implying upward pressure on sector i's prices (green line figure 6).*

7.1 The model economy

Firms

There are K sectors in the economy (where K is both the set of sectors and the number of sectors). Firms operate under perfect competition in each sector, and the production technology is heterogeneous across sectors. The production in sector i is a constant returns-to-scale Cobb-Douglas technology given by

$$y_i = z_i l_i^{\alpha_i} x_i^{1-\alpha_i}, \tag{11}$$

where y_i is the representative firm's output, z_i is sector-specific productivity, l_i its labor input, and x_i is a composite of the firm's intermediate goods inputs. The parameter α_i denotes the sector-specific labor share and z_i is a sector-specific productivity shifter. As in Ghassibe (2021), the firm's intermediate goods basket is a Cobb-Douglas composite given by

$$x_i = \prod_{j \in K} {\nu_{ij}}^{-\nu_{ij}} x_{ij}^{\nu_{ij}} \tag{12}$$

where x_{ij} is the amount of the commodity produced by sector j the firm in sector i purchases, and ν_{ij} denotes the share of good j in this composite.

We follow Neumeyer and Perri (2005) and Chang and Fernández (2013) in modeling sector-specific financial frictions. Firms need to borrow to finance the purchase of working capital in advance. The gross interest rate for financing such borrowing being is given by $1 + i\varphi_i$. Following Chen (2025), φ_i captures the extent to which producers must borrow to purchase working capital inputs in advance. In our model, we explicitly allow this share to vary across sectors.[27] Profits of the representative firm in sector i are given by

$$\pi_i = p_i y_i - (l_i + \sum_{j \in K} p_j x_{ij}) - i\varphi_i(l_i + \sum_{j \in K} p_j x_{ij}) \tag{13}$$
$$\Leftrightarrow \pi_i = p_i y_i - (1 + i_t \varphi_i)(l_i + \sum_{j \in K} p_j x_{ij})$$

where p_i is the sector's own output price, and p_j is the price at which it purchases input x_{ij} from sector j. We define labor as the numéraire input, thereby normalizing the wage rate to one.

The firm in sector i maximizes profits (equation 13) subject to the production technology (equation 11). This yields the optimality conditions described in appendix C.1.1. In particular, we get the following equation for prices and marginal costs:

$$p_i = (1 + i\varphi_i) mc_i, \tag{14}$$

$$mc_i = \frac{1}{z_i} \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{i \in K} p_i^{\nu_{ij}} \right)^{1-\alpha_i}. \tag{15}$$

Equation 14 defines the price p_i in sector i as a function of the marginal production cost mc_i scaled by the financing cost $i\varphi_i$. Equation 15 shows that the marginal cost for sector i is proportional to a weighted average of the prices of the intermediate inputs that sector i purchases for production.

[27] Alternatively to interpreting our financial friction as a sector-specific cash-in-advance constraint, one could interpret φ_i as a sector-specific interest rate shifter, i.e. as an exogenous shock to the interest rate the firm has to pay on its working capital. While such a disturbance may be due to idiosyncratic sectoral shocks (e.g. changes in investor risk perception towards specific sectors affecting φ_i), we treat the source of variation in φ_i as exogenously determined here.

Households

The household problem straightforwardly follows the one in Bigio and La'O (2020). The representative households maximizes utility by choosing consumption, with C determining the final consumption basket, and labor supply L. Preferences are given by

$$\max U(C) - V(L) \tag{16}$$

We assume the following regularity conditions: U and V are twice differentiable with

$$U' > 0, \quad V' > 0, \quad U'' < 0,$$

and satisfy the Inada conditions. The final consumption basket is a Cobb-Douglas composite of the sectoral goods:

$$C = \prod_{i \in K} \nu_{ci}^{-\nu_{ci}} c_i^{\nu_{ci}}, \quad \sum_{i=1}^{K} \nu_{ci} = 1 \tag{17}$$

The household is the ultimate owner of firms and maximizes utility subject to the budget constraint

$$P^c C = \sum_{i \in K} p_i c_i \leq L + \sum_{i \in K} \pi_i + \sum_{i \in K} \varphi_i \left(l_i + \sum_{j \in K} p_j x_{ij} \right), \tag{18}$$

implying that consumption expenditure $P^c C$ has to be financed by labor income L, firm dividends and interest payments by firms in different sectors. The optimality conditions for the household are described in appendix section C.1.2.

Market clearing and equilibrium

To close the model, we assume market clearing on the goods market for each sector and on the labor market:

$$y_i = c_i + \sum_{j \in K} x_{j,i} \ \ \forall \ i \tag{19}$$

$$L = \sum_{i \in K} l_i \tag{20}$$

In this economy, an equilibrium is given by an allocation $\{\{y_i, l_i, \{x_{ij}\}_{j\in K}, c_i, x_i\}_{i\in K}, C, L\}$ and a system of prices $\{\{p_i, mc_i, P^i\}_{i\in K}, P^c, 1\}$ such that:

- firms' output and input bundles maximize firm profits (equations 11, 14, 30, 31, 37, 38);
- household's consumption bundle and labor supply are chosen optimally (equations 39, 40, 41);
- all markets clear (equations 19, 20).

7.1.1 Mapping the model to the empirical specification

In the following, we analyze how financial frictions across the production network impact prices in each sector in the model.[28] In doing so, we derive two distinct measures from the model, one describing the impact of direct and upstream financial frictions, and one attributed to downstream financial frictions. As our model only features one sectoral price, we distinguish both measures by defining direct and upstream effects as affecting sectoral prices, while downstream frictions are affecting nominal sectoral output – i.e. the product of sectoral prices and real production.[29] In this way, we are able to derive expressions that directly map the model into the key empirical findings in section 6. The resulting measures therefore also explicitly account for the essence of the empirical finding that, from the viewpoint of a specific sector, upstream financial frictions seem to induce cost-channel dynamics arising on the supply side, while downstream financial frictions seem to add to the demand-side effects.

[28] Since it does not change our qualitative results, in the following we set $z_i = 1 \; \forall \; i$ to simplify the calculations, see table 5.

[29] In an alternative, yet more complex modeling approach one could differentiate between two prices explicitly, i.e. between a purchasing price at which the firm in sector i buys intermediary inputs, and a selling price at which it sells its output, and associate the former with supply-side (upstream), and the latter with demand-side (downstream) frictions. For the sake of simplicity and tractability, we decided in favor of having only one sectoral price in the model.

Direct and upstream financial frictions. We start with deriving model-consistent expressions for direct and upstream financial frictions. These link the pricing decision of firms in sector i to the degree of financial frictions its suppliers face – either within the firm's own sector or across the network. Thereby, they map our empirical measures $\varphi_{ic,t}$ and $\Phi_{ic,t}$ in equations 8, 9, and 10:[30]

$$p_i = (1+i\varphi_i)^{1+\nu_{i,i}(1-\alpha_i)}\, mc_i^{\nu_{i,i}(1-\alpha_i)} \frac{(1-\alpha_i)^{\alpha_i-1}}{\alpha_i^{\alpha_i}} \times \\ \times \left(\prod_{j\in K} 1(j\neq i)\, [(1+i\varphi_j)mc_j]^{\nu_{i,j}} \right)^{1-\alpha_i} \tag{21}$$

Taking the logarithm of this expression and forming the derivative with respect to i yields

$$\frac{d}{di}\log(p_i) \approx \underbrace{[1+\nu_{i,i}(1-\alpha_i)]\varphi_i}_{\substack{\text{Own}\\ \text{financial frictions}}} + \underbrace{\nu_{i,i}(1-\alpha_i)\frac{mc_i'(i)}{mc_i(i)}}_{\text{Roundabout}} \\ \underbrace{+(1-\alpha_i)\sum_{j\neq i}\nu_{i,j}\left(\varphi_j + \frac{mc_j'(i)}{mc_j(i)}\right)}_{\substack{\text{Upstream}\\ \text{financial frictions}}} \tag{22}$$

where the approximation is due to the logarithmic approximation for $\log(1+i\varphi_j)$. The first term, $[1+\nu_{i,i}(1-\alpha_i)]\varphi_i$, on the right-hand side of equation 22 corresponds to the model-based counterpart of our empirical measures for the direct degree of financial tightness in the firm's own sector, with the latter given by the φ_{ic} terms in equations 8, 9 and 10. The second term, $\nu_{i,i}(1-\alpha_i)\frac{mc_i'(i)}{mc_i(i)}$, reflects the second-order effects on sector i due to roundabout production. The third term, $(1-\alpha_i)\sum_{j\in K}\nu_{i,j}\left(\varphi_j + \frac{mc_j'(i)}{mc_j(i)}\right)$, corresponds to the upstream financial frictions exposure given by the Φ_{ic} terms in the empirical specification. To facilitate the intuition, consider a sector i that is not involved in roundabout trade, i.e. that does not use its own output as input in production ($\nu_{i,i}=0$) and whose suppliers only use labor in production ($\alpha_j = 1\ \forall j\ s.t.\ \nu_{i,j}\neq 0$). In this case equation 22 becomes

$$\frac{d}{di}\log(p_i) \approx \underbrace{\varphi_i}_{\substack{\text{Direct}\\ \text{financial frictions}}} \underbrace{+(1-\alpha_i)\sum_{j\neq i}\nu_{i,j}\varphi_j}_{\substack{\text{Upstream}\\ \text{financial frictions}}}$$

[30]See appendix C.2.0.1 for detailed derivations.

where again the approximation is only due to the logarithmic approximation. In this case, an increase in the interest rate will affect the price in sector i through two channels: a direct one that depends on sector i's own financial friction φ_i, and an indirect one that depends on its exposure to its suppliers' financial frictions, $(1-\alpha_i)\sum_{j\neq i}\nu_{i,j}\varphi_j$. Intuitively, equation 22 shows that, while keeping the marginal costs in other sectors fixed, an increase in the interest rate will have a direct effect on the price in sector i through sector i's own financial frictions (φ_i). Interest payments increase for sector i, and an indirect effect stemming from suppliers' financial frictions, which increase prices due to the marginal increase in financing costs for an additional unit of production. The latter effect depends on sector i's input purchases from other sectors: sectors using only labor as input will only be exposed to interest rate changes through their own sector's level of financial frictions φ_i.

Downstream financial frictions. Next, we analyze how sector i's production is affected by its exposure to downstream customers' financial frictions. We do so by combining the market clearing condition for the goods market with households' optimal variety of consumption and the sectoral optimal intermediate input use. This yields the following expression for sector i's nominal output:[31]

$$p_i y_i = \underbrace{\nu_{ci}P^cC}_{\substack{\text{Final}\\ \text{consumption}}} + \underbrace{\frac{\nu_{i,i}(1-\alpha_i)}{(1+\varphi_i i)}(\nu_{ci}P^cC + \sum_{s\in K}P^s\nu_{s,i}x_s)}_{\text{Roundabout expenditure}} + \underbrace{\sum_{j\neq i}\frac{\nu_{j,i}(1-\alpha_j)}{(1+\varphi_j i)}(\nu_{cj}P^cC + \sum_{s\in K}P^s\nu_{s,j}x_s)}_{\text{Other sectors}} \tag{23}$$

Equation 23 decomposes nominal output $p_i y_i$ into its three expenditure components: the part of nominal production bought by the final consumer, the part bought by firms in sector i (roundabout expenditure), and the part bought by downstream customers within other sectors of the production network. It also allows for three important observations. First, up to a first order, sector i's financial frictions as measured by φ_i only affect sector i's nominal output if roundabout trade within sector i takes place, i.e. if $\nu_{i,i} > 0$. To see this, we consider again a case without roundabout trade ($\nu_{i,i} = 0$) and where sector i's customers sell all of their output

[31] See appendix C.2.0.2 for detailed derivations

to the final customer ($\nu_{s,j} = 0 \ \forall j$ such that $\nu_{j,i} \neq 0$). In this case, equation 23 simplifies to

$$p_i y_i = P^c \nu_{ci} C + \sum_{j \neq i} \frac{\nu_{j,i}(1-\alpha_j)}{(1+\varphi_j i)} P^c \nu_{cj} C \tag{24}$$

such that an increase in the interest rate negatively affects sector i's nominal output only through its customers' level of financial frictions: an increase in the interest rate raises the price that sector i's downstream customers charge, which in turn lowers demand for their goods. Sector i supplies goods to these sectors, such that lower demand for goods produced by sector i's downstream customers also reduces (nominal) output in sector i. Note that in the specific case in which firms in sector i do not use inputs from their own sector, the direct financial frictions parameter, φ_i, does not affect the reaction of sector i's nominal output in response to changes in the interest rate through this channel. Therefore, equation 24, in contrast to equations 21 and 22, does not account for direct effects of sector i's own degree of financial tightness but only for the indirect downstream effect.

Turning to the more general case with roundabout trade, equation 23 still shows that the direct balance sheet channel of monetary policy a specific firm i in sector i is exposed to is not affecting nominal output; it only accounts for the effect that balance sheet constraints of firm j in the same sector i have via roundabout purchases. Second, equation 23 shows that roundabout (other sector) expenditure in turn depends on the total purchases of sector i (sector j) output by final consumers and *all* other sectors s included in K. Thus, nominal output in sector i is prone to amplification effects stemming from the fact that the output of customers in both sector i itself and in the other sectors is in turn also bought by final consumers and other firms across the network. Finally, equation 23 shows that an increase in the interest rate i leads to a larger drop in total expenditure on sector i's nominal output the more financially constrained its customers are.

7.2 Comparative statics

In the following, we report comparative statics for a two-sector version of the model described in the previous section, with sectors 1 and 2 being calibrated such that network-related aspects for the sectors match key characteristics of the European industry and services sectors, respectively. In doing so, we shed light on basic dynamics in our key variables of interest: sectoral prices p_i expressed as capturing both direct and upstream demand effects, and sectoral nominal output $p_i y_i$ acting as a proxy for downstream demand of sector i's good. In the set of analyses, we investigate deviations of these variables from the baseline when varying either the aggregate (policy) interest rates i, sector-specific levels of financial frictions φ_i, or the shares of real production traded across sectors as intermediary inputs, ν_{ij}. In doing so, we emphasize potential amplification effects stemming from tightening financial conditions across the network.

7.2.1 Calibration

We report the baseline calibration of the model in table 5. We set production shares for sectors 1 and 2 to levels that broadly match empirical counterparts for the industry and services sectors. In the 2022 vintage of the Eurostat FIGARO tables, the split between intermediary inputs stemming from industry and services amounts to 60 vs. 40 percent for the industrial sector, and to 20 vs. 80 percent for services, respectively, and we set the sectoral input shares ν_{ij} to these values for sectors 1 and 2. We calibrate the shares of both sectors in final household consumption ν_{ci} to the relative weights of goods and services in total HICP as reported in the classification of individual consumption by purpose (COICOP) data provided by Eurostat.[32] For 2024, the respective weight on services stood at 45 percent, and we calibrate ν_{c2} to that level. For simplicity, we assume non-network related sectoral parameters to be identical across sectors. We set the labor share in production (α_i) to 20 percent in both sectors, and normalize sector-specific levels of total factor productivity (TFP) to one. Regarding financial frictions, we calibrate the baseline level of the policy interest rate i to one percent (which is mainly for ease of visualization in the below figures), and assume that both sectors need to fund working capital expenditure completely with borrowed funds, such that $\varphi_1 = \varphi_2 = 1$. Finally, we assume an additive separable utility function for equation 16, with the specific form given by:

$$U(C, L) = \frac{C^{1-\phi}}{1-\phi} - \frac{L^{1+\sigma}}{1+\sigma} \tag{25}$$

and we set both ϕ and σ to 1.

[32] Results are robust to changing the calibration towards a larger services sector share than the share reported in table 5, e.g. when using the non-energy industrial goods (NEIG) category instead of the all goods item reported in the COICOP data for industry, which would yield a services consumption share of approximately 2/3. The respective weights can be found here.

Table 5: Calibration

Parameter	Description	Values	
		Sector 1	Sector 2
Sector-specific			
ν_{1i}	Sector 1 input shares	0.6	0.4
ν_{2i}	Sector 2 input shares	0.2	0.8
ν_{ci}	Final consumption shares of sectoral output	0.55	0.45
α_i	Sectoral production labor share	0.2	0.2
φ_i	Sector-specific financial frictions	1	1
$\bar{z}_i$	Baseline sectoral productivity	1	1
Aggregate			
ϕ	Household risk aversion	1	1
σ	Inverse Frisch elasticity of labor supply	1	1
$\bar{i}$	Baseline interest rate level	0.01	0.01

7.2.2 Aggregate and sectoral financial frictions

We report the model solution for the three variables of interest – p_i, y_i, and $p_i y_i$ – in table 6, obtained by setting the respective parameters as reported in table 5. Starting from these levels, we assess changes in model variables as the policy interest rate i paid on working capital increases from 1 percent in the baseline case to 10 percent (while extreme, we again mainly choose this value to more clearly visualize the differences). At the same time, we allow the two parameters determining sectoral network exposure in our approach to vary: the degree of sector-specific financial frictions, φ_i, and the degree of sectoral production linkages across the network, ν_{ij}. In doing so, we take the perspective of sector 1, i.e. we assess network exposure via sectoral financial frictions by varying φ_2, and production network exposure stemming from the fact that sector 1 relies on inputs from sector 2 by varying ν_{12}.

Variable	Sector 1	Sector 2
p_i	7.92	7.92
y_i	0.13	0.28
$p_i y_i$	1.06	2.25

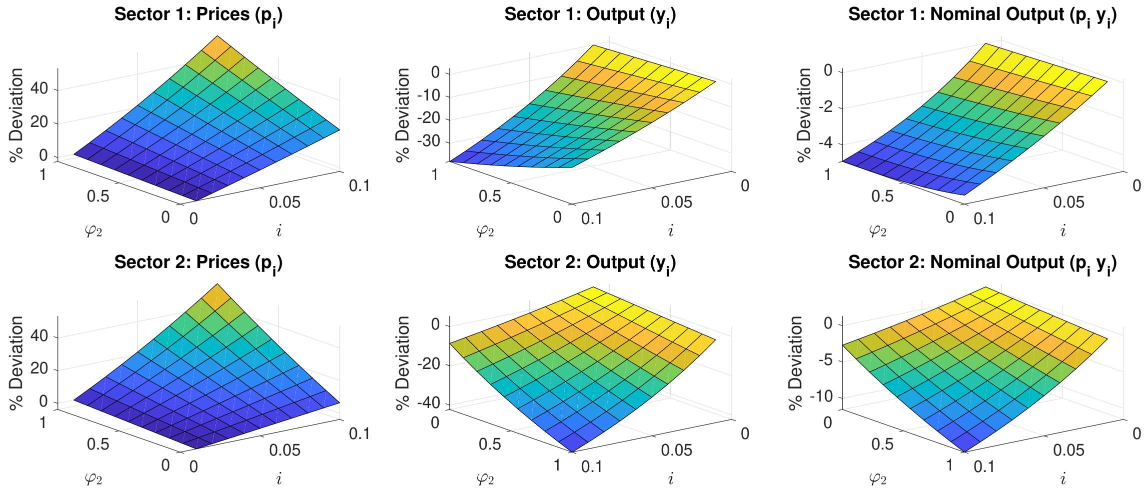
Table 6: Baseline model solutions

Indirect financial frictions. Figure 7 shows percentage deviation from baseline levels for each sector when varying both the policy rate i and the financial frictions variable φ_2, keeping all other parameters fixed at the levels shown in table 5. In line with presumed cost-channel dynamics, higher policy rates i translate into upward pressure on sectoral prices (left panels), and dampen production in both sectors (middle panels). At the same time, an additional increase of sector-specific financial frictions (an increase in φ_2) by itself raises financing costs and thus prices in the sector directly affected (sector 2, lower-left panel), as postulated by equations 14 and 21. Tighter sector-specific financing conditions are furthermore associated with a drop of the directly affected sector's output (lower-middle panel), with the relatively strong decline in real output driving the respective decline in nominal output (lower-right panel), consistent with the roundabout effect in equation 23. Importantly, a tightening in financing conditions of sector 2 also spills over to sector 1 (upper panels), thereby amplifying the effects of an increase in the policy rate i. This result is consistent with the presence of φ_j in equations 21 and 23 and rationalizes the first bullet in proposition 1 on the empirical finding of additional amplification from indirect effects in figures 5 and 6.

Upstream and downstream financial frictions. As discussed in the previous section, we can map our empirical measures for direct, upstream and downstream sectoral financial frictions into model equations 21 and 23, such that changes in prices p_i can be attributed to changes in direct and upstream financial frictions, while changes in (nominal) output are largely attributable to changes in downstream financial frictions. Results in figure 7 thus also provide validation for the empirical findings summarized in the second and third point in proposition 1: A tightening of financial conditions in one sector does not only put upward pressure on its own prices via direct effects (φ_2 in lower-left panel), but also increases prices in other sectors via upstream financial frictions effects (φ_2 in upper-left panel). At the same time, the respective tightening lowers nominal output in both sectors (φ_2 in right panels), consistent with downstream financial effects affecting demand for sector i's good by downstream customers in the production network.

Input shares. Figure 8 sheds light on the importance of real production linkages across the network, the second component of network exposure determining the degree of up- and downstream financial frictions. We again take the perspective of sector 1, by varying the share of inputs this sector acquires from sector 2 (ν_{12}). For sector 1, a higher dependence on inputs from sector 2, as indicated by a higher value of ν_{12}, results in lower output as overall demand for sector 1's own goods declines

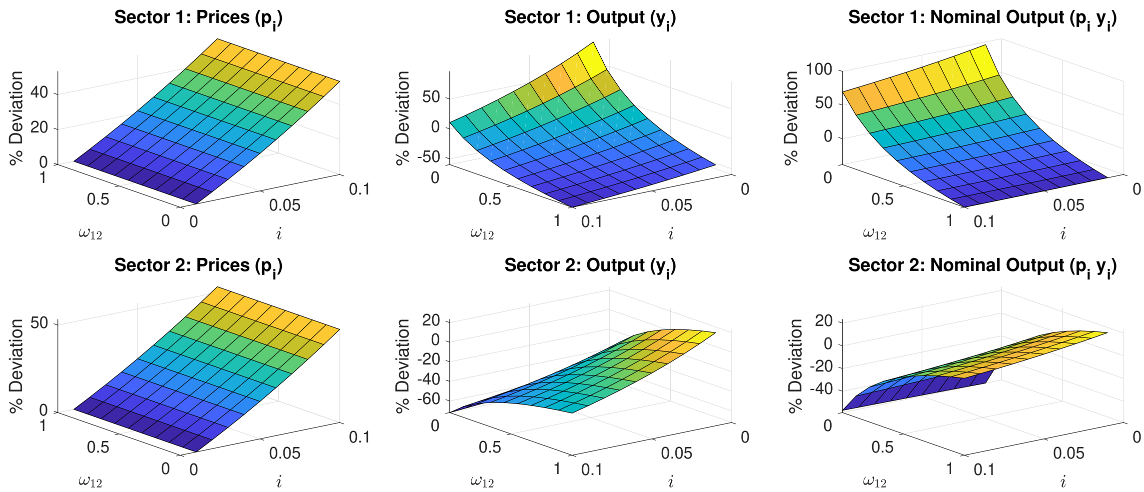
Figure 7: Policy rate and sectoral financial friction



Notes: Percentage deviations from levels obtained under baseline calibration in table 5, for respective changes in the policy interest rate i and the sectoral financial friction parameter φ_2.

relative to an increase in demand for sector 2 goods. This is matched by an increase in output of sector 2, consistent with higher demand for this good by sector 1 as ν_{12} increases (middle panels). Importantly, a shift in the input-output structure alone has no effect on sectoral prices, which are only responsive to a tightening in financing conditions (figure 7).

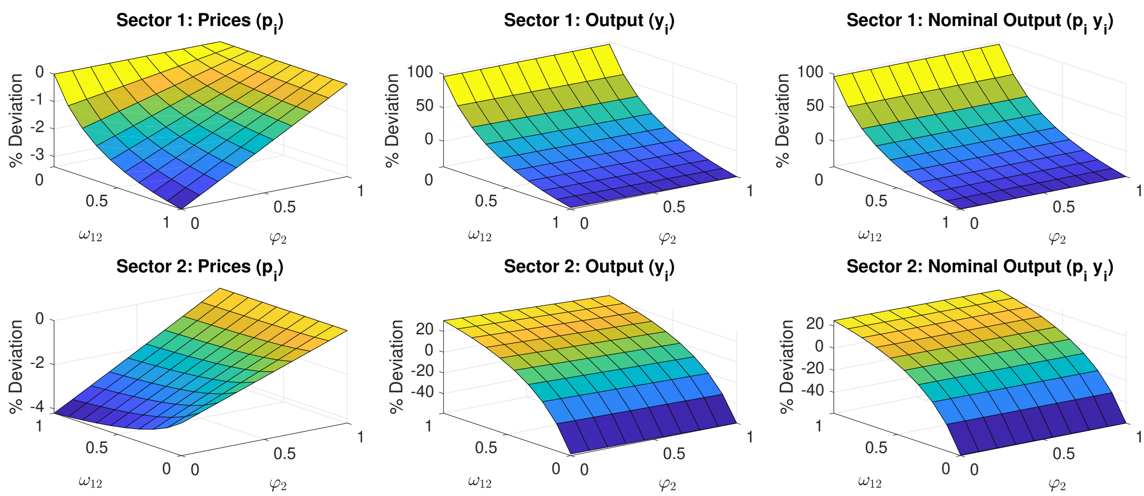
Figure 8: Policy rate and sectoral input shares



Notes: Percentage deviations from levels obtained under baseline calibration in table 5, for respective changes in the policy interest rate i and sectoral input weight ν_{12} determining sector 1's share of inputs obtained from sector 2.

Figure 9 shows that while changes in the input-output structure (ν_{12}) alone do not affect sectoral prices p_i, they potentially amplify the impact of sector-specific financial frictions: a combination of a higher degree of financial frictions in sector 2 (higher φ_2) and a higher share of sector 2's output taken up as input by sector 1 (higher ν_{12}) is associated with relatively higher upward pressure on p_i. Taken together, the evidence in figures 8 and 9 thus implies that the real input-output linkages are important determinants for a sector's exposure to upstream financial frictions, while their importance for sector-specific upstream financial frictions is negligible in the case of changes to the economy-wide policy rate i. This distinction further qualifies the validation of points 2 and 3 of proposition 1 not apparent from the empirical results in section 6.

Figure 9: Sectoral financial friction and input shares



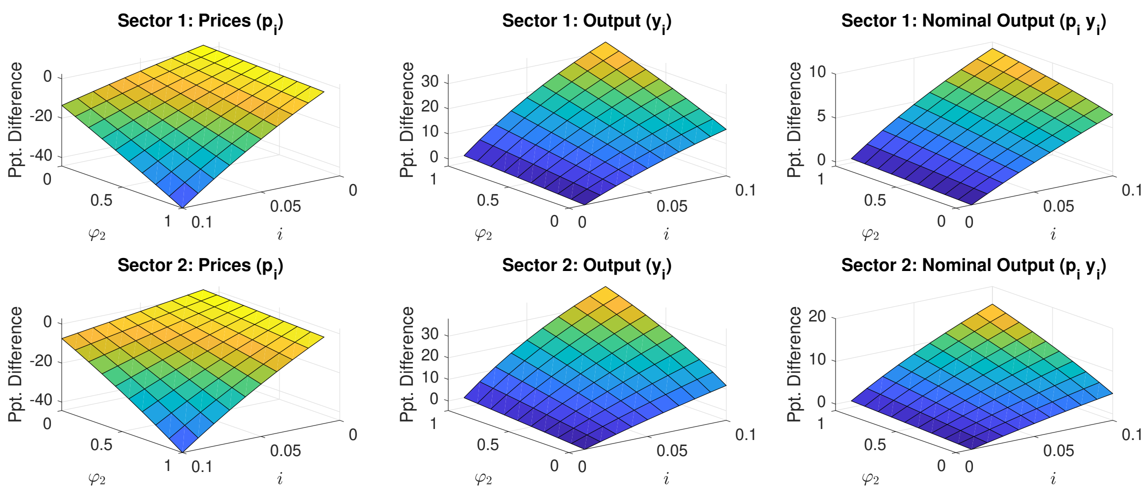
Notes: Percentage deviations from levels obtained under baseline calibration in table 5, for respective changes in the sectoral financial friction parameter φ_2 and sectoral input weight ν_{12} determining sector 1's share of inputs obtained from sector 2.

7.2.3 Amplification via network effects

We further assess the importance of direct vs. indirect financial frictions by explicitly quantifying the additional impact on sectoral output and prices stemming from feedback loops across the production network. To this end, we compare the results from the previous section showing full equilibrium effects including such feedback loops to comparable results obtained when "shutting" off the production network. A straightforward way to mute sectoral spillovers is to assume that both sectors do not draw on intermediate inputs acquired from the production network, but only rely on labor as the sole production input. We therefore set the labor shares in production (α_1, α_2) equal to one and simulate the model again for the isolationist economy. In doing so, only direct financial frictions effects matter for sectoral outcomes, while indirect effects are muted. Figures 10 to 12 show the percentage point differences from carrying out the same exercises as in the previous section for both economies.

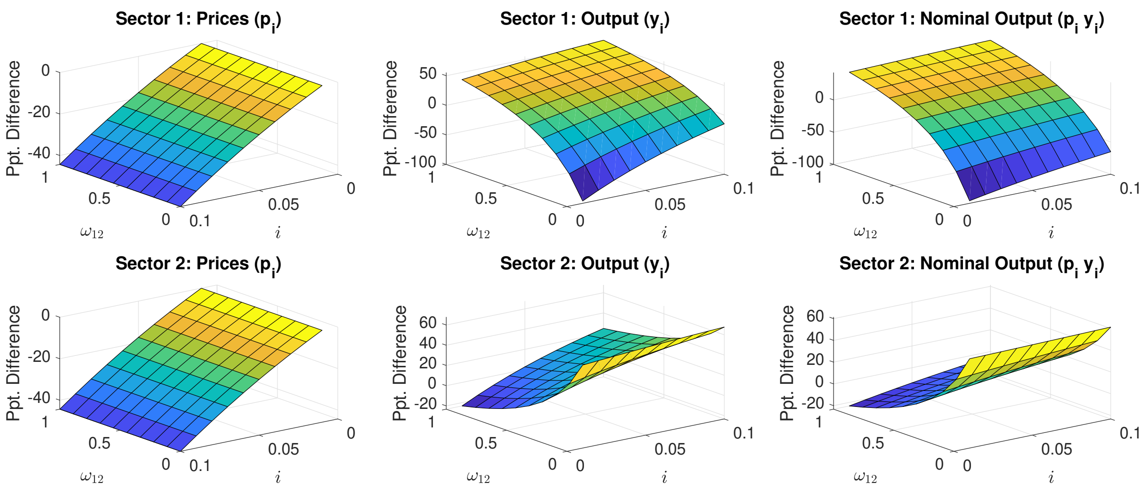
Taken together, these results show that allowing for production networks in the model amplifies the effect of tighter financing conditions. For instance, figure 10 shows that upward pressure on sectoral prices would be significantly lower in an economy without sectoral linkages. With interest rates i at 10 percent and the tight financing conditions ($\varphi_2 = 1$), the upward effect on sector 1's prices would be 44 percentage points lower in the isolationist economy than in the baseline economy with sectoral linkages (upper-left panel in figure 10, where the comparable effect amounted to 53 percent (upper-left panel in figure 7). Similarly, sector 1's output would be 34 percentage points higher in the isolationist economy in the most adverse financing frictions scenario ($i = 0.1$, $\varphi_2 = 1$, upper-middle panel of figure 10), thus severely mitigating the drop in output in the baseline economy standing at 38 percent in tis scenario (upper-middle panel of figure 7). Similar findings for other combinations of the parameters of interest are reported in figures 11 and 12, underscoring the importance of network amplification effects and providing additional validation of the key empirical findings summarized in proposition 1.

Figure 10: Policy rate and sectoral financial friction - network amplification



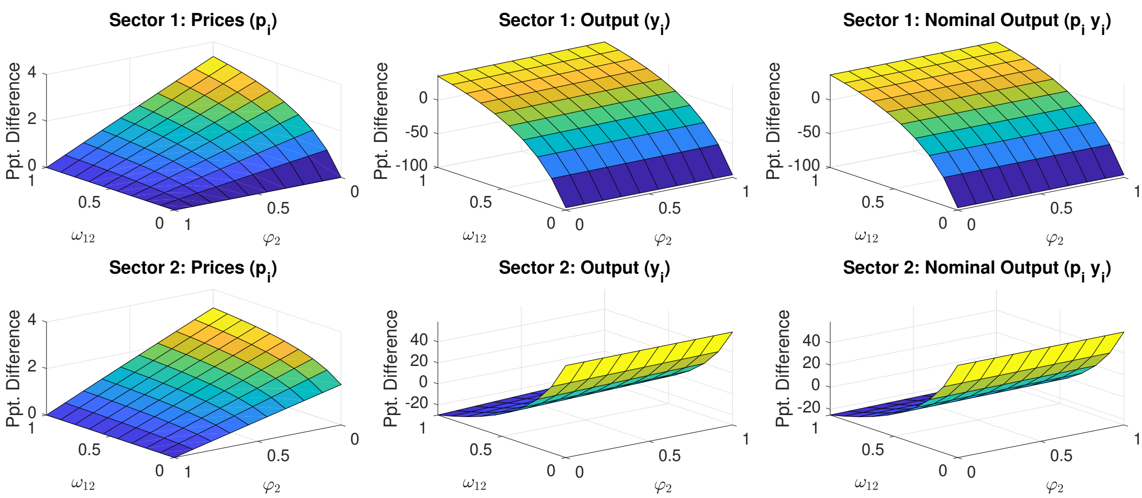
Notes: Percentage point deviations in an isolationist economy with $\alpha_1 = \alpha_2 = 1$ from percentage levels obtained in the baseline models as reported in figure 7, for respective changes in interest rate i and the sectoral financial friction parameters φ_i. All other parameters set to the baseline calibration in table 5.

Figure 11: Policy rate and sectoral input shares - network amplification



Notes: Percentage point deviations in an isolationist economy with $\alpha_1 = \alpha_2 = 1$ from percentage levels obtained in the baseline models as reported in figure 8, for respective changes in the policy interest rate i and sectoral input weight ν_{12} determining sector 1's share of inputs obtained from sector 2. All other parameters set to the baseline calibration in table 5.

Figure 12: Sectoral financial friction and input shares - network amplification



Notes: Percentage point deviations in an isolationist economy with $\alpha_1 = \alpha_2 = 1$ from percentage levels obtained in the baseline models as reported in figure 9, for respective changes in the sectoral financial friction parameter φ_2 and sectoral input weight ν_{12} determining sector 1's share of inputs obtained from sector 2. All other parameters set to the baseline calibration in table 5.

8 Conclusion

In this paper, we provide new empirical evidence on the transmission of monetary policy along the production network, taking the role of sector-specific financial frictions into account. We do so using a comprehensive dataset that combines sectoral information at the disaggregated NACE-2 level with granular firm-level balance sheet information. We then build a set of novel measures of sectoral financial frictions that allowing us to account for the role of financial tightness along the production chain. We show that this interaction between the network structure and sectoral financial frictions matters for the transmission of monetary policy, and we rationalize the choice of empirical measures and our key empirical results in a canonical multisector model.

First, our results show that both direct and indirect financial frictions significantly amplify the dampening effect of a monetary policy tightening shock, with indirect financial frictions accounting for a large share in the overall effect of financial frictions on prices and output. Second, we find that while downstream financial frictions seem to reinforce the decline in prices and output following a monetary policy tightening shock, upstream constrains tend to partly mitigate these effects. While an intensification of financial frictions seems to lower downstream customers' demand for intermediate goods produced by sector i ("demand channel"), it may foster incentives for upstream suppliers to raise prices to alleviate financial frictions ("cost channel").

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A Impulse response scaling

We scale the size of a monetary policy tightening shock s_t in model 10 to imply a peak increase in the 3m OIS rate – the market-based monetary policy rate proxy from which monetary policy shocks are identified – by 25 basis points in the first year after the shock. We then scale the impulse response functions for the macroeconomic variables of interest to be consistent with such a 25bs peak impact monetary policy tightening shock. To do so, we proceed in two steps. First, we estimate a euro area local projection model including broadly the same control variables as in the country-sector panel model 10, but at the aggregate level, to account for the fact that the dependent variable y_t is observed at the euro area level only in this setting. We then derive a scaling parameter $\tau \equiv \frac{0.25}{\psi}$, with ψ referring to the peak of the impulse response of the OIS 3m rate to a monetary policy tightening shock within the first year after the shock, expressed in percentage points. We finally use τ as a scaling parameter in the impulse response functions of industrial production and producer prices shown in section 6.

The euro area aggregate model is given by:

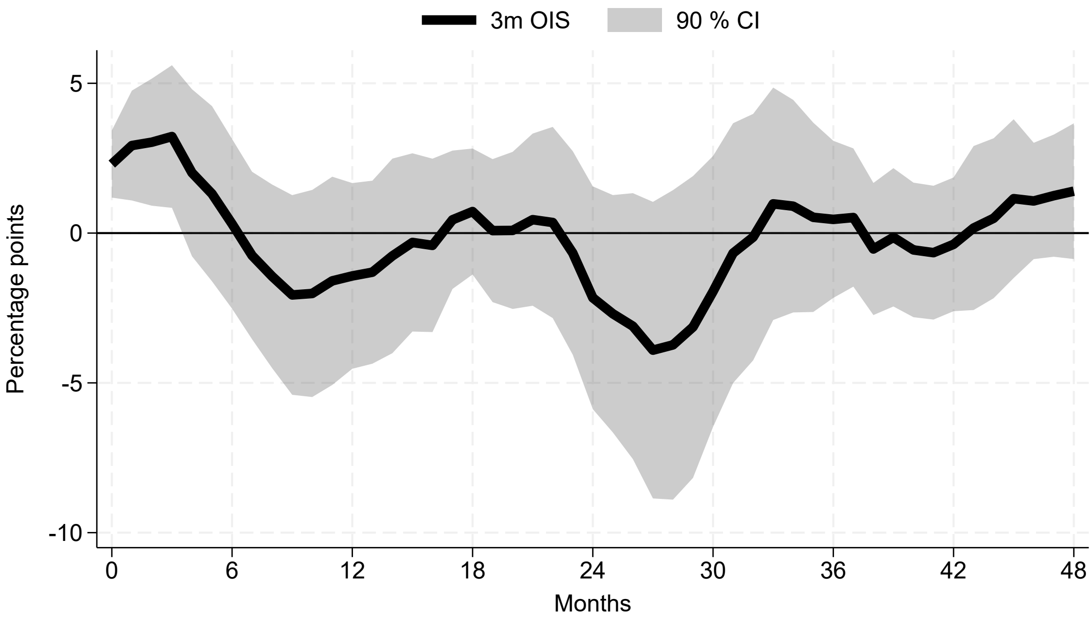
$$y_{t+h} = \beta_1^h s_t + \sum_{l=1}^{L} \boldsymbol{\delta^h K_{t-l}} + \sum_{l=0}^{L} \boldsymbol{\eta^h X_{t-l}} + \epsilon_{t+h} \tag{26}$$

$$\text{with} \qquad h = 1, 2, ..., H, \boldsymbol{K_t} = \begin{bmatrix} y_t \\ s_t \end{bmatrix}$$

with vector $\boldsymbol{K_t}$ indeed collecting lags of the dependent variable y_t and of the shock s_t. Matrix $\boldsymbol{X_t}$ contains the contemporaneous values and lags of the same set of macro-financial control variables as included in model 10, i.e. a GDP-weighted 10y composite euro area sovereign bond yield, the euro-dollar exchange rate, and log-levels of the euro area Composite Indicator of Systemic Stress (CISS), the IMF Commodities Price Index, the euro area harmonized index of consumer prices (HICP) and the euro area unemployment rate. It also includes our main variables of interest, industrial production and producer prices, now measured at the euro area aggregate level.

Figure 13 shows the impulse response function to a monetary policy tightening shock as obtained from model 26. Without scaling, the shock refers a one percentage point increase in the shock series from the mean. Given that the mean monetary policy shock in our sample only amounts to 0.2 basis points, the shock impact as measured by β_1^h in equation 26 and shown in figure 13 turns out large.[33] Within the first year, the peak increase of 3.2 percentage points in response the OIS 3m rate amounts to percentage points and is reached three months after the shock. In turn, this implies that $\tau \approx 0.078$.

Figure 13: Impulse responses to monetary policy tightening shock - aggregate model



Notes: Impulse responses to a monetary policy tightening shock. Estimates for model 26 estimated on aggregate euro area data with Newey and West (1987) standard errors.

[33] As discussed in section 3, we identify monetary policy shocks by applying the Jarociński and Karadi (2020) "poor man's" sign restrictions to the innovations in the 3m OIS rate around policy events as identified by Altavilla et al. (2019).

B Robustness checks

In the following, we provide robustness checks to the results obtained with empirical model presented in section 6. We particularly assess the robustness of our main empirical results in figures 4 to 6 to using a different financial frictions measures, firms' working capital as listed in table 3, and across using input-output weights (matrices 4 and 5) or Leontief and Gosh inverses (matrices 6 and 7).

B.1 Financial frictions measures

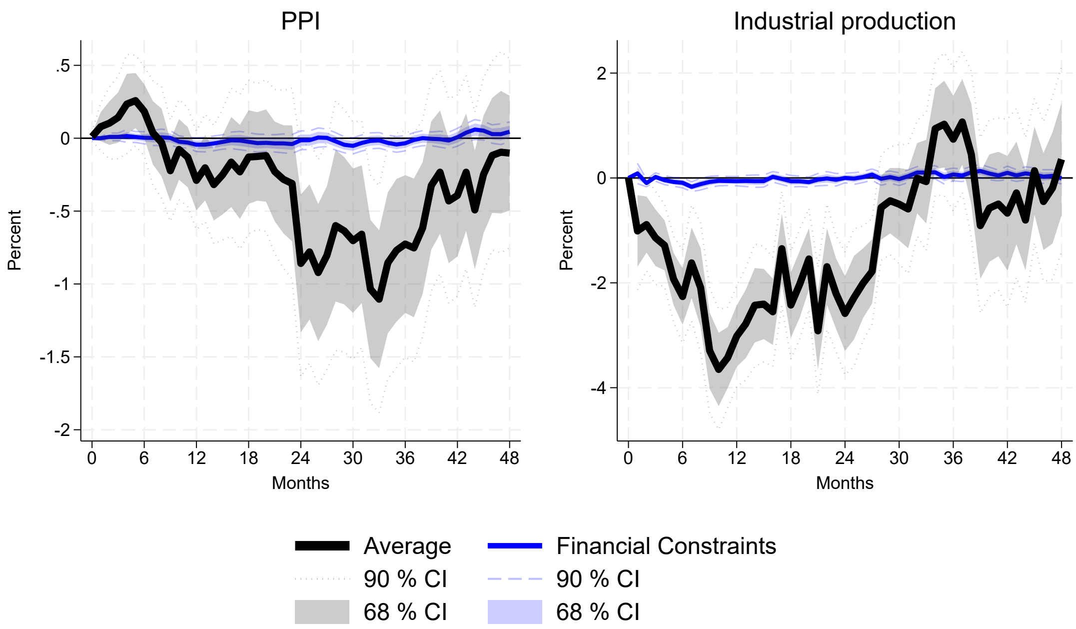
In this section, we show that our results remain broadly robust when using an alternative empirical financial frictions measure for φ in equations 8, 9, and 10. Figures 14 to 16 show the same set of impulse response as depicted in figures 4 to 6 when sector-aggregates of firm level data on the working capital share, defined as working capital expenses/total assets instead of total leverage is used (table 3). We assess robustness to working capital also in light of its importance in the theoretical analysis we carry out in section 7. Overall, results are robust to using the working capital share, with upward price effects stemming from upstream financial frictions significantly playing out earlier, after already half a year, compared to only after 2 years in the baseline specification (figures 6 vs. 16). At the same time, significance when separating direct from indirect effects turns out lower when using the using working capital share (figures 5 vs. 15).

We also test for differences in aggregating firm-level data on financial frictions measures to the sectoral level. While main results in figures 4 to 6 where derived using sales-based weighted averages of firm level data to generate sectoral measures, figures 17 to 19 show the same set of results when sectoral levels of total leverage reflect the median firm's leverage holdings. While results remain broadly consistent, the trough effect of the average monetary policy shock on PPIs turns out stronger than in the main results (figure 17), and an upward drift in the direct financial frictions effect plays out over the latter part of the projection horizon (figure 18).

B.2 Production network measures

In addition to testing different measures for financial frictions, we also check robustness of our results when altering the second element determining our sector-specific financial frictions effects, i.e. bilateral exposures of sectors across the production

Figure 14: Impulse responses to monetary policy tightening shock - working capital

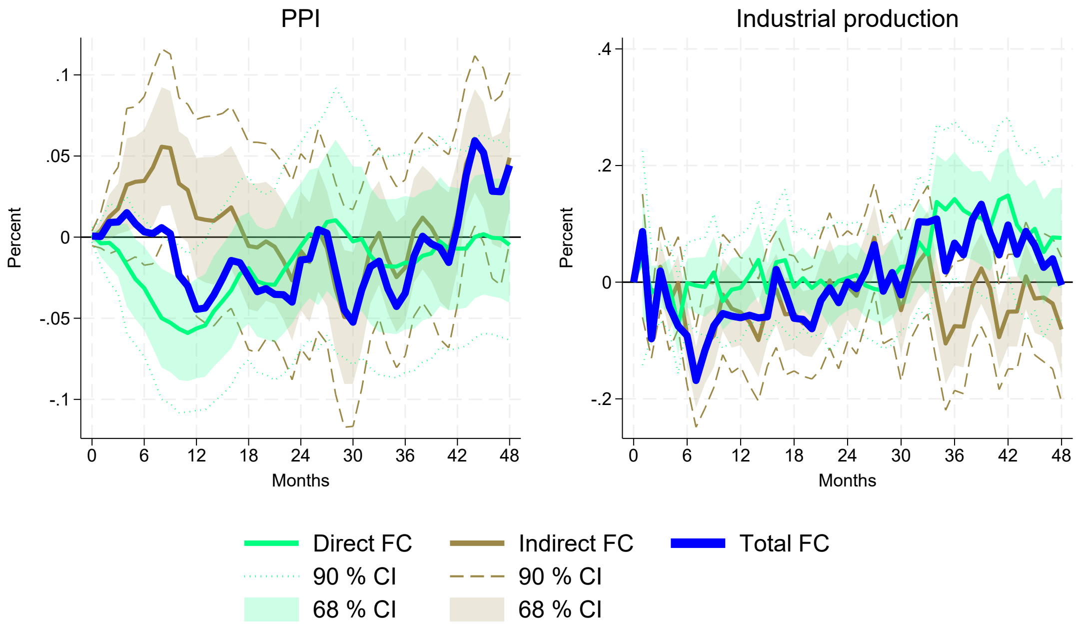


Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

network. In the baseline results of figures 4 to 6, we used the technical and allocation coefficients (equations 4 and 5) for measuring network exposures in our financial frictions measures, given by $\Phi_{ic,t_{12}}$ and $\tilde{\Phi}_{ic,t_{12}}$ in equation 8. However, these coefficients only account for first-order effects stemming from input-output linkages across the production network, therefore neglecting higher-order cascading effects stemming from second-round trading. As discussed in section 3, Leontief and Gosh inverses are able to account for such higher.order effects. In figures 20 to 22, we report results when using such matrices, computed following equations 6 and 7 in the financial constrains measures, i.e. when using the measures $\Phi'_{ic,t_{12}}$ $\tilde{\Phi}'_{ic,t_{12}}$ described by equation 9 instead.

Overall, results are both quantitatively and qualitatively in line with the baseline results of figures 4 to 6. However, we find that the price puzzle at the beginning of the projection horizon turns out somewhat more pronounced when using Leontief/Gosh inverses, extending over the first 18 months following the shock (figure 20). However, this effect is also statistically insignificant at the conservative 90 percent confidence level. In addition, we find that the upward price effect stemming from upstream financial frictions materializes only after approx. 2 years when using Leontief/Gosh

Figure 15: Impulse responses to monetary policy tightening shock - direct vs. indirect financial frictions effects - working capital



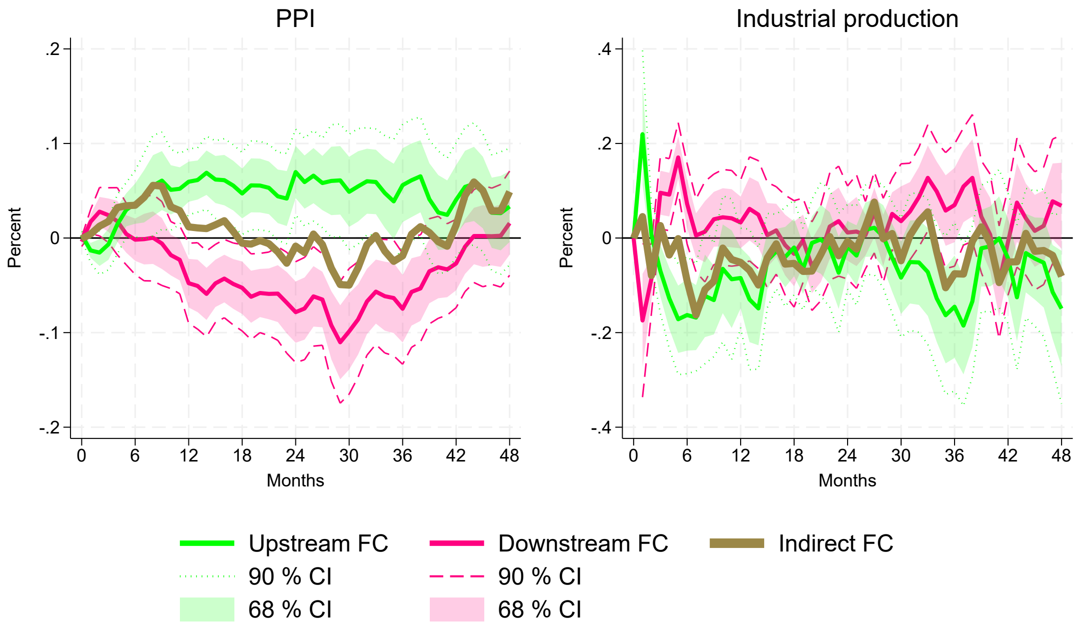
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

inverses, whereas a slight counteracting effect prevails over the first part of the projection horizon (figure 22).

B.3 Model specification

Finally, we also assess the robustness of our results across different specifications of the model, beyond the choice of financial frictions measures and the representation of input-output linkages. In particular, we assess whether estimating the model in level terms instead of long-differences. The level variant of the long-difference model 10 is given by:

Figure 16: Impulse responses to monetary policy tightening shock - upstream vs. downstream financial frictions effects - working capital



Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

$$y_{ic,t+h} = \underbrace{\beta_1^h \varphi_{ic,t_{12}-1} \times s_t}_{\substack{\text{Direct financial frictions} \\ \text{effect}}} + \underbrace{\overbrace{\beta_2^h \Phi_{ic,t_{12}-1} \times s_t}^{\text{Upstream effect}} + \overbrace{\beta_3^h \tilde{\Phi}_{ic,t_{12}-1} \times s_t}^{\text{Downstream effect}}}_{\substack{\text{Indirect financial frictions} \\ \text{effect}}} + \tag{27}$$

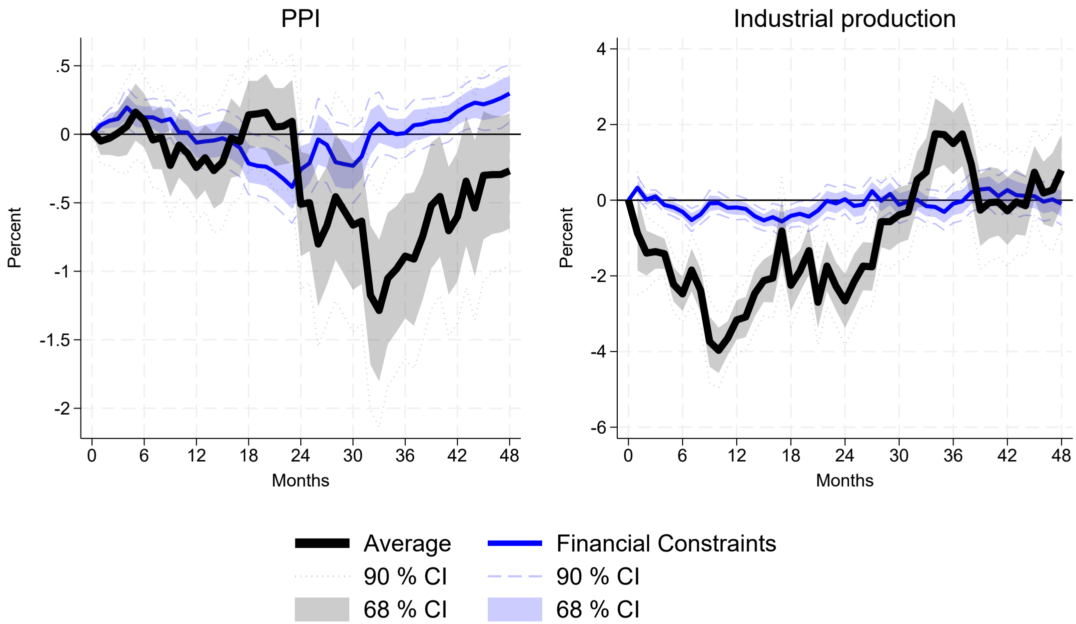
$$\underbrace{\beta_4^h a_{ic,t_{12}-1} \times s_t + \beta_5^h \tilde{a}_{ic,t_{12}-1} \times s_t + \beta_6^h s_t}_{\text{Non-network effect}}$$

$$+ \sum_{l=0}^{L} \boldsymbol{\gamma^h H_{t-l}} + \sum_{l=1}^{L} \boldsymbol{\delta^h K_{t-l}} + \sum_{l=0}^{L} \boldsymbol{\eta^h X_{t-l}} + \phi_{ic} + \theta_{t_{12}} + \kappa_{t+h} + \epsilon_{ic,t+h}$$

with $\quad h = 1, 2, ..., H$

$$\boldsymbol{H_t} = \begin{bmatrix} a_{ic,t_{12}} \\ \tilde{a}_{ic,t_{12}} \\ \varphi_{ic,t_{12}} \\ \Phi_{ic,t_{12}} \\ \tilde{\Phi}_{ic,t_{12}} \end{bmatrix}, \boldsymbol{K_t} = \begin{bmatrix} y_{ic,t} \\ \varphi_{ic,t_{12}} \times s_t \\ a_{ic,t_{12}} \times s_t \\ \tilde{a}_{ic,t_{12}} \times s_t \\ \Phi_{ic,t_{12}} \times s_t \\ \tilde{\Phi}_{ic,t_{12}} \times s_t \\ s_t \end{bmatrix}$$

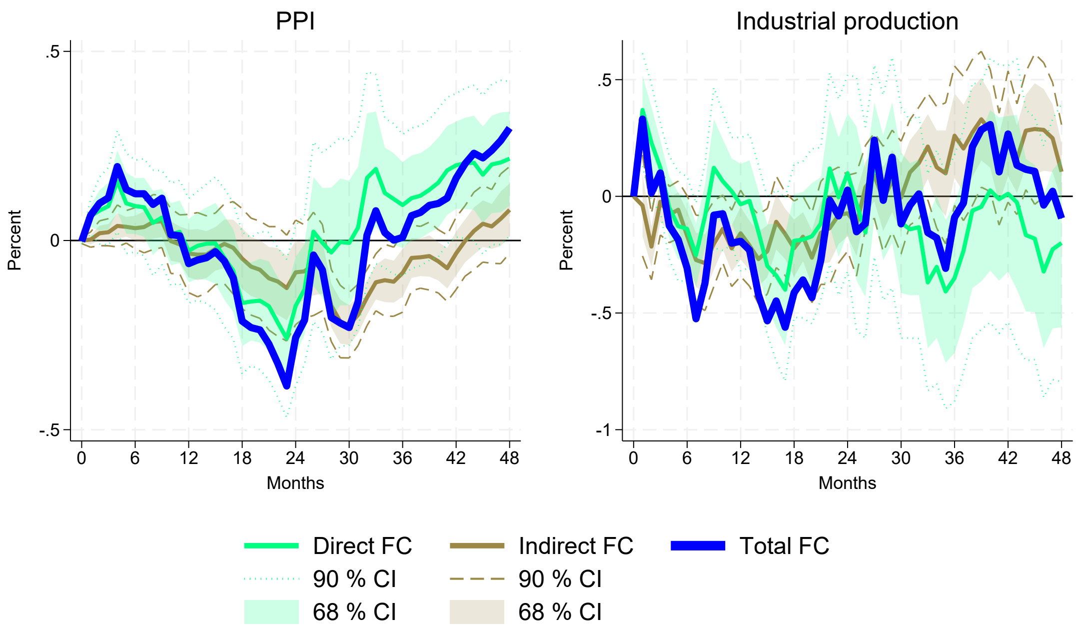
Figure 17: Impulse responses to monetary policy tightening shock - median level of sectoral total leverage



Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

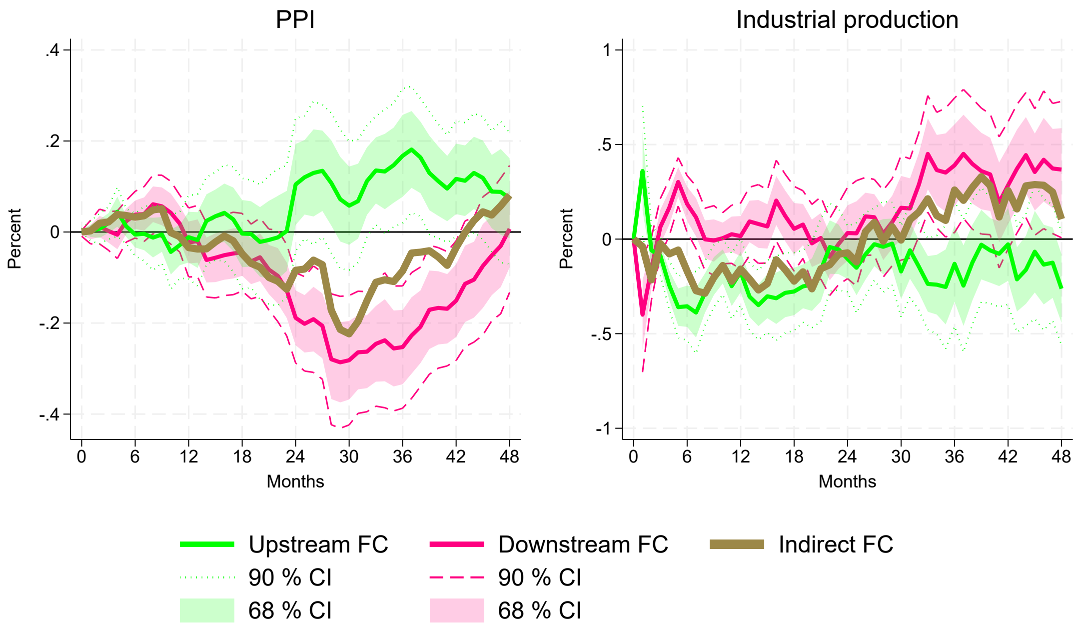
Compared to the long-difference variant, we include country-sector fixed effects ϕ_{ic}, which are not present in the differenced version of the model. Jordà and Taylor (2024) suggest using long-differences to mitigate concerns regarding small sample biases, and comparing results in figures 23 to 25 with our main results in figures 4 to 6 confirm that our findings would be broadly robust to such concerns when estimating the model in levels.

Figure 18: Impulse responses to monetary policy tightening shock - direct vs. indirect financial frictions effects - median level of sectoral total leverage



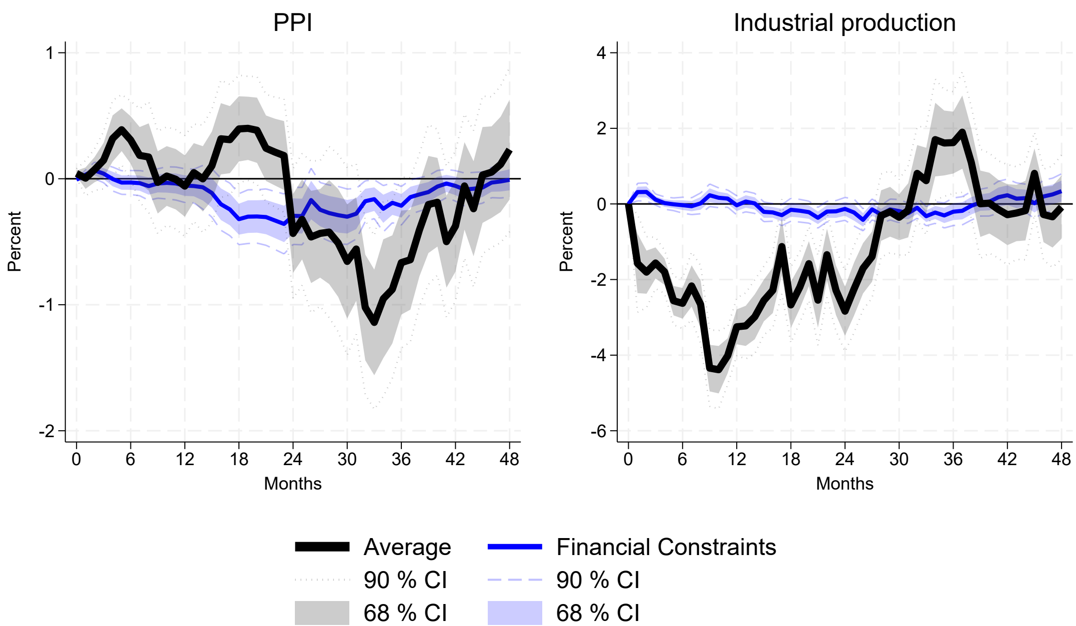
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 19: Impulse responses to monetary policy tightening shock - upstream vs. downstream financial frictions effects - median level of sectoral total leverage



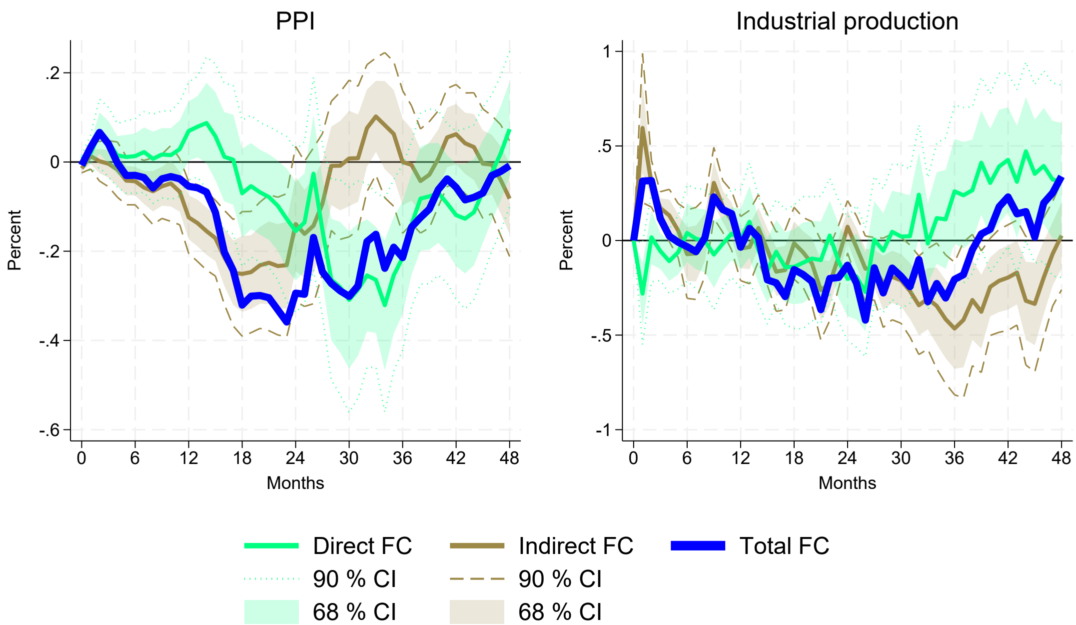
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 20: Impulse responses to monetary policy tightening shock - Leontief/Gosh inverses



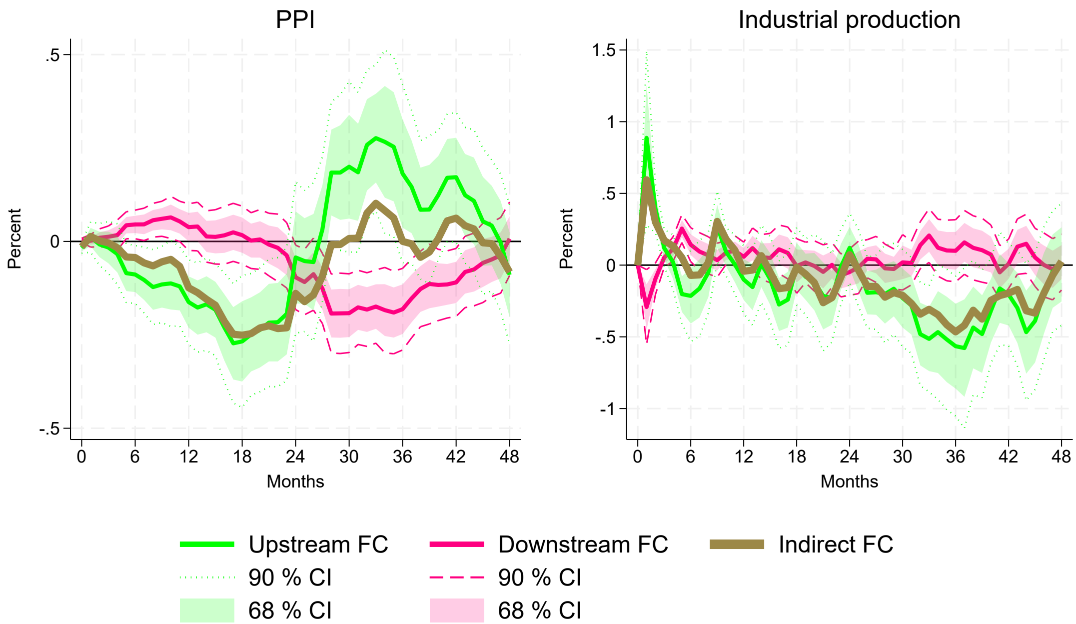
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 21: Impulse responses to monetary policy tightening shock - direct vs. indirect financial frictions effects - Leontief/Gosh inverses



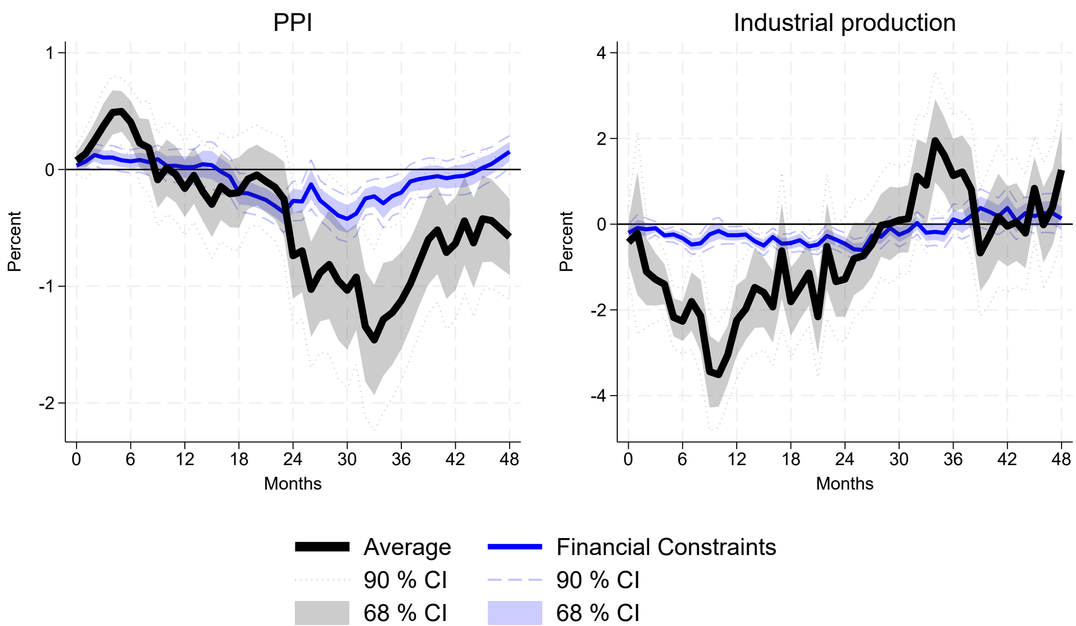
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 22: Impulse responses to monetary policy tightening shock - upstream vs. downstream financial frictions effects - Leontief/Gosh inverses



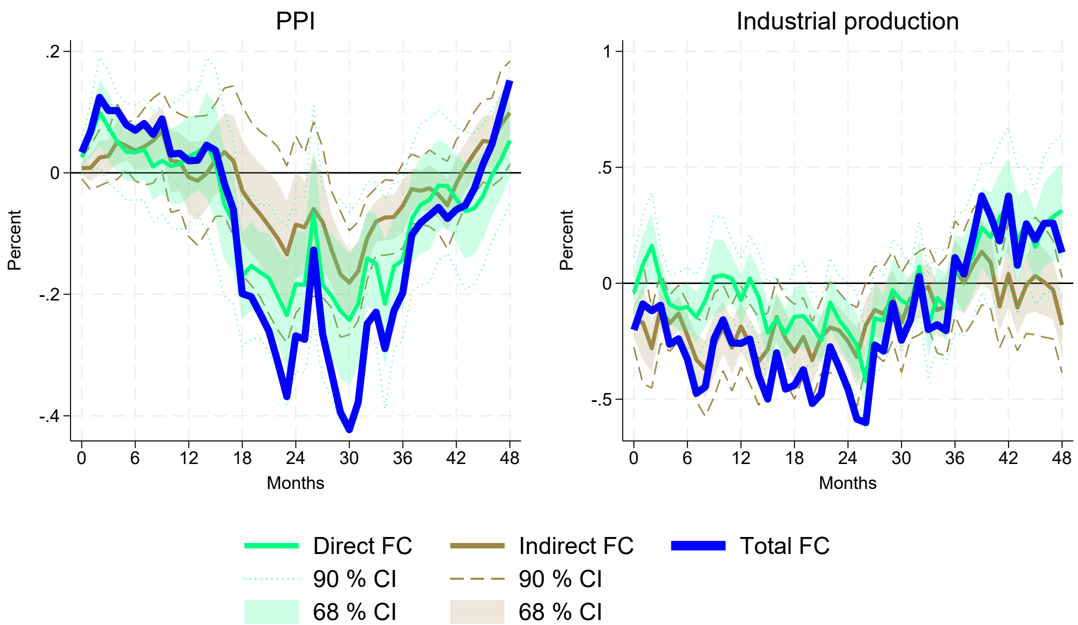
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 23: Impulse responses to monetary policy tightening shock - level specification



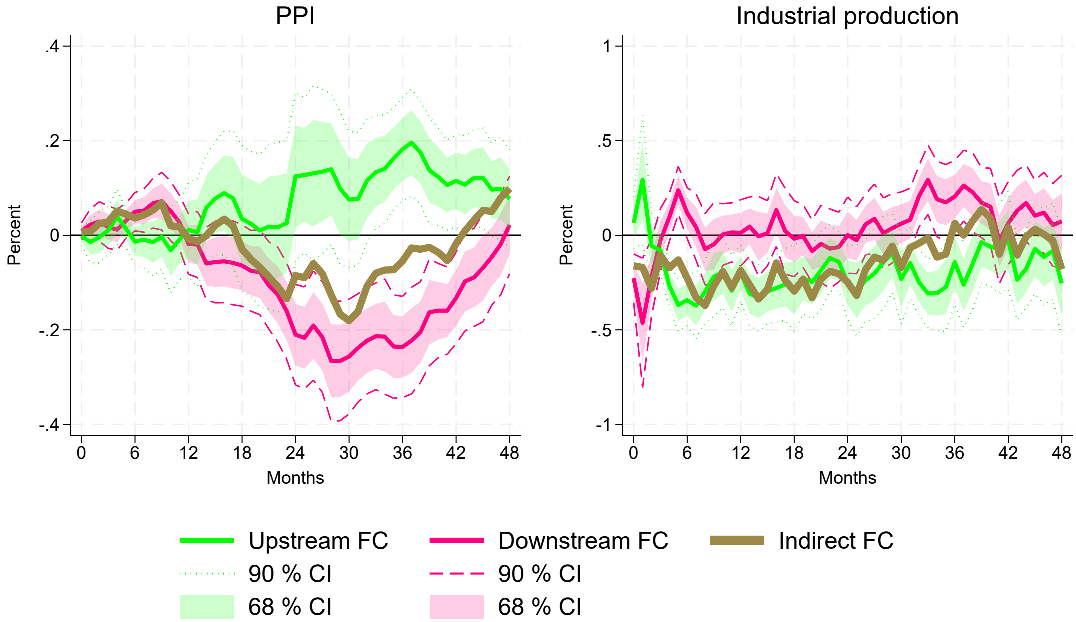
Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 24: Impulse responses to monetary policy tightening shock - direct vs. indirect financial frictions effects - level specification



Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

Figure 25: Impulse responses to monetary policy tightening shock - upstream vs. downstream financial frictions effects - level specification



Notes: Impulse responses to a monetary policy tightening shock scaled to a peak increase in the 3m OIS rate of 25bp. Estimates for model 10 estimated on the full country-sector euro area panel.

C Theoretical model derivations

In this section, we provide the full set of derivations underlying the key equations of section 7.

C.1 Equilibrium conditions

C.1.1 Firms

As specified in section 7, firms in sector i maximize profits (equation 13) subject to the production technology (equations 11 and 12), taking all prices as given. The representative firm takes input prices as given, with P^i defined as the aggregate price index accruing to intermediate inputs firms in sector i purchase. We derive this index below when solving the firm's optimization problem.

The monopolistic competitive firm's problem can be split in two parts. First, the firm solves an *outer problem* to maximize profits, given by

$$\pi_i = max_{\{y_i\}}\ p_i y_i - (1 + i\varphi_i) mc_i y_i \tag{28}$$

where mc_i is the firm's marginal cost of producing good y_i. Solving the optimization problem yields the price equation 14.

Second, the *inner problem* of the firm is given by a dual cost minimization problem determining the firms marginal cost function. First, the firm minimizes

$$mc_i y_i = min_{\{l_i, x_i\}}\ l_i + P^i x_i \tag{29}$$

subject to the firm's production function given by equation 11. The first-order conditions of this problem with respect to x_{ij} and l_i yield the optimal amounts of factor inputs:

$$\begin{aligned} P^i &= \lambda_i (1 - \alpha_i) \frac{y_i}{x_i} \\ \Leftrightarrow x_i &= \lambda_i (1 - \alpha_i) \frac{y_i}{P^i} \end{aligned} \tag{30}$$

$$\begin{aligned} 1 &= \lambda_i \alpha_i \frac{y_i}{l_i} \\ \Leftrightarrow l_i &= \lambda_i \alpha_i y_i \end{aligned} \tag{31}$$

Hence, by equating the marginal rate of technical substitution to the ratio of prices, we obtain:

$$\frac{1-\alpha_i}{\alpha_i}\frac{l_i}{x_i} = P^i.$$

Substituting optimal factor inputs (equations 31 and 30) in equation 29 yields

$$\begin{aligned} mc_i y_i = \ & l_i + P^i x_i = \lambda_i \alpha_i y_i + \lambda_i (1-\alpha_i) y_i = \lambda_i y_i \\ & \Leftrightarrow \lambda_i = mc_i \end{aligned} \tag{32}$$

This yields the optimal labor and intermediate good input equations:

$$x_i = mc_i (1-\alpha_i) \frac{y_i}{P^i} \tag{33}$$

$$l_i = mc_i \alpha_i y_i \tag{34}$$

Equation 33 determines the optimal level of the intermediate inputs bundle x_i, which depends positively on total sectoral output y_i and negatively on the intermediate inputs bundle price index P^i. Equation 34 defines labor demand l_i as a function of output y_i, marginal cost mc_i, and the labor share α_i. Furthermore, substituting equations 31 to 32 into the production function (equation 11) yields a handy expression for marginal costs:

$$mc_i = \frac{1}{z_i} \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} (P^i)^{1-\alpha_i} \tag{35}$$

Finally, the firm decides on the mix of intermediate inputs in order to minimize:

$$P^i x_i = \sum_{j \in K} p_j x_{ij}, \tag{36}$$

subject to

$$x_i = \prod_{j \in K} {\nu_{ij}}^{-\nu_{ij}} x_{ij}^{\nu_{ij}}.$$

This leads to the following expression for the input price mix

$$P^i = \prod_{j \in K} p_j^{\nu_{i,j}}, \tag{37}$$

Equation 37 defines the intermediate input bundle price P^i as a geometric weighted average of individual input prices p_j. Substituting 37 into equation 35 gives the equation 15 in the main text.

This equation is a result of the cost minimization problem the firm solves, and to the optimal use of variety j in the production of sector i

$$x_{ij} = \frac{P^i}{p_j} \nu_{i,j} x_i. \tag{38}$$

Equation 38 determines the optimal demand for a specific intermediate input x_{ij} as a function of the relative price $\frac{P^i}{p_j}$, the weight $\nu_{i,j}$, and the total intermediate input bundle x_i.

C.1.2 Households

The household solves a standard optimization problem, which yields the following optimality conditions:

$$U'(C) = V'(L) P^c \tag{39}$$

$$c_i = \frac{P^c}{p_i} \nu_{ci} C \tag{40}$$

with the price of the consumption bundle being given by

$$P^c = \prod_{i \in K} p_i^{\nu_{ci}}. \tag{41}$$

C.2 Derivations of indirect financial frictions measures

C.2.0.1 Direct and upstream financial frictions Using the expression for sector i's input price index (equation 37) in the marginal costs definition (equation 15) we obtain

$$mc_i = \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{j \in K} p_j^{\nu_{i,j}} \right)^{1-\alpha_i},$$

the marginal cost condition determined by the firm's inner cost minimization problem. Combining this expression with the firm's optimality condition stemming from the outer profit maximization problem (equation 14) yields

$$p_i/(1+i\varphi_i) = mc_i = \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{j \in K} p_j^{\nu_{i,j}} \right)^{1-\alpha_i} \tag{42}$$

$$\Leftrightarrow p_i = (1+i\varphi_i) \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{j \in K} p_j^{\nu_{i,j}} \right)^{1-\alpha_i}.$$

Combining with the profit maximizing relation for all j suppliers of sector i gives

$$p_i = (1+i\varphi_i) \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \left(\prod_{j \in K} [(1+i\varphi_j) mc_j]^{\nu_{i,j}} \right)^{1-\alpha_i} \tag{43}$$

$$\begin{aligned}
\Leftrightarrow p_i &= (1+i\varphi_i) \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} [(1+i\varphi_1) mc_1]^{\nu_{i,1}(1-\alpha_i)} \times \dots \\
&\quad \times [(1+i\varphi_i) mc_i]^{\nu_{i,i}(1-\alpha_i)} \times \dots \times [(1+i\varphi_j) mc_j]^{\nu_{i,j}(1-\alpha_i)} \times \\
&\quad \dots \times [(1+i\varphi_K) mc_K]^{\nu_{i,K}(1-\alpha_i)} \\
\Leftrightarrow p_i &= (1+i\varphi_i)^{1+\nu_{i,i}(1-\alpha_i)} \, mc_i^{\nu_{i,i}(1-\alpha_i)} \frac{(1-\alpha_i)^{\alpha_i - 1}}{\alpha_i^{\alpha_i}} \times \\
&\quad \times \left(\prod_{j \in K} 1(j \neq i) \, [(1+i\varphi_j) mc_j]^{\nu_{i,j}} \right)^{1-\alpha_i}
\end{aligned}$$

Taking the logarithm of this expression yields:

$$\begin{aligned}
\log(p_i) &= [1+\nu_{i,i}(1-\alpha_i)] \, [\log(1+i\varphi_i)] + \nu_{i,i}(1-\alpha_i) \log(mc_i) \\
&\quad + (\alpha_i - 1) \log(1-\alpha_i) - \alpha_i \log(\alpha_i) \\
&\quad + (1-\alpha_i) \sum_{j \neq i} \nu_{i,j} \, [\log(1+i\varphi_j) + \log(mc_j)]
\end{aligned} \tag{44}$$

The derivative of this expression with respect to i is given by:

$$\frac{d}{di} \log(p_i) = [1+\nu_{i,i}(1-\alpha_i)] \frac{\varphi_i}{1+i\varphi_i} + \nu_{i,i}(1-\alpha_i) \frac{mc_i'(i)}{mc_i(i)} \tag{45}$$

$$+ (1-\alpha_i) \sum_{j \neq i} \nu_{i,j} \left(\frac{\varphi_j}{1+i\varphi_j} + \frac{mc_j'(i)}{mc_j(i)} \right) \tag{46}$$

Finally, using the logarithm approximation for $\log(1+i\varphi_j)$, we obtain equation 22 in the main text:

$$\frac{d}{di}\log(p_i) = [1+\nu_{i,i}(1-\alpha_i)]\varphi_i + \nu_{i,i}(1-\alpha_i)\frac{mc_i'(i)}{mc_i(i)} \tag{47}$$

$$+ (1-\alpha_i)\sum_{j\neq i}\nu_{i,j}\left(\varphi_j + \frac{mc_j'(i)}{mc_j(i)}\right) \tag{48}$$

C.2.0.2 Downstream financial frictions We start with combining the household optimality condition 40 with sector i's market clearing condition 19, yielding:

$$y_i = \frac{P^c}{p_i}\nu_{ci}C + \sum_{j\in K}\frac{P^j}{p_i}\nu_{i,j}x_j \tag{49}$$

$$\Leftrightarrow p_i y_i = P^c\nu_{ci}C + \sum_{j\in K}P^j\nu_{j,i}x_j$$

Equation 49 links the nominal value of production in sector i to total household consumption and the total intermediate input use by other sectors. We now use equation 36 describing sector i's optimal intermediate input use by other sectors and obtain

$$p_i y_i = P^c\nu_{ci}C + \sum_{j\in K}\nu_{j,i}mc_j(1-\alpha_j)y_j \tag{50}$$

We now use the market clearing condition 19 of each of the varieties j and obtain

$$p_i y_i = P^c\nu_{ci}C + \sum_{j\in K}\nu_{j,i}mc_j(1-\alpha_j)\left(c_j + \sum_{s\in K}x_{s,j}\right) \tag{51}$$

We can now split the term in parenthesis at the end of the equation and use the household optimality condition 40 with respect to sector j and equation 38 describing the optimal use of variety j by sector s:

$$p_i y_i = P^c\nu_{ci}C + \sum_{j\in K}\nu_{j,i}mc_j(1-\alpha_j)\frac{P^c}{p_j}\nu_{cj}C + \sum_{j\in K}\nu_{j,i}mc_j(1-\alpha_j)\sum_{s\in K}\frac{P^s}{p_j}\nu_{s,j}x_s \tag{52}$$

Optimality condition 14 implies that $\frac{mc_j}{p_j} = \frac{1}{(1+i\varphi_j)}$. Substituting in equation 52 yields:

$$p_i y_i = P^c\nu_{ci}C + \sum_{j\in K}\frac{\nu_{j,i}(1-\alpha_j)P^c\nu_{cj}C}{(1+\varphi_j i)} + \sum_{j\in K}\nu_{j,i}\frac{(1-\alpha_j)\sum_{s\in K}P^s\nu_{s,j}x_s}{(1+\varphi_j i)} \tag{53}$$

$$\Leftrightarrow p_i y_i = P^c\nu_{ci}C + \sum_{j\in K}\frac{\nu_{j,i}(1-\alpha_j)}{(1+\varphi_j i)}(P^c\nu_{cj}C + \sum_{s\in K}P^s\nu_{s,j}x_s)$$

Following the same step as before to differentiate between the direct effect accruing to sector i and the network effect yields:

$$p_i y_i = \underbrace{P^c \nu_{ci} C}_{\substack{\text{Final}\\ \text{consumption}}} + \underbrace{\frac{\nu_{i,i}(1-\alpha_i)}{(1+\varphi_i i)}(P^c \nu_{ci} C + \sum_{s \in K} P^s \nu_{s,i} x_s) +}_{\text{Roundabout}} \tag{54}$$
$$+ \underbrace{\sum_{j \neq i} \frac{\nu_{j,i}(1-\alpha_j)}{(1+\varphi_j i)}(P^c \nu_{cj} C + \sum_{s \in K} P^s \nu_{s,j} x_s)}_{\text{Other sectors}}$$

C.3 Full set of equilibrium conditions

In this economy, an equilibrium is an allocation $\{\{y_i, l_i, \{x_{ij}\}_{j \in K}, c_i, x_i\}_{i \in K}, C, L\}$ and a system of prices $\{\{p_i, mc_i, P^i\}_{i \in K}, P^c, 1\}$, where the wage has been normalized to 1, such that:

- firms' output and input bundles maximize firm profits
- household's consumption bundle and labor supply are chosen optimally
- all markets clear

The full set of equilibrium conditions is given by:

$$y_i = z_i l_i^{\alpha_i} x_i^{1-\alpha_i} \quad \forall\, i \tag{55}$$
$$x_i = mc_i(1-\alpha_i)\frac{y_i}{P^i} \quad \forall\, i \tag{56}$$
$$l_i = mc_i \alpha_i y_i \quad \forall\, i \tag{57}$$
$$p_i = (1 + i\varphi_i) mc_i \quad \forall\, i \tag{58}$$
$$P^i = \prod_{j \in K} p_j^{\nu_{i,j}} \quad \forall\, i \tag{59}$$
$$x_{ij} = \frac{P^i}{p_j} \nu_{i,j} x_i \quad \forall\, j, i \tag{60}$$
$$U'(C) = V'(L) P^c \tag{61}$$
$$c_i = \frac{P^c}{p_i} \nu_{ci} C \quad \forall\, i \tag{62}$$
$$P^c = \prod_{i \in K} p_i^{\nu_{ci}} \tag{63}$$
$$y_i = c_i + \sum_{j \in K} x_{j,i} \quad \forall\, i \tag{64}$$
$$L = \sum_{i \in K} l_i \tag{65}$$