International Inflation Spillovers Through Input Linkages*

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February 2, 2018

Abstract

We document that international input-output linkages contribute substantially to synchronizing producer price inflation (PPI) across countries. Using a multi-country, industry-level dataset that combines information on PPI and exchange rates with global input-output linkages, we recover the underlying cost shocks that are propagated internationally via the global input-output network, thus generating the observed dynamics of PPI. We then compare the extent to which common global factors account for the variation in actual PPI and in the underlying cost shocks. Our main finding is that across a range of econometric tests, input-output linkages account for half of the global component of PPI inflation. We report two additional findings: (i) the results are similar when allowing for imperfect cost pass-through and demand complementarities; and (ii) PPI synchronization across countries is driven primarily by common sectoral shocks and input-output linkages amplify co-movement primarily by propagating sectoral shocks.

JEL Classifications: F33, F41, F42

Keywords: international inflation synchronization, input linkages

*We are grateful to the editor (Amit Khandelwal), three anonymous referees, João Amador, Ariel Burstein, Stefan Gerlach, Sophie Guilloux-Nefussi, Federico Mandelman, Benoit Mojon, Paolo Surico, Ben Tomlin, and workshop participants at various institutions for helpful suggestions, and to Andreas Kropf, Bogdan Bogdanovic, Julian Ludwig, Pierre Yves Deléamont, Gian Marco Humm, Barthélémy Bonadio, and Burcu Erik for excellent research assistance. We would especially like to thank Christopher Otrok for sharing his factor model estimation code with us. The views expressed in this study do not necessarily reflect those of the Bank for International Settlements. E-mail: raphael.auer@bis.org, alev@umich.edu, philip.saure@uni-mainz.de.

1 Introduction

One of the most contentious issues in monetary policy is whether inflation rates are primarily driven by national or international factors (see, e.g., Bernanke 2007, Fischer 2015, Draghi 2016, Carney 2017). While it is well established that inflation comoves closely across countries, the reasons for this synchronization are not well understood. The international synchronization of inflation could on the one hand be due to common structural trends and similar policies, or on the other hand to cross-country propagation of inflationary shocks via real and financial channels. Understanding the mechanisms behind international inflation synchronization is important for inflation forecasting, optimal monetary policy, international policy coordination, and currency unions, among other areas (see, e.g., Corsetti, Dedola and Leduc 2010, Galí 2010).

This paper documents that the cross-border propagation of cost shocks through input-output linkages contributes substantially to synchronizing producer price inflation (PPI) across countries. In the first step of the analysis, we recover the unobserved cost shocks that are consistent with observed price dynamics and the global network of input-output trade. In the second step, we compare the extent of global synchronization in observed PPI and the recovered cost shock series, and attribute the difference to the impact of linkages.

The following simple expression conveys the main idea. Abstracting from the sectoral dimension, suppose that country c's production uses inputs from country e. Then, the log change in the PPI of country c can be expressed as

$$\widehat{PPI}_c = \gamma_{c,e} \times \widehat{PPI}_e + (1 - \gamma_{c,e}) \times \widehat{C}_c, \tag{1}$$

where $\widehat{C}_c$ is the change in the local costs in c (which could be due to e.g., changes in productivity or prices of primary factors). The extent to which e's inflation shocks propagate to c is governed by the cost share $\gamma_{c,e}$ of inputs from e in the value of output of c.

We assemble a unique dataset that combines monthly disaggregated producer price indices (PPI_c) with data on sectoral domestic and international input trade from the World Input Output Database (WIOD). The WIOD provides information on cross-border input shares $\gamma_{c,e}$ by country pair and sector pair. Our data cover 30 countries and 17 sectors over the period 1995-2011.[1]

As a preliminary investigation, we simulate hypothetical inflation shocks and use the WIOD to compute how they propagate across countries. Input-output linkages transmit global inflation shocks significantly into countries. On average, a shock that raises inflation by 1% in all countries in the world other than the one under observation increases domestic inflation by 0.19%; and by well over 0.3% in some small open economies. The propagation of shocks between individual countries is highly unbalanced. For instance, an inflationary shock to Germany transmits with an elasticity of more than 0.1 to Hungary, the Czech Republic, and Austria. Similar magnitudes characterize other closely integrated regions, such China and Chinese Taipei, and the US, Canada, and Mexico.

The main analysis then examines the extent to which international input-output linkages affect the comovement of actual PPI inflation ($\widehat{PPI}_c$). It uses a generalization of the relationship (1) and data on $\widehat{PPI}_c$ and $\gamma_{c,e}$ to recover the underlying cost shocks $\widehat{C}_c$. It then compares the extent of cross-country synchronization in the actual $\widehat{PPI}_c$ with the extent of synchronization in the underlying cost shocks $\widehat{C}_c$. The incremental increase in synchronization of actual $\widehat{PPI}_c$ compared to $\widehat{C}_c$ is then attributed to the cross-border propagation of inflationary shocks through input linkages.[2] Our quantification of inflation synchronization builds on Ciccarelli and Mojon (2010) and Jackson, Kose, Otrok and Owyang (2015). The metrics of synchronization are based on the share of the variance of a country's inflation that is accounted for by either a single global factor or by a finer set of global and sector

[1] The baseline analysis assumes full pass-through of cost shocks to input buyers. This allows us to focus more squarely on the properties of the global input-output structure, and is an appropriate benchmark in this context. Section 4.1.1 provides the detailed discussion and presents results under different assumptions on pass-through.

[2] The approach is akin to Foerster, Sarte and Watson (2011)'s analysis of the role of input linkages in US sectoral output comovement.

factors.

The main finding is that international input-output linkages matter a great deal for inflation synchronization. The extent of synchronization of observed PPI is roughly double the level of synchronization in the underlying cost shocks. For the median country, the global component accounts for 51% of the variance of PPI, whereas the global component accounts for only 28% of the variance of the cost shocks, according to the static factor analysis following Ciccarelli and Mojon (2010). These differences are even more pronounced in the dynamic factor analysis.

We next examine the channels through which global input-output linkages give rise to inflation comovement. We investigate the role of exchange rate movements, pricing-to-market, and the heterogeneity in cross-border input linkages in generating inflation co-movement.

Exchange rate movements play no role in synchronizing inflation across countries. In a counterfactual that ignores exchange rate movements when recovering the underlying shocks, the common component in the recovered cost shocks is approximately the same as in the baseline. Because the exchange rate is a relative price and a bilateral exchange rate movement thus tends to increase prices in one country but decrease them in another, one might expect exchange rate movements to result in less synchronization. However, it could also be the case that exchange rates are correlated among subgroups of countries, thereby also affecting inflation comovement. In our sample, these effects appear to balance and exchange rates have no net impact on the extent of synchronization.

The degree of pricing-to-market also does not play a large role in inflation synchronization. We implement a scenario that features price complementarities following Burstein and Gopinath (2015), such that each seller's pricing rule is a function of both its cost shock, and the prices of all other sellers supplying that market. Under a range of values of this pass-through parameter, the recovered cost shocks exhibit if anything even less synchronization than in the baseline. Thus, the main result that input linkages contribute substantially to synchronization is unchanged when allowing for pricing-to-market.

We next document that the heterogeneity in the input coefficients across sectors and countries contributes modestly to international comovement. We compute two different balanced linkages counterfactual PPIs that would arise under the baseline recovered cost shocks, but in a world in which there was no sectoral or country heterogeneity in input linkages. The first counterfactual eliminates differences across sectors but keeps differences across countries. Specifically, for each importer-exporter country pair, sectoral input use is set equal to the average input use in the country. The second counterfactual in addition eliminates differences across foreign source countries. The global factor explains 10-20% less of the variation in these balanced linkages counterfactual PPIs compared to the observed PPIs, suggesting that input linkage heterogeneity itself – over and above the average level of linkages – does contribute to global inflation synchronization, but rather modestly.

Our baseline procedure infers the underlying cost shocks from PPI data and the extent of input linkages. We supplement the main analysis by collecting direct data on one type of underlying cost: unit labor costs (ULC). The extent of synchronization in ULC is if anything lower than in the baseline cost shocks, and much closer to the cost shocks than to actual PPI. Thus, direct measurement confirms the main finding of the paper.

Finally, we document that PPI synchronization across countries is driven by common sectoral shocks and that input-output linkages amplify comovement primarily by propagating sectoral shocks. We implement a dynamic factor model that decomposes the underlying sector-level PPI fluctuations into the global, sectoral, and country factors following the methodology developed in Jackson et al. (2015). In this model, international comovement in PPI could be due to a common global factor affecting all PPI series or to sectoral factors that are also common across countries. The first main result is that global PPI comovement is not accounted for by global shocks (i.e., shocks common to all sectors and all countries) but rather by sectoral ones (i.e., shocks to a specific sector in all countries conditional on the global shock). Second, international input-output linkages increase global comovement by increasing the share of the variance explained by sectoral shocks. These results are consistent with the view that global comovement arises due to idiosyncratic developments in individual sectors such as the energy or transportation equipment industries, which spill over both across borders and sectors via input-output linkages, thereby synchronizing national PPIs.

From a theoretical perspective, our finding that input linkages contribute substantially to the synchronization of international producer price inflation is directly relevant for monetary policy. The literature has shown that in models with input-output linkages, central banks should also target producer price inflation. This is because in the presence of nominal rigidities in both final and intermediate goods markets, a central bank faces a trade-off between stabilizing consumer price inflation and producer price inflation (see e.g. Huang and Liu 2005, de Gregorio 2012, Lombardo and Ravenna 2014). Even if central banks only cared about consumer price inflation, our work is still informative, since producer prices pass through into consumer prices. Although we leave the formal modeling of the link between the CPI and the PPI for future work, the statistical association between these two inflation rates is substantial.[3]

Our analysis contributes to the literature on cross-border inflation synchronization and its determinants. Monacelli and Sala (2009), Burstein and Jaimovich (2012), Andrade and Zachariadis (2016), and Beck, Hubrich and Marcellino (2016) study the comovement of international prices using sectoral and regional inflation data, while Ciccarelli and Mojon (2010), Mumtaz and Surico (2009, 2012) and Mumtaz, Simonelli and Surico (2011) examine the role of aggregate real linkages in inflation comovement. Borio and Filardo (2007) and Bianchi and Civelli (2015) address the related question of the extent to which global

[3]In our sample of 30 countries, simple country-by-country regressions of rolling 12-months CPI inflation on 12-months PPI inflation rates produce an average regression coefficient of 0.40 and an R^2 of 0.49. Clark (1995), focusing on the US over the period 1977 to 1994 finds that the forecasting power of producer prices for consumer prices is limited. In our data for the US, the simple regression of CPI on PPI results in a coefficient on the PPI of 0.19. However, due to the higher variance of the PPI compared to that of the CPI, the R^2 is actually 0.72, and thus PPI inflation has strong predictive power for CPI in our data.

output gaps affect domestic inflation dynamics. Bems and Johnson (2012, 2017) and Patel, Wang and Wei (2014) combine data on global input linkages with domestic prices and exchange rates to construct theoretically founded measures of real exchange rates. Also related is the literature on the role of input linkages in business cycle synchronization more broadly (see, e.g., Kose and Yi 2006, Burstein, Kurz and Tesar 2008, di Giovanni and Levchenko 2010, Johnson 2014).

The role of input linkages for inflation synchronization is receiving increasing attention. Auer and Sauré (2013) and Antoun de Almeida (2016) adapt the approach of di Giovanni and Levchenko (2010) to examine whether sector pairs trading more intensively with one another display greater inflation synchronization. Auer, Borio and Filardo (2017) present evidence that cross-border trade in intermediate goods and services is the main channel through which global economic slack influences domestic CPI inflation. Our approach accounts not only for direct cross-country spillovers through input linkages but also spillovers that travel through third markets.

The remainder of the paper is organized as follows. Section 2 presents the conceptual framework and the empirical strategy. Section 3 describes the data and the basic features of the world input-output matrix, and Section 4 reports the main results. Section 5 presents the exercise of implementing the model on sector-level data. Section 6 concludes.

2 Conceptual Framework

There are N countries, indexed by c and e, and S sectors, indexed by s and u. Time is indexed by t. The world is characterized by global input linkages: sector u producing output in country c has a cost function

$$W_{c,u,t} = W(C_{c,u,t}, \mathbf{p}_{c,u,t}),$$

where $\mathbf{p}_{c,u,t} \equiv \{p_{c,u,e,s,t}\}_{e=1,\ldots,N}^{s=1,\ldots,S}$ is the vector of prices of inputs from all possible source countries e and sectors s paid by sector u in country c. Input prices $p_{c,u,e,s,t}$ are indexed by the purchasing country-sector to reflect the fact that prices actually paid by each sector in each country for a given input may differ. The cost of non-materials inputs is denoted by $C_{c,u,t}$. This cost embodies the wage bill, the cost of capital, and the cost of service inputs.[4]

Standard steps using Shephard's Lemma yield the following first-order approximation for the change in the cost function:

$$\widehat{W}_{c,u,t} \approx \gamma^{C}_{c,u,t-1}\widehat{C}_{c,u,t} + \sum_{e,s} \gamma_{c,u,e,s,t-1}\widehat{p}_{c,u,e,s,t}, \tag{2}$$

where the hat denotes proportional change ($\widehat{x}_t = x_t/x_{t-1} - 1$). In this expression, $\gamma^{C}_{c,u,t-1}$ is the share of non-materials inputs in the value of total output and $\gamma_{c,u,e,s,t-1}$ is the share of expenditure on input e,s by sector-country c,u in the value of total output of sector c,u at time $t-1$.

To apply this expression to the data, we make two assumptions. First, the percentage change in the producer price index as measured in the data equals the change in the cost function:

$$\widehat{PPI}_{c,u,t} = \widehat{W}_{c,u,t}. \tag{3}$$

Two settings that would satisfy this assumption are marginal cost pricing and constant markups over marginal cost.

Second, the change in the price paid by producers in c,u for inputs from e,s is given by

$$\widehat{p}_{c,u,e,s,t} = \widehat{W}_{e,s,t} + \widehat{E}_{c,e,t}, \tag{4}$$

where $\widehat{E}_{c,e,t}$ is the change in the exchange rate between c and e. That is, the changes in

[4]As the PPI data used in the empirical implementation only cover industrial sectors, in the analysis below $C_{c,u,t}$ includes the cost of any inputs that are not in the set of sectors that comprise the PPI. The procedure adopted in the baseline analysis is valid if the non-materials inputs are non-traded and do not use traded inputs. Section 4.2 and Appendix B present a series of robustness checks on this approach, and show that accounting in different ways for shock transmission through sectors outside of PPI if anything strengthens the results.

prices paid by c,u for inputs are proportional to the change in the cost function of the input-supplying sector $\widehat{W}_{e,s,t}$ and the change in the exchange rate. A complete pass-through rate is consistent with some recent micro estimates of input cost shock pass-through at the border. Closest to our framework, Ahn, Park and Park (2016) construct effective input price indices using sector-level price and input usage data and show that the pass-through of imported input price shocks to domestic producer prices is nearly 1 for European countries and 0.7 for Korea. Berman, Martin and Mayer (2012) find that the exchange rate pass-through into import prices is close to complete (0.93) and considerably higher than that into the prices of consumer goods. Similarly, Amiti, Itskhoki and Konings (2014) document that for non-importing Belgian firms, exchange rate pass-through into export prices is close to 1, again suggesting that exporters transmit their cost shocks almost fully to buyers. Section 4.1.1 returns to the question of pass-through, and examines the sensitivity of the results to the various assumptions on imperfect pass-through.

2.1 Recovering Underlying Cost Shocks

The cost shock $\widehat{C}_{c,u,t}$ for each country c and sector u is then recovered directly, based on combining equations (2), (3), and (4):

$$\widehat{C}_{c,u,t} = \frac{1}{\gamma^C_{c,u,t-1}} \left[\widehat{PPI}_{c,u,t} - \sum_{e \in N, s \in S} \gamma_{c,u,e,s,t-1} \left(\widehat{PPI}_{e,s,t} + \widehat{E}_{c,e,t} \right) \right]. \tag{5}$$

In this expression, $\widehat{PPI}_{c,u,t}$, $\widehat{E}_{c,e,t}$, $\gamma_{c,u,e,s,t-1}$, and $\gamma^C_{c,u,t-1}$ are all taken directly from the data.

It will be convenient to express (5) in matrix notation:[5]

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1} \left[(\mathbf{I} - \mathbf{\Gamma}')\widehat{\mathbf{PPI}} - \widetilde{\mathbf{\Gamma}}'\widehat{\mathbf{E}} \right]. \tag{6}$$

$\widehat{\mathbf{C}}$ and $\widehat{\mathbf{PPI}}$ are the $NS \times 1$ vectors of all country-sector cost shocks and PPIs. The matrix

[5]To streamline exposition, the time subscripts are suppressed in the matrix notation.

$\mathbf{\Gamma}$ is the $NS \times NS$ global input-output matrix, the ij'th element of which is the share of spending on input i in the total value of sector j's output, where i and j index country-sectors. Finally, $\mathbf{D}$ is a $NS \times NS$ diagonal matrix whose diagonal entries are the $\gamma^C_{c,u,t-1}$ coefficients.

In the last term,

$$\widehat{\mathbf{E}} = \left(\begin{pmatrix} \widehat{E}_{1,t} \\ \vdots \\ \widehat{E}_{N,t} \end{pmatrix} \otimes 1_{S \times 1} \right)$$

where $\widehat{E}_{c,t}$ is a $N \times 1$ vector of exchange rate changes experienced by country c relative to its trading partners, and thus $\widehat{\mathbf{E}}$ is the $NNS \times 1$ vector of stacked exchange rate changes that only vary by country pair. The matrix $\widetilde{\mathbf{\Gamma}}'$ is:

$$\widetilde{\mathbf{\Gamma}}' = \begin{pmatrix} \mathbf{\Gamma}_1' & 0 & \ldots & 0 \\ 0 & \mathbf{\Gamma}_2' & 0 & \ldots \\ 0 & 0 & \ldots & 0 \\ 0 & \ldots & 0 & \mathbf{\Gamma}_N' \end{pmatrix}, \tag{7}$$

with $\mathbf{\Gamma}_c'$ defined as the $S \times NS$ matrix whose rows are country c's rows of $\mathbf{\Gamma}'$.

Our procedure takes the exchange rate changes as given, and thus ignores the possibility that exchange rates themselves react to cost shocks and other inflationary shocks. To capture the endogenous responses of exchange rates to inflation would require a full-fledged model with various levels of rigidities and monetary authorities. Such an exercise exceeds the scope of the this paper. At the same time, a large literature going back to Meese and Rogoff (1983) documents that exchange rates follow a random walk and that movements in nominal exchange rates are difficult to tie to macro fundamentals (see Itskhoki and Mukhin 2017, for a recent treatment). Thus, the assumption of exogenous nominal exchange rates may not be a bad approximation in our context. Below we assess robustness of the results to assuming that PPIs react only to cost shocks and not to exchange rates.

Equation (5) is used together with PPI data at monthly frequency to recover the underlying cost shocks $\widehat{C}_{c,u,t}$ for every country, sector, and month. Equation (5) does not involve any lags, amounting to the assumption that imported inputs are shipped and used within the month. Monthly data exhibit seasonality that potentially differs by country and sector, and correcting explicitly for such seasonality is not feasible in our data. Thus, we follow the common practice of transforming both the actual PPI data and the underlying cost shock data into 12-month changes:

$$\widehat{PPI12}_{c,u,t} = \prod_{\tau=0}^{11}(1 + \widehat{PPI}_{c,u,t-\tau}) - 1$$

and

$$\widehat{C12}_{c,u,t} = \prod_{\tau=0}^{11}(1 + \widehat{C}_{c,u,t-\tau}) - 1.$$

This transformation has the additional advantage that lagged effects due to shipping time and delayed price reactions are captured by the year-to-year changes.

The ultimate object of interest is the country-level rather than sector-level inflation. Thus we aggregate sectoral PPI series and cost shocks using sectoral output weights:

$$\widehat{PPI12}_{c,t} = \sum_{u\in S} \omega_{c,u}\widehat{PPI12}_{c,u,t} \tag{8}$$

and

$$\widehat{C12}_{c,t} = \sum_{u\in S} \omega_{c,u}\widehat{C12}_{c,u,t}, \tag{9}$$

where $\omega_{c,u}$ is the share of sector u in the total output of country c. We employ the sectoral output weights from 2002, the year closest to the middle of the sample.

The object in (8) has a clear interpretation: it is the aggregate PPI of country c. The aggregate PPI series we build track closely (though not perfectly) the official aggregate PPIs in our sample of countries.[6] The object in (9) is the output-share-weighted composite cost shock in country c. It can be interpreted as the PPI in country c in the counterfactual world

[6]In our sample of countries, the mean correlation between our constructed aggregate PPI and the official PPI, in 12 month changes, is 0.70, and the median is 0.83. The minimum is 0.02 for Bulgaria, which experienced hyperinflation between 1995 and 1998 (after 1998, the correlation for Bulgaria is 0.76). The maximum is 0.99 (Japan).

without input linkages in production. For maximum consistency between the two measures, the construction of $\widehat{C12}_{c,t}$ uses the same sectoral weights $\omega_{c,u}$ as that of $\widehat{PPI12}_{c,t}$. This approach ignores the possibility that in the absence of input linkages, output shares would be different. Without a full-fledged model calibrated with all of the relevant elasticities, it would be impractical to specify a set of counterfactual output shares. Our approach has the virtue of transparency and maximum comparability between the actual PPIs and the counterfactual cost measures.

2.2 Metrics of Synchronization

We employ three metrics for the extent of international synchronization in $\widehat{PPI12}_{c,t}$ and $\widehat{C12}_{c,t}$. It is important to emphasize that these are simply statistical devices that summarize the extent of the comovement in a data sample. The first, following Ciccarelli and Mojon (2010), is the R^2 of the regression of each country's $\widehat{PPI12}_{c,t}$ and $\widehat{C12}_{c,t}$ on the corresponding unweighted global average of the same measure (excluding the country itself).

The second and third are based on estimating a factor model on the panel of PPI and cost shock series:

$$X_{c,t} = \lambda_c F_t + \epsilon_{c,t}, \tag{10}$$

where the left-hand side variable $X_{c,t}$ is, alternatively, $\widehat{PPI12}_{c,t}$ or $\widehat{C12}_{c,t}$. According to (10), the cross-section of inflation rates/cost shocks at any t is equal to a factor F_t common to all countries times a country-specific, non-time-varying coefficient λ_c, plus a country-specific idiosyncratic shock $\epsilon_{c,t}$. None of the objects on the right-hand side of (10) are observed, but they can be estimated. As is customary, the factor analysis is implemented after standardizing each country's data to have mean zero and standard deviation 1. This ensures that countries with more volatile inflation rates do not have a disproportionate impact on the estimated values of the common factor. After estimating the factor model, the metric for synchronization is the share of the variance of inflation in country c accounted for by the global factor F_t: $Var(\lambda_c F_t)/Var(X_{c,t})$.

We implement two variations of (10). The first is a static factor model in which the parameters are recovered through principal components, as in Ciccarelli and Mojon (2010). The second is a dynamic factor model based on Jackson et al. (2015) in which both F_t and $\epsilon_{c,t}$ are assumed to follow AR(p) processes:

$$F_t = \sum_{l=1..p_F} \phi_l F_{t-l} + u_t \tag{11}$$

$$\epsilon_{c,t} = \sum_{l=1..p_\epsilon} \rho_{c,l} \epsilon_{c,t-l} + \mu_{c,t}. \tag{12}$$

The precise implementation of the Bayesian estimation of this model's parameters is a simplified special case of the more general one described in Section 5 below.

3 Data and Basic Patterns

3.1 Data

The empirical implementation requires data on (i) industry-level PPI and (ii) cross-border input-output linkages. A contribution of our paper is the construction of a cross-country panel dataset of monthly sectoral producer prices that can be merged with existing datasets on input-output use.

The PPI data were collected from international and national sources. The frequency is monthly. The PPI series come from the Eurostat database for those countries covered by it. Because many important countries (the US, Canada, Japan, China) are not in Eurostat, we collected PPI data for these countries from national sources, such as the BLS for the US and StatCan for Canada. Unfortunately, the sectoral classifications outside of Eurostat tend to be country-specific and require manual harmonization.

Information on input linkages comes the World Input-Output database (WIOD) described in Timmer, Dietzenbacher, Los, Stehrer and de Vries (2015), which provides a global input-output matrix. It reports, for each country and output sector, input usage broken down by source sector and country. The WIOD is available at yearly frequency and covers approximately 40 countries. Merging the PPI and WIOD databases required further harmonization of the country and sector coverage. The sectoral classifications of the original PPI series are concorded to a classification that can be merged with the WIOD database, which uses two-letter categories that correspond to the ISIC (rev. 3) sectoral classification. Appendix Table A1 shows the conversion tables used in the process.

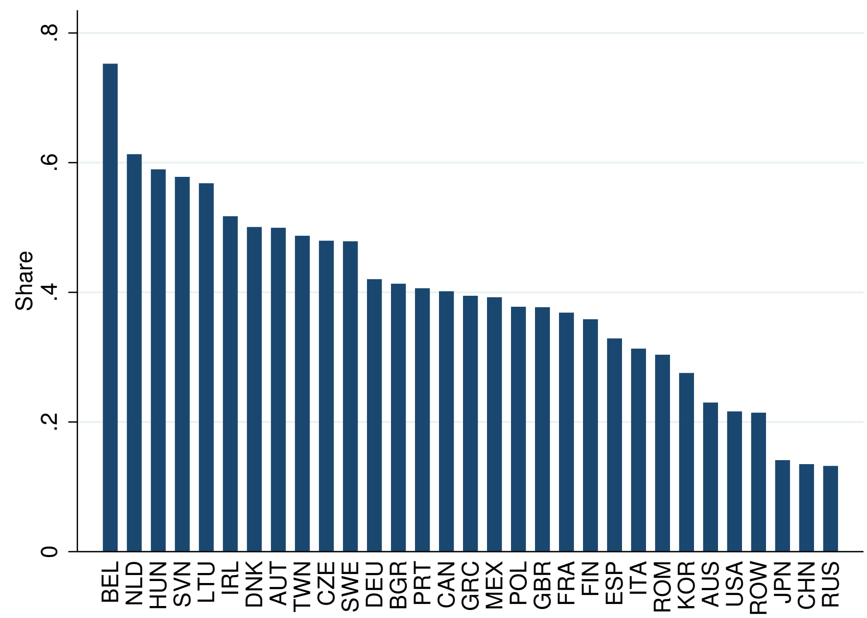
The final sample includes 30 countries plus a composite Rest of the World (ROW) category, 17 tradable sectors, and runs from 1995m1 to 2011m12. Appendix Table A2 reports the list of countries and sectors used in the analysis. Additionally, some countries are included in the "Rest of the World" category because of an excessive share (> 0.4) of missing data in the PPI. These are summarized in Appendix Table A3. While the PPI data are recorded monthly, the input coefficients $\gamma_{c,u,e,s,t}$ come from WIOD and thus change annually.

The empirical methodology requires a balanced sample of countries$\times$sectors$\times$months, necessitating some interpolation. When the original PPI frequency is quarterly, the monthly PPI levels are interpolated from the quarterly information. Other missing PPI observations are extrapolated using a regression of a series inflation on seasonal monthly dummies (e.g., a missing observation for January is set to the average January inflation for that series). If a country-sector series is missing over the entire time horizon (9 cases out of the 527 series), its inflation values are extrapolated based on the rest of the country's series. Overall, 9.8% of the PPI values are extrapolated.

An important feature of the PPI index is that it only covers the industrial sector in the majority of countries. Thus, service sector prices are not included in the baseline analysis. Section 4.2 and Appendix B present a battery of robustness exercises that assess the role of non-PPI sectors in the cost shock transmission across countries.

Figure 1 reports the share of foreign inputs in the overall input usage in each country. On

Figure 1. Imported Input Use by Country



Notes: This figure displays the share of imported inputs in total input purchases, by country.

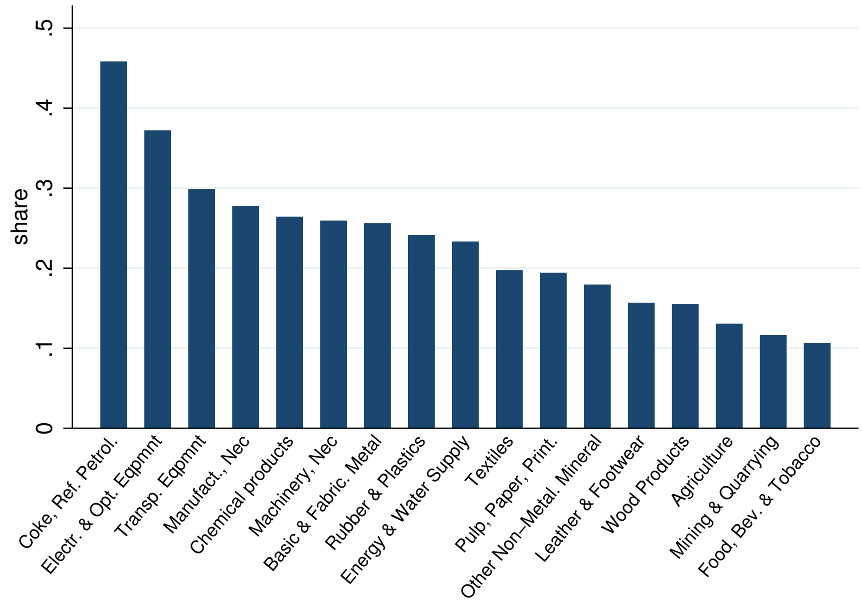
average in this sample of countries, 0.4 of the total input usage comes from foreign inputs, but there is considerable variation, from less than 0.2 for Russia, China, and Japan to nearly 0.8 for Belgium. Figure 2 reports the cross-sectoral variation in the same measure, defined as the share of imported inputs in the total input usage in a particular sector worldwide. Sectors differ in their input intensity, with over 0.4 of all inputs being imported in the Coke and Petroleum sector but only approximately 0.1 in the Food and Beverages sector.

Figure 3 gives a sense of the time variation in the intensity of foreign input usage. The share of foreign inputs in total input purchases rose from approximately 0.2 to nearly 0.3 from 1995 to the eve of the Great Trade Collapse and then fell to 0.24.

3.2 Tracing Inflation Shocks Through Input Linkages

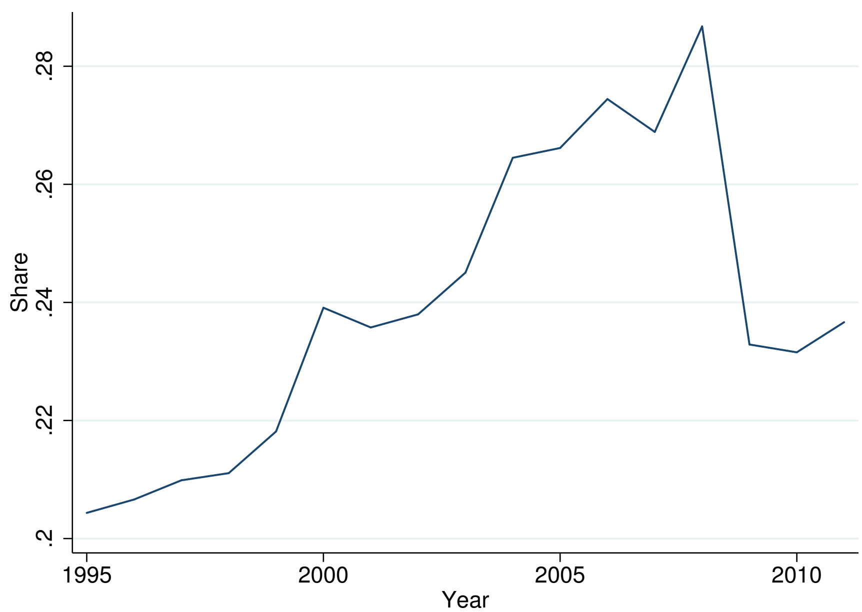
Before using the PPI data in the estimation of the common factors, we use the WIOD to examine the nature of the cross-border input-output linkages. We make use of the relation

Figure 2. Imported Input Use by Sector



Notes: This figure displays the share of imported inputs in total input purchases, by sector.

Figure 3. Imported Input Use over Time



Notes: This figure displays the share of imported inputs in total input purchases, over time.

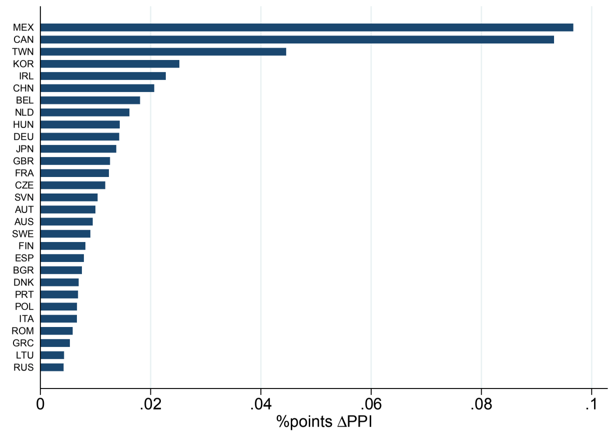
(6) to go from the shocks to the resulting PPI. This requires solving for the equilibrium PPI series using the Leontief inverse. Stacking countries and sectors, and ignoring exchange rate movements, the equilibrium PPI series given a vector of cost shocks are as follows:

$$\widehat{\mathbf{PPI}} = (\mathbf{I} - \mathbf{\Gamma}')^{-1}\,\mathbf{D}\widehat{\mathbf{C}}. \tag{13}$$

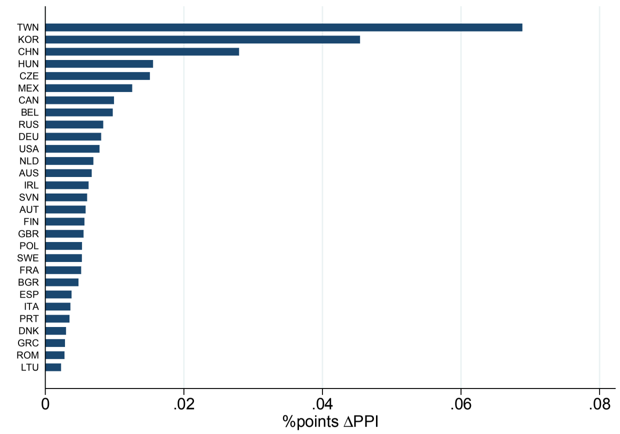
To gauge the extent to which input linkages propagate inflationary shocks, we feed into the world input-output matrix several hypothetical underlying cost shocks $\widehat{\mathbf{C}}$. The first set are inflationary shocks to three largest economies in the world: the US, Japan, and China. In the case of the US, for instance, these are shocks to $\widehat{\mathbf{C}}$ that lead to a PPI inflation of 1% in the US. By construction, only US entries of the cost shock $\widehat{\mathbf{C}}$ are non-zero: the assumption is that only the US experiences a shock. Nonetheless, other countries' PPIs can react to the US shock because the US sectors are part of the global value chain (equation 13). Another shock we feed in is a worldwide 10% shock to the energy sector, intended to simulate an increase in oil prices. Note that the magnitude and sign of the shock do not matter in this exercise, as evidenced by the linear system (13), so these could be deflationary shocks to the key countries or declines in energy prices.

Figure 4 presents the results. Several conclusions are noteworthy. First, the foreign impact of a cost shock to an individual country is quantitatively limited. A 1% inflation rate in the US produces inflation of approximately one-tenth that amount in Canada and Mexico, by far the most closely connected economies to the US. In 5 other countries, the impact is 0.02% or greater, or one-fiftieth of US inflation. In nearly half the countries, the impact is smaller than 0.01%, or one-hundredth of US inflation. The pattern is similar for the Japanese and Chinese shocks. In each case, there are 2-3 countries with an inflation rate of approximately one-tenth of the country being subjected to the shock, while the rest of the sample experiences small inflation changes.

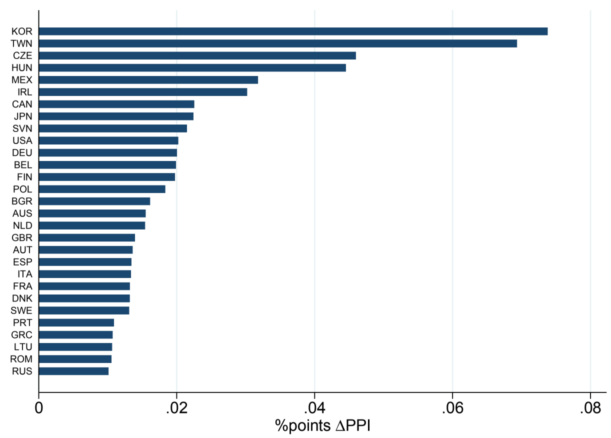
Figure 4. Spillovers from Cost Shocks to Selected Countries and Energy Prices



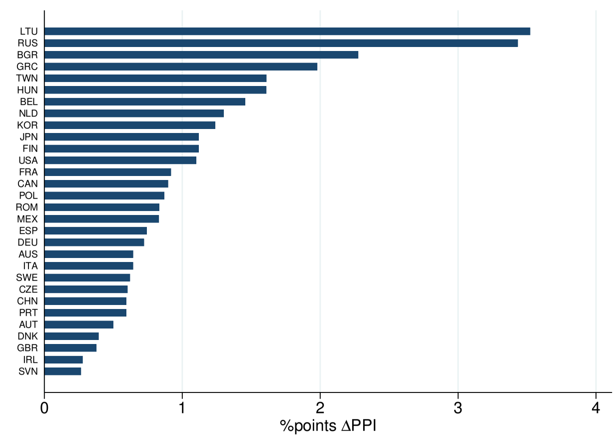
(a) A 1% US Inflationary Shock



(b) A 1% Japan Inflationary Shock



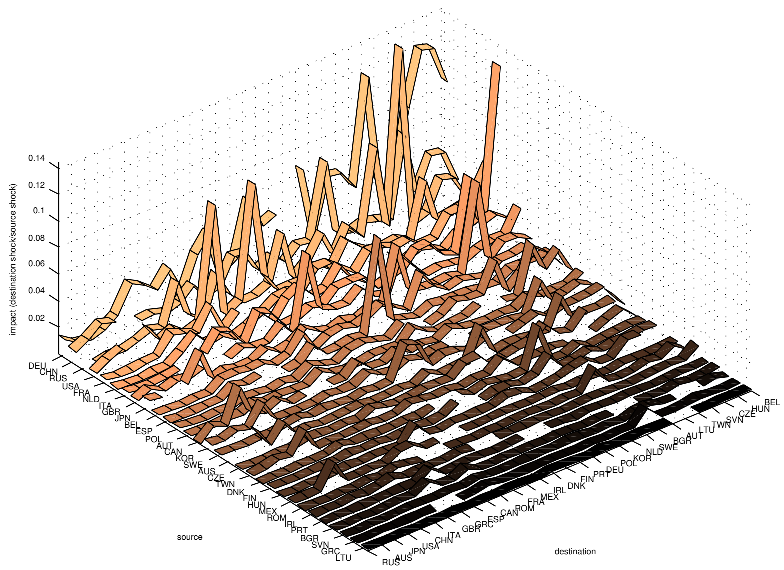
(c) A 1% China Inflationary Shock



(d) A 10% Rise in Energy Prices Worldwide

Notes: This figure presents the change in PPI in each country in our sample following 4 hypothetical shocks: (a) a shock that leads to 1% inflation in the US; (b) a shock that leads to 1% inflation in Japan; (c) a shock that leads to 1% inflation in China; and (d) a worldwide 10% increase in energy prices.

Figure 5. The Proportional Impact of Each Source Country's Inflation Shock on Each Destination Country's Inflation



Notes: This figure displays the proportional impact of an inflationary shock in each source country (right axis) on inflation in each destination country (left axis).

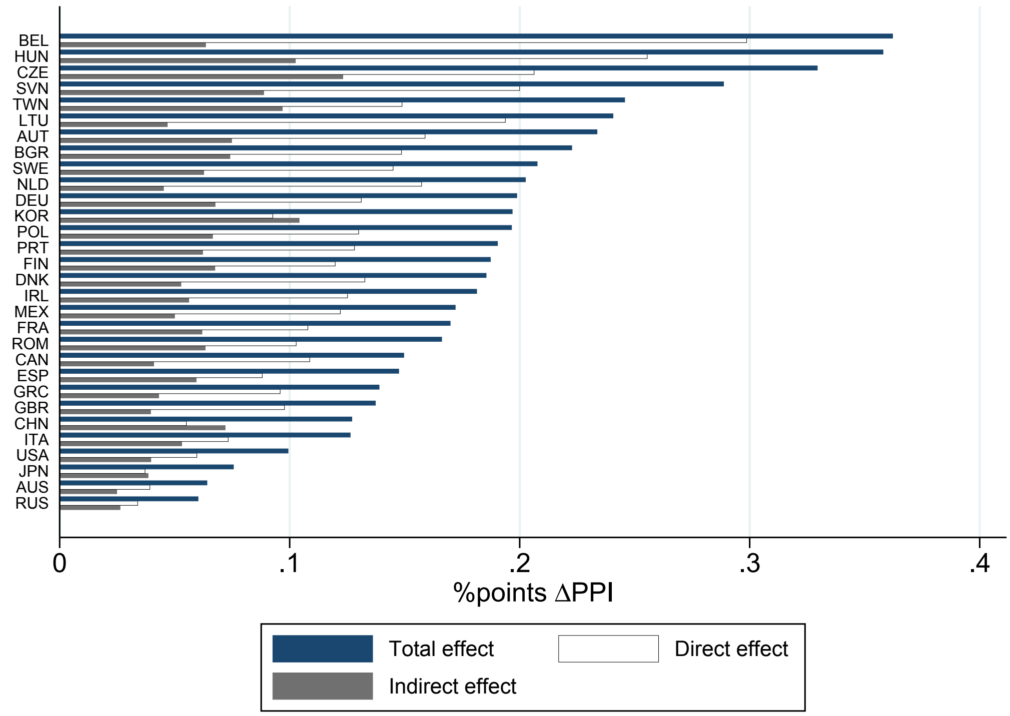
The last panel of Figure 4 reports the global impact of a 10% global energy sector shock. Unsurprisingly, as the shock is global, the impact is much stronger and much more widespread. Nonetheless, it is also remarkable how much heterogeneity there is, from a 3.5% impact in Lithuania and Russia to 0.3% in Ireland and Slovenia. Figure 5 presents the generalization of Figures 4(a)-4(c) by plotting the proportional impact of an inflationary shock affecting each source country on each destination country in the sample. That is, it reports

$$\frac{\Delta PPI_{dest}}{\Delta PPI_{source}}$$

when *source* is the country experiencing an inflation shock. To make the plot more readable, we drop the own impact entries ($source = dest$), which accounts for the "blank" spots on the graph. The source countries are sorted from most to least important in average outward impact, and the same is done for destination countries.

The impact of inflationary shocks is highly heterogeneous across both sources and des-

Figure 6. Spillovers from a 1% Inflationary Shock in Every Other Country



Notes: This figure displays the impact of an inflationary shock that leads to average 1% inflation in the other countries in the world.

tinations. Inflationary shocks to some countries, such as Lithuania, Greece, Slovenia, or Bulgaria, have virtually no discernible impact on inflation in other countries. This is because those countries are not important input suppliers to other countries. At the other end of the spectrum, the top 5 countries in terms of their impact on foreign inflation are Germany, China, Russia, the US, and Italy. Germany's impact is both highest on average (0.04 of $\Delta PPI_{dest}/\Delta PPI_{DEU}$ when averaging over $dest$) across the whole sample and the most diffuse. For 10 countries (all of which are in Europe), the impact is above 0.05, and for the top 3 – Hungary, the Czech Republic, and Austria – the impact is above 0.1. Russia's impact is approximately half of Germany's (0.02) and more concentrated, with only 2 countries – Lithuania and Bulgaria – with an impact of over 0.05.

It is not surprising that the bilateral impact of an inflationary shock is limited. A related question is whether global inflation shocks transmit significantly into countries. We thus consider an experiment in which, for each country, we generate a shock that raises inflation by an average of 1% in all the other countries in the world. The blue/dark bars in Figure 6 report the results. Global inflationary shocks can have substantial impacts on country-level inflation. On average, a 1% shock to global PPI inflation leads to a 0.19% increase in domestic PPI. There is substantial heterogeneity, and at the top end, there are 3 countries that exhibit elasticities with respect to global inflation of over 0.3: Belgium, Hungary, and the Czech Republic. Russia, Australia, Japan, and the US appear the least susceptible to global inflation shocks, with impacts in the range 0.06-0.10.

We also assess the extent to which the total impact of foreign inflation on domestic prices is due to the direct (first round) vs. indirect effects. The direct effect is simply the change in domestic prices due to the change in foreign input prices following the cost shock:

$$\widehat{\mathbf{PPI}} = (\mathbf{I} + \mathbf{\Gamma}')\, \mathbf{D}\widehat{\mathbf{C}}.$$

The indirect effect captures the fact that a country's foreign inputs in turn use other inputs, that also experienced a cost shock, and so on ad infinitum. The white and gray/light bars of Figure 6 report the direct and indirect effects, respectively. Both are quantitatively important. The mean of the indirect component, at 0.06, is about one third of the mean total impact. In three countries – China, South Korea, and Japan – the indirect component accounts for more than half of the total effect. The size of indirect effects underscores the importance of analyzing the full global network of input trade rather than only bilateral linkages.

Because the baseline analysis is undertaken primarily using sectors covered by PPI (listed in Appendix Table A2), Figures 4-6 plot the responses of PPI sectors to cost shocks in the PPI sectors. However, since these exercises use no actual price data, we could also simulate the cost shocks and price responses of all sectors – both PPI and services – covered by WIOD. Appendix figures A1-A3 repeat the exercises above on all the WIOD sectors.

The magnitudes are quite similar to those in Figures 4-6.

4 Input Linkages and Global Inflation Comovement

Table 1 reports the main inflation synchronization results. Panel A reports the R^2 metric, Panel B the static factor model metric, and Panel C the dynamic factor model metric. The columns labeled $\widehat{PPI12}_{c,t}$ present the results for the actual PPI. We confirm that there is considerable global synchronization in PPI, just as was found for CPI in previous work. The simple average of other countries' inflation produces an average R^2 of 0.365 at the mean and 0.317 at the median in this sample of countries. The global static factor accounts for 0.463 of the variance of the average country's inflation at the mean and 0.511 at the median. The dynamic factor delivers very similar averages: 0.447 at the mean and 0.488 at the median.

The three methods thus reveal quite similar levels of synchronization in actual PPI. They also produce similar answers regarding the cross-country variation. In the cross-section of countries, the R^2 metric has a nearly 0.9 correlation with both the static and the dynamic variance shares. The static and dynamic variance shares have a 0.997 correlation across countries. According to all three measures, there is a fair bit of country heterogeneity around these averages, with Spain, Germany, and Italy being the most synchronized countries according to both metrics, and Romania, Slovenia, and Korea at the other extreme.

The columns labeled $\widehat{C12}_{c,t}$ present the same statistics for the cost shocks. It is clear that input linkages have considerable potential to explain observed synchronization in PPI. The average R^2 for the cost shocks falls to 0.166 (mean) and 0.122 (median). The static global factor explains 0.294 (mean) and 0.281 (median) of the variation in $\widehat{C12}_{c,t}$ for the average country, and the dynamic factor explains 0.252 (mean) and 0.240 (median).

The difference between synchronization metrics for $\widehat{C12}_{c,t}$ and $\widehat{PPI12}_{c,t}$ can be inter-

Table 1. Synchronization in Actual PPI and Cost Shocks

	Panel A: R^2		Panel B: Static Factor		Panel C: Dynamic Factor	
Country	$\widehat{PPI12}_{c,t}$	$\widehat{C12}_{c,t}$	$\widehat{PPI12}_{c,t}$	$\widehat{C12}_{c,t}$	$\widehat{PPI12}_{c,t}$	$\widehat{C12}_{c,t}$
AUS	0.529	0.203	0.596	0.371	0.538	0.188
AUT	0.261	0.031	0.570	0.140	0.515	0.180
BEL	0.646	0.447	0.755	0.562	0.745	0.436
BGR	0.524	0.029	0.461	0.001	0.420	0.012
CAN	0.560	0.174	0.604	0.510	0.573	0.271
CHN	0.317	0.094	0.665	0.408	0.651	0.214
CZE	0.323	0.188	0.264	0.197	0.252	0.328
DEU	0.729	0.382	0.860	0.404	0.860	0.550
DNK	0.226	0.330	0.224	0.242	0.223	0.293
ESP	0.736	0.435	0.931	0.789	0.918	0.795
FIN	0.318	0.123	0.652	0.470	0.598	0.337
FRA	0.617	0.489	0.689	0.368	0.699	0.472
GBR	0.217	0.031	0.524	0.433	0.480	0.277
GRC	0.118	0.035	0.090	0.000	0.079	0.023
HUN	0.277	0.123	0.075	0.001	0.073	0.031
IRL	0.081	0.048	0.104	0.035	0.096	0.044
ITA	0.730	0.234	0.826	0.506	0.860	0.617
JPN	0.439	0.104	0.735	0.388	0.690	0.210
KOR	0.013	0.000	0.048	0.048	0.027	0.025
LTU	0.369	0.019	0.678	0.228	0.637	0.266
MEX	0.054	0.000	0.063	0.018	0.064	0.003
NLD	0.716	0.480	0.808	0.671	0.831	0.577
POL	0.103	0.258	0.184	0.299	0.165	0.298
PRT	0.524	0.122	0.499	0.196	0.495	0.247
ROM	0.046	0.073	0.000	0.017	0.002	0.005
RUS	0.281	0.130	0.215	0.264	0.225	0.144
SVN	0.104	0.024	0.025	0.006	0.021	0.043
SWE	0.261	0.024	0.499	0.227	0.473	0.154
TWN	0.286	0.053	0.492	0.445	0.466	0.233
USA	0.541	0.308	0.766	0.572	0.737	0.288
mean	0.365	0.166	0.463	0.294	0.447	0.252
median	0.317	0.122	0.511	0.281	0.488	0.240
min	0.013	0.000	0.000	0.000	0.002	0.003
max	0.736	0.489	0.931	0.789	0.918	0.795

Notes: Panel A reports the R^2s of the regression of the country's inflation ($\widehat{PPI12}_{c,t}$) or the cost shock ($\widehat{C12}_{c,t}$) on the simple average inflation or the cost shock of all the other countries in the sample. Panel B reports the share of the variance in the country's inflation ($\widehat{PPI12}_{c,t}$) or the cost shock ($\widehat{C12}_{c,t}$) accounted for by the common static factor F_t. Panel C reports the results when assuming a dynamic factor. Country code definitions are reported in Appendix Table A2.

preted as the contribution of global input linkages to the observed inflation synchronization. According to the most modest metric – the static factor – input linkages account for 37% (45%) of observed synchronization at the mean (median). The R^2 metric implies the largest contribution, with input linkages responsible for 54% (62%) of observed synchronization at the mean (median). The dynamic factor results lie in between.

4.1 Understanding the Mechanisms

We now perform a battery of alternative implementations designed to better understand under what conditions input linkages create inflation comovement. Namely, we examine the role of exchange rates; the importance of incomplete pass-through; and the nature of domestic and international linkages. Section 5 estimates the relative roles of global and sectoral shocks.

4.1.1 Imperfect Pass-Through and Pricing-to-Market

We begin by evaluating the role of exchange rates in the baseline results. Examining equation (5) that states how the cost shocks are recovered, it is clear that the procedure assumes that exchange rate shocks are transmitted to the input-importing country with the same intensity as price shocks. That is, a change in the local cost of the foreign input-supplying country is simply additive with the change in the exchange rate. While to us this appears to be the most natural case to consider, it is possible that the pass-through of exchange rate shocks is different from the pass-through of marginal cost shocks. It is also well-known that exchange rates are much more volatile than price levels, and thus, when we in effect recover the cost shocks as linear combinations of price and exchange rate changes, the variability in exchange rates can dominate and make the cost shocks more volatile.[7]

[7]Note that this will not mechanically reduce comovement in the cost shocks compared to PPIs, as both data samples are standardized prior to applying factor analysis.

Table 2. Alternative Implementations: Imperfect Pass-Through and Pricing-to-Market

	R^2	Static Factor	Dynamic Factor		R^2	Static Factor	Dynamic Factor
	Baseline						
$\widehat{PPI12}_{c,t}$							
mean	0.365	0.463	0.447				
median	0.317	0.511	0.488		Alt. cost shocks: No $\widehat{E}_{c,e,t}$		
$\widehat{C12}_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.166	0.294	0.252	mean	0.171	0.327	0.300
median	0.122	0.281	0.240	median	0.091	0.313	0.229
	Pricing complementarity, $\beta = 2/3$				Mechanical pass-through, $\beta^m = 2/3$		
$\widehat{C12}_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.106	0.200	0.165	mean	0.258	0.379	0.354
median	0.051	0.187	0.085	median	0.231	0.378	0.372
	Pricing complementarity, $\beta = 1/3$				Mechanical pass-through, $\beta^m = 1/3$		
$\widehat{C12}_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.085	0.214	0.159	mean	0.277	0.416	0.390
median	0.040	0.141	0.143	median	0.259	0.469	0.421
	Pricing complementarity, β_u				Mechanical pass-through, β_u^m		
$\widehat{C12}_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.105	0.205	0.165	mean	0.266	0.387	0.365
median	0.051	0.187	0.081	median	0.243	0.402	0.388

Notes: This table reports the mean and median of the R^2s (first column) and of the shares of variance explained by the static and dynamic factors (second and third columns) under alternative implementations of the analysis. The assumptions in each scenario are described in detail in the text.

To determine the role of exchange rate shocks in our results, we carry out the same analysis of recovering the cost shocks and extracting a common component, while ignoring the exchange rate movements. Note that this is deliberately an extreme case: exchange rate pass-through is positive according to virtually all available estimates, whereas here we in effect set it to zero and retain only the PPI changes as cost shocks. Table 2 presents the results. To facilitate comparison across scenarios, the top left panel of the table reproduces from Table 1 the mean and median of the R^2's and of the shares of variance accounted for by the static and dynamic factors for actual PPI and the baseline recovered cost shocks. The panel labeled "Alt. cost shocks: No $\widehat{E}_{c,e,t}$" reports the results ignoring exchange rate movements. It turns out that doing so leaves the implied contribution of input linkages to inflation synchronization virtually unchanged. According to all three metrics, the variance shares of the global factor for cost shocks recovered while ignoring exchange rates are quite similar to the baseline.

An active literature has explored the role of demand complementarities and pricing-to-market in the determination of international prices and exchange rate pass-through (Dornbusch 1987, Atkeson and Burstein 2008). Under some market structures and demand systems, firms set their prices as a function of both their cost shocks and the prices of other firms serving a particular market. In other words, instead of (4), prices and costs have the following relationship:

$$\widehat{p}_{c,u,e,s,t} = \beta(\widehat{W}_{e,s,t} + \widehat{E}_{c,e,t}) + (1-\beta)\widehat{P}_{c,u,t} \tag{14}$$

where

$$\widehat{P}_{c,u,t} = \sum_{e,s} \sigma_{c,u,e,s,t-1}\widehat{p}_{c,u,e,s,t} \tag{15}$$

and $\sigma_{c,u,e,s,t-1} = \gamma_{c,u,e,s,t-1}/(1-\gamma^{C}_{c,u,t-1})$ is the market share of good e,s in market c,u (see, e.g. Burstein and Gopinath 2015).[8] Since in this formulation all prices depend on all the

[8]In this formulation, the "market" defined by price complementarities is all the inputs purchased by sector u in country c, rather than the entire country c. This assumption is important for tractability, but

other prices, extracting the cost shocks from observed PPI series is more challenging, but can still be done in one step. Appendix A sets up a general framework that nests multiple assumptions on pass-through, and presents the detailed derivations.

We implement the counterfactuals allowing for price complementarities under three alternative assumptions on β: (i) 1/3, (ii) 2/3, and (iii) sector-specific β_u. The values for β of 1/3 to 2/3 reflect the considerable uncertainty in the literature regarding the correct value for the pass-through coefficient. For example, Goldberg and Campa (2010) report an estimate of the exchange rate pass-through rate into import price indices of 0.61 in a sample of 19 advanced economies, and Burstein and Gopinath (2015) report an updated estimate of 0.69. However, pass-through into import prices is estimated to be much lower when looking at individual import prices. For example, Burstein and Gopinath (2015) report an average pass-through rate of 0.28 in the large micro dataset underlying the official US import price indices.[9] In the third scenario, we use sector-specific values of β_u from Osbat and Wagner (2010). The resulting values of β_u have a mean of 2/3, and a range of 0.4 to 0.92.

The three panels labeled "Pricing complementarity" in Table 2 report the results for the three assumptions on β. If anything, allowing for pricing-to-market further reduces the amount of synchronization in $\widehat{C}$. According to all three of our metrics, a smaller share

implies that markets are segmented between input-purchasing sectors in each country. This would be the case, for instance, if inputs are sufficiently customized that the input-purchasing sector cannot arbitrage away price differences across sectors within its country.

[9] See also Gopinath and Rigobon (2008) or Auer and Schoenle (2016). Note however that studies examining the response of highly disaggregated firm-and-product-specific *unit values* to the exchange rate obtain much larger pass-through coefficients (Berman et al. 2012, Amiti et al. 2014). The discrepancy between the pass-through for individual goods and that for aggregate series may relate to the difficulty of handling product substitutions in microeconomic data and of aggregating microeconomic price fluctuations into import price indices when the bundle of goods is non-constant (see Nakamura and Steinsson 2012, Gagnon, Mandel and Vigfusson 2014). In this context, an important finding is that of Cavallo, Neiman and Rigobon (2014), who focus on the relative price of newly introduced products and document that the relative price of identical new goods introduced in two different markets tracks the nominal exchange rate with an elasticity of approximately 0.7. A further difficulty concerns the distinction between exchange rate and cost pass-through. While the literature has yielded a range of estimates for exchange rate pass-through, there is comparatively little work on the pass-through of cost shocks or on how the import content of exports affects pass-through (for exceptions, see Auer and Mehrotra, 2014 and Amiti, Itskhoki and Konings, 2014, 2016).

of variance in these recovered cost shocks is explained by the common factor than in the baseline, though the magnitudes are similar. The results are also not sensitive to whether we set β to 1/3 or 2/3. Introducing sectoral heterogeneity in β_u (bottom panel) leads to very similar conclusions. The results are exceedingly similar to those under $\beta = 2/3$, which is not surprising since that is also the average value of the sector-specific β_u's.

We contrast these results with a simpler alternative, in which pass-through is imperfect but there are no demand complementarities. Corsetti and Dedola (2005) provide a microfoundation for such a pass-through formulation in a framework with CES demand and a competitive distribution sector, which leads to variable elasticity of demand perceived by firms. That is, cost shocks are passed through to prices with elasticity β^m strictly less than 1:

$$\widehat{PPI}_{c,u,t} = \beta^m \widehat{W}_{c,u,t},$$

and

$$\widehat{p}_{c,u,e,s,t} = \beta^m \left(\widehat{W}_{e,s,t} + \widehat{E}_{c,e,t} \right).$$

We refer to this scenario as "mechanical pass-through," and report the results in the three bottom right panels of Table 2, for the same three assumptions on β^m as in the price complementarity exercises: 1/3; 2/3; and sector-specific. Under mechanical incomplete pass-through, the results are sensitive to β^m, and imply a smaller contribution of input linkages to synchronization when β^m is substantially less than 1. This is sensible: a lower β^m by construction reduces the difference between $\widehat{PPI}_{c,u,t}$ and $\widehat{C}_{c,u,t}$. Because under lower pass-through the two series become more similar, the share of variance explained by the global factor also becomes more similar. Once again, the sector-specific results in the bottom panel look quite similar to those under $\beta^m = 2/3$.

The difference between these results and the ones with demand complementarities is stark. Whereas lower mechanical pass through rates imply a smaller impact of input linkages on inflation synchronization, that is not the case once we use a realistic pricing-to-market framework taking into account that more limited pass-through also means a higher degree of price complementarities. Imperfect cost pass-through and price complementarities interact in such a way that allowing for pricing-to-market does not change the magnitude of the contribution of input linkages to inflation comovement. As β decreases, the higher price complementarities thus seem to offset the reduced impact of direct cross-border spillovers.

4.1.2 Heterogeneity in International Input Linkages

An active recent literature has argued that the extent of heterogeneity in the input-output linkages matters for the propagation of idiosyncratic shocks to the aggregate economy through the input-output network (see, e.g. Acemoglu, Carvalho, Ozdaglar and Tahbaz-Salehi 2012, Acemoglu, Ozdaglar and Tahbaz-Salehi 2017). We thus evaluate the role of heterogeneity in input usage across countries and sectors for synchronizing national inflation rates. To this end, we construct two counterfactual scenarios for PPI under "balanced" input-output linkages. The first scenario preserves the cross-country heterogeneity in input linkages but assumes that within each pair of importer-exporter countries, there are no differences across sectors. That is, we assume a counterfactual input-output matrix $\mathbf{\Gamma}'_{b1}$ with the following elements:

$$\gamma^{b1}_{c,u,e,s} = \frac{1}{S^2} \sum_{k \in S, l \in S} \gamma_{c,k,e,l}.$$

This counterfactual, labeled "$b1$", suppresses sectoral heterogeneity within each country-pair. It is designed to mimic a one-sector model, in which countries use one another's aggregate inputs to produce a single output.

The second counterfactual instead focuses on cross-country heterogeneity. It implements a counterfactual scenario in which the input-output matrix $\mathbf{\Gamma}'_{b2}$ is assumed to have the elements

$$\gamma^{b2}_{c,u,e,s} = \begin{cases} \frac{1}{S^2} \sum\limits_{k \in S, l \in S} \gamma_{c,k,e,l} & \text{if } c = e \\ \frac{1}{(N-1)S^2} \sum\limits_{k \in S, l \in S, e' \in N \setminus \{c\}} \gamma_{c,k,e',l} & \text{if } c \neq e \end{cases}$$

That is, it assumes that all domestic linkages are equal to the average domestic linkage observed in the data and that all international linkages for all sectors and countries are equal to the average international linkage. Finally, these counterfactual γ values are rescaled such that the total share of non-materials inputs in output in each sector and country $\gamma^C_{c,u}$ remains the same as in the baseline, to avoid confounding the heterogeneity in input linkages *per se* with overall input intensity.

The counterfactual PPI is given by

$$\widehat{\mathbf{PPI}}_{counter} = (\mathbf{I} - \mathbf{\Gamma}'_{counter})^{-1} \left(\mathbf{D}\widehat{\mathbf{C}} + \widetilde{\mathbf{\Gamma}}'_{counter} \widehat{\mathbf{E}} \right), \tag{16}$$

for $counter = \{b1, b2\}$, where $\widetilde{\mathbf{\Gamma}}_{counter}$ is the counterfactual version of (7), which uses the elements of the counterfactual $\mathbf{\Gamma}$ matrix instead of the actual values. Just as in the baseline analysis, equation (16) assumes complete pass-through of cost shocks to prices.

The panels "Balanced 1" and "Balanced 2" of Table 3 report the results. The variance shares accounted for by the common factors are lower than for the actual PPI in these counterfactuals, but these values are closer to the actual PPI than to the baseline cost shocks. The magnitudes also differ somewhat across metrics. The difference between the balanced counterfactual PPIs and the actual PPIs is highest according to the R^2 metric, with the mean R^2 being 33% lower than in the data in the Balanced 1 scenario and 16% lower in the Balanced 2 scenario. The factor models imply smaller differences, only approximately 20% for Balanced 1 and less than 10% for Balanced 2. Indeed, comparing medians in the Balanced 2 scenario, there is actually a small increase in the common component relative to the baseline. This suggests there may be some role for the input linkage heterogeneity in generating the observed comovement, but that the average overall linkages *per se* represents the single most important mechanism.

Table 3. Alternative Implementations: Input Linkages

	R^2	Static Factor	Dynamic Factor
		Baseline	
$\widehat{PPI12}_{c,t}$			
mean	0.365	0.463	0.447
median	0.317	0.511	0.488
$\widehat{C12}_{c,t}$			
mean	0.166	0.294	0.252
median	0.122	0.281	0.240
		Symmetric input linkages	
Balanced 1 (sectors), $\widehat{PPI12}_{c,t}^{counter}$			
mean	0.243	0.363	0.338
median	0.183	0.397	0.326
Balanced 2 (countries+sectors), $\widehat{PPI12}_{c,t}^{counter}$			
mean	0.306	0.430	0.414
median	0.265	0.543	0.520
		Domestic input linkages	
$\widehat{PPI12}_{c,t}^{counter}$			
mean	0.258	0.367	0.335
median	0.228	0.325	0.313

Notes: This table reports the mean and median of the R^2s (first column) and of the shares of variance explained by the static and dynamic factors (second and third columns) under alternative implementations of the analysis. The assumptions in each scenario are described in detail in the text.

4.2 Robustness

As emphasized above, the baseline analysis simply aggregates the cost shocks and thus cleans out the effect of not only international but also domestic input linkages. There is no obvious reason why purely domestic linkages should synchronize inflation internationally. Nonetheless, we construct an alternative counterfactual to be compared to $\widehat{PPI}12_{c,t}$, that assumes away international input linkages but preserves the domestic linkages. This exercise constructs counterfactual PPI changes that would obtain under recovered cost shocks $\widehat{C}12_{c,u,t}$ in an economy in which there is input usage, but all of it domestic. Namely, we define the "autarky" counterfactual PPI change as follows:

$$\widehat{\mathbf{PPI}}_{AUT} = \left(\mathbf{I} - \mathbf{\Gamma}'_{AUT}\right)^{-1} \mathbf{D}\widehat{\mathbf{C}},$$

where $\mathbf{\Gamma}'_{AUT}$ is the counterfactual input-output matrix that forces all linkages to be domestic:

$$\mathbf{\Gamma}'_{AUT} = \begin{pmatrix} \mathbf{\Gamma}'_{AUT,1} & 0 & \dots & 0 \\ 0 & \mathbf{\Gamma}'_{AUT,2} & 0 & \dots \\ 0 & 0 & \dots & 0 \\ 0 & \dots & 0 & \mathbf{\Gamma}'_{AUT,N} \end{pmatrix},$$

and the elements of the $S \times S$ matrix $\mathbf{\Gamma}_{AUT,c}$ are defined as:

$$\gamma_{c,u,s,t} = \sum_{k=1}^{N} \gamma_{c,u,k,s,t}.$$

That is, in each country c, output sector u, all of the usage of sector s inputs observed in the global input-output matrix is reassigned to be supplied domestically.

The results are reported in the panel labeled "Domestic input linkages" of Table 3. These are between the observed PPI and the baseline $\widehat{C}12_{c,t}$, indicating that allowing only for domestic linkages does synchronize inflation rates somewhat relative to the series of cost shocks. At first glance, this may be surprising: in a scenario that "zeros out" international linkages, so that only domestic linkages are operating, one would expect the PPI inflation synchronization to remain low, but it turns out to be higher that synchronization in $\widehat{C12}_{c,t}$. This effect may arise if the underlying cost shocks of some sectors (such as oil and energy) are highly synchronized internationally and, at the same time, constitute important inputs in many other sectors. Nevertheless, introducing domestic linkages does not qualitatively change the main conclusion regarding the importance of cross-border linkages for international synchronization.

A potential concern with our procedure is that not all sectors in WIOD are covered by PPI data. Thus, our baseline procedure will miss the transmission of price shocks through sectors for which PPI data are not available. For instance, if a sector uses imported service inputs, and there is an inflationary shock to services abroad, that would not be captured by our procedure. Similarly, if a PPI sector uses domestic service inputs, and the domestic service sector uses foreign intermediates, then the foreign inflationary shock will be transmitted indirectly through the domestic service sector. We do not have the producer price data for the full set of sectors available in WIOD. Nonetheless, to assess the importance of these omitted sectors, we perform the following three exercises.

First, we explicitly model the higher-order effects. This exercise takes into account the second example above, namely that a sector uses service sector inputs, while the service sector in turn uses imported inputs from a PPI sector. We iterate through the second-, third-, etc. order effects to compute the infinite-order transmission of shocks via the unmeasured sectors. Appendix B presents the procedure for recovering the cost shocks that takes into account the higher-order effects transmitted through the non-PPI sectors.[10] Panel "Higher-order input linkages" of Table 4 reports the results. Once again, if anything the results are strengthened: the common component of $\widehat{C12}_{c,u,t}$ is lower than in the baseline, implying a greater contribution of input linkages to the synchronization of PPI inflation.

Second, we repeat the analysis using all of the sectors in WIOD, and attributing the

[10] The exercise is analogous to applying the Leontief inverse to calculate the Total Requirements Table from the Direct Requirements Table.

Table 4. Robustness: Non-PPI Sectors, Energy Prices, Currency Denomination

	R^2	Static Factor	Dynamic Factor		R^2	Static Factor	Dynamic Factor
		Baseline					
$\widehat{PPI}12_{c,t}$							
mean	0.365	0.463	0.447				
median	0.317	0.511	0.488			Higher-order input linkages	
$\widehat{C12}_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.166	0.294	0.252	mean	0.139	0.253	0.210
median	0.122	0.281	0.240	median	0.074	0.249	0.110
		No Oil				Imputed service inputs	
$\widehat{PPI}12_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.328	0.416	0.396	mean	0.113	0.208	0.182
median	0.277	0.444	0.413	median	0.089	0.153	0.110
		USD-denominated				Service Sector CPI	
$\widehat{PPI}12_{c,t}$				$\widehat{PPI}12_{c,t}$			
mean	0.652	0.670	0.633	mean	0.211	0.323	0.281
median	0.757	0.791	0.731	median	0.112	0.227	0.261
$\widehat{C12}_{c,t}$				$\widehat{C12}_{c,t}$			
mean	0.548	0.575	0.556	mean	0.114	0.201	0.179
median	0.593	0.664	0.629	median	0.047	0.172	0.110

Notes: This table reports the mean and median of the R^2s (first column) and of the shares of variance explained by the static and dynamic factors (second and third columns) under alternative implementations of the analysis. The assumptions in each scenario are described in detail in the text.

overall PPI inflation to the sectors for which actual sectoral PPI data are not available. This procedure captures the transmission of non-PPI sector shocks under the assumption that the non-PPI sectors experience similar inflation as PPI sectors in each country, at least when it comes to the high-frequency movements. The panel "Imputed service prices" of Table 4 presents the results. The cost shocks recovered in this way have an even lower common component than the baseline $\widehat{C12}_{c,u,t}$, making the results stronger.

Third, we collect data on service sector CPI for our sample of countries, and use the service sector CPI as the prices of the non-PPI sectors. This allows us to perform the analysis on all the sectors covered by WIOD. The downside of this exercise is that it is not clear whether consumer prices in the service sector are a good proxy for the producer prices, and thus the service side of the data may not be very comparable to the PPI side of the data. The results are reported in the panel labeled "Service Sector CPI" of Table 4. Adding service sector prices of course leads to a different overall price index, and thus we must compute a new "PPI" baseline aggregate price index that covers the whole economy. We then compare the synchronization in those observed price indices to the recovered cost shocks.

The synchronization of the observed PPI-cum-service CPI is lower than of the PPI itself. This is because service CPI is less correlated across countries than PPI (something that we confirmed separately). Nonetheless, input linkages contribute about as much synchronization in relative terms in this combined price index as in the baseline. The synchronization in the cost shocks is noticeably lower than in the price index itself.

Next, we assess to what extent the synchronization of inflation is due to the energy price shocks. To that end, we construct a counterfactual PPI series that sets all of the $\widehat{C12}_{c,t}$ in the energy sector (Coke, Refined Petroleum, and Nuclear Fuel) to zero, while keeping all of the other cost shocks and the observed global IO structure. The panel labeled "No Oil" in Table 4 presents the synchronization metrics of the resulting counterfactual PPI series. The energy price shocks do contribute modestly to the synchronization of the PPI inflation rates across countries. The metrics of synchronization are about 0.05 lower than for actual PPI across the board. On the one hand, these results reveal the relative importance of this single sector. On the other, it is clear that the bulk of synchronization in the global PPI is not driven by common shocks in, or cross-border transmission of, energy prices.

Finally, we compute our synchronization metrics on the PPI data expressed in common currency. To do that, we convert every country's PPI series to US dollars before running the analysis. Of course, in this version the exchange rate term is always zero, as all the series are in the same currency. The panel labeled "USD-denominated" of Table 4 reports the results. PPIs expressed in the same currency exhibit greater comovement than PPI in local currency. This is intuitive, as every country's inflation is now multiplied by a dollar exchange rate, and if the dollar appreciates/depreciates against multiple currencies at the same time, that introduces a mechanical common component to cross-country price changes. In this setting, input linkages still increase comovement, but the results are more muted. The share of the variance explained by the common factor is about 10 percentage points higher for the actual prices compared to the recovered cost shocks.

To summarize, the baseline results clearly show that the extent of input trade is at present sufficiently high that input linkages could be responsible for the bulk of observed PPI synchronization across countries. This finding is not sensitive to (i) the assumptions placed on exchange rates; (ii) allowing for pricing-to-market with demand complementarities; or (iii) the role of non-PPI sectors. Furthermore, it appears primarily driven by the average volumes of input trade rather than their heterogeneity across countries and sectors (though heterogeneity does play a modest role).

4.3 Direct Measurement of Cost Shock Synchronization

Our cost shocks are recovered from the PPI data itself, and capture all of the shocks to the cost of primary factors (labor and capital), as well as non-tradeable inputs. We adopt this approach because precise measures of the primitive cost shocks are not available. To provide additional evidence on the synchronization of cost shocks, we collected data on Unit Labor Costs (ULC) from Eurostat, OECD, as well as national sources. The ULCs are defined as the nominal unit labor costs in the total economy. This data series is available for only 26 countries in our sample, over the period 1996-2011. The ULC data are also quarterly, and thus cannot be combined with our baseline analysis, which is at monthly frequency. Most importantly, the ULC data are just for labor costs, and thus do not correspond directly to our $\widehat{C}$, which is an encompassing cost variable.[11]

Table 5 reports the results of implementing our analysis on ULCs. Because the sample of countries is different, and the ULC data are quarterly, the top two panels report our baseline results for $\widehat{PPI}$ and $\widehat{C}$ for this subsample of countries and converted to quarterly frequency. The qualitative and quantitative outcomes are very similar to the baseline analysis. The bottom panel implements the factor models on the ULCs. The extent of synchronization in ULCs is lower than for $\widehat{C}$, and much closer to $\widehat{C}$ than to $\widehat{PPI}$. Thus, evidence based on direct measurement accords quite well with our finding that the cost shocks are less synchronized than actual inflation.

5 The Sectoral Dimension

Thus far, we have used different approaches to evaluate the importance of a common global component from the panel of aggregated country series in the model (10). Our underlying data, however, are disaggregated at the country-sector level. Examining sector-level data can tell us more about the nature of the common global factor found above. In particular, by implementing a sector-level decomposition, we can reveal how much of the common global component is in fact due to global sectoral shocks and how a country's sectoral composition affects its comovement with the global factor.

To that aim, we use the dynamic factor model developed in Jackson et al. (2015),

[11] Unit labor costs changes coincide with $\widehat{C}$ when the production function is Cobb-Douglas and markups are either zero or constant.

Table 5. Direct Evidence: Unit Labor Costs

	R^2	Static Factor	Dynamic Factor
$\widehat{PPI12}_{c,t}$, quarterly			
mean	0.434	0.497	0.486
median	0.468	0.560	0.513
$\widehat{C12}_{c,t}$, quarterly			
mean	0.182	0.312	0.301
median	0.131	0.332	0.294
Unit Labor Costs			
mean	0.083	0.266	0.243
median	0.024	0.183	0.151

Notes: This table reports the mean and median of the R^2s (first column) and of the shares of variance explained by the static and dynamic factors (second and third columns) under alternative implementations of the analysis. The assumptions in each scenario are described in detail in the text.

that generalizes the model (10)–(12) and is implemented directly on sector-level data. Specifically, we estimate the following model:

$$X_{c,u,t} = \alpha_{c,u} + \lambda^w_{c,u} F^w_t + \lambda^c_{c,u} F^c_t + \lambda^u_{c,u} F^u_t + \epsilon_{c,u,t} \tag{17}$$

where $X_{c,u,t}$ is the 12-month inflation rate in country c, sector u, which can be either the actual $\widehat{PPI12}_{c,u,t}$ or the recovered cost shock $\widehat{C12}_{c,u,t}$. It is assumed to comprise of a global factor F^w_t common to all countries and sectors in the sample, the country factor F^c_t common to all u in country c, a sectoral factor F^u_t common to all sector u prices worldwide, and an idiosyncratic error term. Each of the factor series and the error term in the sector-level model (17) in turn are assumed to follow an AR process parallel to (11). Additional details on the factor model structure and estimation are collected in Appendix C.

Because we are ultimately interested in the comovement of aggregate inflation, we aggregate the sector-level model (17) to the country level in the same manner as in the baseline analysis. To decompose the aggregate country inflation into the global, sectoral, country, and idiosyncratic components, we combine (17) with (8):

$$\begin{aligned} X_{c,t} &= \sum_{u\in S}\omega_{c,u}X_{c,u,t} \\ &= \sum_{u\in S}\omega_{c,u}\lambda^{w}_{c,u}F^{w}_{t} + \sum_{u\in S}\omega_{c,u}\lambda^{c}_{c,u}F^{c}_{t} + \sum_{u\in S}\omega_{c,u}\lambda^{u}_{c,u}F^{u}_{t} + \sum_{u\in S}\omega_{c,u}\epsilon_{c,u,t}. \end{aligned}$$

Denoting $\Lambda^w_c = \sum_{u\in S}\omega_{c,u}\lambda^w_{c,u}$, $\Lambda^c_c = \sum_{u\in S}\omega_{c,u}\lambda^c_{c,u}$, and $G^s_{c,t} = \sum_u w_{c,u}\lambda^u_{c,u}F^u_t$, we obtain

$$X_{c,t} = \Lambda^w_c F^w_t + \Lambda^c_c F^c_t + G^s_{c,t} + \sum_{u\in S}\omega_{c,u}\epsilon_{c,u,t}. \tag{18}$$

Equation (18) is the aggregation of the sector-level factor model (17). It states that the country-level inflation rate $X_{c,t}$ can be decomposed into the component due to the global factor, the component due to the country factor, the component due to the sector factors, and an idiosyncratic component. We can then compute the variance share of the global and country factors as

$$share_{c,k} = \frac{(\Lambda^k_c)^2 Var(F^k_t)}{Var(X_{c,t})} \qquad k = w, c, \tag{19}$$

and the share of the variance attributable to sector factors as

$$share_{c,u} = \frac{Var(G^s_{c,t})}{Var(X_{c,t})}. \tag{20}$$

We are especially interested in the combined role of the global factors, that is, the sum of the share of variance of the global factor and the sectoral factors, $share_{c,w} + share_{c,u}$. This would tell us the total share of the variance of country c's inflation that is due to global factors, both overall and sectoral.

We estimate a factor model directly on sector-level price data, extracting global, country, and sector shocks following (17), and then decompose aggregate inflation into the contribution of those components as in (18). Table 6 reports the summary statistics for shares of variance of overall country-level $\widehat{PPI12}_{c,t}$ and $\widehat{C12}_{c,t}$ accounted for by the different

Table 6. Variance Shares Due to Global, Sector, and Country Shocks

	Panel A: $\widehat{PPI12}_{c,t}$			Panel B: $\widehat{C12}_{c,t}$		
	Global	Sector	Country	Global	Sector	Country
mean	0.070	0.426	0.338	0.109	0.259	0.303
median	0.027	0.481	0.261	0.084	0.225	0.240
min	0.002	0.005	0.026	0.001	0.002	0.000
max	0.392	0.846	0.948	0.425	0.735	0.902

Notes: This table reports the summary statistics for shares of the variances of country PPIs and cost shocks accounted for by global, sector, and country shocks, estimated as described in Section 5. Country code definitions are reported in Appendix Table A2.

shocks, calculated as in (19)-(20). Appendix Table A4 reports the results for each country.

Two observations stand out from the table. First, most of the global component in PPI inflation is due to global sectoral shocks, rather than a single global shock. Panel A shows that the global shock accounts for 0.070 (0.027) of the variance of country PPI for the mean (median) country. Sectoral shocks, by contrast, account for 0.426 (0.481) at the mean (median). The combined share of variance of actual $\widehat{PPI12}_{c,t}$ accounted for by the global and sectoral shocks (0.070 + 0.426 at the mean, 0.027 + 0.481 at the median) is quite comparable to the shares of variance reported in Table 1 that use much simpler factor models.

Second, the reductions in the extent of comovement in $\widehat{C12}_{c,t}$ compared to actual $\widehat{PPI12}_{c,t}$ come primarily from the reductions in the share of variance explained by sectoral rather than global shocks. Indeed, the global component accounts for slightly more of the variance of $\widehat{C12}_{c,t}$ on average than of $\widehat{PPI12}_{c,t}$. However, the share of variance explained by the sectoral shocks falls by almost the same amount as in the simpler models of Table 1.

These results suggest that common sectoral shocks are the primary driver of PPI synchronization across countries and that input linkages synchronize price shocks along the sectoral dimension.

6 Conclusion

Inflation rates are highly synchronized across countries. In a dataset of PPI for 30 countries, the single common factor explains nearly half of the fluctuations in PPI inflation in the average economy. It is important to understand the reasons for this internationalization of inflation. This paper evaluates a particular hypothesis: international input linkages are synchronizing inflation rates.

Our main finding is that input linkages indeed contribute substantially to the observed PPI comovement. We undertake a number of additional exercises to better understand this result. The main conclusion is not sensitive to the assumption on the rate of exchange rate pass-through or to the extent of pricing to market with demand complementarities. Both the average level of input linkages and their heterogeneity matter for generating the full extent of synchronization. Finally, the bulk of observed synchronization is due to common sectoral shocks.

The policy relevance of our findings goes beyond potential usefulness in inflation forecasting, as the propagation channel we document also has implications for optimal monetary policy. In particular, the extent to which foreign marginal costs affect domestic distortions has been shown to play a pivotal role in whether optimal monetary policy in an open economy targets only domestic prices and output gaps (Corsetti et al. 2010). As international input-linkages represent a direct link between foreign marginal costs and domestic production costs, their prevalence has a first-order effect on the extent to which optimal monetary policy is inward-looking.

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ONLINE APPENDIX (NOT FOR PUBLICATION)

Appendix A Extracting $\widehat{C}$ under Pricing-to-Market

This Appendix derives the procedure for extracting the cost shocks under partial exchange rate pass-through and pricing-to-market, possibly under demand complementarities. In particular, we assume that cost changes are passed through into prices at the rate $\beta \in [0, 1]$. Further, exchange rate changes pass through into prices at the rate $\beta^x \in [0, 1]$, which we allow to differ from β. Finally, we reflect demand complementarities by assuming that prices depend on competitors' prices through the sectoral ideal price index. We allow all of these pass-through rates to depend on u, the using sector, indicated by an according subscript. Time subscripts are dropped to improve readability. Formally, we generalize (4) to

$$\widehat{p}_{c,u,e,s} = \beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e} + \beta_u^d \widehat{P}_{c,u} \tag{A.1}$$

where

$$\widehat{P}_{c,u} = \sum_{e,s} \sigma_{c,u,e,s} \widehat{p}_{c,u,e,s}$$

with $\sigma_{c,u,e,s} = \gamma_{c,u,e,s}/(1 - \gamma_{c,u}^C)$. This formulation captures partial pass-through rates with some generality. The term $\widehat{P}_{c,u}$ reflects price complementarities as in Atkeson and Burstein (2008) or Auer and Schoenle (2016), who adopt a nested CES framework featuring a low demand elasticity across sectors and a high elasticity across varieties with each sector. As large firms internalize their impact on the sectoral price index, they face a low perceived elasticity of demand. Both changes in a firm's price and changes in competitor prices affect a firm's market share, thus giving rise to a pass-through and price complementarities as modeled here.[12]

Note that under reduced-form partial cost pass-through, we have $\beta_u^d = 0$, while in a model à la Atkeson and Burstein (2008) $\beta_u^d = 1 - \beta_u$.

Combining the two equations above and using $\sum_{e,s} \sigma_{c,u,e,s} = 1$ yields

$$\begin{aligned} \widehat{P}_{c,u} &= \sum_{e,s} \sigma_{c,u,e,s} \left[\beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e} + \beta_u^d \widehat{P}_{c,u} \right] \\ &= \sum_{e,s} \sigma_{c,u,e,s} (\beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e}) + \widehat{P}_{c,u} \beta_u^d \end{aligned}$$

so that

$$\widehat{P}_{c,u} = \left(1 - \beta_u^d\right)^{-1} \sum_{e,s} \sigma_{c,u,e,s} (\beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e}). \tag{A.2}$$

[12] See also Burstein and Gopinath (2015), who show that this functional form result is shared by a class of preference frameworks. Our specification of a constant β_u can be thought of as the case of symmetric firms in Atkeson and Burstein (2008). Alternatively, Auer and Schoenle (2016) derive the sector-specific average rate of pass through and price complementarities in the presence of underlying firm heterogeneity.

We use the expression (A.2) to eliminate the term $\widehat{P}_{c,u}$ in equation (A.1), which yields

$$\widehat{p}_{c,u,e,s} = \beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e} + \beta_u^d \left(1-\beta_u^d\right)^{-1} \sum_{e',s'} \sigma_{c,u,e',s'} (\beta_u \widehat{W}_{e',s'} + \beta_u^x \widehat{E}_{c,e'}). \tag{A.3}$$

Next, we use the approximation for changes in production costs in country c and sector u:

$$\widehat{W}_{c,u} = \gamma_{c,u}^C \widehat{C}_{c,u} + \sum_{e',s'} \gamma_{c,u,e',s'} \hat{p}_{c,u,e',s'} = \gamma_{c,u}^C \widehat{C}_{c,u} + (1-\gamma_{c,u}^C) \widehat{P}_{c,u}.$$

Here again, we use (A.2) to substitute the term $\widehat{P}_{c,u}$ in this expression:

$$\widehat{W}_{c,u} = \gamma_{c,u}^C \widehat{C}_{c,u} + \left(1-\gamma_{c,u}^C\right) \left(1-\beta_u^d\right)^{-1} \sum_{e,s} \sigma_{c,u,e,s} (\beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e}).$$

Solving for $\widehat{C}_{c,u}$ (and using $\sigma_{c,u,e,s} = \gamma_{c,u,e,s}/(1-\gamma_{c,u}^C)$) yields

$$\widehat{C}_{c,u} = \frac{1}{\gamma_{c,u}^C} \left\{ \widehat{W}_{c,u} - \left(1-\beta_u^d\right)^{-1} \sum_{e,s} \gamma_{c,u,e,s} (\beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{c,e}) \right\}.$$

With the objective to turn to convenient matrix notation, we rewrite the expression above, exploiting the following properties of log exchange rate changes $\widehat{E}_{c,e} = \widehat{E}_{c,0} + \widehat{E}_{0,e}$ and $\widehat{E}_{c,0} = -\widehat{E}_{0,c}$ (with some arbitrary reference currency 0):

$$\widehat{C}_{c,u} = \frac{1}{\gamma_{c,u}^C} \left\{ \widehat{W}_{c,u} + \beta_u^x \left(1-\beta_u^d\right)^{-1} (1-\gamma_{c,u}) \widehat{E}_{0,c} - \left(1-\beta_u^d\right)^{-1} \sum_{e,s} \gamma_{c,u,e,s} (\beta_u \widehat{W}_{e,s} + \beta_u^x \widehat{E}_{0,e}) \right\}. \tag{A.4}$$

Now, we define the $1 \times NS$ vectors

$$\widehat{\mathbf{W}} = (\underbrace{\widehat{W}_{1,1}, ... \widehat{W}_{1,S}}_{S}, \widehat{W}_{2,1} ..., \widehat{W}_{N,S})'$$

(i.e., the $(c-1)N + u$'s element of $\widehat{\mathbf{W}}$ form the vector $\widehat{W}_{c,u}$) and

$$\widehat{\mathbf{E}}_0 = (\underbrace{\widehat{E}_{0,1}, ... \widehat{E}_{0,1}}_{S}, \widehat{E}_{0,2} ..., \widehat{E}_{0,N})'.$$

Further, define the $NS \times NS$ global input-output matrix $\mathbf{\Gamma}$ by its elements:

$$\Gamma_{(e-1)S+s,(c-1)S+u} = \gamma_{c,u,e,s},$$

and, finally, $\mathbf{D}$ as an $NS \times NS$ diagonal matrix with diagonal elements $D_{(c-1)S+u,(c-1)S+u} = \gamma_{c,u}^C$.

With this notation, we can rewrite equation (A.4) as

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1}\left\{\left(\mathbf{I}-(\mathbf{I}-\mathbf{B}^{d})^{-1}\mathbf{B}\mathbf{\Gamma}'\right)\widehat{\mathbf{W}} + (\mathbf{I}-\mathbf{B}^{d})^{-1}\left(\mathbf{B}^{x}(\mathbf{I}-\mathbf{D}) - \mathbf{B}^{x}\mathbf{\Gamma}'\right)\widehat{\mathbf{E}}_{\mathbf{0}}\right\} \tag{A.5}$$

where $\mathbf{B}$, $\mathbf{B}^x$ and $\mathbf{B}^d$ are the $NS \times NS$ diagonal matrices

$$\mathbf{B}^{(y)} = diag(\beta_1^{(y)}, \beta_2^{(y)} ..., \beta_S^{(y)}, \beta_1^{(y)}, ...\beta_S^{(y)})$$

with $y = x, d$. (We note that $\mathbf{D}$, $\mathbf{\Gamma}$, and $\mathbf{E}_0$ are defined as in (6).)

To recover the cost shocks $\widehat{\mathbf{C}}$ we need an expression for the unobserved $\widehat{\mathbf{W}}$. Specifically, we aim to express $\widehat{W}_{e,s}$ as a function of the observables $\widehat{\mathbf{E}}_0$, input shares and the producer price index $\widehat{PPI}_{c,u}$.

The $\widehat{PPI}_{c,u}$ may be defined either based on local and export prices or based on local prices only. In the former case, the weights are

$$\alpha_{r,s,c,u} = \frac{Y_{r,s,c,u}}{\sum_{r',s'} Y_{r',s',c,u}} \tag{A.6}$$

where $Y_{r,s,c,u}$ are sales of products form c, u in market r, s. In the latter case, instead, the weights are

$$\alpha_{r,s,c,u} = \frac{\delta_{r,c} Y_{r,s,c,u}}{\sum_{r',s'} \delta_{r,c} Y_{r',s',c,u}} \tag{A.7}$$

with $\delta_{c,c} = 1$ and $\delta_{r,c} = 0$ if $r \neq c$.

We aim to apply these weights to build sums over observed prices $\widehat{p}_{r,s,c,u}$. Notice, however, that the export prices entering the PPI need to be expressed in the exporter's currency. Given our convention to express $\widehat{p}_{r,s,c,u}$ in destination currency (i.e., in the currency of the destination market), we need to correct for the currency mismatch, thus building the weighted sums over $\widehat{p}_{r,s,c,u} - \widehat{E}_{r,c}$. The producer price index is thus defined as

$$\widehat{PPI}_{c,u} = \sum_{r,s} \alpha_{r,s,c,u}\left[\widehat{p}_{r,s,c,u} - \widehat{E}_{r,c}\right]. \tag{A.8}$$

Using (A.3), i.e.,

$$\widehat{p}_{r,s,c,u} = \beta_s \widehat{W}_{c,u} + \beta_s^x \widehat{E}_{r,c} + \beta_s^d (1-\beta_s^d)^{-1} \sum_{e',s'} \sigma_{r,s,e',s'} \left(\beta_s \widehat{W}_{e',s'} + \beta_s^x \widehat{E}_{r,e'}\right)$$

expression (A.8) can be written as

$$
\begin{aligned}
\widehat{PPI}_{c,u} &= \sum_{r,s} \alpha_{r,s,c,u} \left[-\widehat{E}_{r,c} + \beta_s \widehat{W}_{c,u} + \beta_s^x \widehat{E}_{r,c} + \beta_s^d (1-\beta_s^d)^{-1} \sum_{e',s'} \sigma_{r,s,e',s'} \left(\beta_s \widehat{W}_{e',s'} + \beta_s^x \widehat{E}_{r,e'} \right) \right] \\
&= \sum_{r,s} \alpha_{r,s,c,u} \left[\beta_s \widehat{W}_{c,u} - (1-\beta_s^x)\widehat{E}_{r,c} + \frac{\beta_s^d \beta_s^x}{1-\beta_s^d} \widehat{E}_{r,0} + \frac{\beta_s^c}{1-\beta_s^d} \sum_{e',s'} \sigma_{r,s,e',s'} (\beta_s \widehat{W}_{e',s'} + \beta_s^x \widehat{E}_{0,e'}) \right] \\
&= \sum_{r,s} \alpha_{r,s,c,u} \beta_s \widehat{W}_{c,u} - (1 - \sum_{r,s} \alpha_{r,s,c,u} \beta_s^x) \widehat{E}_{0,c} + ... \\
&\quad ... + \sum_{r,s} \alpha_{r,s,c,u} \left[\left(1 - \beta_s^x - \frac{\beta_s^d \beta_s^x}{1-\beta_s^d} \right) \widehat{E}_{0,r} + \frac{\beta_s^d}{1-\beta_s^d} \sum_{e',s'} \sigma_{r,s,e',s'} (\beta_s \widehat{W}_{e',s'} + \beta_s^x \widehat{E}_{0,e'}) \right] \quad \text{(A.9)}
\end{aligned}
$$

Here again, we used that $\widehat{E}_{r,c} = \widehat{E}_{r,0} + \widehat{E}_{0,c} = -\widehat{E}_{0,r} + \widehat{E}_{0,c}$ as well as $\sum_{r,s} \alpha_{r,s,c,u} = 1$ and $\sum_{e',s'} \sigma_{r,s,e',s'} = 1$.

Turning to matrix notation, we define the $NS \times NS$ matrices $\mathbf{A}$ and $\mathbf{M}$ through their elements

$$
A_{(r-1)S+s,(c-1)S+u} = \alpha_{r,s,c,u} \quad \text{and} \quad M_{(r-1)S+s,(c-1)S+u} = \sigma_{r,s,c,u}.
$$

as well as the diagonal matrices $\mathbf{\Lambda}^{(x)}$ by their elements on the diagonal

$$
\Lambda^{(x)}_{(c-1)s+u,(c-1)+u} = \sum_{r,s} \alpha_{r,s,c,u} \beta_s^{(x)}
$$

Making use of this notation, expression (A.9) becomes

$$
\widehat{\mathbf{PPI}} = \mathbf{\Lambda}\widehat{\mathbf{W}} - (\mathbf{I} - \mathbf{\Lambda}^x)\widehat{\mathbf{E}}_0 + \mathbf{A}' \left[\left(\mathbf{I} - \mathbf{B}^x - (\mathbf{I} - \mathbf{B}^d)^{-1} \mathbf{B}^d \mathbf{B}^x \right) \widehat{\mathbf{E}}_0 + (\mathbf{I} - \mathbf{B}^d)^{-1} \mathbf{B}^d \left(\mathbf{B}\mathbf{M}\widehat{\mathbf{W}} + \mathbf{B}^x \mathbf{M} \widehat{\mathbf{E}}_0 \right) \right]
$$

so that

$$
\begin{aligned}
\widehat{\mathbf{W}} &= \left[\mathbf{\Lambda} + \mathbf{A}'(\mathbf{I} - \mathbf{B}^d)^{-1} \mathbf{B}^d \mathbf{B}\mathbf{M} \right]^{-1} ... \\
&\quad ... \left[\widehat{\mathbf{PPI}} + \left((\mathbf{I} - \mathbf{\Lambda}^x) - \mathbf{A}' \left[\left(\mathbf{I} - \mathbf{B}^x - (\mathbf{I} - \mathbf{B}^d)^{-1} \mathbf{B}^d \mathbf{B}^x \right) + (\mathbf{I} - \mathbf{B}^d)^{-1} \mathbf{B}^d \mathbf{B}^x \mathbf{M} \right] \right) \widehat{\mathbf{E}}_0 \right].
\end{aligned}
$$

We can use this expression to eliminate $\widehat{\mathbf{W}}$ in (A.5), which finally yields an expression for $\widehat{\mathbf{C}}$ in terms of variables that are observable in the data as well as $\left\{ \beta_s, \beta_s^x, \beta_s^d \right\}$.

All of the alternative pass-through scenarios in the paper are special cases of this general framework. Using the expression above and (A.5), the formal expressions describing $\widehat{\mathbf{C}}$ for the alternative models are as follows.

The baseline. The baseline model features complete pass-through ($\beta_u = \beta_u^x = 1$, implying $\mathbf{B}^{(x)} = \mathbf{I}$ and $\mathbf{\Lambda}^{(x)} = \mathbf{I}$), and no complementarities ($\beta_u^d = 0$, implying $\mathbf{B}^d = 0$). This scenario yields $\widehat{\mathbf{C}} = \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}')\,\widehat{\mathbf{W}} + (\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\}$ and $\widehat{\mathbf{W}} = \widehat{\mathbf{PPI}}$ so that

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}')\,\widehat{\mathbf{PPI}} + (\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\}.$$

We have thus recovered equation (6) in the main text.

No exchange rate pass-through. The second scenario is one in which there is no pass-through of exchange rate shocks ($\beta_u^x = 0$), but full pass-through of cost shocks and no complementarities ($\beta_u = 1$, $\beta_u^d = 0$). The results for this scenario are reported in the panel "Alt. cost shocks: No $\widehat{E}_{c,e,t}$" of Table 2. In this case, the cost shocks are

$$\begin{aligned}\widehat{\mathbf{C}} &= \mathbf{D}^{-1}(\mathbf{I}-\mathbf{\Gamma}')\,\widehat{\mathbf{W}} \\ \widehat{\mathbf{W}} &= \widehat{\mathbf{PPI}} + (\mathbf{I}-\mathbf{A}')\,\widehat{\mathbf{E}}_0\end{aligned}$$

Since further $\mathbf{A}'\widehat{\mathbf{E}}_0 = \widehat{\mathbf{E}}_0$ in our case (A.7), this yields

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1}(\mathbf{I}-\mathbf{\Gamma}')\,\widehat{\mathbf{PPI}}. \tag{A.10}$$

Pricing complementarity. The third scenario features cost and exchange rate pass-through are identical and equal across sectors ($\beta_u^x = \beta_u = \beta$, implying $\mathbf{B}^{(x)} = \beta\mathbf{I}$ and $\mathbf{\Lambda}^{(x)} = \beta\mathbf{I}$), as well as complementarities a la Atkeson and Burstein (2008) ($\beta_u^d = 1-\beta$, implying $\mathbf{B}^d = (1-\beta)\mathbf{I}$). In this case,

$$\begin{aligned}\widehat{\mathbf{C}} &= \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}')\,\widehat{\mathbf{W}} + (\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\} \\ \widehat{\mathbf{W}} &= [\beta\mathbf{I} + (1-\beta)\,\mathbf{A}'\mathbf{M}]^{-1}\left[\widehat{\mathbf{PPI}} + (1-\beta)\,(\mathbf{I}-\mathbf{A}'\mathbf{M})\,\widehat{\mathbf{E}}_0\right]\end{aligned}$$

so that the cost shocks are

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}')\,[\beta\mathbf{I} + (1-\beta)\,\mathbf{A}'\mathbf{M}]^{-1}\left[\widehat{\mathbf{PPI}} + (1-\beta)\,(\mathbf{I}-\mathbf{A}'\mathbf{M})\,\widehat{\mathbf{E}}_0\right] + (\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\}. \tag{A.11}$$

The results under this assumption are reported in panels labeled "Price complementarities" of Table 2 under alternative values of β.

Mechanical pass-through. The fourth scenario is the same as the third but without complementarities ($\beta_u^d = 0$, implying $\mathbf{B}^d = 0$). In this case, we have

$$\begin{aligned}\widehat{\mathbf{C}} &= \mathbf{D}^{-1}\left\{(\mathbf{I}-\beta\mathbf{\Gamma}')\,\widehat{\mathbf{W}} + \beta(\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\} \\ \widehat{\mathbf{W}} &= \beta^{-1}\left[\widehat{\mathbf{PPI}} + (1-\beta)\,(\mathbf{I}-\mathbf{A}')\,\widehat{\mathbf{E}}_0\right]\end{aligned}$$

so that

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1}\left\{\left(\beta^{-1}\mathbf{I}-\mathbf{\Gamma}'\right)\left[\widehat{\mathbf{PPI}}+(1-\beta)\left(\mathbf{I}-\mathbf{A}'\right)\widehat{\mathbf{E}}_0\right]+\beta(\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\}. \tag{A.12}$$

The results are reported in the panels labeled "Mechanical pass-through" of Table 2 under alternative values of β.

Mechanical pass-through, sectoral β's. In the fifth scenario cost and exchange rate pass-through are identical but differ by using sector and may be partial ($\beta_u^x = \beta_u$, implying $\mathbf{B}^x = \mathbf{B}$ and $\mathbf{\Lambda}^x = \mathbf{\Lambda}$) and there are no complementarities ($\beta_u^d = 0$, implying $\mathbf{B}^d = 0$).

In this case, we have

$$\begin{aligned}\widehat{\mathbf{C}} &= \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}'\mathbf{B})\,\widehat{\mathbf{W}}+\mathbf{B}\,(\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\,\widehat{\mathbf{E}}_{\mathbf{0}}\right\}\\ \widehat{\mathbf{W}} &= \mathbf{\Lambda}^{-1}\left[\widehat{\mathbf{PPI}}+((\mathbf{I}-\mathbf{\Lambda})-\mathbf{A}'\,[\mathbf{I}-\mathbf{B}])\,\widehat{\mathbf{E}}_0\right]\end{aligned}$$

or

$$\widehat{\mathbf{C}} = \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}'\mathbf{B})\,\mathbf{\Lambda}^{-1}\left[\widehat{\mathbf{PPI}}+((\mathbf{I}-\mathbf{\Lambda})-\mathbf{A}'\,[\mathbf{I}-\mathbf{B}])\,\widehat{\mathbf{E}}_0\right]+\mathbf{B}\,(\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\,\widehat{\mathbf{E}}_{\mathbf{0}}\right\}.$$

Pricing complementarity, sectoral β's. Finally, the last scenario corresponds to the full model laid out above, with sector-specific cost and exchange rate pass-through ($\beta_u^x = \beta_u$), and Atkeson-Burstein complementarities ($\beta_u^d = 1-\beta_u$). In this case, $\mathbf{B}^x = \mathbf{B}$ and $\mathbf{B}^d = \mathbf{1}-\mathbf{B}$ as well as $\mathbf{\Lambda}^{\mathbf{x}} = \mathbf{\Lambda}$. Thus, we have

$$\begin{aligned}\widehat{\mathbf{C}} &= \mathbf{D}^{-1}\left\{(\mathbf{I}-\mathbf{\Gamma}')\,\widehat{\mathbf{W}}+(\mathbf{I}-\mathbf{D}-\mathbf{\Gamma}')\widehat{\mathbf{E}}_0\right\}\\ \widehat{\mathbf{W}} &= \left[\mathbf{\Lambda}+\mathbf{A}'(\mathbf{I}-\mathbf{B})\mathbf{M}\right]^{-1}\left[\widehat{\mathbf{PPI}}+((\mathbf{I}-\mathbf{\Lambda})-\mathbf{A}'\,[\mathbf{I}+(\mathbf{I}-\mathbf{B})\mathbf{M}])\widehat{\mathbf{E}}_0\right].\end{aligned}$$

In combination, these two equations describe our model with sectoral pass-through rates and price complementarities.

Appendix B Higher-Order Terms

This Appendix expands the model to include sectors outside the PPI coverage and describes the recovery of the cost shocks, accounting explicitly for second- and higher-order transmission through those sectors, for which price shocks are not observed. Time subscripts are dropped to improve readability. Section 4.2 in the main body of the paper presents the results when recovering the cost shocks using the method described here. We set $\beta = 1$ throughout the derivations.

There are two sets of sectors, those for which PPI data exist (S^o, superscripted by o for "observed") and those for which PPI data do not exist (S^n, superscripted by n for "not observed"). The PPI change in any sector (o or n) is given by

$$\begin{aligned}\widehat{PPI}_{c,u} &= \gamma^{VA}_{c,u}\widehat{VA}_{c,u} + \sum_{e\in N, s\in S^o} \gamma^I_{c,u,e,s}\left(\widehat{PPI}^o_{e,s} + \widehat{E}_{c,e}\right) \\ &\quad + \sum_{e\in N, s\in S^n} \gamma^I_{c,u,e,s}\left(\widehat{PPI}^n_{e,s} + \widehat{E}_{c,e}\right),\end{aligned} \tag{B.1}$$

where $\widehat{VA}_{c,u}$ is the change in the cost of value added. As noted in Section 2, the baseline analysis recovers the cost shock as a residual between actual $\widehat{PPI}_{c,u}$ and the price shocks in the observed sectors, $\sum_{e\in N, s\in S^o} \gamma^I_{c,u,e,s}\left(\widehat{PPI}^o_{e,s} + \widehat{E}_{c,e}\right)$. The expression (B.1) shows, however, that a correct recovery of the cost shocks in the o-type sectors must be based on the full system of PPIs and linkages of the o-type as well as the n-type sectors. For example, the second-order term becomes explicit when plugging (B.1) into itself to eliminate $\widehat{PPI}_{c,u}$:

$$\begin{aligned}\widehat{PPI}_{c,u} &= \gamma^{VA}_{c,u}\widehat{VA}_{c,u} + \sum_{e\in N, s\in S^o} \gamma^I_{c,u,e,s}\left(\widehat{PPI}^o_{e,s} + \widehat{E}_{c,e}\right) \\ &\quad + \sum_{e\in N, s\in S^n} \gamma^I_{c,u,e,s}\left[\sum_{e'\in N, s'\in S^o} \gamma^I_{e,s,e',s'}\left(\widehat{PPI}_{e',s'} + \widehat{E}_{e,e'}\right)\right] \\ &\quad + \sum_{e\in N, s\in S^n} \gamma^I_{c,u,e,s}\left[\gamma^{VA}_{e,s}\widehat{VA}_{e,s}\right. \\ &\quad \left. + \sum_{e'\in N, s'\in S^n} \gamma^I_{e,s,e',s'}\left(\widehat{PPI}^n_{e',s'} + \widehat{E}_{e,e'}\right) + \widehat{E}_{c,e}\right].\end{aligned} \tag{B.2}$$

The second line of this expression is the second-order term operating through the n-type sectors: the impact of input cost shocks in the observed sectors on PPI through the usage of n-type sector inputs and, in turn, the usage of o-type inputs by the n-type sectors.

To account for higher-order terms, we adopt the following matrix notation. First, we define $\widehat{VA}^{unscal}_o$ as the vector of the $\gamma^{VA}_{c,u}\widehat{VA}_{c,u}$'s (*unscal* stands for "unscaled"). Then, we collect the terms in (B.1) and write

$$\begin{pmatrix}\widehat{PPI}_o \\ \widehat{PPI}_n\end{pmatrix} = \begin{pmatrix}\widehat{VA}^{unscal}_o \\ \widehat{VA}^{unscal}_n\end{pmatrix} + \begin{pmatrix}\Gamma_{o,o} & \Gamma_{o,n} \\ \Gamma_{n,o} & \Gamma_{n,n}\end{pmatrix}\begin{pmatrix}\widehat{PPI}_o \\ \widehat{PPI}_n\end{pmatrix} + \widetilde{\mathbf{\Gamma}}'\widehat{\mathbf{E}},$$

where $\widehat{\mathbf{E}}$ is defined in Section 2 and the sub-matrices $\Gamma_{k,l}$ through

$$\begin{pmatrix} \Gamma_{o,o} & \Gamma_{o,n} \\ \Gamma_{n,o} & \Gamma_{n,n} \end{pmatrix} = \widetilde{\mathbf{\Gamma}}'.$$

The n-type sector PPI changes are equal to

$$\widehat{PPI}_n = \widehat{VA}_n^{unscal} + \Gamma_{n,o}\widehat{PPI}_o + \Gamma_{n,n}\widehat{PPI}_n + \tilde{\Gamma}_n\widehat{\mathbf{E}} \tag{B.3}$$

where $\tilde{\Gamma}_n = \begin{pmatrix} \Gamma_{n,o} & \Gamma_{n,n} \end{pmatrix}$. Substituting $\widehat{PPI}_n$ repeatedly into (B.3) yields

$$\begin{aligned} \widehat{PPI}_n &= \prod_{k=0}^{\infty}\Gamma_{n,n}^k(\widehat{VA}_n^{unscal} + \Gamma_{n,o}\widehat{PPI}_o + \tilde{\Gamma}_n\widehat{\mathbf{E}}) \\ &= (I - \Gamma_{n,n})^{-1}(\widehat{VA}_n^{unscal} + \Gamma_{n,o}\widehat{PPI}_o + \tilde{\Gamma}_n\widehat{\mathbf{E}}). \end{aligned}$$

The term $\widehat{PPI}_o$ can thus be expressed as

$$\begin{aligned} \widehat{PPI}_o &= \widehat{VA}_o^{unscal} + \Gamma_{o,o}\widehat{PPI}_o + \Gamma_{o,n}\widehat{PPI}_n + \tilde{\Gamma}_o\widehat{\mathbf{E}} \\ &= \widehat{VA}_o^{unscal} + \Gamma_{o,o}\widehat{PPI}_o + \Gamma_{o,n}(I - \Gamma_{n,n})^{-1}(\widehat{VA}_n^{unscal} + \Gamma_{n,o}\widehat{PPI}_o + \tilde{\Gamma}_n\widehat{\mathbf{E}}) + \tilde{\Gamma}_o\widehat{\mathbf{E}} \\ &= \widehat{VA}_o^{unscal} + \left(\Gamma_{o,o} + \Gamma_{o,n}(I - \Gamma_{n,n})^{-1}\Gamma_{n,o}\right)\widehat{PPI}_o + \\ &\quad + \left(\Gamma_{o,n}(I - \Gamma_{n,n})^{-1}\tilde{\Gamma}_n + \tilde{\Gamma}_o\right)\widehat{\mathbf{E}} + \Gamma_{o,n}(I - \Gamma_{n,n})^{-1}\widehat{VA}_n^{unscal} \end{aligned}$$

where $\tilde{\Gamma}_o = \begin{pmatrix} \Gamma_{o,o} & \Gamma_{o,n} \end{pmatrix}$. This expression can now be used to recover the cost shocks by simply neglecting the contributions of the unobserved shocks, setting $\widehat{VA}_n^{unscal} = 0$. We now define the cost shocks that take into account all higher-order effects of the observed variables through $\widehat{VA}_o^{unscal} = \mathbf{D}\widehat{C}_o^{\infty-order}$, where $\mathbf{D}$ is defined in Section 2. Thus, we can solve for these cost shocks

$$\begin{aligned} \widehat{C}_o^{\infty-order} &= \mathbf{D}^{-1}\left[I - \Gamma_{o,o} - \Gamma_{o,n}(I - \Gamma_{n,n})^{-1}\Gamma_{n,o}\right]\widehat{PPI}_o + \\ &\quad -\mathbf{D}^{-1}\left(\Gamma_o + \Gamma_{o,n}(I - \Gamma_{n,n})^{-1}\Gamma_n\right)\widehat{\mathbf{E}} \end{aligned} \tag{B.4}$$

Notice finally that the expression (B.4) collapses to equation (5) with $\Gamma_{o,o} = \Gamma'$ if o-type sectors do not use inputs from n-type sectors ($\Gamma_{n,o} = 0$) or vice versa ($\Gamma_{o,n} = 0$).

Appendix C Sector-Level Factor Model

Each of the factor series and the error term in the sector-level model (17) are assumed to follow an AR process:

$$F_t^k = \sum_{l=1..p_F} \phi_{k,l} F_{t-l}^k + u_{k,t}, \qquad k = w, c, u$$

and

$$\epsilon_{c,u,t} = \sum_{l=1..p_\epsilon} \rho_{c,u,l} \epsilon_{c,u,t-l} + \mu_{c,u,t}.$$

Under the assumptions that $u_{k,t} \sim N(0,1)$ for $k = w, c, u$, and the restriction that the sign of the loading of the first series on the global factor be positive, the decomposition is well-defined. The residuals $\mu_{cs,t}$ are assumed to be distributed

$$\mu_{c,u,t} \sim N(0, \sigma_{c,u}^2).$$

We follow the Bayesian estimation procedure from Jackson et al. (2015), briefly summarized here. First, we denote the parameter vector by $\boldsymbol{\xi}_{c,u} = [\, \boldsymbol{\alpha}_{c,u} \; \boldsymbol{\lambda}_{c,u} \; \boldsymbol{\rho}_{c,u} \,]$, where the vector $\boldsymbol{\alpha}_{c,u}$ collects the constant terms, $\boldsymbol{\lambda}_{c,u}$ summarizes all loadings, and $\boldsymbol{\rho}_{c,u} = (\rho_{c,u,1}, ..., \rho_{c,u,p_\epsilon})$ all the AR coefficients of the errors. The priors of these model parameters are set to

$$\boldsymbol{\xi}_{c,u} \sim N(0, \bar{B}_{c,u}^{-1})$$

where $\bar{B}_{c,u}^{-1} = diag([.001 * \mathbf{1}_{1+n_{factors}}, \mathbf{1}_{p_\epsilon}])$, and $\mathbf{1}_n$ the n-dimensional vector with the elements 1. Thus, the constants, the loadings, and the error AR coefficients have a prior mean of 0, the constant and loading a prior variance of 0.001, and the error AR coefficients a prior variance of 1.

Next, the remaining model parameters $\boldsymbol{\phi}_k = (\phi_{k,1}, ..., \phi_{k,p_F})$ have the priors

$$\boldsymbol{\phi}_k \sim N(0, \bar{\Phi}_k^{-1}), \qquad k = w, c, u$$

where $\bar{\Phi}_k^{-1} = diag\left(1 \; \frac{1}{0.85} \; \cdots \; \frac{1}{0.85^{p_F}} \right)$. The prior variance is thus exponentially decreasing with the lag length, reflecting that further lags have a smaller probability of having a non-zero effect.

Moreover, the variances of $\mu_{c,u,t}$, $\sigma_{c,u}^2$, have the priors

$$\sigma_{c,u}^2 \sim IG(\bar{v}_{c,u}/2, \bar{\delta}_{c,u}/2),$$

where IG is the inverted gamma distribution, $\bar{v}_{c,u} = 6$, and $\bar{\delta}_{c,u} = 0.001$. Finally, we set $p_F = 3$ and $p_\epsilon = 2$. The starting values are 0 for all coefficients and random standard normal draws for the factors.

The algorithm then computes (implicitly determines) the posterior distribution of each of the parameters conditional on all other parameters, in the order $\boldsymbol{\xi}_{c,u}$, $\sigma_{c,u}^2$, $\boldsymbol{\phi}_k$, and F_t^k. At each step, a new draw from the posterior distribution replaces the starting value (if granted a likelihood-ratio criterion, see Chib and Greenberg 1994). Repeating this procedure, the (conditional) posterior distributions converge and the frequency of the draws approaches the joint posterior distribution of all coefficients and factors. The procedure is repeated 1500 times (3500 times in case of the reduced model (10) without the sector dimension). To avoid dependence on initial conditions (and after verifying convergence) the first 500 draws are discarded. The remaining draws are used to compute our statistics.

Although the factors are distributionally uncorrelated, the sample realizations might be correlated, and thus we orthogonalize F^w, F^c, and G^s before computing the decomposition to ensure that the variance shares sum to unity. We orthogonalize first on the global factor, then on the sectoral component. The share is computed for each draw, and the median share is reported in Table 6.

Table A1. PPI Data Origin Summary Table

Country	Original source	Original classification	Conversion table
AUS	Aust. Bureau of Stats.	ANZSIC	5
AUT	Eurostat	NACE rev. 2	1
BEL	Eurostat	NACE rev. 2	1
BGR	Eurostat	NACE rev. 2	1
CAN	Statistics Canada	NAICS 2007	3,4
CHN	NBS of China	CSIC	5
CZE	Eurostat	NACE rev. 2	1
DNK	Eurostat	NACE rev. 2	1
FIN	Eurostat	NACE rev. 2	1
FRA	Eurostat	NACE rev. 2	1
DEU	Eurostat	NACE rev. 2	1
GRC	Eurostat	NACE rev. 2	1
HUN	Eurostat	NACE rev. 2	1
IRL	Eurostat	NACE rev. 2	1
ITA	Eurostat	NACE rev. 2	1
JPN	Bank of Japan	JSIC	5
KOR	The Bank of Korea	KSIC	5
LTU	Eurostat	NACE rev. 2	1
MEX	INEGI Mexico	SCIAN	5
NLD	Eurostat	NACE rev. 2	1
POL	Eurostat	NACE rev. 2	1
PRT	Eurostat	NACE rev. 2	1
ROM	Eurostat	NACE rev. 2	1
RUS	FSSS (Rosstat)	OKVED	5
SVN	Eurostat	NACE rev. 2	1
ESP	Eurostat	NACE rev. 2	1
SWE	Eurostat	NACE rev. 2	1
TWN	DGBAS, Chinese Taipei	SIC of ROC	5
GBR	Eurostat	NACE rev. 2	1
USA	BLS	NAICS 2012	2,3,4

Notes: Legend for last column:

1. Eurostat NACE rev. 2 to rev. 1.1 (http://ec.europa.eu/eurostat/web/nace-rev2/correspondence_tables). Once the series are in NACE rev. 1.1, conversion to the ISIC 2-letters categories used in WIOD is straightforward.
2. US Census Bureau: NAICS 2012 to NAICS 2007 (https://www.census.gov/eos/www/naics/concordances/concordances.html).
3. US Census Bureau: NAICS 2007 to NAICS 2002.
4. US Census Bureau: NAICS 2002 to NACE rev. 1.1. Once the series are in NACE rev. 1.1, conversion to the ISIC 2-letters categories used in WIOD is straightforward.
5. PPI series downloaded through Datastream. We manually match the description of these series in the original classification to match them with the ISIC 2-letters description used in the WIOD.

Table A2. Country and Sector Coverage

Country	Code	Sector
Australia	AUS	Agriculture, Hunting, Forestry, and Fishing
Austria	AUT	Basic Metals and Fabricated Metal
Belgium	BEL	Chemicals and Chemical Products
Bulgaria	BGR	Coke, Refined Petroleum and Nuclear F..
Canada	CAN	Electrical and Optical Equipment
China	CHN	Electricity, Gas and Water Supply
Chinese Taipei	TWN	Food, Beverages and Tobacco
Czech Republic	CZE	Leather, Leather and Footwear
Denmark	DNK	Machinery, Nec
Finland	FIN	Manufacturing, Nec; Recycling
France	FRA	Mining and Quarrying
Germany	DEU	Other Non-Metallic Mineral
Greece	GRC	Pulp, Paper, Paper , Printing and Pub..
Hungary	HUN	Rubber and Plastics
Ireland	IRL	Textiles and Textile Products
Italy	ITA	Transport Equipment
Japan	JPN	Wood and Products of Wood and Cork
Korea	KOR	
Lithuania	LTU	
Mexico	MEX	
Netherlands	NLD	
Poland	POL	
Portugal	PRT	
Rest of the World	ROW	
Romania	ROM	
Russian Federation	RUS	
Slovenia	SVN	
Spain	ESP	
Sweden	SWE	
United Kingdom	GBR	
United States	USA	

Notes: This table reports the countries (along with 3-letter codes) and the sectors used in the analysis.

Table A3. PPI Data Origin Summary Table for ROW Countries

Country	Original source	Original classification	Conversion table
BRA	IBGE	CNAE	5
CYP	Eurostat	NACE rev. 2	1
EST	Eurostat	NACE rev. 2	1
IDN	Statistics Indonesia	KBLI	5
IND	Office of Econ. Advisor to the Gov. of India	NIC	5
LUX	Eurostat	NACE rev. 2	1
LVA	Eurostat	NACE rev. 2	1
MLT	Eurostat	NACE rev. 2	1
SVK	Eurostat	NACE rev. 2	1
TUR	Eurostat	NACE rev. 2	1

Notes: Legend for last column:

1. Eurostat conversion table (http://ec.europa.eu/eurostat/web/nace-rev2/correspondence_tables). Once the series are in NACE rev. 1.1, conversion to the ISIC 2-letters categories used in WIOD is straightforward.

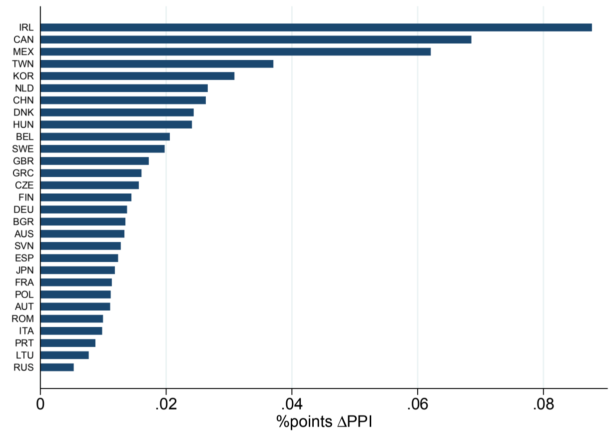
5. PPI series downloaded through Datastream. We manually match the description of these series in the original classification to match them with the ISIC aggregates used in the WIOD.

Table A4. Global, Sector, and Country Shocks

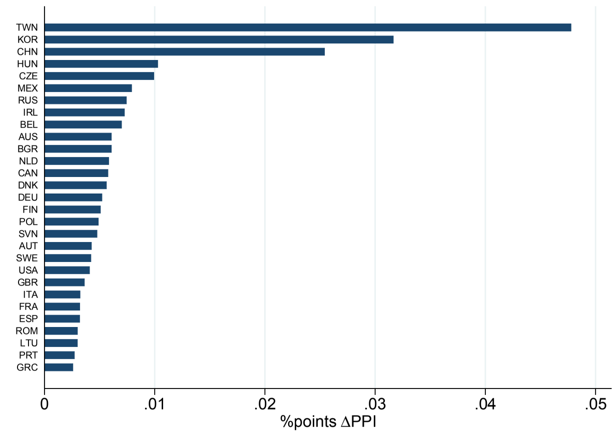
	Panel A: $\widehat{PPI12}_{c,t}$			Panel B: $\widehat{C12}_{c,t}$		
Country	Global	Sector	Country	Global	Sector	Country
AUS	0.108	0.350	0.373	0.134	0.214	0.127
AUT	0.004	0.594	0.260	0.280	0.235	0.210
BEL	0.300	0.586	0.026	0.173	0.484	0.026
BGR	0.111	0.370	0.316	0.077	0.018	0.845
CAN	0.109	0.494	0.262	0.425	0.371	0.064
CHN	0.007	0.761	0.101	0.006	0.336	0.024
CZE	0.016	0.220	0.643	0.044	0.278	0.580
DEU	0.044	0.799	0.079	0.106	0.626	0.026
DNK	0.002	0.249	0.193	0.003	0.002	0.000
ESP	0.045	0.846	0.047	0.029	0.735	0.058
FIN	0.101	0.520	0.229	0.008	0.486	0.168
FRA	0.022	0.643	0.172	0.011	0.484	0.007
GBR	0.004	0.658	0.090	0.099	0.289	0.070
GRC	0.101	0.076	0.432	0.278	0.016	0.321
HUN	0.197	0.040	0.664	0.004	0.098	0.771
IRL	0.008	0.038	0.652	0.001	0.007	0.631
ITA	0.129	0.699	0.109	0.005	0.532	0.269
JPN	0.003	0.696	0.195	0.002	0.215	0.570
KOR	0.015	0.067	0.814	0.066	0.092	0.612
LTU	0.015	0.703	0.123	0.178	0.406	0.161
MEX	0.012	0.122	0.607	0.192	0.012	0.349
NLD	0.180	0.700	0.066	0.185	0.556	0.007
POL	0.034	0.182	0.557	0.028	0.304	0.440
PRT	0.003	0.468	0.405	0.005	0.200	0.201
ROM	0.028	0.005	0.948	0.004	0.016	0.902
RUS	0.392	0.173	0.337	0.357	0.102	0.304
SVN	0.027	0.040	0.783	0.237	0.046	0.023
SWE	0.044	0.370	0.310	0.093	0.171	0.582
TWN	0.011	0.538	0.240	0.091	0.136	0.434
USA	0.024	0.778	0.097	0.145	0.291	0.300

Notes: This table reports the shares of the variances of country PPIs and cost shocks accounted for by global, sector, and country shocks, estimated as described in Section 5. Country code definitions are reported in Appendix Table A2.

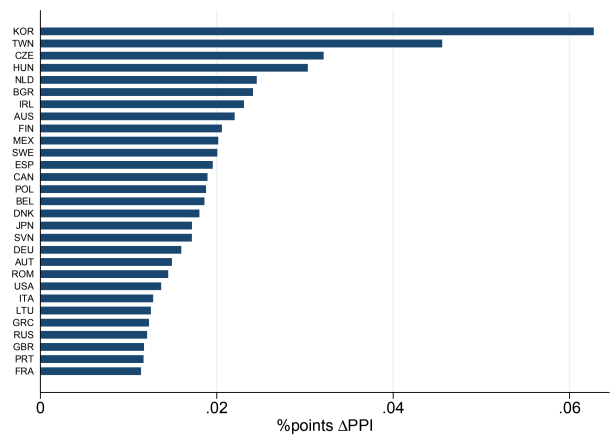
Figure A1. Full Economy: Spillovers from Cost Shocks to Selected Countries and Energy Prices



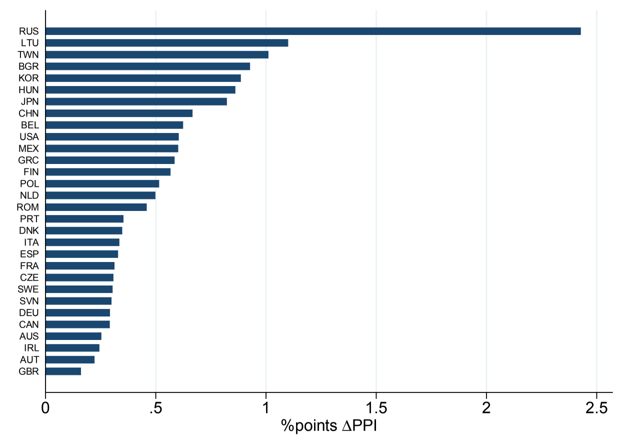
(a) A 1% US Inflationary Shock



(b) A 1% Japan Inflationary Shock



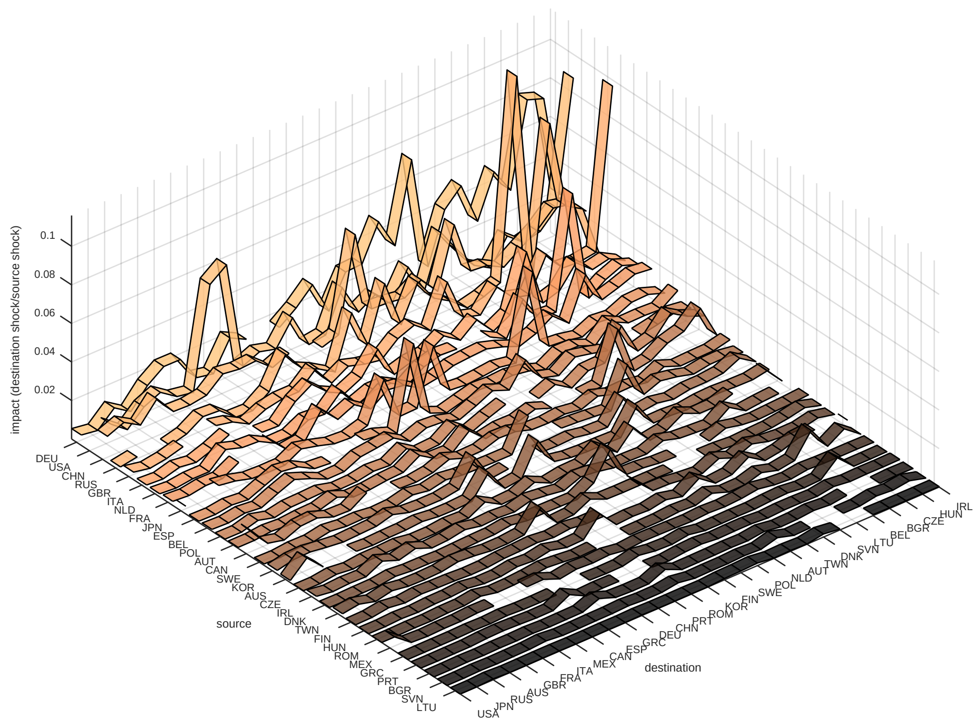
(c) A 1% China Inflationary Shock



(d) A 10% Rise in Energy Prices Worldwide

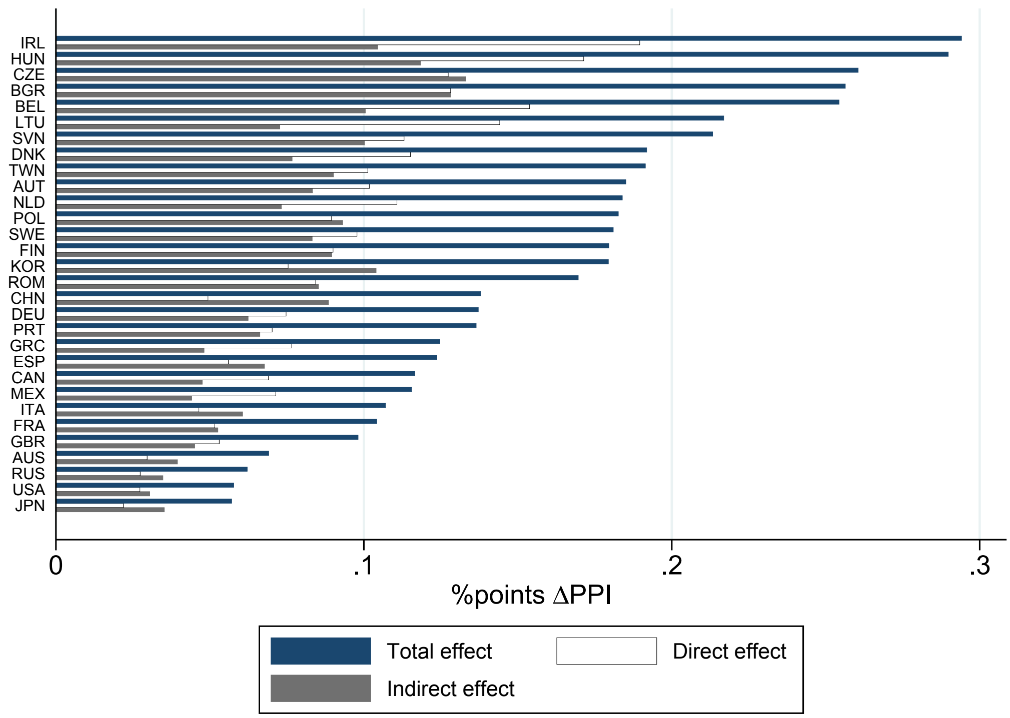
Notes: This figure presents the change in the aggregate price level in each country in our sample following 4 hypothetical shocks: (a) a shock that leads to 1% inflation in the US; (b) a shock that leads to 1% inflation in Japan; (c) a shock that leads to 1% inflation in China; and (d) a worldwide 10% increase in energy prices. These scenarios include sectors that are excluded from the scenarios reported in the main text, as they are not part of the PPI.

Figure A2. Full Economy: The Proportional Impact of Each Source Country's Inflation Shock on Each Destination Country's Inflation



Notes: This figure displays the proportional impact of an inflationary shock in each source country on inflation in each destination country. These scenarios include sectors that are excluded from the scenarios reported in the main text, as they are not part of the PPI.

Figure A3. Full Economy: Spillovers from a 1% Inflationary Shock in Every Other Country



Notes: This figure displays the impact of an inflationary shock that leads to average 1% inflation in the other countries in the world. These scenarios include sectors that are excluded from the scenarios reported in the main text, as they are not part of the PPI.