Beyond Energy: Inflationary Effects of Metals Price Shocks in Production Networks*

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Abstract

We examine the role of metals as economic inputs by constructing a small-open-economy production network model, calibrated for various countries using domestic input-output (I-O) tables and sectoral imports data. Empirically, we employ local projections to test the implications from the model on how metal shocks influence inflation. Our findings indicate that metals price shocks have significant and persistent effects on core and headline inflation, with particularly pronounced effects on countries that are highly exposed to metals in their production networks. This is in contrast to oil supply shocks, which predominantly affect headline inflation. Hence, metal price shocks are less visible on impact but more persistent, which central banks should consider when assessing inflation dynamics and risks.

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Keywords: International macroeconomics, inflation, metals, production networks, supply shocks.

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1 Introduction

Energy price shocks have been considered a major source of business cycle fluctuations, especially for headline inflation globally (see e.g., Hamilton, 1983; Blanchard and Gali, 2007; Nakov and Pescatori, 2010; Gagliardone and Gertler, 2023; Bernanke and Blanchard, 2023; Di Giovanni et al., 2023). However, the literature has overlooked a group of commodities embedded in the production of large durable sectors such as motor vehicles, equipment, and machinery, and which are expected to become more relevant in the energy transition (see, e.g., IEA, 2022; Boer, Pescatori, and Stuermer, 2024): primary metals (e.g., copper and aluminum).[1]

In this paper, we examine the role of metals in the economy and how metals supply shocks propagate through production networks and impact inflation globally. To this end, we construct a small open-economy model featuring production networks and imported intermediates. Taking advantage of the heterogeneity in metals' network exposure across countries, we identify how global metal price shocks affect headline and core inflation in a panel of 39 countries.

We first establish that metals, whether imported or sourced domestically, are key inputs for production, particularly for the production of investment goods (e.g., machinery, electrical equipment, motor vehicles, construction). For the US, for example, the total exposure of metals in production is comparable, and even larger, than the production exposure to energy inputs.

A key feature of metals and metal-intensive goods is that they are widely traded. Therefore, shocks to global metal prices can impact countries' consumer price index (CPI) through imports of metals or metal-intensive intermediate and final goods. To understand the inflationary effects of a shock on imported metals prices, we develop a small open economy model with imported intermediate inputs and a domestic production net-

[1]The overlook is surprising as metals are at the heart of recent tariff increases (e.g., the US announced tariff increases on Chinese aluminum and steel by 25 percent in May 2024), and metals are cited as a reason for stubborn inflation by media (see, e.g., Simon, 2024).

work.

Our model extends the framework of Silva (2023) by also accounting for the import content of non-metal products. Following Gali and Monacelli (2005), we consider a continuum of small open economies that import both metals and non-metal products for final consumption and sectoral production. Metals and non-metal products are produced and exported by two distinct groups of small open economies, from which the benchmark small open economy imports. As a result, our framework implicitly captures indirect (second-order) linkages across countries, without explicitly solving for the world economy's general equilibrium.

The model has clear predictions for how a shock to global metals prices, which the small open economy takes as given, affects sectoral prices and, therefore, inflation. An increase in metal prices increases the marginal cost of sectors that import metals, or metal-intensive goods, directly or indirectly. If the metals sector imports all its copper, a rise in copper prices will affect the metals sector price and, therefore, the marginal cost of all sectors that use metals sector's inputs in production, be directly or indirectly through the production network. Similarly, sectors that import metal-intensive goods are exposed to the shock. For example, the broadcasting and telecommunications sector imports cars and machinery, which were also produced using metals.

We start by analyzing the average effect of metals and energy price shocks on inflation for our panel of countries. In particular, we show that copper supply shocks have significant and persistent effects on both headline and core inflation. On average, a one percent increase in copper prices driven by an exogenous copper supply shock leads to a roughly 0.02 percentage point increase in both headline and core inflation after 12 months. The impact increases to 0.05 and 0.03 percentage points after 24 months, respectively, and is quite persistent. Since copper represents about 30 percent of the global trade in industrial metals, these estimates are a lower bound for the impact of a generalized increase in metals prices. In comparison, oil supply shocks impact mostly headline inflation. A one percent increase in oil prices has a 0.05 percentage points impact on headline inflation after 12 and also 24 months but becomes insignificant after 40 months. There is no significant impact on core inflation.

We then use the model-implied equations to study the inflationary effects of global metal price shocks through production networks. The network model, calibrated for a wide set of countries, allows us to calculate the country-level *exposure* to metals (energy), for final consumption. Exploiting this information we test how this heterogeneity affects our results. For countries with high exposure, the impact of a one percent increase in copper price due to a supply shock raises headline inflation by 0.06 percentage points after 12 months and 0.1 percentage points after 24 months. The impact on core inflation is 0.04 percentage points after 12 months and 0.06 percentage points after 24 months. For countries with low exposure, there is no statistically significant on both types of inflation.[2]

In comparison, oil supply shocks mostly impact headline inflation, immediately. Our results show that a one percent increase in oil prices has a large impact on headline inflation, reaching 0.05 percentage points after 12 months. We also observe heterogeneity between countries with high and low production network exposure to oil. However, the differences are less pronounced compared to metals.[3]

Our results imply that if the world economy became more metals intense due to the energy transition, inflationary shocks could be more persistent. In contrast to oil supply shocks that are more temporary, central banks may need to react to changes in core inflation due to metals supply shocks. At the same time, metals prices could become more volatile due to geopolitical tensions. New restrictive trade policies, including on metals trade, have almost doubled since the onset of the war in Ukraine (see, e.g., Gopinath

[2]Recently, Minton and Wheaton (2023) have documented the indirect network effects of oil price fluctuations on downstream sectoral prices, which consequently amplifies the inflationary effect of oil price shocks. These results complement the findings in Auer, Levchenko, and Sauré (2019) where network spillovers are responsible for global inflation comovement.

[3]A potential reason for the lack of heterogeneity in the propagation of oil supply shocks is the limited granularity of the input-output data. The energy sector used to describe the 'oil sector' also includes gas and coal, which can be significant in some countries.

et al., 2024; Alvarez et al., 2023). Because most metals production is geographically concentrated and not easy to substitute, disrupting trade would lead to sharp swings in their prices with a growing impact on the economy due to the energy transition (see Alvarez et al., 2023)

Related literature: The paper builds on the literature on production networks by emphasizing metals as inputs in the production of intermediate and investment goods. Vom Lehn and Winberry (2022) examine the role of the machinery and construction sectors in amplifying and propagating shocks in the US, while Silva et al. (2024) investigates the role of the agriculture and mining sectors in the propagation of commodity price shocks to small open economies. Silva (2023) studies the role of production networks in the transmission of imported input price shocks to inflation. Our contribution is to show that shocks to primary metal prices can significantly affect prices, and therefore inflation, through the key role that metals play as inputs in the production of investment goods, such as machinery, electrical equipment, and construction materials. We also show that the metal content of non-metals imports (e.g., electrical equipment) is important in the transmission of metal price shocks.

We also make contributions to the literature that examines the drivers of inflation comovement across countries (see, e.g., Auer, Levchenko, and Sauré, 2019; Bernanke and Blanchard, 2023, and others). The central role of primary metals in manufacturing could help explain the significant inflationary effects of changes in primary metals prices following US monetary policy shocks as documented in Miranda-Pinto et al. (2023). Our work shows that supply shocks to metals prices can have significant and persistent effects on core inflation, potentially leading to comovement across countries.

Finally, our work contributes to the extensive literature studying the transmission channels of commodity price shocks (see, e.g., Kilian, 2009; Baumeister and Hamilton, 2019; Schmitt-Grohé and Uribe, 2018; Di Pace, Juvenal, and Petrella, 2024; Albrizio et al., 2023; Benguria, Saffie, and Urzúa, 2024; Silva et al., 2024; Minton and Wheaton, 2023).

We built on a small but growing literature that identifies shocks to metals prices (see, e.g., Stuermer, 2018; Jacks and Stuermer, 2020; Vega-Olivares, 2022; Boer, Pescatori, and Stuermer, 2024; Baumeister, Ohnsorge, and Verduzco-Bustos, 2024). Our contribution is to show that metal supply shocks are important direct and indirect channels for inflation because metals are important inputs for intermediate and investment goods.

The remainder of the paper is structured as follows. Section 2 provides stylized facts about the role of metals in the economy. Section 3 lays out the theoretical framework. Section 4 presents the empirical results and Section 5 the robustness checks. Finally, Section 6 concludes.

2 Stylized Facts

Before outlining our theoretical framework, we provide simple facts on the importance of metals in the economy. We show that metals and energy commodities enter the economy differently. While metals are mostly used for investment goods, oil, gas, and coal are used as a flow in the production of energy, mostly in the transportation sector. We quantify the role of metals and oil in the economy, using input-output tables, which offer a snapshot of direct linkages between different sectors. Building on these tables, we employ a simple metric to gauge each sector's exposure to metals (i.e., the Leontief's inverse) capturing both the direct and indirect dependencies within the production network.

2.1 Measuring Direct and Indirect Linkages

To gauge the sectoral exposure to metals for both the US and other countries, we follow the literature on the propagation of sectoral shocks in the macroeconomy through production networks. Balke and Wynne (2000), for example, studies a closed economy model featuring input-output linkages and sectoral productivity shocks in the spirit of Long Jr and Plosser (1983). In this class of models, the total exposure of a given sector i

to a productivity shock in sector j ($\frac{\partial \log P_i}{\partial \log Z_j}$), is given by the element ij of a version of the Leontief inverse matrix $(I - \Omega)^{-1}$, where the element $\{\Omega\}_{ij} = \frac{P_j M_{ij}}{P_i Q_i}$ represents the direct linkages between supplier j and customer i, as a fraction of sector i's gross output.[4]

Therefore, when focusing on the metals sector (M), the element iM of the Leontief inverse characterizes both the direct and indirect effects of an increase in metals prices on sector i's total intermediate input costs. This term accounts not only for the direct share of metals in sector i's production but also for the share of metals in the production of i's suppliers and the suppliers of i's suppliers.[5]

2.2 Data: Input-Output Tables

The data used are from 3-digit US Bureau of Economic Analysis input-output tables for 2018. We define the metals sector as the sum of the mining sector, except oil and gas, and the primary metals sector. Due to lack of granularity in the input-output tables, we cannot identify crude oil precisely. Instead, we use the sum of the oil and gas extraction and the petroleum and coal products sectors (Energy). Annex B describes data-sources and definitions.

For other countries, we use input-output data from the OECD. The sectoral definitions for metals and energy are broadly consistent with those used in the US analysis. For metals, we consider the combined mining and quarrying of non-energy producing products sector and the basic metals sector. For energy, we sum up the mining and quarrying of energy-producing products sector as well as the coke and refined petroleum products manufacturing sector.

Given that a large fraction of metals and energy are imported, following Vom Lehn and Winberry (2022) and to provide a simple measure of exposure, we also account for

[4]This result has been stablished by several papers in the literature. Among them, see Baqaee and Farhi (2019), Vom Lehn and Winberry (2022), and Silva (2023).

[5]The Leontief inverse $(I - \Omega)^{-1}$ captures all direct and indirect linkages. It can be expanded as an infinite sum of higher-order network effects: $I + \Omega + (\Omega)^2 + (\Omega)^3 + \ldots$.

imports of metals and energy by domestic sectors when calculating intermediate inputs.[6]

2.3 Metals and Energy in the Production Network: the US Case

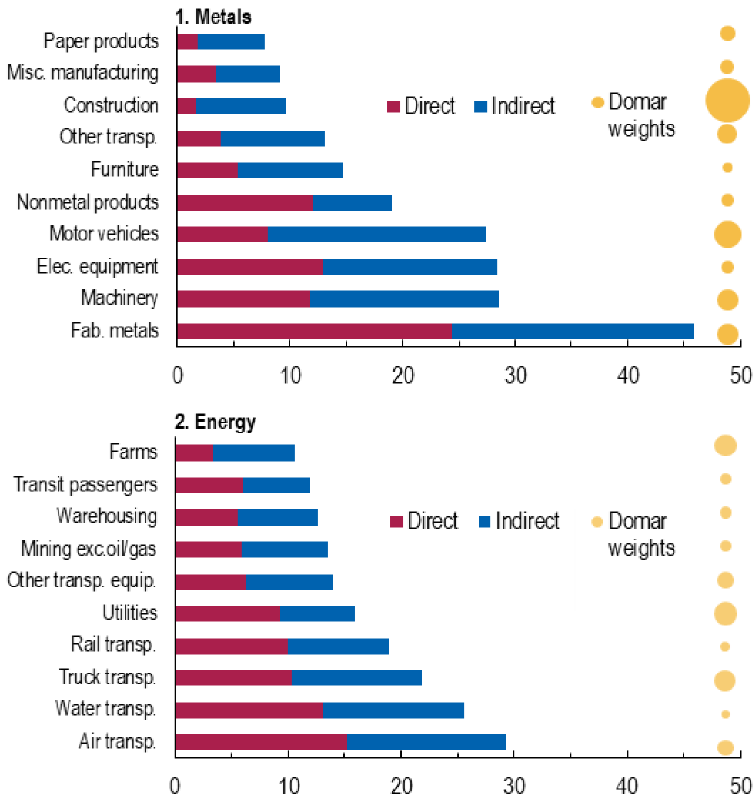
Figure 1 shows the sectoral exposure to metals (top panel) and Energy (bottom panel) for the US. We further decompose the sectoral exposure into direct exposure (in red), which is the input-output share (Ω), and indirect exposure (in blue), which is total exposure (the Leontief inverse) minus the direct exposure. Additionally, we plot each sector's Domar weight (in yellow), the ratio between sectoral gross output and aggregate GDP, to give an intuition about the size of different sectors in the US economy.

Looking first at direct exposure, we find that, unlike energy, primary metals are embedded in the production of investment goods. While metals like copper and aluminum represent only a small fraction of final consumption expenditure (e.g., 0.01 percent vs 2.6 percent for oil and coal products, in the US), they are critical direct intermediate inputs into the production of investment goods. For example, metals represent more than 10 percent of direct input expenditure in the US sectors for electrical equipment and machinery.

Because metals are embodied in investment goods, they are also indirect inputs across sectors. For example, to produce vehicles, metals are not only used for the body of the car but also for the machines used to assemble the car. Once the indirect component is taken into account, fabricated metals and machinery stand out with a 28 and 46 percent share, respectively. The most notable difference, however, is in the construction sector, where indirect exposure is 4 times as large as direct exposure. Construction also carries the highest Domar weight in the US economy, underscoring the importance of accounting for indirect linkages when assessing the role of metals.

[6] The methodology we use is derived from a closed economy framework. To present stylized facts, we adapt this method to include imports, effectively "forcing" imports into the closed economy setup. The main analysis in later sections includes explicitly a tradable sector, where we focus directly on exposure to imported metals and oil.

Figure 1: The Top 10 US Sectors with the Largest Intermediate Input Expenditure Shares of Metals and Energy in Gross Output (Percent)



Note: The direct expenditure share is defined as the sectoral intermediate input expenditure of metals (energy) as a share of sectoral gross output. The indirect expenditure share is the Leontief inverse share element minus the direct expenditure share. The Domar weight is the ratio of the nominal value of each industry's gross output to GDP. Construction shows the highest Domar Weight (9.59 percent) and the water transportation sector the lowest (0.03 percent). We define the metals sector as the sum of the non-oil and non-gas mining sector and the primary metal sector. The energy sector is the sum of the mining of oil and gas sector and the petroleum and coal products manufacturing sector.

In contrast, energy sector products are much less embodied in machines and investment goods. Instead, they are generally used as fuel to produce energy, mostly in transportation (air, water, truck, and rail) and utilities. Thus, while indirect exposure is still important, it plays a less prominent role compared to metals.

In summary, metals and energy enter the production network differently. What does this imply for the propagation of shocks? The fact that key upstream sectors providing capital are highly exposed to metals suggests that metals price shocks may lead to a more persistent impact on inflation, particularly on core inflation. Energy price shocks, on the other hand, are likely to have a more immediate effect, mainly on headline inflation. In the next section, we move to the cross-country sample.

2.4 Production and Consumption Exposures to Metals and Oil

An aggregate measure is needed to summarize the relevance of a sector in an economy's aggregate price index, including through the network. To derive one, it is possible to define a country's aggregate exposure to a sector (i.e., metals or energy) by using the expressions for CPI inflation and GDP deflator derived from the network model. For simplicity, in this section, we continue using the closed-economy exposures that include imports. In the next section, we specifically lay out the transmission channel from imported metals (energy) through domestic I-O linkages.

Assuming that the household aggregate consumption bundle is $C = \prod_k \left(\frac{C_K}{b_k}\right)^{b_k}$, the cost minimization problem of the household implies the following consumer price index (CPI):

$$\log CPI_t = \sum_k b_k \cdot \log P_{kt},$$

in which b_k is the final consumption expenditure share of sector k and P_k is the price of sector k's output. One could also define the simile of the GDP deflator as follows

$$\log DGDP_t = \sum_k va_k \cdot \log P_{kt},$$

with va_k representing the value-added share of sector k.

As emphasized above, the price of sector k depends on metals productivity through the Leontief inverse element kM. Hence, if the only shock in the economy is the shock to metals' productivity Z_M, the change in the GDP deflator and the CPI, in response to the metals exogenous shock, are defined as:

$$d \log DGDP_t = \sum_k v_{ak} \cdot \frac{\partial \log P_{kt}}{\partial \log Z_M} = \sum_k v_{ak} \cdot (I - \Omega_{total})^{-1}_{kM}, \tag{1}$$

$$d \log CPI_t = \sum_k b_k \cdot \frac{\partial \log P_{kt}}{\partial \log Z_M} = \sum_k b_k \cdot (I - \Omega_{total})^{-1}_{kM}, \tag{2}$$

where Ω_{total} is the total economic I-O network that, for now, includes imported intermediates. These equations gauge the importance of metals for each sector component in the GDP deflator and the consumer price index (CPI). This approach captures the inflationary pressure stemming from an exogenous shock to metals prices. The overall impact on inflation, however, will depend on the chosen monetary policy rule. In this case, nominal variables are pinned down by assuming that money supply targets a given level of nominal GDP.

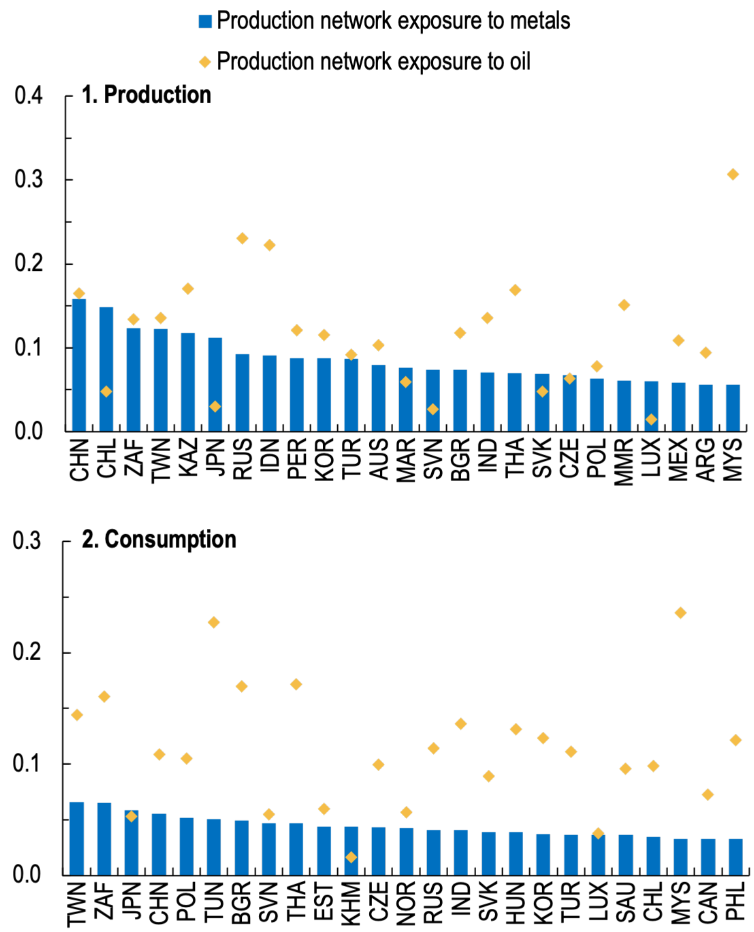
Figure 2 plots the (total input-output network) exposure to metals and energy at the aggregate level, for the top 25 countries in the OECD sample. The top panel aggregates sectoral exposures to metals and energy using value-added shares, which are suited to gauge the exposure of the economy to metals and oil on the production side—i.e., the GDP deflator. The bottom panel shows the exposure to metals and energy on the consumption side. It uses final consumption expenditure shares, the relevant measure for CPI, to construct the consumption exposure, which indicates the percent increase in the CPI index of a country to a 10 percent negative supply shock that results in an about a 15 (16) percent increase in metals (energy) prices on average across countries. For instance, a 10 percent supply-driven increase in metals prices, would generate a 0.36 p.p. increase in China's CPI, compared to a 0.1 p.p. increase for the US, according to the network model.

Several results stand out in Figure 2. First, the heterogeneity in the exposure of production is starker than the one in the exposure of consumption across countries. This is because consumption preferences are likely similar across countries, leading to less heterogeneity in consumption exposure. At the same time, the location of production of tradable goods is independent from the location of consumption, creating more heterogeneity in production exposure. Moreover, differences in technological adoption also induce significant heterogenity in sectoral exposures to metals and oil across countries. For instance, while the total metal exposure of the motor vehicle sector in the average country is 16 percent, the 10th percentile is 5 percent and the 90th percentile is 34 percent.

Second, metals are more relevant than oil in production in seven out of the top twenty-five countries. Nevertheless, because metals are less embedded in downstream sectors, once consumptions shares are used to aggregate, only three countries display larger exposure to metals than oil. Indeed, the median CPI exposure is three times larger for oil than for metals.

Third, there are significant cross-country differences. While the median country has a metal exposure of 0.03, a country in the 90th percentile has an exposure that is five times larger than a country in the 10th percentile of the distribution.

Figure 2: Countries' Input-Output Exposure to Metals and Energy (Percent)



Note: The figure depicts countries' production network exposure for the year 2018. Data labels in the figure use International Organization for Standardization (ISO) country codes. Sectoral exposures are weighted by: i) sectors' value added share in total value added (top panel) and ii) sectors' final consumption share (bottom panel).

3 Theoretical Framework for Cross-country Regressions

Having established the importance of metals in production networks, we turn to a theoretical framework where a key element is the open economy aspect. This framework helps to understand the inflationary effects of a shock to imported metals prices, which the small open economy takes as given. Metals and energy are highly traded intermediate inputs for production whose prices are determined in global markets. Moreover, non-metal imports (e.g., motor vehicles and computers) also use large amount of metals in production, which is why our model accounts for the metal (energy) content of non-metal (non-energy) imports.

Our model adapts and extends the framework in Silva (2023), who incorporates production networks into a small open economy to study inflation. In particular, we tailor the model to focus on the role of imported metal price shocks and then explicitly account for the metal content of non-metal imports (e.g., cars or electrical equipment). Our model entails a continuum of small open economies as in Gali and Monacelli (2005). The benchmark small open economy imports metals and non-metal products for final consumption and for sectoral production. Non-metal imports are produced by a subgroup of small open economies who also import metals. Hence, we implicitly consider indirect linkages (second order only) across countries without formally solving for the world economy's equilibrium.

In the data, metal importers can also be metals producers. Thus, the model explicitly separates between imported metals used as intermediate inputs by domestic sectors and domestically produced metals supplied as intermediate inputs to domestic sectors. In particular, while the international price of imported metals is exogenous, the domestic price of metals is endogenous and depends on domestic cost pressures. Given that domestic metal sectors tend to import significant amounts of metals, the domestic and the international price naturally comoves.

The model will provide testable implications in terms of the heterogeneity in exposures to international metals price shocks at the country-level.

Here we describe the benchmark economy but a similar structure applies for other small open economies. In this model, there exists a collection of N goods and services produced within the country with each good identified as i. These domestically produced goods have multiple uses: they can be consumed within the country, serve as intermediate inputs for other domestic industries, or be exported. The set of imported goods is symbolized by M with each imported item denoted by m. These imports can either be used as intermediate inputs in the production of domestic goods or consumed directly as final products. Additionally, there exists a set F that comprises various factors of production, each factor labeled as f.

In this section, we first outline the model, then review the key equation and discuss its application to analyzing metal supply shocks. We follow the notation in Silva (2023). Hence, matrices and vectors are denoted using bold letters (i.e., $\boldsymbol{Z}$). The transpose of a matrix $\boldsymbol{Z}$ is $\boldsymbol{Z}^T$. Log changes are expressed as $dlogZ = \hat{Z}$.

3.1 Representative Household

A representative household consumes both domestic and foreign goods, deriving instantaneous utility represented by $U(\boldsymbol{C}_D, \boldsymbol{C}_M)$, where $\boldsymbol{C}_D = \{C_i\}_{i \in N}$ indicates domestic goods consumption and $\boldsymbol{C}_M = \{C_m\}_{m \in M}$ represents foreign goods consumption. Consumption of these goods is tied to their respective price vectors $\boldsymbol{P}_D = \{P_i\}_{i \in N}$ for domestic and $\boldsymbol{P}_M = \{P_m\}_{m \in M}$ for foreign goods, typically in local currency unless specified otherwise. The utility function $U(\cdot)$ is assumed to scale linearly with its inputs. This household owns and supplies all production factors at fixed prices. It seeks to minimize costs given the price vectors of both domestic and foreign goods:

$$PC = \min_{\boldsymbol{C}_D, \boldsymbol{C}_M} \sum_{i \in N} P_i C_i + \sum_{m \in M} P_m C_m,$$
$$\text{subject to } U(\boldsymbol{C}_D, \boldsymbol{C}_M) \geq \overline{U}.$$

The solution to this problem yields a price index that is a function of good prices:

$$P = P\left(\boldsymbol{P}_D, \boldsymbol{P}_M\right).$$

Up to a first order, prices in this economy satisfy:

$$\widehat{P} = \overline{\boldsymbol{b}}_D^T \widehat{\boldsymbol{P}}_D + \overline{\boldsymbol{b}}_M^T \widehat{\boldsymbol{P}}_M,$$

where $\overline{\boldsymbol{b}}_D = \{\bar{b}_i\} = \frac{P_i C_i}{E}$, $\overline{\boldsymbol{b}}_M = \{\bar{b}_m\} = \frac{P_m C_m}{E}$, and $E = \boldsymbol{P}_D^T \boldsymbol{C}_D + \boldsymbol{P}_M^T \boldsymbol{C}_M = PC$ are the expenditure shares of domestically produced goods $\left(\bar{b}_i\right)$, imported goods $\left(\bar{b}_m\right)$, and total expenditure (E), respectively. The consumer's budget constraint is given by:

$$PC + T = \sum_{f \in F} W_f L_f + \sum_{i \in N} \Pi_i,$$

where T is an exogenous net transfer to the rest of the world.

3.2 Firms

Within each sector i, there is a representative firm with a production function of the form:

$$Q_i = Z_i F_i \left(\{L_{if}\}_{f \in F}, \{M_{ij}\}_{j \in N}, \{M_{im}\}_{m \in M}\right),$$

where Z_i is sector-specific productivity, L_{if} is the demand for factor f by firm i, M_{ij} represents intermediate input demand for good $j \in N$ by firm i, and M_{im} represents input demand for imported good $m \in M$.

The cost minimization of firm i delivers a marginal cost that only depends on productivity and input prices:

$$MC_i = MC_i\left(Z_i, \boldsymbol{P}_D, \boldsymbol{P}_M, \boldsymbol{W}\right),$$

where $\boldsymbol{W} = \{W_f\}_{f \in F}$ is a vector of factor prices. The assumption of constant returns to scale is key for the result that marginal costs are independent of the scale of production. Moreover, in perfectly competitive markets with constant returns to scale, each firm operates at zero profit:

$$P_i Q_i = \sum_{f \in F} W_f L_{if} + \sum_{j \in N} P_j M_{ij} + \sum_{m \in M} P_m M_{im} \quad \text{for all } i \in N.$$

3.3 Equilibrium

The market clearing conditions for sectoral output are given by:

$$Q_i = C_i + X_i + \sum_{j \in N} M_{ji} \quad \text{for each } i \in N.$$

X_i is an exogenous variable so that there is always a price that clears the market for each domestically produced good, even if the good is exported.

3.4 Nominal Anchor

As this model is in real terms, a money rule is needed. Assume the following cash-in-advance constraint:

$$PC \leq M^u = E.$$

In the small open economy, the central bank, with money supply (M^u) as an exogenous factor, dictates nominal spending (E) to maintain a set benchmark. By monitoring consumption (C) affected by real factors, the central bank can implement any price level

(P) accordingly.

Equilibrium is achieved by taking factor prices ($\boldsymbol{W}$) and expenditure (E) as given to pinpoint both feasible and equilibrium allocations. Households select $(\boldsymbol{C}_D, \boldsymbol{C}_M)$ to maximize utility constrained by their budget based on sequences $(\boldsymbol{W}, \boldsymbol{P}_D, \boldsymbol{P}_M, \boldsymbol{\pi})$ and exogenous parameters (T). Given $(\boldsymbol{W}, \boldsymbol{P}_D, \boldsymbol{P}_M)$ and production technologies, firms choose (L_i, M_i) to minimize production costs. Market clearance is achieved given X. The cash-in-advance constraint is binding: $P_C = M^u = E$.

3.5 Changes in the Price Index

We study the role of imported goods prices and production networks in driving inflation through a log-linear approximation of changes in the consumer price index P. This approach examines inflation from a cross-sectional view rather than the traditional time-based analysis. The main result in Silva (2023) is summarized in Proposition 1. In particular, consider a perturbation $\left(\widehat{\boldsymbol{Z}}, \widehat{\boldsymbol{W}}, \widehat{\boldsymbol{P}}_M\right)$ around some initial equilibrium. Up to a first order, changes in the aggregate price index $\widehat{P}$ satisfy:

$$\widehat{P} = -\left(\overline{\boldsymbol{\lambda}}^T - \widetilde{\boldsymbol{\lambda}}^T\right)\widehat{\boldsymbol{Z}} + \left(\overline{\boldsymbol{\Lambda}}^T - \widetilde{\boldsymbol{\Lambda}}^T\right)\widehat{\boldsymbol{W}} + \left(\overline{\boldsymbol{b}}_M^T + \widetilde{\boldsymbol{b}}_M^T\right)\widehat{\boldsymbol{P}}_M, \tag{3}$$

where

$$\widetilde{\boldsymbol{\lambda}}^T = \overline{\boldsymbol{x}}^T \boldsymbol{\Psi}_D; \quad \widetilde{\boldsymbol{\Lambda}}^T = \overline{\boldsymbol{x}}^T \boldsymbol{\Psi}_D A; \quad \widetilde{\boldsymbol{b}}_M^T = \overline{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}; \quad \boldsymbol{\Psi}_D = (\boldsymbol{I} - \boldsymbol{\Omega})^{-1},$$

where $\overline{\boldsymbol{x}}$ is the export share ($\frac{P_i X_i}{GDP}$), Ω the domestic input-output matrix ($\Omega_{ij} = \frac{P_j M_{ij}}{P_i Q_i}$), A is the factor spending matrix ($a_{if} = \frac{W_f L_{if}}{P_i^D Q_i}$), and Γ the matrix of intermediate input shares ($\Gamma_{ij} = \frac{P_m M_{im}}{P_i Q_i}$).

The first two terms in Equation (3) contain the effects of shocks to sectoral productivity and wages. The last term considers the effect of changes in import prices. Import prices influence inflation via intersectoral connections and the network-adjusted share of import consumption. Note that the input-output network Ω considers only domestic input-output linkages.

In a closed-economy setting, where all prices react endogenously to productivity shocks, and there are no imports or exports, Equation 3 becomes Equation 2. The advantage of using Equation 3, and separating productivity shocks from import price shocks, is that one can use externally identified shocks to import prices, in this case metals price shocks, to characterize the role of production networks in driving inflation.

Our point of departure from Silva (2023) is that we consider the metal content of other imports. With some abuse of notation, consider M as metal imports and NM as non-metal imports. For simplicity, assume that the currency of the group of small open economies producing and exporting metals is the same as the currency of the group of small open economies producing and exporting metal-intensive goods.

The following proposition describes the direct and indirect effects of metal price shocks on inflation.

Proposition 1. *Consider a perturbation to imported metal prices $\widehat{P}_M$ around some initial equilibrium, with fixed productivity and wages. Up to a first order, changes in the aggregate price index, $\widehat{P}$ satisfy*

$$\widehat{P} = \left(\bar{\boldsymbol{b}}_M^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{M}} + (\bar{\boldsymbol{b}}_{NM}^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{NM}}) \boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}_{\boldsymbol{M}}^*\right) \widehat{\boldsymbol{P}}_M, \tag{4}$$

where $\widehat{\boldsymbol{P}}_M$ is the change in global metal prices, in units of the benchmark small open economy's currency. $\boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}^*$ measures the intensity of metals in the production of non-metal imports in the second group of small open economies.

Proof. See Appendix E. □

3.6 The Mechanism

Equation (4) highlights the importance of accounting for both direct import consumption $\left(\bar{\boldsymbol{b}}_M\right)$, where consumers purchase imported metals (energy) directly, and indirect import consumption through domestic production $\left(\bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}\right)$, where consumers purchase imports indirectly by buying domestic goods that use imports as inputs, either directly or indirectly. The intuition behind the second term is that the domestic production network is aggregated based on each sector's expenditure on imports and households' final consumption of each sector.

Turning to metals, this theoretical framework helps us understand the inflationary effects of a shock to imported metals prices, which the small open economy takes as given. Equation (4) shows that an increase in metal prices M elevates producer h 's marginal costs via $\boldsymbol{\Gamma}_{hM}$, pushing up prices for their products P_h, and indirectly affecting the prices of domestically produced goods through intermediate production networks ($\boldsymbol{\Psi}_D$). This impact, along with sectoral spending on metals, reflects on the consumer price index through consumption shares ($\bar{\boldsymbol{b}}_D$). Naturally, it can also affect the consumer price index through direct consumer purchases of metals as final goods ($\bar{\boldsymbol{b}}_M$).

The second term in Equation (3) $\left(\left(\bar{\boldsymbol{b}}_{NM}^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{NM}}\right) \boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}^*\right)$ captures the metal content of non-metal imports. In particular, the share of imported cars or machinery ($\bar{\boldsymbol{b}}_{NM}^T$) is weighted by the amount of metals used in the production of cars in the second group of small open economies ($\boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}^*$). Moreover, we consider the fact that domestic firms import metal-intensive goods (e.g., electrical equipment or machinery) in the production of their own goods/services (e.g., broadcasting and telecommunications). This last effect is characterized by the term $\bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{NM}} \cdot \boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}^*$.

In contrast to the stylized facts, where we used the total input-output table (the sum of domestic and imports) directly, here we can isolate the inflationary effect of an exogenous foreign commodity supply shock, focusing specifically on how external shocks influence production costs and propagate through the economy. Since metal production is usually geographically concentrated, this framework is well-suited for studying the inflationary effects of metal supply shocks in most economies that are metals (oil) importers.[7]

[7]For large metal-producing countries, such as Chile, this approach may be less applicable. In those cases, metal price increases not only raise production costs through the input-output network but also generate an

4 Empirical Evidence

This section empirically tests the predictions of the theoretical framework on a balanced panel of 39 economies for which we have information on headline and core inflation. We start by describing data sources and the calculation of network exposure. Then, we show that copper price shocks have significant effects on core and headline inflation, especially for the countries with high network exposure to metals. We also compare these effects to those of oil price shocks.

4.1 Data and Descriptive Statistics

4.1.1 Network Exposure to Metals and Oil

We calibrate the production network model for a sample of 39 economies using OECD input-output tables. The data cover 45 sectors, include imports of intermediates, which are sizable for the cases of metals and energy.

Country i's network exposure to metals and energy can be constructed by applying Equation (4) for each country. In particular, $\bar{b}_M^T$ is the consumption expenditure share of imported metals (energy) in total household consumption expenditure (a scalar). This measures the direct exposure, without considering network connections. $\bar{\boldsymbol{b}}_D^T$, $\boldsymbol{\Psi}_D$, $\boldsymbol{\Gamma}_M$, $\widehat{\boldsymbol{P}_M}$ are the vector of sectoral domestic consumption expenditures, the domestic IO network (Leontief inverse matrix), the vector of sectoral shares of imported metals (energy) in gross output, and the log change in international metals (energy) prices.

All vectors and matrices can be calculated from the I-O table. As in the previous section, for exposure to metals, we focus on primary metals: mining and quarrying of non-energy producing products and basic metals. Fabricated metal products are included in the robustness checks. For energy, we use fossil fuels, including mining and coke and refined petroleum products. See Table B.3 in the appendix for the full list of OECD sectors.

income effect, which can contribute to inflation through the demand channel from the cost-push inflation focused in this paper.

To measure the metal content of non-metal imports, the second term in Equation (4), we proxy for $\mathbf{\Psi}^*_D\mathbf{\Gamma}^*$ as follows. We calculate the total use of metals and energy, direct and indirect, for all the non-metals and non-energy sectors in our sample of countries. We obtain the average sectoral use of metals and energy across countries and then select the top-5 sectors in the use of metals and energy. Table 1 shows that fabricated metals, electrical equipment, machinery and equipment, motor vehicles, and other transport equipment are the top users of metals. On the other hand, the top energy users are air transport, electricity, water transport, land transport, and chemical products.

Table 1: Top Non-Metal and Non-Energy Sectors by Exposure

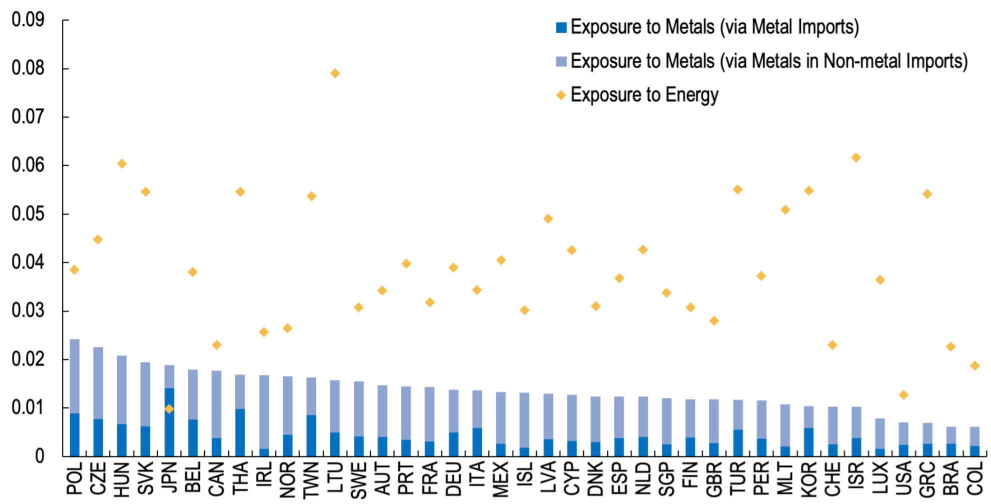
Sector	**Metals Exposure**	**Energy Exposure**
Fabricated metal products	0.37	–
Electrical equipment	0.25	–
Machinery and equipment, nec	0.22	–
Motor vehicles, trailers and semi-trailers	0.16	–
Other transport equipment	0.15	–
Air transport	–	0.27
Electricity, gas, steam and air conditioning supply	–	0.25
Water transport	–	0.21
Land transport and transport via pipelines	–	0.21
Chemical and chemical products	–	0.19

Note: this table reports the cross-country average of production exposure to metals ($\mathbf{\Psi}_D\mathbf{\Gamma}_M$) and energy ($\mathbf{\Psi}_D\mathbf{\Gamma}_E$) for the top-5 sectors in our sample.

Figure 3 plots the exposures based on Equation (4). The first term in Equation (4), the network exposure from metal imports, is depicted in dark blue. The second term, the metal content of non-metal imports, is depicted in light blue. In yellow, we report the total exposure to energy.

Data show significant cross-country differences in exposure similarly to section 2. In our sample, the mean exposure to metals (energy) is 0.014 (0.04), with a standard deviation of 0.004 (0.01). According to the theoretical framework, this heterogeneity can be attributed to several factors: First, reliance on metals (energy) imports plays a significant role – countries that depend heavily on imports tend to exhibit higher exposure. Second, differences in production networks across countries. For instance, while the motor vehicle sector's exposure to metals is around 10% in both Germany and France, it is 30% in China. This reflects variations in technological adoption, and could also be driven by differences in production cost components across economies, such as Germany's and France's relatively higher labor costs and potentially higher R&D expenditure compared to China.

Figure 3: Network adjusted exposure to metal imports and energy imports



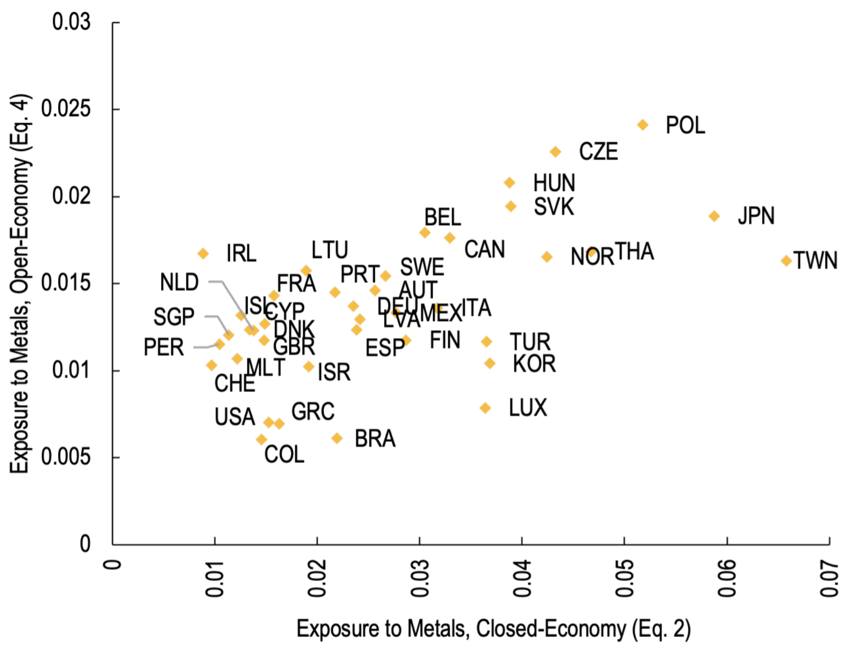
Note: This figure shows cross-country exposures to metals and energy for 39 economies in our sample. Exposures are constructed following Equation 4. The blue columns display exposure to metals: "Exposure to Metals (via Metal Imports)" corresponds to the first term in the equation, while "Exposure to Metals (via Metals in Non-metal Imports)" reflects the second. Exposure to energy is constructed analogously, we report only the total exposure without separating the two components. Data labels use International Organization for Standardization (ISO) country codes.

Countries also differ in their imports of metal-intensive goods. This heterogeneity affects the second term in Equation (4). For example, while Canada and Israel are similarly exposed (dark blue exposure) to the import of metals (directly and indirectly through domestic linkages), Canada is much more exposed to the import of metal-intensive goods (light blue exposure) than Israel.

Lastly, household spending patterns on goods vary across countries. Zooming in on car industry again, while car exposure to metals is similar in both Germany and France, German households spend more on cars than the French, leading to higher overall exposure in Germany.[8]

In Figure 4 we provide a comparison between our model-implied exposure to metal imports and the reduced-form closed-economy exposure we provide in Section 2. The correlation between these measures is 0.82 for metals and 0.68 for energy. These exposures do present differences in their magnitudes. While the small open economy exposure only captures the effect of international prices (assuming productivity fixed in the domestic metal or energy sector), the closed-economy exposure accounts for any shock that affects prices in the metal or energy sector. In this sense, while the small open economy model provides a lower bound for the exposure, it is also a more direct empirical test as we estimate the effect of identified shocks to international metal (energy) prices, rather than country-specific metals (energy) productivity, on inflation.

Figure 4: Closed- vs. Open-Economy Exposure to Metals



Note: This figure compares the closed-economy exposure to metals (based on Equation 2 in the stylized fact analysis) with the adjusted small open economy exposure constructed using Equation 4. Data labels in the figure use International Organization for Standardization (ISO) country codes.

Although the network exposure vary across countries, for each country, it remains

[8] The consumption share of domestically produced cars is 0.84% in France and 3.29% in Germany. Including imported cars, the shares are 3.2% and 4.8%, respectively.

relatively stable over time. For our empirical analysis, we use the exposure of 2018.

4.2 Inflationary Effect of Metals Price Shocks

We start by estimating the average effects of metal price shocks on inflation. We use instrumental variable (IV) local projections (LP) methods (Jordà, 2005). We estimate the following panel regressions:

$$\log CPI_{it+h} - \log CPI_{it-1} = \alpha_i^h + \beta^h p_t^M + \sum_{l=0}^{L} \phi_{xl}^h X_{it-l} + \epsilon_{it+h} \quad \text{for } h = 0, 1, 2, \ldots, \tag{5}$$

where CPI_{it+h} is the consumer price index (headline or core) of country i at time $t+h$. α_i^h is the country fixed effects. p_t^M is the log of real metal (energy) price at time t.[9] The set of controls X_{it-l} includes $L = 12$ lags of real metal (energy) price and the log change of CPI, as well as a global economic activity index from Baumeister, Korobilis, and Lee (2022), US 1 year treasury bill yield, bilateral exchange rates, and the Gilchrist and Zakrajšek (2012) excess bond premium (EBP) for the US. We also include contemporaneous and 12 lags of logs of food prices and oil prices. The regression is estimated using monthly data from 1996:m2 to 2019:m12, for a balanced panel with 39 countries.

To correct for the potential endogeneity in metals and oil prices, we use commodity price shocks identified in the literature as instruments for commodity prices. There is a small and recent literature identifying shocks to metal prices (see, e.g., Stuermer, 2018; Jacks and Stuermer, 2020; Vega-Olivares, 2022; Boer, Pescatori, and Stuermer, 2024; Baumeister, Ohnsorge, and Verduzco-Bustos, 2024). We use copper supply shocks from Baumeister, Ohnsorge, and Verduzco-Bustos (2024) and oil supply shocks sourced from Baumeister and Hamilton (2019).[10]

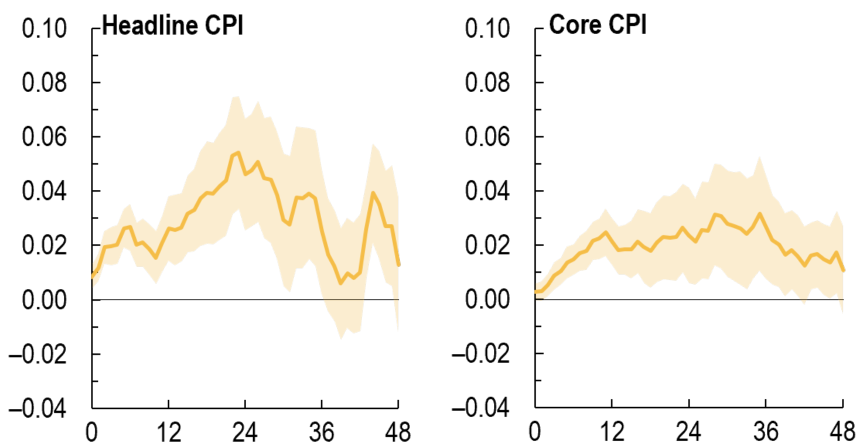
Figure 5 shows the average response of headline CPI inflation (left) and core CPI infla-

[9] Prices are deflated using the trend of US CPI derived from the Hodrick-Prescott filter.

[10] In Appendix C we provide more details on the shock identified by Baumeister, Ohnsorge, and Verduzco-Bustos (2024).

tion (right), in cumulative terms, to a one percent increase in copper prices. Copper price shocks have significant effects on both headline and core inflation. A 1 percent increase in copper prices raises both headline and core inflation by about 0.02 p.p. within 12 months. Responses peak around 2 to 3 years after the shock, reaching 0.05 p.p. for headline and 0.03 p.p. for core.

Figure 5: Impulse Responses of Inflation to Copper Supply Shocks



Note: Cumulative impulse responses of headline CPI inflation (left) and core CPI inflation (right) to a one percent increase in copper prices (using the copper supply shock from Baumeister, Ohnsorge, and Verduzco-Bustos (2024) as an instrument). The x-axis denotes months after the shock. Shaded areas are 90% confidence bands based on cluster-robust standard errors.

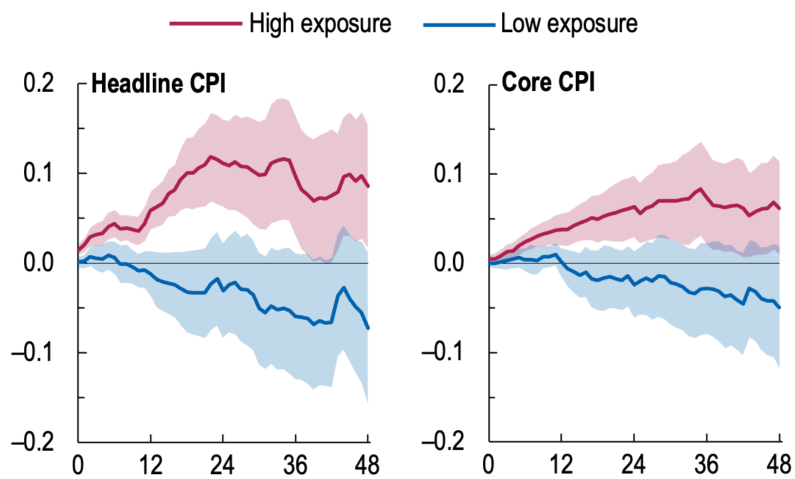
4.2.1 The Production Network Channel

Here we directly test the implications from Proposition 1 in Equation (4). We include the exposure to metals (energy) interacted with the metals (energy) price into our LP-IV regressions:

$$\log CPI_{it+h} - \log CPI_{it-1} = \alpha_i^h + \beta_1^h p_t^M + \beta_2^h p_t^M (z_i - \bar{z}) + \sum_{l=0}^{L} \phi_{xl}^h X_{t-l}^i + \epsilon_{it+h} \quad , \quad (6)$$

where $z_i = \left(\bar{\boldsymbol{b}}_{M_i}^T + \bar{\boldsymbol{b}}_{D_i}^T \boldsymbol{\Psi}_{D_i} \boldsymbol{\Gamma}_{\boldsymbol{M_i}} + (\bar{\boldsymbol{b}}_{NM_i}^T + \bar{\boldsymbol{b}}_{D_i}^T \boldsymbol{\Psi}_{D_i} \boldsymbol{\Gamma}_{\boldsymbol{NM_i}}) \boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}_{\boldsymbol{M}}^* \right)$ represents country i's measure of primary metal exposure as defined in equation (4). $\bar{z}$ is the average exposure across countries. The term $\beta_1^h p_t^M + \beta_2^h p_t^M (z_i - \bar{z})$ captures the impact of negative metals supply shocks that increase real metals prices. For robustness and to show that our results still hold without considering the metal content of non-metal imports, we later consider the following exposure $z_i = \bar{\boldsymbol{b}}_{M_i}^T + \bar{\boldsymbol{b}}_{D_i}^T \boldsymbol{\Psi}_{D_i} \boldsymbol{\Gamma}_{M_i}$.[11]

Figure 6: IRFs: Inflation response for countries with high and low metal exposure according to Equation 4



Note: Cumulative impulse responses of headline CPI inflation (left) and core CPI inflation (right) to a one percent increase in copper prices (using the copper supply shock from Baumeister, Ohnsorge, and Verduzco-Bustos (2024) as an instrument). High (low) exposure is defined as a country in the 90th (10th) percentile of the distribution of z_i. The x-axis denotes months after the shock. Shaded areas are 90% confidence bands based on cluster-robust standard errors.

We evaluate the impact of copper supply shocks for countries with a metal exposure at the 90th and 10th percentiles of our sample – that is, a metal exposure of 0.019 and 0.007, respectively.

Figure 6 shows the results. The effect of a copper price increase is significantly larger for countries with high metal exposure. The 12-months cumulative effect of a 1 percent increase in copper prices leads to positive effects of 0.06 p.p. and 0.04 p.p. on headline and core, respectively. For countries with low network exposure, there is no significant inflationary effect of copper price shocks, with estimated responses close to zero for both headline and core. More importantly, the heterogeneity effect lasts long. For countries

[11]The exposure in Proposition 1 measures the commodity price in domestic currency. Hence, we measure each country's metals (energy) price shock in domestic currency. We also include each country's bilateral exchange rate with the USD dollar as a control in the regression.

with high network exposure, the inflationary effect of copper price shocks builds up over time, reaching its maximum effect of 0.12 p.p. on headline and 0.08 p.p. on core between 2 to 3 years, and remains elevated. After 48 months of the shock, we still observe a 0.06 p.p. increase in core inflation.

In Figure D.2 of our Appendix D, we show that similar results hold when we do not consider the metal content of metal-intensive goods (top panel of Figure D.2). However, the effects are quantitatively smaller, which highlights the role of nonmetal imports in the transmission of metal price shocks. We also show that by ignoring the metal content of non-metal imports but by adding the Fabricated Metals sectors in the definition of metals (bottom panel of Figure D.2), we obtain results that resemble Figure 6.

We then examine how replacing the copper price series by a base metal price index affects results (Appendix Figure D.6, top panel). We construct a weighted average of six base metal prices. We use copper supply shocks as an instrument to study the impact of changes in the base metal price index. Countries with high network exposure to metals have a stronger response of headline and core inflation. The difference between high and low exposure countries is statistically different, at the 90% confidence level, although less precisely estimated compared to the case when we use copper prices.

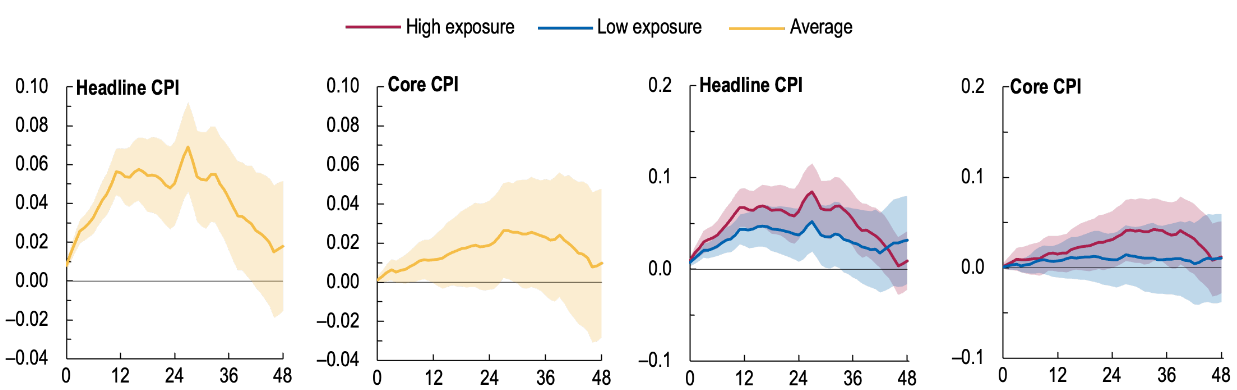
4.3 Inflationary Effect of Energy Price Shocks

We now compare the effects of energy price shocks. We repeat our baseline regressions, using oil prices instrumented by Baumeister and Hamilton (2019)'s oil supply shocks. We include contemporaneous values and lags of copper prices as controls, mirroring the earlier section where contemporaneous values and lags of oil prices were used as controls.

Figure 7 shows the response of inflation to a one percent increase in oil prices. Similar to the previous section, we first estimate the average inflationary effect of oil supply shock, using the regression without the interaction term between shock and exposure. Then, we evaluate the impact of oil supply shocks at the 90th and 10th percentiles of oil exposure, 0.055 and 0.023, respectively.

Compared to the effects of copper price shocks, three key results stand out. First, oil supply shocks have a substantial impact on headline inflation, peaking at 0.07 percentage points after 2 to 3 years, but they have no significant effect on core inflation. Second, there is heterogeneity in the impact based on the energy exposure levels. Countries with higher energy exposure experience higher headline and core inflation. However, these differences are not statistically significant. Third, the impact on headline inflation diminishes over the long term, in contrast to the highly persistent impact of metals on core inflation in high-exposure countries. We obtain similar results when we use the IMF energy price index, instrumented by the oil price shock, instead (Appendix Figure D.6, bottom panel).

Figure 7: Impulse Responses of Inflation to Oil Supply Shocks



Note: Cumulative impulse responses of headline CPI inflation and core CPI inflation to a one percent increase in oil prices (using the oil supply shock from Baumeister and Hamilton (2019) as an instrument). Yellow line denotes the average responses. Red/Blue line denotes oil exposure at the 90th/10th percentile of the sample in 2018. Shaded areas are 90% confidence bands. The x-axis denotes months after the shock.

In the previous sections, we documented high energy exposures, on average, which potentially suggest that consumer prices should be more sensitive to energy price shocks than to metals price shocks. How do we then understand the muted response of core inflation? The difference between headline and core inflation lies in the exclusion of the food and energy sectors. Our results suggest that oil shocks primarily spillover into the energy sector and food prices, likely because agriculture relies heavily on fuel for production and transportation. However, the increase in marginal costs driven by the shock does not seem to materialize in other sectors of the production network.

Our results on oil are consistent with Kilian and Zhou (2023). The authors examine the inflationary effects of energy price shocks in five major economies and find no support for the view that energy price shocks cause high and sustained inflation. Specifically, they find significant effects on core inflation only in the Euro area and the U.K. Additionally, for headline inflation, their results for Japan exhibits the smallest response, which is consistent with our exposure ranking: the Euro area and the U.K. have relatively high exposure, while Japan has the lowest.

For the lack of significant heterogeneity in the transmission of oil shocks, one reason could be that our energy exposure measure includes all fossil fuels. It is possible that some economies with high oil exposure are heavily reliant on coal and gas rather than oil, and thus less sensitive to oil price shocks. Moreover, our sample does not exclude oil exporters, where inflation may be highly sensitive to oil price shocks through an alternative demand channel. In this case, rising oil prices lead to increased income, which in turn drives up inflation.

Finally, our metal exposure could be underestimating the importance of metals. In the stylized facts, we showed that energy and metals enter the production network very differently, with energy mainly used as fuel and more involved in downstream sectors, and metals as key inputs in the production of capital and investment goods. However, due to data availability we do not use information on countries' investment network. As shown in Foerster, Sarte, and Watson (2011) and Vom Lehn and Winberry (2022), the investment network can play a crucial role in amplifying shocks.

5 Robustness

We study in more detail the importance of additional exposure measures. We run our local projections using two alternative measures: a) the consumption expenditure share of imported metals (or oil) (b_M), excluding indirect network linkages, and b) the net import share of metals (or oil) for each country. We find that, for the transmission of copper price shocks, the heterogeneity between high and low exposure is no longer significant, highlighting the importance of the production network for shock propagation (Appendix Figure D.4 and Figure D.5).

Finally, we conduct robustness checks testing whether our baseline results remain robust to: (i) including the COVID-19 period; (ii) varying the set of control variables, specifically by substituting the 1-year treasury with the 2-year treasury or by reducing the number of controls. We find that this is the case.

6 Conclusion

This paper establishes that primary metals are an important source for inflation due to their role as intermediate inputs for investment goods in the production network. Given how they enter in the production network, metals supply shocks can have significant, persistent effects on core and headline inflation. In contrast, oil supply shocks mostly impact headline inflation.

While shocks to oil supply affect only one commodity, supply shocks to metals markets are more dispersed. Supply shocks to each of the metals markets may not hit at the same time. This has made so far the magnitude of supply shocks to the aggregate primary metals sector smaller than in the petroleum sector, helping to tame the impact on inflation.

One implication of our finding is that if the world economy became more metals intense due to the energy transition, inflationary shocks could be more persistent. As there could also be more metals supply shocks due to trade fragmentation, central banks need to be aware of this risk.

Would this make the work of central banks easier or more difficult? Central banks have typically looked through oil price shocks, provided these were not excessively large. As the energy system moves away from fossil fuels, however, this approach may not work well when facing major fluctuations in metals prices. The monetary authority may, thus, eventually need to react to metals supply shocks as these shocks have a more persistent effect on core inflation. Central banks need to be prepared for a potentially more metals-intense global economy where metals price shocks will gain importance and their effects on inflation could be initially less visible but more persistent.

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A Data

We collect monthly data on nominal commodity prices and indexes for the period January 1996 to December 2019. For oil prices, we use the average of Brent and WTI. For food prices we employthe Food and Beverage Index from IMF Primary Commodity Price system.

We obtain headline CPI and core CPI data from the global inflation database assembled by Ha, Kose, and Ohnsorge (2023). For control variables, we use the Global economic activity index from Baumeister, Korobilis, and Lee (2022), US 1-year treasury bill yield from FRED, bilateral exchange rates from BIS, and the Gilchrist and Zakrajšek (2012) excess bond premium (EBP) for the USA.

We also collect information on input-output data from the BEA for the US (71 sectors) and from the OECD (45 sectors) for cross-country comparisons for the year 2018. See Tables B.1 and B.3 for details on the sectoral classification.

To correct for the potential endogeneity in copper prices, we use the estimated copper supply shock series from Baumeister, Ohnsorge, and Verduzco-Bustos (2024) for the same period. For oil supply shocks, we use Baumeister and Hamilton (2019).

B Definitions

B.1 OECD Data

The combination of Organisation for Economic Cooperation and Development (2023) and United Nations (2008) defines the mining and quarrying of non-energy producing products sector to include mining of iron ores, non-ferrous metal ores, uranium and thorium ores, other non-ferrous metal ores, quarrying of stone, sand and clay, mining and quarrying n.e.c., mining of chemical and fertilizer minerals, extraction of peat, extraction of salt as well as other mining and quarrying n.e.c. The basic metals sector includes manufacturing of basic iron and steel, manufacturing of basic precious and other non-ferrous metals, casting of metals, casting of iron and steel as well as casting of non-ferrous metals.

The sector for mining and quarrying of energy-producing products includes mining of hard and lignite coal as well as the extraction of crude petroleum and natural gas.

B.2 US Bureau of Economic Analysis Data

According to the US Bureau of Economic Analysis (2024), the mining sector, except oil and gas, includes coal mining, iron, gold, silver, and other metal ore mining, copper, nickel, lead, and zinc mining, stone mining and quarrying as well as other nonmetallic mineral mining and quarrying. The primary metals sector encompasses iron and steel mills and manufacturing from purchased steel (notably iron and steel mills and ferroalloy manufacturing and steel product manufacturing from purchased steel) as well as nonferrous metal production and processing and foundries. The latter includes primary and secondary smelting and refining of non-ferrous metals but also rolling, drawing, extruding, and alloying of non-ferrous metals.

The definition of the oil and gas extraction sector by the is straight forward. The nondurable goods manufacturing sector for petroleum and coal products includes petroleum refineries, asphalt paving mixture and block manufacturing, asphalt shingle and coating materials manufacturing as well as other petroleum and coal products manufacturing. For simplicity, we refer to this as the "oil sector".

Table B.1: BEA Sectoral Classification

Farms	Water transportation
Forestry, fishing, and related activities	Truck transportation
Oil and gas extraction	Transit and ground passenger transportation
Mining except oil and gas	Pipeline transportation
Support activities for mining	Other transportation and support activities
Utilities	Warehousing and storage
Construction	Publishing industries (except internet)
Wood products	Motion picture and sound recording industries
Nonmetallic mineral products	Broadcasting and telecommunications
Primary metals	Data processing, internet publishing, and other information services
Fabricated metal products	Federal Reserve banks, credit intermediation, and related activities
Machinery	Securities, commodity contracts, and investments
Computer and electronic products	Insurance carriers and related activities
Electrical equipment, appliances, and components	Funds, trusts, and other financial vehicles
Motor vehicles, bodies, trailers, and parts	Housing
Other transportation equipment	Other real estate
Furniture and related products	Rental and leasing services, and lessors of intangible assets
Miscellaneous manufacturing	Legal services
Food and beverage and tobacco products	Computer systems design and related services
Textile mills and textile product mills	Miscellaneous professional, scientific, and technical services
Apparel and leather and allied products	Management of companies and enterprises
Paper products	Administrative and support services
Printing and related support activities	Waste management and remediation services
Petroleum and coal products	Educational services
Chemical products	Ambulatory health care services

Table B.2: BEA Sectoral Classification (cont.)

Plastics and rubber products	Hospitals
Wholesale trade	Nursing and residential care facilities
Motor vehicle and parts dealers	Social assistance
Food and beverage stores	Performing arts, spectator sports, museums, and related activities
General merchandise stores	Amusements, gambling, and recreation industries
Other retail	Accommodation
Air transportation	Food services and drinking places
Rail transportation	Other services except government

Note: The BEA sectoral classification table includes 66 sectors. Sectors related to government, such as the Federal general government sector, are not included. For the complete list, refer to the BEA website.

Table B.3: OECD Sectoral Classification

Agriculture, hunting, forestry	Electricity, gas, steam and air conditioning supply
Fishing and aquaculture	Construction
Mining and quarrying, energy producing products	Wholesale and retail trade; repair of motor vehicles
Mining and quarrying, non-energy producing products	Land transport and transport via pipelines
Mining support service activities	Water transport
Food products, beverages and tobacco	Air transport
Textiles, textile products, leather and footwear	Warehousing and support activities for transportation
Wood and products of wood and cork	Postal and courier activities
Paper products and printing	Accommodation and food service activities
Coke and refined petroleum products	Publishing, audiovisual and broadcasting activities
Chemical and chemical products	Telecommunications
Rubber and plastics products	IT and other information services
Other non-metallic mineral products	Financial and insurance activities
Basic metals	Real estate activities
Fabricated metal products	Professional, scientific and technical activities
Computer, electronic and optical equipment	Administrative and support services
Electrical equipment	Education
Machinery and equipment, nec	Human health and social work activities
Motor vehicles, trailers and semi-trailers	Arts, entertainment and recreation
Other transport equipment	Other service activities
Manufacturing nec; repair and installation of machinery and equipment	Water supply; sewerage, waste management and remediation activities
Pharmaceuticals, medicinal chemical and botanical products	Public administration and defence; compulsory social security

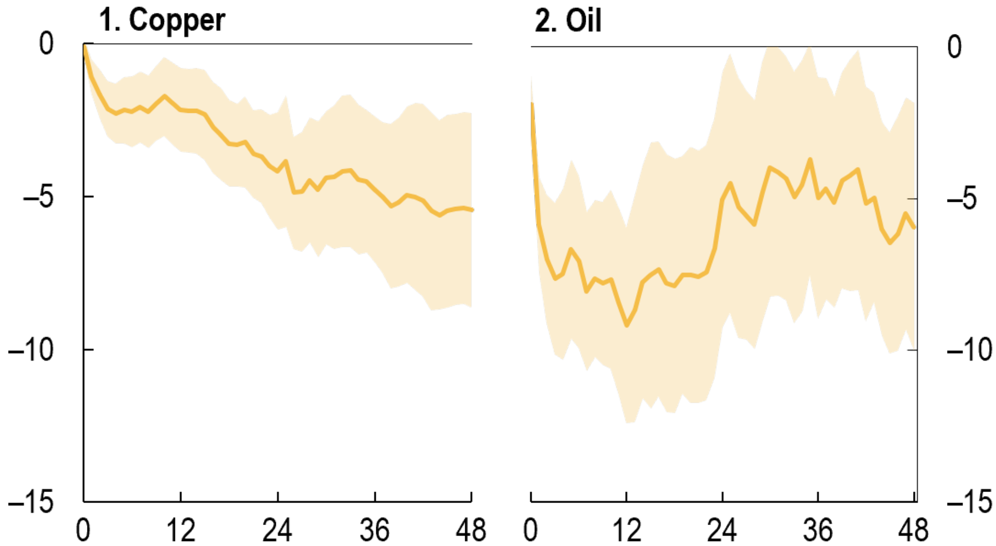
C Copper Price Shock

We use Baumeister, Ohnsorge, and Verduzco-Bustos (2024)'s copper supply shock. The authors estimate a 4-equation Bayesian SVAR with a supply equation, economic activity equation, a commodity-specific demand equation, and an inventory equation. The Bayesian estimation uses sign restrictions for the mass prior probabilities. In particular, the standard sign restrictions imply: that copper supply shocks affect positively copper production, economic activity, and inventories but negatively prices. The economic activity shock affects positively production, economic activity, prices, but negatively inventories. The copper consumption-specific shock affects production and prices positively but economic activity and inventories negatively. The inventories demand shock affects production, prices and inventories positively and economic activity negatively.

In addition to these mass priors, the authors use previous literature estimates on the copper supply elasticity, the effect of copper prices on economics activity, the income elasticity of copper demand, the copper demand elasticity, the response of inventories to copper production changes and to copper price changes.

The authors use data from 1995M1 to 2022M7. Copper production is measured in metric tons per month from the World Bureau of Metal Statistics, real copper prices is deflated by U.S. CPI (Pink Sheet and FRED), metal inventories are measured using registered metal inventories at the London Metal Exchange and WBMS, the World Industrial Production measured by the extended version of the OECD's index of monthly industrial production in the OECD and six major other countries (Baumeister and Hamilton, 2019). All data, except copper inventories which, are in month to month log changes.

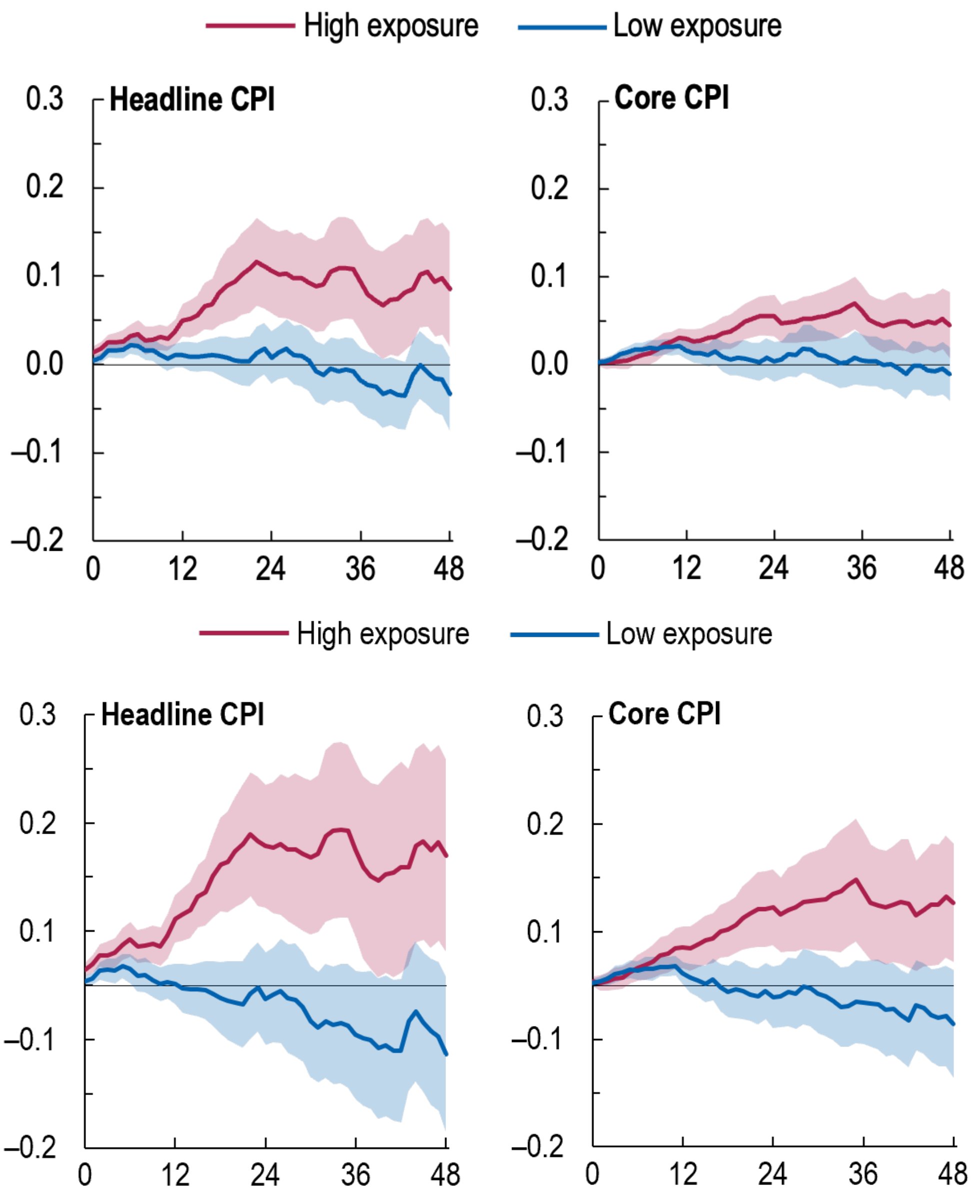
Figure C.1: Impulse Responses of Real Copper and Oil Prices to Positive Copper and Oil Supply Shocks, Respectively.



Note: Cumulative Responses are estimated using local projection, with 12 lags of shocks on the RHS. Shaded areas are 90% confidence bands based on Newey-West standard errors.

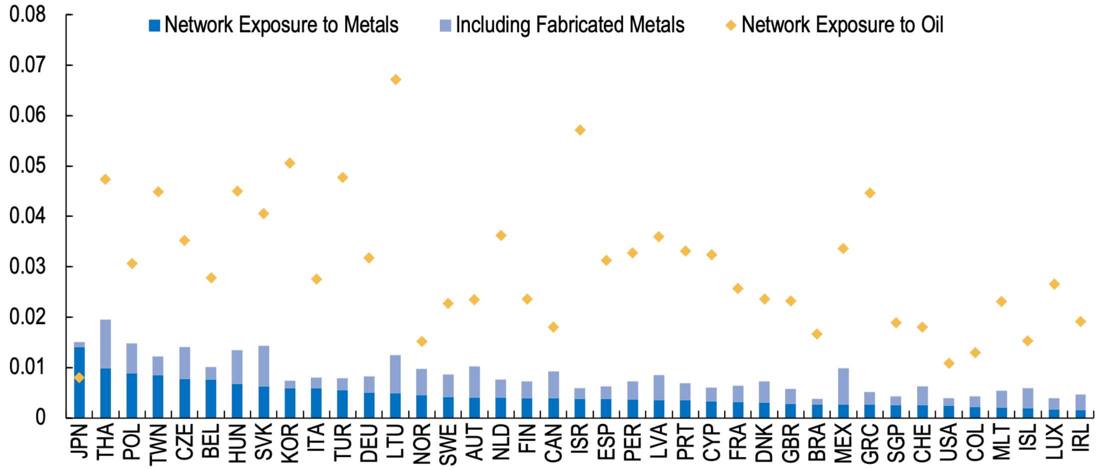
D Additional Empirical Results and Robustness

Figure D.2: IRFs: Baseline Without Import-Content (Top Panel); Baseline Without Import-Content, With Fabricated Metals Included in the Definition of Metals (Bottom Panel)



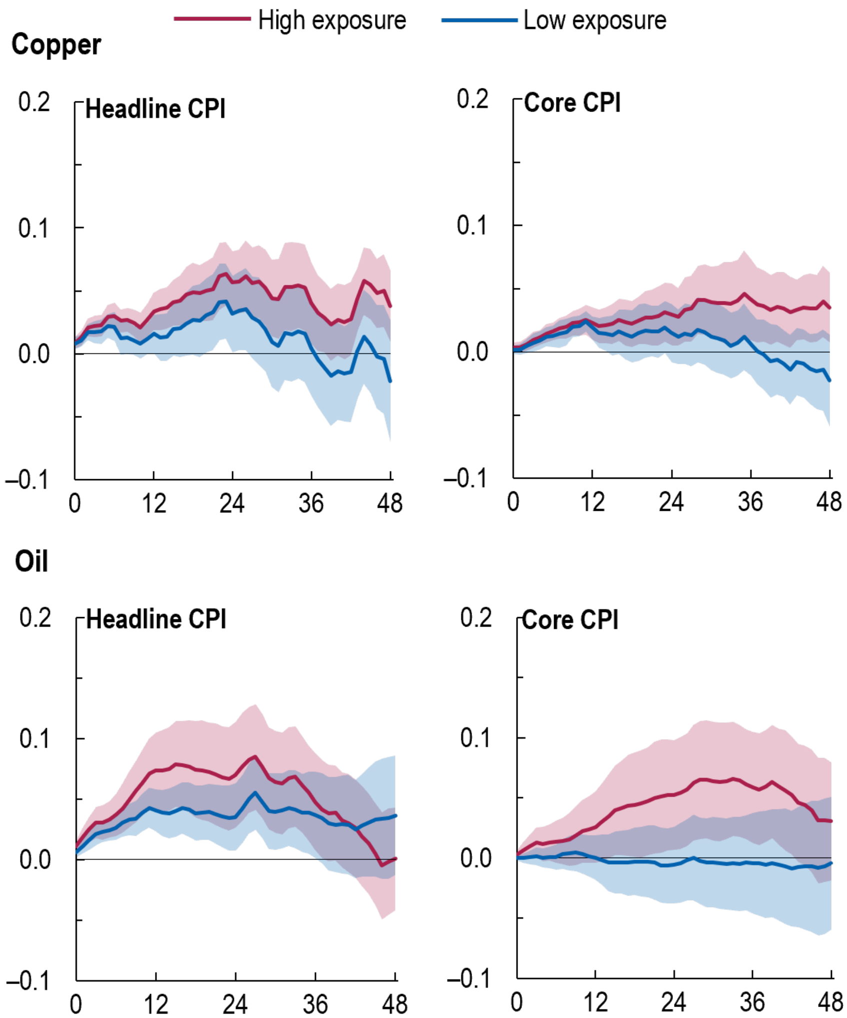
Note: Cumulative impulse responses of headline CPI inflation and core CPI inflation to a one percent increase in copper (left) and oil (right) price shocks. Exposure is calculated as consumption expenditure share of imported metals (or oil) in total household consumption expenditure. Red and blue lines denote the exposure at the 90th/10th percentile of the sample in 2018, respectively. Shaded areas are 90% confidence bands. The x-axis denotes months after the shock.

Figure D.3: Exposure to Metals (small open economy model) including also the Fabricated Metals Manufacturing Sector.



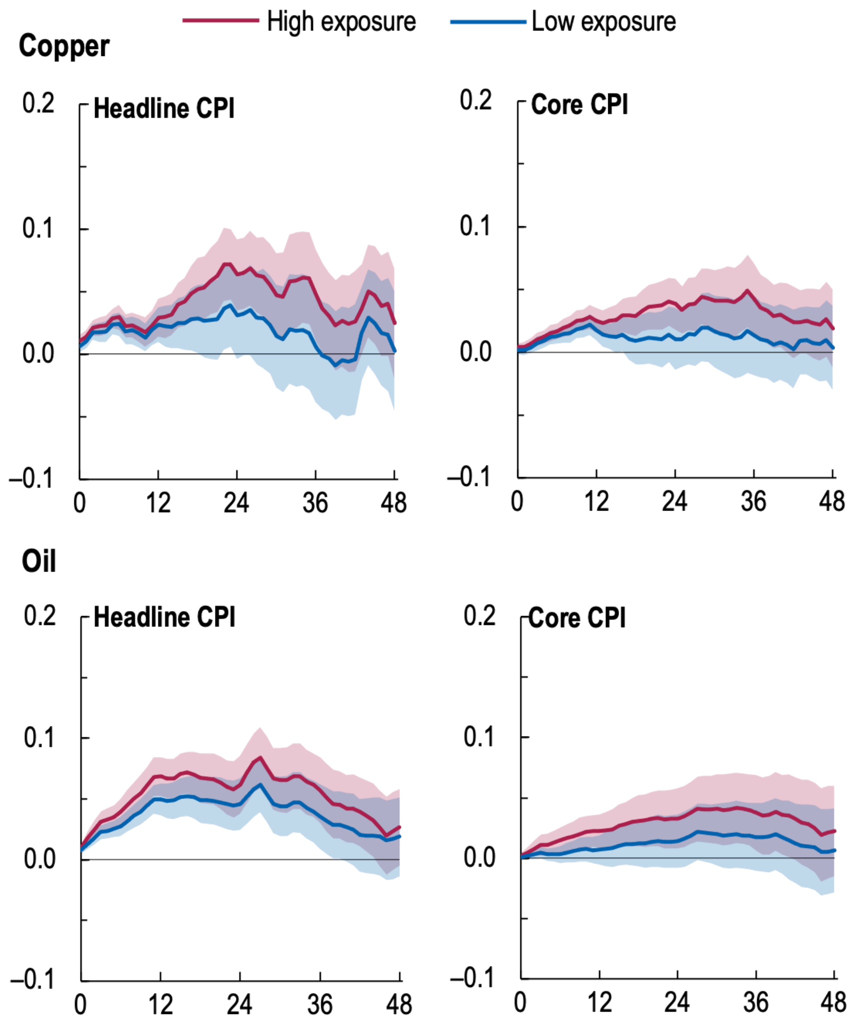
Note: Cross-country exposures to metals (Silva, 2023). Exposure used in this analysis is based on the sum of three OECD sectors: mining and quarrying, non-energy producing products; basic metals; and fabricated metal products.

Figure D.4: Impulse Response Functions Taking Heterogeneity Across Countries into Account and Using the Consumption Expenditure Share of Imported Metals and Oil (b_M), Excluding Indirect Network Linkages.



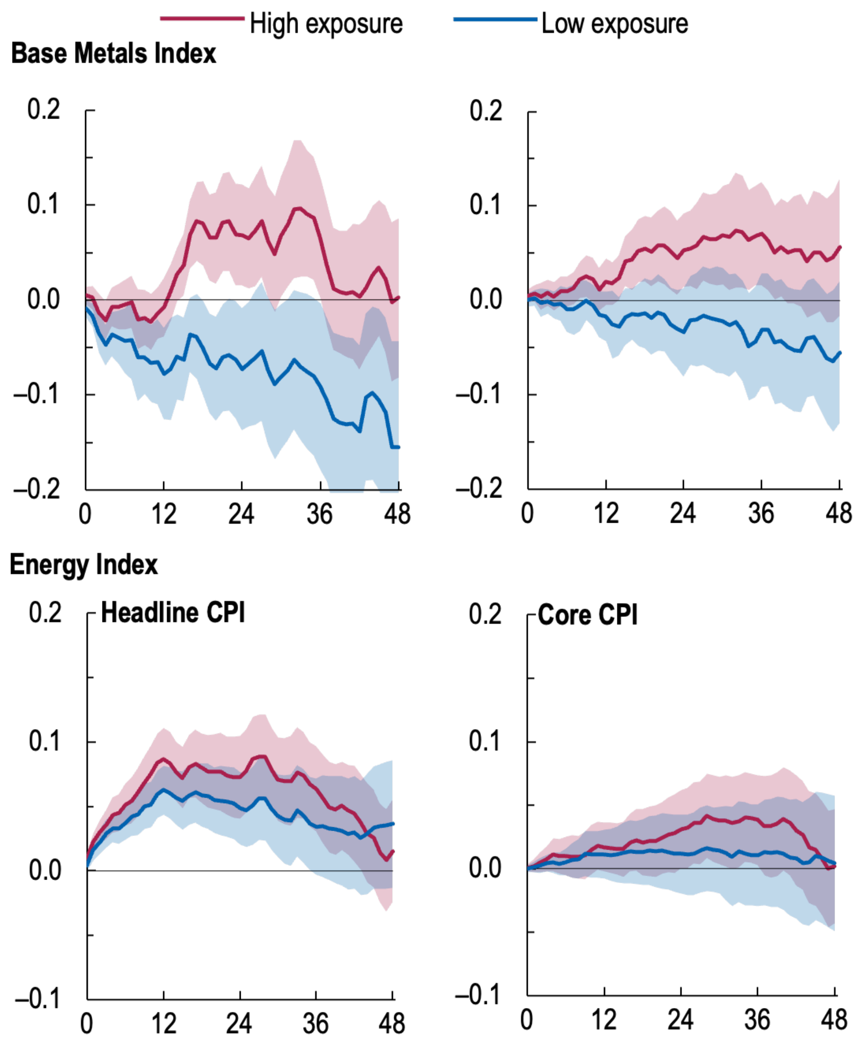
Note: Cumulative impulse responses of headline CPI inflation and core CPI inflation to a one percent increase in copper (left) and oil (right) price shocks. Exposure is calculated as consumption expenditure share of imported metals (or oil) in total household consumption expenditure. Red and blue lines denote the exposure at the 90th/10th percentile of the sample in 2018, respectively. Shaded areas are 90% confidence bands. The x-axis denotes months after the shock.

Figure D.5: Impulse Response Functions Taking Heterogeneity in the Net Import Share of Metals and Oil Into Account.



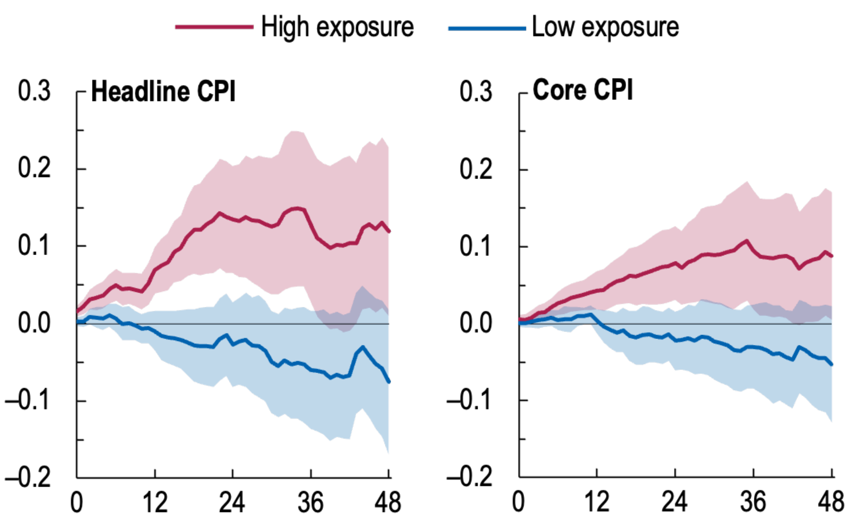
Note: Cumulative impulse responses of headline CPI inflation and core CPI inflation to a one percent increase in copper (left) and oil (right) price shocks. Exposure is calculated as country's net import share of metals or oil. Red and blue lines denote the exposure at the 90th/10th percentile of the sample in 2018, respectively. Shaded areas are 90% confidence bands. The x-axis denotes months after the shock.

Figure D.6: Impulse Responses of Inflation to Base Metals Index Shocks Instrumented by Copper Supply Shocks, and Energy Index Shocks Instrumented by Oil supply Shocks



Note: Cumulative impulse responses of headline CPI inflation (left) and core (right) to a one percent increase in base metal price index (using the copper supply shock from Baumeister, Ohnsorge, and Verduzco-Bustos (2024) as an instrument) and energy price index (using the oil supply shock from Baumeister and Hamilton (2019) as an instrument)

Figure D.7: Inflation Response for Countries with High and Low Metal Exposure According to Equation 4, Including Fabricated Metals



Note: Cumulative impulse responses of headline CPI inflation (left) and core CPI inflation (right) to a one percent increase in copper prices (using the copper supply shock from Baumeister, Ohnsorge, and Verduzco-Bustos (2024) as an instrument). High (low) exposure is defined as a country in the 90th (10th) percentile of the distribution of z_i. The x-axis denotes months after the shock. Shaded areas are 90% confidence bands based on cluster-robust standard errors.

E Proofs

Assume $\widehat{Z} = \widehat{W} = 0$ and that the small open economy imports metals and non-metals products. Equation 3 becomes:

$$\widehat{P} = \left(\bar{\boldsymbol{b}}_M^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{M}}\right) \underbrace{\widehat{\boldsymbol{P}}_M^G \cdot e}_{\widehat{P}_M} + \left(\bar{\boldsymbol{b}}_{NM}^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{NM}}\right) \widehat{\boldsymbol{P}}_{NM}^* \cdot e^*, \tag{7}$$

where $\widehat{\boldsymbol{P}}_M^G$ is the global price of metals and e is the nominal exchange rate between the benchmark small open economy and the group of global metal exporters. The non-metal products are produced in another group of small open economies (denoted by $*$). e^* is the exchange rate between the benchmark group of small open economies and the group of exporters of metal-intensive goods. For simplicity, we assume that the currency in the group of metal producers is the same as in the group of metal-intensive goods producers ($e = e^*$).

In the economy $*$, the non-metal sector, which exports to the baseline small open economy, also uses imported metals to produce non-metal products. Hence, sectoral prices in economy $*$ are ($\widehat{Z}^* = \widehat{W}^* = 0$)

$$\widehat{P}_D^* = \boldsymbol{\Psi}_D^* \boldsymbol{\Gamma}_{\boldsymbol{M}}^* \widehat{\boldsymbol{P}}_M^G \cdot e^{**}, \tag{8}$$

where e^{**} is the nominal exchange rate between economy $*$ and the group of metal exporters. As these groups of country share the same currenty, we have that $e^{**} = 1$ Therefore, $\widehat{\boldsymbol{P}}_M^G$ is the price of metals in units of country $*$'s currency.

Let $\widehat{\boldsymbol{P}}_{NM}^*$, the metal-intensive sector (or group of sectors), be the element i of $\widehat{P}_D^*$, therefore,

$$\widehat{\boldsymbol{P}}_{NM}^* = \widehat{P}_{D_i}^* = (\boldsymbol{\Psi}_{D_i}^* \boldsymbol{\Gamma}_{\boldsymbol{M}}^*) \widehat{\boldsymbol{P}}_M^G,$$

implying

$$\widehat{P} = \left(\bar{\boldsymbol{b}}_M^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{M}}\right) \underbrace{\widehat{\boldsymbol{P}}_M^G \cdot e}_{\widehat{P}_M} + \left(\bar{\boldsymbol{b}}_{NM}^T + \bar{\boldsymbol{b}}_D^T \boldsymbol{\Psi}_D \boldsymbol{\Gamma}_{\boldsymbol{NM}}\right) (\boldsymbol{\Psi}_{D_i}^* \boldsymbol{\Gamma}_{\boldsymbol{M}}^*) \underbrace{\widehat{\boldsymbol{P}}_M^G \cdot e}_{\widehat{P}_M}. \tag{9}$$