Pandemic-Era Inflation Drivers and Global Spillovers*

Julian di Giovanni
Federal Reserve Bank of New York
CEPR

Şebnem Kalemli-Özcan
University of Maryland
CEPR and NBER

Alvaro Silva
University of Maryland

Muhammed A. Yıldırım
Harvard University
Koç University

September 11, 2023

Abstract

We estimate a multi-country multi-sector model to quantify the drivers of inflation during 2020–2023 and to measure inflation spillovers across countries. This exercise yields four key findings. First, negative supply shocks arising from constrained domestic labor and imported intermediates sparked inflation in advanced economies initially. Second, positive aggregate demand shocks created by expansionary fiscal policy widened demand-supply imbalances, intensifying inflation during 2021–2022. Third, reallocation of consumption between goods and service sectors further amplified these imbalances and transmitted inflation across countries through global production networks. Fourth, complementarities in production amplified the impact of energy shocks and tight labor markets on inflation.

*A previous version of this paper titled "Global Supply Chain Pressures, International Trade, and Inflation" was prepared for the European Central Bank Forum on Central Banking, 2022. We thank David Baqaee, Gabriel Felbermayr, and participants of the European Central Bank Forum and NBER-EFG-IFM for their comments. The views expressed herein are those of the authors and not necessarily those of the Federal Reserve Banks of New York or any other person affiliated with the Federal Reserve System. E-mail: juliandigiovanni@gmail.com, kalemli@umd.edu, asilvub@umd.edu, muhammed_yildirim@hks.harvard.edu.

1 Introduction

Advanced countries' have experienced inflation rates not seen in four decades. Central bankers were critiqued for their slow reaction to inflation in 2021 since they perceived inflation to be a transitory phenomenon. By the beginning of 2022, advanced economies' central banks reacted to the mounting inflation and started a regime of aggressive rate hikes. At the time of our writing, mid-2023, the U.S. Federal Reserve appears to have turned the corner in its fight on inflation relative to other countries. The economic landscape faced by policy makers over 2020–2023 was clearly complex as the world economy was hit by multiple demand and supply shocks both at the country level (pandemic, fiscal stimulus) and global level (pandemic, energy shocks) and also specific to certain industries (low and high demand in services sectors at different times).

We shed light on this period by estimating a global structural macroeconomic network model in order to quantify the different forces that drove the pandemic-era inflation. Our analysis not only allows us to unpack the relative importance of different shocks hitting the economy but it also enables us to measure the importance of interconnections across sectors and countries. We are thus able to formally quantify the following narrative of different phases in the rise of global inflation. In the early phase of 2020–2021, supply shocks arising from pandemic-induced scarcity in factors of production, such as constrained imported intermediates and domestic labor, sparked inflation across advanced economies. This period was characterized by local and global supply chain bottlenecks together with slack in labor markets. This led to a rise in product prices (absent changes in wages), as also highlighted by Blanchard and Bernanke (2023). During this first phase there were also large fiscal packages, especially in advanced countries, aimed at mitigating the economic hardship of higher unemployment. Fiscal impulses in the U.S. came in different phases and lasted into 2022. This aggregate demand shock intensified the original supply chain bottleneck problem by stimulating demand in a low supply world, characterizing rising inflation during the second phase of 2021–2022.[1] The final phase (2022–2023) was characterized by the Russian invasion of the Ukraine further intensifying inflation given the impact on energy prices, particularly in Europe.

We extend the seminal *closed-economy* contribution of Baqaee and Farhi (2022) to *multiple countries*, where a fall in sector-specific labor supply (and other factors) impacts aggregate output, wages and inflation both domestically and abroad given international production linkages.[2] This emphasis on factor markets and factor scarcity is combined with several other ingredients: (i) standard aggregate demand shocks (e.g., fiscal stimuli) and downward wage rigidity, (ii) sector-specific demand shocks modeled as changes in consumers' preferences, and (iii) sector-specific TFP

[1] As we show in di Giovanni, Kalemli-Özcan, Silva, and Yıldırım (2023), the three fiscal package in the U.S. drives 60 percent of the U.S. inflation during 2021–2022. The dates of the U.S. fiscal packages are December 2020, March 2021, December 2021.

[2] Çakmaklı, Demiralp, Kalemli-Özcan, Yeşiltaş, and Yıldırım (2021) also extends Baqaee and Farhi (2022) into multiple countries, focusing on real output losses without nominal rigidities.

shocks which capture the impact of the Russian war on energy prices. Our quantitative exercises are able to cleanly identify the contribution of each these shocks to inflation.

The baseline analysis includes several other features that help match the data. First, given the short-run complementarity between labor and other factors of production in the data (e.g., Boehm, Levchenko, and Pandalai-Nayar, 2023), the effect of any input shortage in a given country-sector is amplified to production worldwide in model calibrations that use data-consistent elasticities. Second, unlike the open-economy versions of New Keynesian (NK) models with nominal rigidities and aggregate demand shocks, we can solve for model-consistent exchanges rates and trade balances based on cross-border ownership of factors that can match excahnge rates and current accounts in the data.[3]

Our model performs well in matching the observed inflation in the U.S. and the Euro Area during 2020–2023. The quantification exercise is performed for a four-region world: the U.S., Euro Area, Russia and Rest of the World. We collect data on employment, vaccination rates, consumption shares, aggregate expenditures, and energy prices at the quarterly level across countries and sectors in order to construct our series of shocks. We combine these data with detailed cross-country input-output tables in order to first solve the model at an initial steady-state and then shock the steady-state each quarter and solve for prices and output for all countries and sectors in the world together with exchange rates. We then compute aggregate annual inflation as average of quarterly inflation. To match the pandemic-era inflation and quantify its drivers, inflation in the model is deviation from steady-state price level due to demand and supply shocks. While this is preferable for our quantification exercise on the sources of inflation, it prevents us from investigating the persistence in inflation. The model is non-linear and needs to be solved computationally. However, like Baqaee and Farhi (2022) our framework allows for an analytical first-order approximation solution for each country's inflation rate, which, differently than Baqaee and Farhi (2022), in an open-economy setting is a function of underlying parameters and shocks in all countries and sectors.

The baseline model generates average quarterly inflation rates of (in percent) 0.93, 5.47, and 1.35 in the United States for the years 2020, 2021, and 2022. Actual percent inflation during these years is 1.31, 6.95, and 6.25, respectively, if we calculate year-on-year inflation. If we calculate the average quarterly inflation for these three years, then we have (in percent) 1.23, 4.98, and 7.71. Our model does a very good job in matching the observed data, with the exception of the last year. This is due to the strong disinflation predicted by the model at the end of our sample to go back to steady state. The end of our sample us 2022q4, where real-life disinflation started in 2023, which is outside our sample.

To quantify the sources of inflation, we run counterfactuals. During 2020, only sectoral supply shocks would have generated 4.88 percent inflation (much higher than reality), only sectoral demand would have generated 3.02 (higher than reality), only aggregate demand -0.86 (much lower than

[3]Our approach is in the spirit of Dekle, Eaton, and Kortum (2007, 2008).

reality) and only energy 1.84 percent inflation (close to reality), respectively. This suggests that supply shocks were more important initially and aggregate demand shocks were disinflationary. In 2021, only sectoral supply would have generated an inflation of 0.73 percent; only sectoral demand 2.65; only aggregate demand 4.35, and only energy 2.8, suggesting aggregate demand shocks are the most important in 2021 given the actual inflation being approximately around 5%.

Turning to the results for the Euro Area, the model performs well in matching actual inflation. The baseline model's generated average quarterly inflation rates of -3.78, 4.72, and 4.65 percent for the years 2020, 2021, and 2022. Actual year-on-year inflation was -0.26, 4.85, 8.80. Average quarterly inflation rates in the data were 0.11, 2.84, and 8.43 percent, respectively. The overall story of the shocks' contribution is similar to the United States but with some important differences, especially in the role of energy. During 2020, only sectoral supply shocks would have generated 3.18 percent inflation (again much higher than reality), only sectoral demand would have generated 1.03, only aggregate demand -3.92, and only energy 0.70 percent inflation, respectively. This suggests that a combination of sectoral supply and aggregate demand can help to rationalize the low inflation during this year. In 2021, these numbers were 0.31, 1.20, 4.38, and 2.77, suggesting that both aggregate demand and energy were important. Finally, the story in 2022 is similar to that of 2021. In particular, these numbers were 0.45, 0.87, 4.86, and 3.02 percent, respectively suggesting again a predominant role for both aggregate demand and energy.

Given that that model features a downward nominal wage rigidity that is expressed in each country's local currency, while the world equilibrium must be solved in a common currency, our model solution delivers bilateral nominal exchange rates. These exchange rates are solved so that markets clear both domestically and internationally at steady-state and after the economies are hit by shocks. While not the main focus of our analysis, it is reassuring that the model-generated USD/euro exchange rate does a good job at matching the behavior of actual USD/euro exchange rate in the data: the correlation between the annual percentage change of the model and data exchange rate is 0.74. This result is somewhat surprising given that the model ignores financial market dynamics, such as risk premia and the "flight to quality" at the onset of the pandemic, that many revert to explain appreciation of the USD early on, which later intensified with the tight monetary policy stance. The models that try to capture USD appreciation in bad times work through a convenience yield/safety premium (e.g. Kekre and Lenel (2023), which we do not have. Our model can match the real-life USD appreciation due to large aggregate demand sock in the US via fiscal stimulus, that decreased savings, widened current account deficit increasing capital inflows to the U.S. and appreciating the USD.[4]

[4]We do not have explicit tightening of monetary policy in 2021-2022, but have it implicitly as lower aggregate expenditures.

Related literature. There is a debate among academics and policy makers as to whether traditional macroeconomic models and historical episodes are appropriate guides for the current inflationary episode. The discussion has centered around understanding what is the the slope of the Phillips curve and whether or not we have witnessed a move from a historically flat Phillips curve to a steeper one as a result of the large pandemic-era fiscal impulses. For example, Eggertson and Kohn (2023) and Benigno and Eggertsson (2023) develop models with a non-linear Phillips curve that links the slope to labor market tightness as measured by vacancies/unemployment, the metric also used by Blanchard and Bernanke (2023), to quantify the role of labor market tightness on inflation. While Benigno and Eggertsson (2023) find that labor shortages have a major role in driving the inflation, Blanchard and Bernanke (2023) argue that the initial inflation was caused by shocks to product prices absent wage changes. Our non-linear sectoral approach can bridge these linear single sector papers since sectoral labor shortages and rise in product prices are linked through complementary in production.

An alternative non-linear approach is taken by Amiti, Heise, Karahan, and Şahin (2023) and Comin, Johnson, and Jones (2023) who model the U.S. as a small-open economy with two sectors, tradeable and non-tradeable. Differnetly than us, these authors model supply constraints arising exogenously as disutility of labor or sector capacity constraints, as in Boehm and Pandalai-Nayar (2022). Other two-sector models with Keynesian supply shocks but no constraints are Guerrieri, Lorenzoni, Straub, and Werning (2020, 2021), and Ferrante, Graves, and Iacoviello (2023). There is also reduced-form empirical work that seeks to identify the different drivers of inflation with sign restrictions in VAR such as Jordá, Liu, Nechio, and Rivera-Reyes (2022), Shapiro (2022a,b), and Jordá and Nechio (2022).

The main advantage of our work over the existing literature is the ability to quantify the contribution of four sets of shocks to the different phases of inflation over 2020–2023 and study the transmission of these shocks across sectors and country-borders given our global network structure.We are further able to examine the role of relative price adjustments, and particularly how endogenous exchange rate adjustments, impact inflation spillovers across countries.[5]Finally, the model's micro-structure is rich enough to study how different assumptions on production and consumption substitutability impact the contribution of different shocks to inflation, both domestically and abroad.

Outline of the paper. Section 2 outlines the multi-country multi-sector model that we use to quantify the drivers of inflation. Section 3 describes the data we use for the analysis. Section 4 presents the quantitative results. Section 5 concludes.

[5]The policy piece we prepared for the 2022 ECB-Sintra conference embedded a fixed-exchange rate regime similar to Gourinchas, Kalemli-Özcan, Penciakova, and Sander (2021).

2 Model

We extend the Baqaee and Farhi (2022) model to the open economy by incorporating cross-country and cross-sector input output linkages. The model allows for a rich set of shocks including country-level aggregate demand shocks, country-sector level demand shifts and country-sector level factor supply and productivity shocks.

The dynamics of the model are simplified such that we assume that all countries are at steady-state production and consumption levels before and after shock periods. In each shock period, the households and producers expect to return this steady state. We label the variables related to the future steady state with an asterisk ($*$).

Denote countries with indices $m, n = 1, \ldots, \mathcal{N}$, where $\mathcal{N}$ is the number of countries. We use $i, j, k = 1, \ldots, \mathcal{J}$ as sector indices. A sector in a country is identified by a pair of indices corresponding to countries and sectors, respectively.

2.1 Households

We assume that households are Ricardian and have perfect foresight. They take the shock periods as transitory and expect to return to steady-state levels once the shock is over. Households in country n makes their consumption decisions by maximizing the following inter-temporal utility:

$$\max_{\{C_n, C_n^*\}} (1 - \beta_n) \log C_n + \beta_n \log C_n^*, \tag{1}$$

where C_n and C_n^* are the consumption bundles for the shock period and the future, respectively. The β_n parameter weights households' time preferences and we assume an inter-temporal elasticity of substitution of 1. While optimizing their consumption decision, households respect their inter-temporal budget constraints:

$$P_n C_n + \frac{P_n^* C_n^*}{1 + i_n} = I_n + \frac{I_n^*}{1 + i_n}, \tag{2}$$

whereP_n (P_n^*) is the price of the consumption bundle and I_n (I_n^*) is nominal income in the current (future) period, and i_n is the nominal interest rate in the shock period.

Households' final consumption bundle is a Cobb-Douglas aggregate over *sectoral* consumption bundles:

$$C_n = \prod_{j=1}^{\mathcal{J}} C_{n,j}^{\Omega_{n,j}^C} \quad \text{with} \quad \sum_{j=1}^{\mathcal{J}} \Omega_{n,j}^C = 1,$$

where $C_{n,j}$ denotes the sectoral consumption bundle in country n for sector j and $\Omega_{n,j}^C \geq 0$ represents the consumption share of this sector. The sectoral consumption bundles are in turn aggregates of different countries varieties of goods in a given sector. Let $C_{n,mj}$ denote the consumption of output of sector j in country m by consumers in country n. Then the country n, sector j consumption

bundle is formed by the following CES aggregation:

$$C_{n,j} = \left[\sum_{m=1}^{\mathcal{N}} \Omega_{n,mj}^{CB} C_{n,mj}^{\frac{1-\xi'}{\xi'}}\right]^{\frac{\xi'}{1-\xi'}} \quad \text{with} \sum_{m=1}^{\mathcal{N}} \Omega_{n,mj}^{CB} = 1,$$

where $\Omega_{n,mj}^{CB} \geq 0$ is the weight of country-sector mj in country n's consumption of sector j, and ξ' captures the elasticity of substitution between these varieties.

2.2 Production

Goods are produced at the sector level by combining different factors of production and intermediate inputs. We assume that factors are sector-specific labor and capital and to help with notation combine these to create a *value-added* bundle. Each sector in each country uses goods from other countries to construct their sector specific intermediate bundles.

Sector i in country n therefore uses sector specific value-added (VA_{ni}) and intermediate bundle (Z_{ni}) to produce its final good via using the following production function:

$$Y_{ni} = A_{ni}\left[\Omega_{ni,\text{VA}}^{Y} \text{VA}_{ni}^{\frac{1-\theta}{\theta}} + \Omega_{ni,Z}^{Y} Z_{ni}^{\frac{1-\theta}{\theta}}\right]^{\frac{\theta}{1-\theta}} \quad \text{with } \Omega_{ni,\text{VA}}^{Y} + \Omega_{ni,Z}^{Y} = 1, \tag{3}$$

where Y_{ni} denotes the output of this sector and A_{ni} is the sector-specific productivity parameter. Production is CES where θ determines the elasticity of substitution between the value added and the intermediate bundle. Finally, $\Omega_{ni,\text{VA}}^{Y}$ and $\Omega_{ni,Z}^{Y}$ are the shares of value added and the intermediate good used in the final good's production, respectively.

The value-added bundle for country-sector ni consists of sector-specific labor and capital. We assume that capital is always fully utilized and is always at its steady-state value (K_{ni}^{*}). Labor levels, on the other hand, may potentially fluctuate from their steady-state value when the economy experiences shocks. The value-added bundle can therefore be written as:

$$\text{VA}_{ni} = \left[\Omega_{ni,L}^{\text{VA}} \left(L_{ni}\right)^{\frac{1-\gamma}{\gamma}} + \Omega_{ni,K}^{\text{VA}} \left(K_{ni}^{*}\right)^{\frac{1-\gamma}{\gamma}}\right]^{\frac{\gamma}{1-\gamma}} \quad \text{with } \Omega_{ni,L}^{\text{VA}} + \Omega_{ni,K}^{\text{VA}} = 1,$$

where γ is the elasticity of substitution between labor and capital, and $\Omega_{ni,L}^{\text{VA}}$ ($\Omega_{ni,K}^{\text{VA}}$) is the weight of value-added that is attributed to labor (capital).

Similar to consumption bundles, the intermediate bundles are constructed from country-specific sector bundles given the following CES aggregator with an elasticity of substitution of ε:

$$Z_{ni} = \left[\sum_{j=1}^{\mathcal{J}} \Omega_{ni,j}^{Z} X_{ni,j}^{\frac{1-\varepsilon}{\varepsilon}}\right]^{\frac{\varepsilon}{1-\varepsilon}} \quad \text{with} \sum_{j=1}^{\mathcal{J}} \Omega_{ni,j}^{Z} = 1,$$

where $\Omega^{Z}_{ni,j} \geq 0$ is sector j's weight in producing country-sector good ni and $X_{ni,j}$ is the amount of sectoral bundle $X_{n,j}$ used by ni. These sectoral bundles are formed using the following CES aggregator of country-specific varieties:

$$X_{n,j} = \left[\sum_{m=1}^{\mathcal{N}} \Omega^{X}_{n,mj} X_{n,mj}^{\frac{1-\xi}{\xi}} \right]^{\frac{\xi}{1-\xi}} \quad \text{with} \quad \sum_{j=1}^{\mathcal{N}} \Omega^{X}_{n,mj} = 1,$$

where $X_{n,mj}$ is the amount of output of country-sector mj used by country n, ξ is the elasticity of substitution between varieties, and $\Omega^{X}_{n,mj}$ is the weight of country-sector mj in the sector bundle for j in country n. Given the production structure of the economy outlined above, it follows that the bilateral flow of intermediate goods produced by country-sector mj and used by country-sector ni is given by:

$$X_{ni,mj} = X_{n,mj} \frac{X_{ni,j}}{X_{n,j}}.$$

2.3 Monetary Policy, Current Account and Exchange Rates

To close the model, we need to assume a monetary policy rule and solve for a world equilibrium. To move forward with this solution, we need to deal with two key variables that are needed when solving a closed-economy version of this model: the current account and the nominal exchange rate.

The majority of the general equilibrium trade literature that analysis shocks in a setting similar to our circumvents the issue of solving for the current account by using "hat algebra" and assuming that current account changes are zero (e.g., see Costinot and Rodríguez-Clare, 2014, for example). However, given that we must solve the model non-linearity, our solution method requires first matching observed data in a global input-output matrix, which turn requires matching observed initial current account balances and solving for their changes. We therefore take a modeling approach similar to the one taken in Dekle, Eaton, and Kortum (2007, 2008) in order to solve for model-consistent current accounts. We further need to solve for each country's exchange rate, relative to some numéraire price as we explain in the following, since we must convert all domestic factor prices into local currency to whether the downward wage constraint is violated or not for each sector.

Since we solve for a world equilibrium, all input-output accounting is done in terms of a fictitious numéraire common (world) currency. At the steady state, we assume the prices are normalized such that all bilateral exchange rates vis-à-vis the common currency are equal to 1. Upon the realization of the shocks that we feed into the model, these exchanges rates may move so they are no longer at parity with the common currency. The following formalizes how we solve for changes in both current accounts and exchange rates when economies are shocked.

First, taking into the account the economic situation pre-Covid shock, we assume all countries are at the zero-lower bound in their interest rates ($i = 0$). With this assumption, the inter-temporal

budget formulated in Equation (2) becomes:

$$P_n C_n + P_n^* C_n^* = I_n + I_n^*.$$

Maximizing the inter-temporal utility in Equation (1) yields:

$$I_n = P_n C_n = \underbrace{\frac{1-\beta_n}{\beta_n} I_n^*}_{\text{In local currency}} . \tag{4}$$

Note that this income level is given in the local currency as the inter-temporal budget allocation is made domestically in local currency units given a change in β_n – the aggregate demand shock.

GDP of country n can be calculated by solving for the total value-added (factor income) created in country n. Denoting the rental rate of capital in country-sector ni with R_{ni}, we calculate the GDP of country n in the common currency as:

$$\text{GDP}_n = \sum_i \left(W_{ni} L_{ni} + R_{ni} K_{ni}^* \right). \tag{5}$$

At the world level, global expenditures are equal to global GDP. But for individual countries, because of the trade surpluses and deficits, income may differ from GDP. Calculating GDP and international trade in terms of common currency, the exchange rate of country n relative to the common currency be denoted by e_n. For country n, we express the expenditures in local currency in terms of GDP and trade balance as:

$$I_n / e_n = \text{GDP}_n + \underbrace{\text{Imports}_n - \text{Exports}_n}_{\text{–Current Account}}.$$

To close the model, we assume that the trade balance (current account) is financed by partial ownership of production in foreign countries.[6] To calculate this ownership ratio, we define the bilateral trade balance between countries m and n as:

$$D_{nm} \equiv \text{Exports}_{m \to n} - \text{Exports}_{n \to m}.$$

A positive trade balance implies that country n is running a deficit vis-à-vis country m. Therefore, country n needs to own a portion of GDP in country m to finance this trade deficit. We define the

[6]The connection between the current account and savings/investment decisions will be provided in the Appendix in the updated draft.

ownership share of factors/sectors of country n in country m as:

$$\chi_{nm} \equiv \begin{cases} \frac{D_{nm}}{\text{GDP}_m} & \text{if } D_{nm} > 0, \\ 0 & \text{otherwise.} \end{cases}$$

With this definition, we can write the total income of country n in terms of common currency as:

$$I_n/e_n = \text{GDP}_n - \underbrace{\sum_m \chi_{mn}\text{GDP}_n}_{\text{Owned by foreigners in } n} + \underbrace{\sum_m \chi_{nm}\text{GDP}_m}_{\text{Owned abroad by } n}. \tag{6}$$

Equating the spending from the expenditure side (Equation (4)) and the income side (Equation (6)), the exchange rate is solved for as:

$$e_n \equiv \frac{(1-\beta_n)I_n^*/\beta_n}{(1-\sum_m \chi_{mn})\text{GDP}_n + \sum_m \chi_{nm}\text{GDP}_m}. \tag{7}$$

2.4 Market Clearing

We assume perfect competition in factors and good markets. Goods can be used as final (consumption) goods and intermediate inputs in many countries. Therefore, we write the goods market clearing condition for country-sector ni as:

$$Y_{ni} = \sum_{m \in \mathcal{N}} \left(C_{m,ni} + X_{m,ni}\right).$$

For the factor markets, we take both labor and capital to be sector-specific. Capital is assumed to be at its steady-state level with:

$$K_{ni} = K_{ni}^*.$$

Labor, on the other hand, is subject to shocks. In addition, we assume that there is a downward wage rigidity relative to the steady-state wage. Denoting the amount of available labor for country-sector ni at the time of the shock with $\overline{L}_{ni}$ and given the sector-specific labor assumption implies that:

$$\overline{L}_{ni} \leq L_{ni}^*.$$

Given the downward wage rigidity, there be slack in a sector's labor market during the shock period. Therefore, the shock-period employment, L_{ni}, maybe be lower than available labor:

$$L_{ni} \leq \overline{L}_{ni}. \tag{8}$$

Finally, the downward wage rigidity necessitates that the wage in a given country sector (W_{ni})

cannot go below its steady state level (W^*_{ni}) in local currency. The downward wage rigidity is then given by:

$$\underbrace{e_n W_{ni} \geq W^*_{ni}}_{\text{In local currency}} \quad \Rightarrow \quad \underbrace{W_{ni} \geq \frac{W^*_{ni}}{e_n}}_{\text{In common currency}} \quad . \tag{9}$$

Optimality implies that at least one of the two preceding inequalities is binding:

$$\left(\overline{L}_{ni} - L_{ni}\right)\left(W_{ni} - \frac{W^*_{ni}}{e_n}\right) = 0. \tag{10}$$

2.5 Solution

To solve the model, we calibrate consumption and input weights, GDP shares and expenditure shares using the OECD Inter-Country Input-Output (ICIO) Tables. We calibrate the CES functions such that the weights coincide with the input and consumption shares. We normalize all prices, wages and rents to 1 at the steady state. We calculate all changes in common currency while keeping track of local exchange rates, which enables us to convert price changes to local currency while calculating inflation.

We provide a unified representation of the model by creating an enhanced input-output table, which is depicted in Figure 1. Each row, i, in this matrix corresponds to a single CES aggregator with corresponding elasticity of substitution of σ_i. Using this notation we can then write the price index for each row as:

$$\begin{aligned} P_i^{1-\sigma_i} &= \sum_j \Omega_{ij} P_j^{1-\sigma_i} \qquad \text{if } \sigma_i \neq 1, \\ \log(P_i) &= \sum_j \Omega_{ij} \log(P_j) \quad \text{if } \sigma_i = 1, \end{aligned} \tag{11}$$

where the second equation corresponds to the Cobb-Douglas case.

We write the market-clearing condition for each row entry using information contained in the columns of the Ω matrix presented in Figure 1. This generalized input-output structure shows that sectoral output, factors or input/consumption bundles all need to be used by other sectors for production or for consumption. In the enhanced Ω matrix, these are all different rows and columns. For a given column j, we denote its total output as Y_i and the amount this output used by row i as X_{ij}. With these definitions, we then write the market-clearing condition for each row as:

$$P_j Y_j = \sum_i P_j X_{ij} = \sum_i \frac{P_j X_{ij}}{P_i Y_i} P_i Y_i. \tag{12}$$

Using the CES assumption, we then write the optimal ratio of i use of j as a function of relative

Figure 1. Structure of enhanced input-output matrix Ω

(a) Ω Matrix

$\Omega =$

	C	Y	Z	VA	X	CB	L	K	Ric	Fut
C	0	0	0	0	0	Ω^C	0	0	0	0
Y	0	0	Ω^Y_Z	Ω^Y_{VA}	0	0	0	0	0	0
Z	0	0	0	0	Ω^Z	0	0	0	0	0
VA	0	0	0	0	0	0	Ω^{VA}_L	Ω^{VA}_K	0	0
X	0	Ω^X	0	0	0	0	0	0	0	0
CB	0	Ω^{CB}	0	0	0	0	0	0	0	0
L	0	0	0	0	0	0	0	0	0	0
K	0	0	0	0	0	0	0	0	0	0
Ric	$1-\beta$	0	0	0	0	0	0	0	0	β
Fut	0	0	0	0	0	0	0	0	0	0

(b) Row / Column Indices

Index	Description	Size	Elasticity
C	Current Consumption	$\mathcal{N}$	1
Y	Goods / Varieties	$\mathcal{N}\times\mathcal{J}$	θ
Z	Intermediate Bundle	$\mathcal{N}\times\mathcal{J}$	ε
VA	Value-Added	$\mathcal{N}\times\mathcal{J}$	γ
X	Country-Sector Bundles	$\mathcal{N}\times\mathcal{J}$	ξ_i
CB	Consumption Bundles	$\mathcal{N}\times\mathcal{J}$	ξ'_i
L	Sector Specific Labor	$\mathcal{N}\times\mathcal{J}$	
C	Sector Specific Capital	$\mathcal{N}\times\mathcal{J}$	
Ric	Ricardian Consumer	$\mathcal{N}$	1
Fut	Future Consumption	$\mathcal{N}$	

Note: All sub-matrix definitions are given in the Sections 2.1 and 2.2. Non-zero sub-matrices are colored and light green colored sub-matrices indicate diagonal matrices.

prices:

$$\frac{P_j X_{ij}}{P_i Y_i} = \left(\frac{P_j}{P_i}\right)^{1-\sigma_i}. \tag{13}$$

Dividing both sides of (12) by global GDP, we express a sector j's output as a function of world output, i.e., as a global Domar weight, which is currency free. Starting with the definition of Domar weights and using the optimal weights for CES functions, we arrive at:

$$\frac{P_j Y_j}{\text{GDP}_W} \equiv \lambda_j = \sum_i \Omega_{ij} \left(\frac{P_j}{P_i}\right)^{1-\sigma_i} \frac{P_i Y_i}{\text{GDP}_W} = \sum_i \Omega_{ij} \left(\frac{P_j}{P_i}\right)^{1-\sigma_i} \lambda_i. \tag{14}$$

Domar weight equations show us the propagation of the consumption of countries, which is given by Equation (6). Equation (7) gives us the exchange rate in terms of GDP of countries. Since we take the β_n and I^*_n as exogenous, these equations are sufficient to pinpoint GDP of each country in terms of common currency. By dividing Equation (5) with world GDP, we can write GDP of each country in terms of factor Domar weights. Equations (11) and (14) can solve for the prices and Domar weights up to country specific constants. Since we can solve for the GDP of countries, this would be enough to adjust the levels for each country. Finally, we also respect the downward wage rigidity and labor constraints in Equations (8) and (9) along with Equation (10), which create a non-linear optimization problem. We use AMPL / Knitro optimizer to solve for these

equations. Since we start calibrated CES functions with equilibrium prices of 1, our methodology yields solutions akin to the hat-algebra methodology often used in the trade literature.

2.6 Approximating Inflation

Generalizing Baqaee and Farhi (2022) to the open economy setting, we are able to provide an analytic first-order approximation of a country's inflation as a function of domestic and foreign shocks shocks along with factor and production shares. We utilize the Ω matrix in order to captures all necessary information in deriving the approximation to inflation. We briefly sketch out the solution details and refer the interested reader to Appendix A for a formal proof.

First, define the Leontief inverse matrix:

$$\Psi = [I - \Omega]^{-1},$$

where I is the appropriately sized identity matrix. The Leontief inverse captures the direct and indirect dependencies between entities (e.g., how much of each sectors output a sector uses as intermediates for in production).

For country n, let its consumption dependencies be captured by the n^{th} row of the Ψ matrix. The entries of this matrix captures the share of expenditure in country n responsible for paying the output of the corresponding entity. For goods, this corresponds to the share of the output value that could be attributed to the consumption in n. For factors, this would correspond to share of their value-added eventually being paid of by the households in n. These constitute the basis cor country specific Domar wights. Hence, we can then define the country-specific Domar weights for each country-sector as:

$$\lambda^n_{mi} = \Psi_{n,mi} \qquad \text{for } mi \in Y.$$

Similarly, for labor, with some abuse of notation we define:[7]

$$\Lambda^n_{mi} = \Psi_{n,mi} \qquad \text{for } mi \in L.$$

We write the corresponding column vector for these Domar weights by dropping the subscripts. With these definitions in hand, we calculate the first-order approximation to the CPI in country n via the following proposition:

Proposition 1. *The first-order approximation to CPI in country n is:*

$$\mathrm{d}\log CPI^n = \underbrace{\mathrm{d}\log I^n}_{AD\ shock} - (\Lambda^n)^T \mathrm{d}\log L - (\lambda^n)^T \mathrm{d}\log A,$$

[7]Since labor is sector specific, we can index them using the country-sector indices

where λ^n (Λ^n) is the vector of country-specific Domar weights for country-sector pairs (labor types), A is the vector of sector-specific productivity improvements, L is the vector of labor and I^n captures the aggregate demand shock.

This first-order approximation captures the importance of international linkages as aggregate demand, labor and productivity changes are calculated globally.

First, note that a positive aggregate demand shock to economy n, ζ^n, creates inflation to the first order. This shock includes both the domestic AD shock as well as the impact of its exchange rate change vis-à-vis the common currency, which in turn captures changes in other economies and their domestic aggregate demand shocks as well. However, when we go to the higher orders, since AD shocks may relax the wage-rigidity condition by depreciating the currency, a positive AD shock might also induce a slight disinflationary component.

To examine how the other shocks impact domestic inflation, we first note that output of any sector is combined with other sectors' output through input-output linkages, but ultimately everything is consumed by households. In other words, households are the terminal nodes of the input-output networks. Starting from the households, we can thus trace back the origin of the goods that are consumed in country n. The Leontief inverse operation captures this path of production to consumption.

Applying this Leontief logic and to further understand the intuition underlying the inflation approximation, denote the output of country-sector mj consumed by households in country n with Y^n_{mj}. Then, the country-specific Domar weight can be written as:

$$\lambda^n_{mi} \equiv \frac{P_{mi} Y^n_{mi}}{I_n}.$$

For each sector, we know the share of the sector-specific labor in its value-added. Then, we can interpret the country-specific Domar weights for labor as:

$$\Lambda^n_{mi} = \Omega^Y_{mi,\mathrm{VA}} \Omega^{\mathrm{VA}}_{mi,L} \lambda^n_{mi}.$$

Therefore, Λ^n_{mi}, captures the labor share of the output of mi to satisfy the consumption in n.

Proposition 1 thus implies that labor shortages, at home and abroad, are inflationary domestically and shocks to labor supply in country-sector mi impact domestic inflation in proportion to λ^n_{mi}. Meanwhile, positive productivity changes, $\mathrm{d}\log A$, are deflationary shocks to productivity in country-sector mi impact inflation is country n in proportion to Λ^n_{mi}.

3 Data and shocks construction

Our empirical exercises require four sets of shocks: country-level aggregate demand changes, country-sector level factor supply changes, country-sector level demand changes, and global energy price changes. To take the model to the data, we set the number of countries to four: the United States, the Euro Area,[8] Russia, and the rest of the world composite (ROW), and four sectors: durables, non-durables, services, and energy.

We choose to focus on these four countries and sectors given data constraints but also because doing so still allows us to capture intertemporal and cross-sectional variation in shocks and inflationary implications that took place over the time period that we study. In particular, the stringency of Chinese lock downs in 2020-2021 (capture by the shocks to the ROW labor supply), the U.S. and European fiscal stimuli of 2021–2022, and the Russia-Ukraine war in early 2022 and their consequences for energy prices worldwide. We include Russia and also an "energy" sector to be able to speak to the role of higher energy prices and their implications for the U.S. and, importantly, for the Euro Area, which seems to be one of the country groups that have been affected the most. We map the energy price shock to a decline in Russia's energy sector productivity and study the inflation spillovers of such a shock to other countries.

We first describe the data we collect. We then explain how we construct the "shocks" series from these data, where given that our model, even 3-period, in essence static, we need to also insure that our shock series are stationary.

3.1 Data

3.1.1 Aggregate demand

According to our model, aggregate demand shocks should be measured as changes in expenditures in local currency, represented by I_n in the model section. We therefore collect these data from various data sources at the quarterly frequency.

United States. We use gross national income (codename: `A023RC1Q027SBEA`) available from the Bureau of Economic Analysis (BEA). These data are available at a quarterly frequency from 2010 to 2022.

Euro Area. Gross national income is only available at a yearly frequency for the Euro Area, which is useless for our empirical application. For this reason, we collected data on absorption from EuroStat. This absorption includes household and consumption expenditure, gross fixed capital formation, and imports.

[8] Note that we rely on Euro Area countries' underlying data and aggregate up.

Russia and Rest of the World. We construct a measure of the rest of the world's expenditures by adding up consumption on durables, non-durables, and services from the OECD quarterly national accounts for all countries except the United States and those in the Euro Area. Since data for Russia have not been updated for 2022, we use numbers from the rest of the world to construct Russia's aggregate demand.

3.1.2 Country-sector level factor supply: total hours worked

We feed in total hours worked from the data to the model as shocks to potential sector-specific labor *supply*, $\bar{L}_{ni}$. Of course, observed changes in total hours worked in the data are an equilibrium object and depend on labor demand and labor supply in each sector. Given our modeling assumption of nominal downward wage rigidity, negative changes in equilibrium labor can be rationalized by a decline in labor demand or a decrease in labor supply. In contrast, positive changes in equilibrium labor can only be rationalized by a combination of labor demand and supply shifts, where a necessary condition is that labor supply shifts at least in the same amount as labor demand. In an extreme case, if labor supply does not shift up while labor demand does, this only creates wage inflation with no effect on the equilibrium level of employment and cannot possibly rationalize increases in total hours worked in equilibrium. As we explain in detail when discussing the results in the next section, we use the model structure in conjunction with the other set of shocks to disentangle changes in total hours worked into supply and demand.

United States. We use Tables B1 and B2 provided by the Bureau of Labor Statistics to collect information to construct our measure of labor supply. These tables contain information on employment and average weekly hours at a monthly frequency, respectively. Since hours in Table B2 are at a higher level of aggregation than those for employment in Table B1, we construct measures of L in the model by multiplying employment in a disaggregated sector by the hours of the aggregate sector. For example, the 'Information sector' contains six sub-sectors in Table B1, but it is only available as an aggregate information sector in Table B2. We thus multiply each sub-sectors employment by the hours of the aggregate sector in Table B2 to obtain a measure of total hours worked in each of the six sub-sectors separately. Our final sample contains information from 2006 to 2022 for 66 sectors that we aggregate up to 4 sectors.

Euro Area. We rely on EuroStat for labor market data. This data set contains sector-level information on both hours (23 sectors) and employment ($\approx$ 90 sectors) for the entire Euro Area at a quarterly frequency from 2008 to 2022. We follow the same procedure as in the U.S. to construct the total hours worked in each sector and aggregate them into four sectors.

Russia and rest of world. Since sectoral and time series data are not readily available for Russia and the ROW for the time span we analyze, we take an indirect approach to construct total hours worked changes, which we explain in detail in the shocks construction section below.

3.1.3 Country-sector level demand: consumption expenditure

United States. We use information on personal consumption expenditures from Table 2.3.5U of the Bureau of Economic Analysis version May 2023. This data set contains disaggregated sector-level information on personal consumption expenditures from 1959 to 2022 at a quarterly frequency. In particular, we use durable, non-durable, services, and energy sector consumption from this table.

Euro Area. We use the information on durables, non-durables, and services from the OECD quarterly national accounts. This is available from 2010 to 2022 at a quarterly frequency. Unfortunately, it does not have consumption in the energy sector separately. Since energy consumption is part of non-durable consumption, we assume it experienced the same changes.

Rest of the world. As with the Euro Area, we construct sectoral consumption by the rest of the world on durables, non-durables, and services using the OECD quarterly national accounts. We consider all countries except the United States and those belonging to the Euro Area. These numbers, however, are denominated in local currency for all countries. We convert all series to U.S. dollars using the average exchange rate between 1990 and 2022 per country that we sourced from the IMF. Finally, we aggregate each consumption series across countries. In doing so, note that we assume the rest of the world's "fictitious" currency moves with the dollar one-to-one. As was the case for the Euro Area, we assume energy consumption experienced the same changes as non-durables.

3.1.4 Energy prices

We proxy energy prices using the energy commodity price index constructed by the IMF (code: `PRNG`). This index contains information on crude oil, natural gas, coal price, and propane price indices and is available at a monthly frequency from 1992 to 2022.

3.1.5 Input-Output matrices, factor and consumption shares

Since we assume two sector-specific factors in each sector in our quantitative exercise, labor and capital, so we need to compute each object's respective share in nominal GDP. Further, note that we only need to construct intermediate input expenditure, factor, and consumption shares at an initial equilibrium.

Input-Output matrices. For input-output matrices, we use the 2018 inter-country input-output (ICIO) tables from OECD. Given that these tables contain 45 sectors and 66 countries, we aggregate these tables into four countries and four sectors. These input-output tables allow us to construct both consumption shares and intermediate input linkages at the country-sector level.

Factor shares. The ICIO tables do not contain information on capital and labor payments at the country-sector level. For that reason, we supplement the ICIO tables with the structural analysis (STAN) database. This database contains information on labor compensation (labor payments) and gross operating surplus (capital payments). These data allow us to construct the fraction of value added that is paid to labor at the country-sector level for the United States and Euro Area. We aggregate all countries different from the Euro Area and the United States into a single rest of the world composite country, sector by sector. Due to data unavailability, we impose the same sector-level labor share of the rest of the world to Russia.

3.2 Shocks construction

3.2.1 Detrending

Our model is static. Thus, shocks constructed from the data need to be stationary in order to be consistent with the shock equilibrium up fo the model. To make series stationary we detrend them following Hamilton (2018). As argued in Hamilton (2018), we chose this detrending procedure as it has been shown to better capture short-run fluctuations around the trend, while other competing methods tend to remove too much of a cyclical variation. This is especially relevant for our purposes since we mostly focus on short-run variation[9].

$$y_t = \beta_0 + \sum_{p=9}^{12} \beta_p y_{t-p} + \varepsilon_t.$$

The shock measures constructed from the data are thus defined as:

$$\hat{\varepsilon}_t = y_t - \hat{\beta}_0 - \sum_{p=9}^{12} \hat{\beta}_p y_{t-p}.$$

These shock measures are constructed for country-level aggregate demand, country-sector total hours worked, country-sector expenditure and the energy price index. We estimate each shock series by running regressions for each series separately.

[9]We also experimented with the Hodrick-Prescott filter which delivers similar results.

3.2.2 Total hours worked "shocks" for Russia and rest of the world.

Due to the unavailability of total hours worked for Russia and the rest of the world composite, we estimate these numbers as a function of how strict Covid measures were between 2020 and 2022. We regress total hours worked shocks computed at the sector level for the U.S. on the U.S. stringency index from Hale et al. (2021) that aimed to capture the strictness of countries' government policies against Covid19. Formally, we run the following specification for the period 2020m1 to 2022m12:

$$\hat{\varepsilon}(hw)_{st}^{US} = \beta_{0s} + \beta_s S_t^{US} + \nu_{st}^{US},$$

where $\hat{\varepsilon}(hw)_{st}^{US}$ are the total hours worked shock (i.e., detrended series) in sector s in the United States at time t constructed as we explained in the previous section. From this regression, we recover the estimated coefficients $(\hat{\beta}_{0s}, \hat{\beta}^{US})$. We then project the stringency index of Russia and ROW using these estimated parameters to get predicted values of total hours worked in each sector for both countries:

$$\hat{\varepsilon}(hw)_{st}^{c} = \hat{\beta}_{0s} + \hat{\beta}_s S_t^{c},$$

where $\hat{\varepsilon}(hw)_{st}^{c}$ is the series total hours worked shocks in country c, sector s at time t and $c = \{\text{Russia}, \text{ROW}\}$.

For Russia we use the direct stringency index provided by Hale et al. (2021). For the rest of the world, we take a population-weighted average of the stringency index in Hale et al. (2021) across all available countries except the United States and countries belonging to the Euro Area. Importantly, China appears in the stringency index, and as a result, our predictions for the rest of the world will contain their strict lockdown policies that were a focal point in creating the early supply chain disruptions in 2020.

4 Results

This section presents results for model quantification exercises using the data and shock series described above. Given the model's rich consumption and production structures, we much choose several parameters in order to perform our calibrations. Crucially, several of these parameter choices will allow us to control how substitutable factors and goods used for production are with each other, both within and across countries.

Our baseline quantification exercises use the parameter values described in Table 1.

A key assumption that we make in our baseline choice of parameters, based on the recent empirical literature, is that inputs to production have a low degree of substitutability in the short run. We assume complementarities both across factors (η) and between factors of production and intermediate inputs (ϵ). Further, intermediates themselves are difficult to substitute for each other

Table 1. Baseline parameter values

Parm.	Value	Source	Related to
η	0.6	Oberfield and Raval (2021)	EoS across factors
ϵ	0.6	Atalay (2017)	EoS btw intermediates and VA
θ	0.2	Boehm et al. (2019)	EoS among intermediate inputs
ξ_s	0.6	Consistent with η, ε	Country-level intermediate bundle EoS
ξ_c	0.6	Consistent with η, ε	Country-level consumption bundle EoS

Notes: 'EoS' stands for elasticity of substitution.

along the whole production process and is meant to capture the difficulty in substituting between types of inputs (e.g., steel vs. plastic, θ) as well as source of inputs (e.g., Chinese vs. U.S. steel, ξ_s). Similarly, we assume that the elasticity of substitution for sectoral consumption across countries is also low in the short run (ξ_c). We will vary the degrees of substitutability in further exercises in order to highlight how these elasticities impact the importance of shock transmission to domestic inflation.

4.1 Baseline quantification exercise

Figure 2 begins by plotting quarterly CPI inflation figures for the model calibration and data for the United States and the Euro Area. Both sets of inflation rates are calculated as year-on-year annual growth rates [10] The model inflation rates are based on calibrations applying all data-constructed shocks to all countries in our world economy.

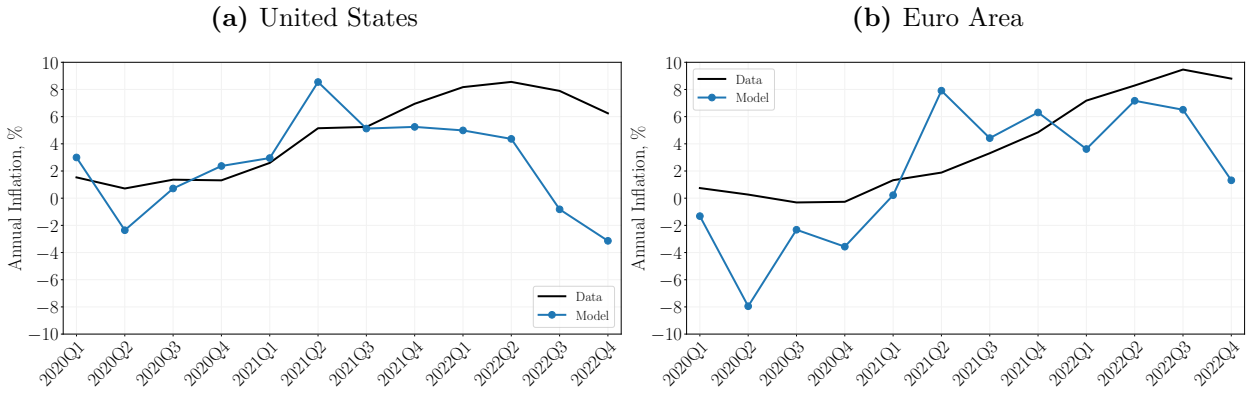
Figure 2 shows that our model matches the observed inflation of 2020q1–2022q4 well both in the U.S. and in Euro area. The exception is falling inflation at the end of our sample, whereas actual inflation only started falling in 2023. This is a data limitation since our data is only available until end of 2022. This issue can be resolved once we use the extended data.

Figure 3 shows that our model can also match the USD/euro exchange rate dynamics. Some depreciation in 2020 but then an appreciation of USD since early 2021. As can be seen in Figure 4, this is due to our model's ability to match the U.S. current account deficit, which widened in 2020, improved in 2021 and then widened again in late 2021–2022. This pattern matches well with the pattern of aggregate demand and savings. Savings originally increased during lockdowns but then reduced given the aggregate demand stimulus (See for similar results, Aggarwal et al. (2023)).

Figure 5 shows our main result. In the absence of sectoral supply shocks, there will be more disinflation early on given lower aggregate demand. Later on energy shocks played a similar role,

[10]The model, however, gives the price level in deviation from steady-state. We convert them to year-on-year annual growth as follows. We take the annual difference between the model implied price levels (recall these are in deviations from steady state). We then add the year-on-year change on the CPI trend computed following Hamilton (2018). The resulting series is our model-based inflation.

Figure 2. United States and Euro Area Inflation rates: Baseline Model vs. Data

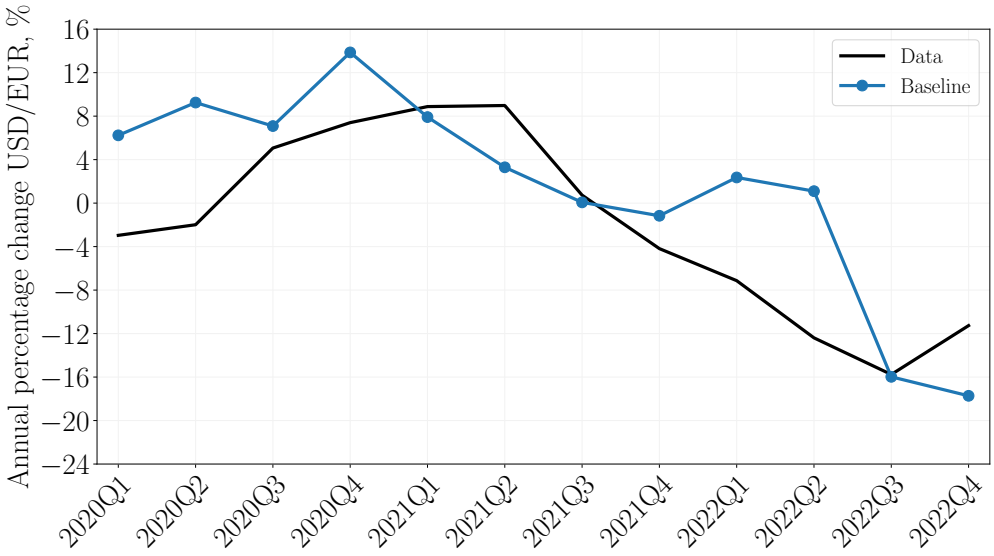


Notes: This figure shows annual inflation implied by the model (blue line) relative to the data when feeding the model with all shocks.

especially for Europe and increased inflation more than the rise in aggregate demand.

Figure 6 shows the importance of international inflation spillovers. For the U.S., inflation is mostly a domestic shock-driven phenomenon, whereas for Europe international shocks have a bigger role. Though even for Europe, the international shocks have less of an effect, given the endogenous adjustment of exchange rates that smooth out these shocks. In our earlier work under fixed exchange rate, we have found that 2/3s of inflation in Europe can be explained by external shocks. This is not the case when exchange rates adjust endogenously.

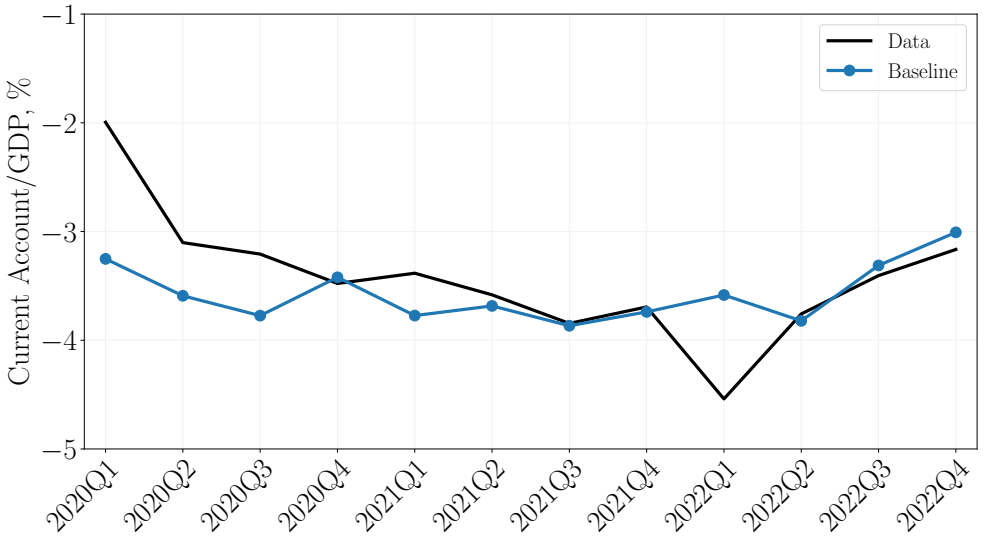
Figure 3. USD-euro Exchange Rate: Model vs. Data



Notes: This figure shows annual change in the exchange rate implied by the baseline model (blue solid line). For comparison, we also plot the exchange rate changes as in the data (black solid line).

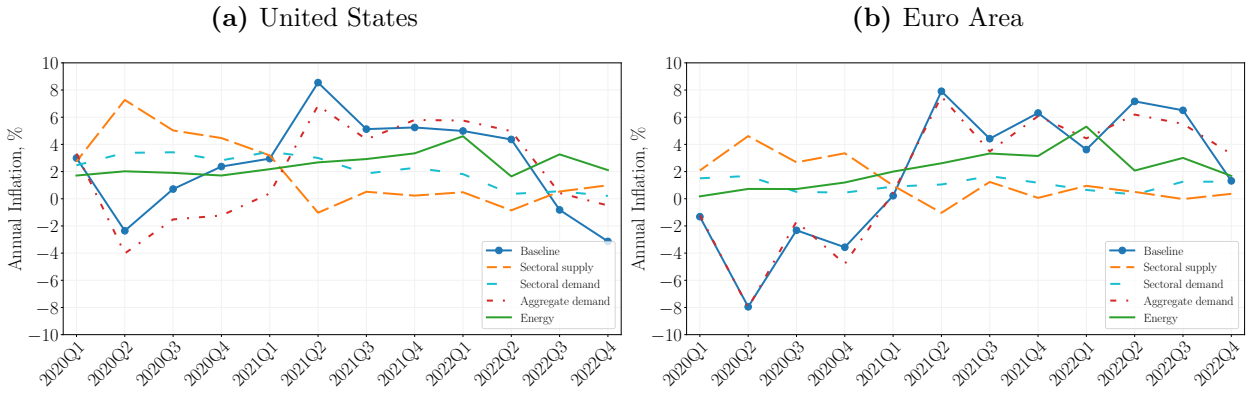
Figure 4. Current Account-to-GDP Ratio: Model vs. Data

(a) United States



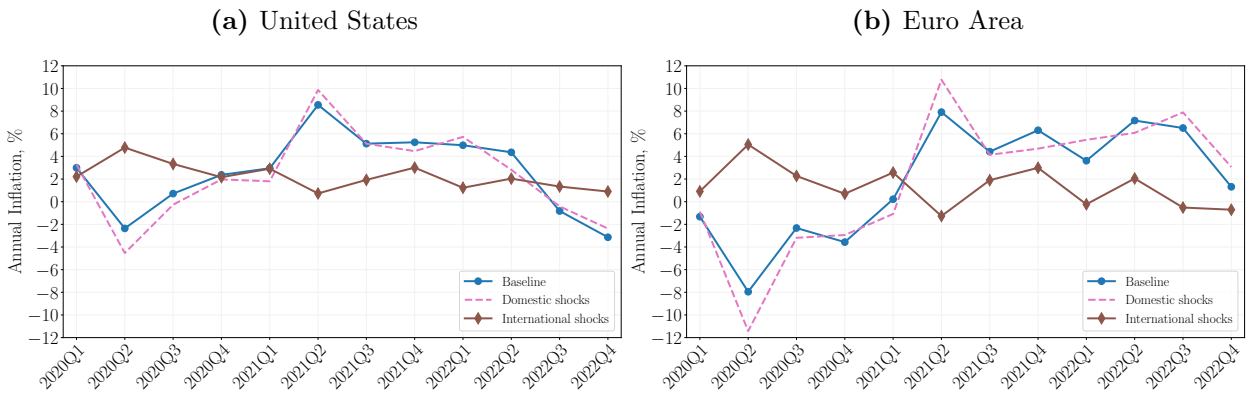
Notes: This figure shows the current account-to-GDP ratio implied by the baseline model (blue solid line). We also plot the current account-to-GDP ratio as in the data (black solid line) for comparison.

Figure 5. United States and Euro Area Sources of Inflation: Shock Decomposition



Notes: This figure shows annual inflation implied by the model (blue line) relative to the data when feeding the model with all shocks and counterfactual scenarios where we feed in one type of shock at a time.

Figure 6. United States and Euro Area Sources of Inflation: Domestic and International Shocks

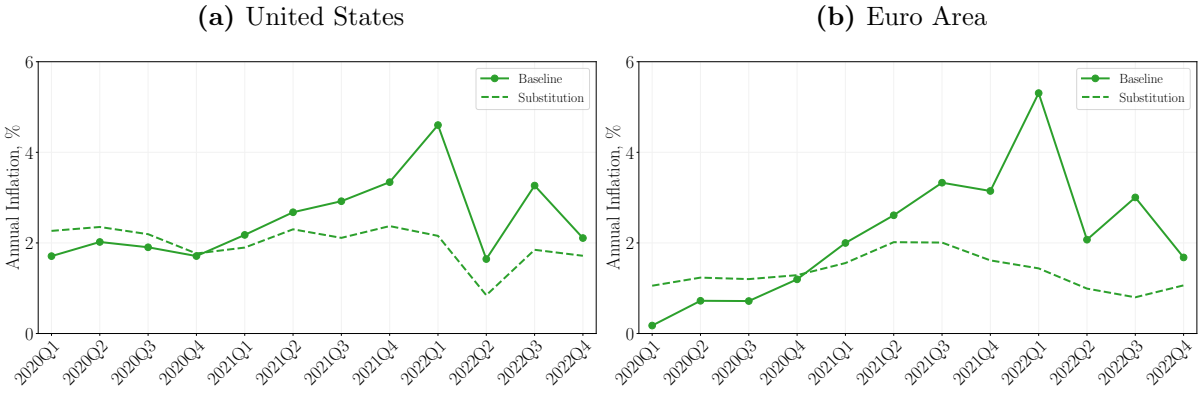


Notes: This figure shows annual inflation implied by the model (gray line) relative to the data when feeding the model with all shocks.

4.2 Role of Complementarities

Finally, figure 7 shows the amplification role of complementarities in production within the global network. When we use elasticities commonly used in the literature that assume instant substitution and reallocation of factors across sectors, then we cannot explain the observed inflation anymore, especially when we focus on supply shocks, such as energy as depicted in this figure.

Figure 7. Production Complementarities and Energy Shocks Transmission to Inflation



Notes: This figure shows annual inflation implied by the baseline model (green solid line) relative to the model with high elasticities of substitution (green dashed line).

5 Conclusion

We estimate a multi-country multi-sector general equilibrium model to quantify the drivers of inflation during 2020–2023. Given the global nature of the model, we also measure inflation spillovers across countries.

We establish four key findings. First, negative supply shocks (pandemic shocks) arising from constrained domestic labor and imported intermediates sparked inflation in advanced economies initially. Second, positive aggregate demand shocks created by expansionary fiscal policy widened demand-supply imbalances, intensifying inflation during 2021–2022. Third, the reallocation of consumption between goods and service sectors further amplified these imbalances and transmitted inflation across countries through global production networks. Fourth, complementarities in production amplified the impact of energy shocks and tight labor markets on inflation.

Our model matches the observed inflation, an untargeted moment. It further quantifies the drivers of inflation in each phase. Inflation started due to pandemic-related supply shocks and increased further due to fiscal stimulus-related demand shocks and amplified through global energy shocks.

References

Aggarwal, Rishabh, Adrien Auclert, Matthew Rognlie, and Ludwig Straub. 2023. "Excess savings and twin deficits: The transmission of fiscal stimulus in open economies." *NBER Macroeconomics Annual* 37 (1): 325–412.

Amiti, Mary, Sebastian Heise, Fatih Karahan, and Ayşegül Şahin. 2023. "Inflation Strikes Back: The Role of Import Competition and the Labor Market." May. 10.3386/w31211, NBER Working Paper 31211.

Atalay, Enghin. 2017. "How important are sectoral shocks?" *American Economic Journal: Macroeconomics* 9 (4): 254–280.

Baqaee, David, and Emmanuel Farhi. 2022. "Supply and Demand in Disaggregated Keynesian Economies with an Application to the Covid-19 Crisis." *American Economic Review* 112 (5): 1397–1436. 10.1257/aer.20201229.

Benigno, Pierpaolo, and Gauti B. Eggertsson. 2023. "It's Baaack: The Surge in Inflation in the 2020s and the Return of the Non-Linear Phillips Curve." April. 10.3386/w31197, NBER Working Paper 31197.

Blanchard, Olivier J., and Ben S. Bernanke. 2023. "What Caused the US Pandemic-Era Inflation?" June. 10.3386/w31417, NBER Working Paper 31417.

Boehm, Christoph E, Aaron Flaaen, and Nitya Pandalai-Nayar. 2019. "Input linkages and the transmission of shocks: Firm-level evidence from the 2011 Tōhoku earthquake." *Review of Economics and Statistics* 101 (1): 60–75.

Boehm, Christoph E., Andrei A. Levchenko, and Nitya Pandalai-Nayar. 2023. "The Long and Short (Run) of Trade Elasticities." *American Economic Review* 113 (4): 861–905. 10.1257/aer.20210225.

Boehm, Christoph E., and Nitya Pandalai-Nayar. 2022. "Convex Supply Curves." *American Economic Review* 112 (12): 3941–69. 10.1257/aer.20210811.

Çakmaklı, Cem, Selva Demiralp, Şebnem Kalemli-Özcan, Sevcan Yeşiltaş, and Muhammed Ali Yıldırım. 2021. "The Economic Case for Global Vaccinations: An Epidemiological Model with International Production Networks." Working Paper 27191, National Bureau of Economic Research.

Comin, Diego A., Robert C. Johnson, and Callum J. Jones. 2023. "Supply Chain Constraints and Inflation." April. 10.3386/w31179, NBER Working Paper 31179.

Costinot, Arnaud, and Andrés Rodríguez-Clare. 2014. "Trade Theory with Numbers: Quantifying the Consequences of Globalization." In *Handbook of International Economics*, edited by Gopinath, Gita, Elhanan Helpman, and Kenneth Rogoff Volume 4. Chap. 4 197–261, Elsevier, . 10.1016/B978-0-444-54314-1.00004-5.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum. 2007. "Unbalanced Trade." *American Economic Review: Papers & Proceedings* 97 (2): 351–355. 10.1257/aer.97.2.351.

Dekle, Robert, Jonathan Eaton, and Samuel Kortum. 2008. "Global Rebalancing with Gravity: Measuring the Burden of Adjustment." *IMF Staff Papers* 55 (3): 511–540. 10.1057/imfsp.2008.17.

di Giovanni, Julian, Şebnem Kalemli-Özcan, Alvaro Silva, and Muhammed A. Yıldırım. 2023. "Quantifying the Inflationary Impact of Fiscal Stimulus under Supply Constraints." *AEA Papers and Proceedings* 113 76–80. 10.1257/pandp.20231028.

Eggertson, Gauti B., and Don Kohn. 2023. "The Inflation Surge of the 2020s: The Role of Monetary Policy." May, Mimeo, Brown University and Brooking Institution.

Ferrante, Francesco, Sebastian Graves, and Matteo Iacoviello. 2023. "The Inflationary Effects of Sectoral Reallocation." Forthcoming, *Jounal of Monetary Economics*.

Gourinchas, Pierre-Olivier, Şebnem Kalemli-Özcan, Veronika Penciakova, and Nick Sander. 2021. "Fiscal Policy in the Age of COVID: Does it 'Get in all of the Cracks?'." *Proceedings of the Jackson Hole Symposium*. 10.3386/w29293.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub, and Ivàn Werning. 2020. "Macroeconomic Implications of COVID-19: Can Negative Supply Shocks Cause Demand Shortages?" April. 10.3386/w26918, NBER Working Paper 26918.

Guerrieri, Veronica, Guido Lorenzoni, Ludwig Straub, and Iván Werning. 2021. "Monetary Policy in Times of Structural Reallocation." *Proceedings of the Jackson Hole Symposium*.

Hale, Thomas, Noam Angrist, Rafael Goldszmidt et al. 2021. "A global panel database of pandemic policies (Oxford COVID-19 Government Response Tracker)." *Nature Human Behaviour* 5 (4): 529–538. 10.1038/s41562-021-01079-8.

Hamilton, James D. 2018. "Why you should never use the Hodrick-Prescott filter." *Review of Economics and Statistics* 100 (5): 831–843.

Jordá, Óscar, Celeste Liu, Fernanda Nechio, and Fabián Rivera-Reyes. 2022. "Why Is U.S. Inflation Higher than in Other Countries?" *FRBSF Economic Letter* 2022 (07): , https://EconPapers.repec.org/RePEc:fip:fedfel:93890.

Jordá, Óscar, and Fernanda Nechio. 2022. "Inflation and Wage Growth Since the Pandemic." https://doi.org/10.24148/wp2022-17, Federal Reserve Bank of San Francisco Working Paper 2022-17.

Oberfield, Ezra, and Devesh Raval. 2021. "Micro data and macro technology." *Econometrica* 89 (2): 703–732.

Shapiro, Adam H. 2022a. "How Much Do Supply and Demand Drive Inflation?" June, FRBSF Economic Letter.

Shapiro, Adam H. 2022b. "Decomposing Supply and Demand Driven Inflation." September, FRBSF Working Paper.

A Proofs

Proof of Proposition 1

The rich structure that we introduced in our model can be simplified to capture the first-order effect of shocks on inflation. Here, we will just focus on factors, goods and consumption ignoring the bundling at different levels. Starting from Equation (3), we can write production in terms of all other sectors and factors as:

$$Y_{ni} = A_{ni} F_{ni} \left(\{X_{ni,mj}\}_{mj \in \mathcal{S}}, L_{ni}, K_{ni} \right),$$

where F_{ni} is a nested CES function, $\mathcal{S}$ is the set of all country-sector pairs and $X_{ni,mj}$ denotes the amount of output of country-sector mj used by ni. With this, we can write the firm profit maximization problem as:

$$\pi_{ni} = P_{ni} Y_{ni} - \sum_{mj \in \mathcal{S}} P_{mj} X_{ni,mj} - W_{ni} L_{ni} - R_{ni} K_{ni}.$$

Using Shepard's Lemma, we can write the change in prices in terms of price changes of all other sectors and factor price changes as:

$$d \log P_{ni} = -d \log A_{ni} + \sum_{mj \in \mathcal{S}} \frac{P_{mj} X_{ni,mj}}{P_{ni} Y_{ni}} d \log P_{mj} + \frac{W_{ni} L_{ni}}{P_{ni} Y_{ni}} d \log W_{ni} + \frac{R_{ni} K_{ni}}{P_{ni} Y_{ni}} d \log R_{ni}.$$

Recall that:

$$X_{ni,mj} = X_{n,mj} \frac{X_{ni,j}}{X_{n,j}}.$$

At steady state, define the country-sector to country-sector input-output matrix as:

$$\begin{aligned}
\Omega^{SS}_{ni,mj} &\equiv \frac{P_{mj} X_{ni,mj}}{P_{ni} Y_{ni}} = \frac{P_{mj} X_{n,mj}}{P_{ni} Y_{ni}} \frac{P_{n,j} X_{ni,j}}{P_{n,j} X_{n,j}} \\
&= \left(\frac{P_{mj} X_{n,mj}}{P_{n,j} X_{n,j}} \right) \left(\frac{P_{n,j} X_{ni,j}}{P^Z_{ni} Z_{ni}} \right) \left(\frac{P^Z_{ni} Z_{ni}}{P_{ni} Y_{ni}} \right) \\
&= \Omega^X_{n,mj} \, \Omega^Z_{ni,j} \, \Omega^Y_{ni,Z}.
\end{aligned}$$

Similarly, we write the labor and capital shares as:

$$\begin{aligned}
\Omega^{SF,L}_{ni} &\equiv \frac{W_{ni} L_{ni}}{P_{ni} Y_{ni}} = \left(\frac{W_{ni} L_{ni}}{P^{\text{VA}}_{ni} \text{VA}_{ni}} \right) \left(\frac{P^{\text{VA}}_{ni} \text{VA}_{ni}}{P_{ni} Y_{ni}} \right) = \Omega^{\text{VA}}_{ni,L} \, \Omega^Y_{ni,\text{VA}}, \\
\Omega^{SF,K}_{ni} &\equiv \frac{R_{ni} K_{ni}}{P_{ni} Y_{ni}} = \Omega^{\text{VA}}_{ni,K} \, \Omega^Y_{ni,\text{VA}}.
\end{aligned}$$

Finally, the consumption share of country-sector mj is expressed as:

$$\Omega^{CS}_{n,mj} \equiv \frac{P_{mj}C_{n,mj}}{P_nC_n} = \left(\frac{P_{mj}C_{n,mj}}{P^{CB}_{n,j}C_{n,j}}\right)\left(\frac{P^{CB}_{n,j}C_{n,j}}{P_nC_n}\right) = \Omega^{CB}_{n,mj}\,\Omega^{C}_{n,j}.$$

With these definitions, we can write the changes in prices in vector notation with (and combining capital:

$$d\log P = -d\log A + \Omega^{SS} d\log P + \Omega^{SF,L} d\log W + \Omega^{SF,K} d\log R.$$

Defining the Leontief inverse for Ω^{SS}:

$$\Psi^{SS} = \left[I - \Omega^{SS}\right]^{-1},$$

we can solve for the price changes in terms of productivity change and factor price changes:

$$d\log P = -\Psi^{SS} d\log A + \Psi^{SS}\Omega^{SF,L} d\log W - \Psi^{SS}\Omega^{SF,K} d\log R.$$

Similarly, the CPI can be written as the weighted average of the good prices with weights $\Omega^{CS}_{n,mj}$. With this, the CPI can be written as:

$$d\log \text{CPI}_n = \sum_{mj} \Omega^{CS}_{n,mj} d\log P_{mj} = \Omega^{CS}_{n} d\log P,$$

where Ω^{CS}_n is the n^{th} row of the Ω^{CS} matrix. Combining with the price change equation, we can write the CPI change as:

$$d\log \text{CPI}_n = -\Omega^{CS}_n\Psi^{SS} d\log A + \Omega^{CS}_n\Psi^{SS}\Omega^{SF,L} d\log W - \Omega^{CS}_n\Psi^{SS}\Omega^{SF,K} d\log R.$$

Let's define the country-specific Domar weight for the labor:

$$(\Lambda^n)^T \equiv \Omega^{CS}_n\Psi^{SS}\Omega^{SF,L}$$

as the share of expenditures of country n that ends up in the owners of L_{mi}. We can write a similar expression for capital with

$$(\kappa^n)^T \equiv \Omega^{CS}_n\Psi^{SS}\Omega^{SF,K}$$

. Since the factors are where all the payments are accumulated, sum over these Domar weights equal to 1:

$$\sum_{mi} \Lambda^n_{mi} + \kappa^n_{mi} = (\Lambda^n)^T 1_{\mathcal{JN}} + (\kappa^n)^T 1_{\mathcal{JN}} = 1,$$

where $1_{\mathcal{JN}}$ is a vector of ones of a dimension $\mathcal{JN}$. Similarly, we can define the country-specific

sector Domar-weights as:

$$(\lambda_n)^T = \Omega_n^{CS} \Psi^{SS}.$$

Hence, the CPI can be written as:

$$d \log \text{CPI}_n = -(\lambda_n)^T d \log A + (\Lambda^n)^T d \log W - (\kappa^n)^T d \log R.$$

The Domar weights for labor and capital also satisfy:

$$\Lambda_{mi}^n = \frac{W_{mi} L_{mi}^n}{I^n},$$

where L_{mi}^n is the portion of the labor in mi that could be attributed to country n. Hence, we can write the change in wages in terms of their Domar weights as:

$$d \log W_{mi} = d \log \Lambda_{mi}^n - d \log L_{mi}^n + d \log I^n = d \log \Lambda_{mi}^n - d \log L_{mi} + d \log I^n.$$

In the last equality, we made the assumption that the labor change reduces proportionately regardless of the destination. Therefore, we can drop the country superscript. For the rental rate:

$$d \log R_{mi} = d \log \kappa_{mi}^n - d \log K_{mi}^n + d \log I^n = d \log \kappa_{mi}^n + d \log I^n,$$

since capital levels are assumed to be constant. With these, we can write the CPI as:

$$\begin{aligned}
d \log \text{CPI}_n &= -(\lambda_n)^T d \log A + (\Lambda^n)^T d \log \Lambda^n - (\Lambda^n)^T d \log L^n \\
&\quad + \underbrace{((\Lambda^n)^T 1_{\mathcal{JN}} + (\kappa^n)^T 1_{\mathcal{JN}})}_{=1} d \log I^n + (\kappa^n)^T d \log \kappa^n \\
&= -(\lambda_n)^T d \log A + \underbrace{(1_{\mathcal{JN}})^T d\Lambda^n + (1_{\mathcal{JN}})^T d\kappa^n}_{d[(1_{\mathcal{JN}})^T \Lambda^n + (1_{\mathcal{JN}})^T \kappa^n] = d(1) = 0} - (\Lambda^n)^T d \log L^n + d \log I^n \\
&= d \log I^n - (\Lambda^n)^T d \log L^n - (\lambda_n)^T d \log A,
\end{aligned}$$

where in the second equality we used the fact that: $L_{mi} \, d \log L_{mi} = d \, L_{mi}$. □