Inflation Puzzles: What is Missing in the Phillips Curve?[1]

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Abstract

We define the global inflation trend by excluding the impact of three factors on headline inflation: idiosyncratic shocks that are country-specific, global economic slack, and oil price inflation. We identify this trend empirically by decomposing the average inflation of a group of economies whose idiosyncratic shocks are assumed to be independent, with the identification assumption that trend forces are uncorrelated with cyclical forces. This decomposition also helps construct a global factor to proxy the impact of global slack. We show that both the global inflation trend and global slack have statistically significant and persistent impacts on headline inflation in advanced economies, with global slack having a strong delayed impact on headline inflation. We develop a New Keynesian Phillips Curve with cross-border input-output linkages to explain these patterns. Importantly, our framework provides a unified explanation for three major inflation puzzles in advanced economies since the Global Financial Crisis (GFC): (i) elevated inflation despite high unemployment post-GFC, (ii) weak reflation amid strong labor market improvements in the 2010s, and (iii) volatile inflation movements despite stable unemployment rates in 2022-23.

[1] This draft is very preliminary. Comments are welcome at wlian@imf.org.

I. Introduction

Inflation has persistently deviated from Phillips curve predictions across multiple economic episodes for advanced economies in recent decades.[2] Three key examples illustrate this disconnect: resilient inflation despite elevated unemployment rates post-GFC ("missing disinflation"), weak inflation despite steadily falling unemployment in the 2010s ("missing reflation"), and volatile inflation with minimal unemployment changes in 2022-23.[3]

The economic literature has developed several complementary explanations for this weakened relationship between inflation and labor market conditions. One prominent strand examines inflation expectations, exploring both expectation anchoring (Ball and Mazumder 2011; Blanchard, Cerutti, and Summers 2015) and the influence of oil prices on price setters' expectations (Coibion and Gorodnichenko 2015; Hasenzagl et al. 2022). Another substantial body of work investigates potential structural changes in the inflation process, exploring the flattening of Phillips curves across economies (McLeay and Tenreyro 2019; Di Giovanni et al. 2019; Hazell et al. 2021) and the increasing influence of global factors, including global slack, intermediate goods prices, and international supply chains (Carney 2017; Forbes 2019; Auer et al. 2019).

Researchers have also pursued alternative approaches, examining different economic slack measures (Hong et al. 2019; Shapiro 2024) and puzzling patterns that relate to the cyclicality of inflation indicators (Mehdi and Shapiro 2014; Stock and Watson 2021; Heise et al. 2021; IMF 2020; Lian and Freitag 2022). Most recently, empirical studies have also explored specific mechanisms driving the volatile inflation dynamics of the COVID-19 era (Bernanke and Blanchard 2024; Di Giovanni et al. 2024; Dao et al. 2024; IMF 2024).

Despite these extensive contributions, two fundamental questions remain unresolved: (i) Why have these inflation puzzles occurred concurrently across multiple countries, as noted by previous studies (Coibion

[2] Throughout the paper, we use the definition of advanced economies from the IMF *World Economic outlook*.

[3] More specifically, these three inflation puzzles can be illustrated quantitatively: First, post-GFC, U.S. headline inflation reached 3.8% in September 2011 despite 9.0% unemployment—significantly higher than pre-crisis averages of 2.8% inflation with 5.0% unemployment. Second, despite substantial labor market improvements throughout the 2010s, inflation remained persistently subdued—by December 2019, inflation had actually declined to 2.3% despite unemployment falling to 3.6%, contradicting traditional Phillips curve predictions. Third, pandemic-era inflation exhibited remarkable volatility—fluctuating dramatically from 7.2% in December 2021 to 9.0% at its peak, then declining to 3.3% by December 2023, all while unemployment remained nearly constant around 3.7%.

and Gorodnichenko (2015), Forbes (2019), and Clarida (2024), among others)? (ii) Are there common forces underlying all three inflation puzzles that existing inflation frameworks fail to capture?

Our key innovation is defining a global inflation trend by excluding three sets of factors: idiosyncratic country-specific shocks, global economic slack, and oil price inflation. We identify this trend by decomposing average inflation across a large number of economies, assuming their idiosyncratic shocks are uncorrelated. Our identification relies on the assumption that trend and cyclical forces remain uncorrelated—specifically, that the global trend is uncorrelated with both global economic slack and oil price inflation.[4]

We assume idiosyncratic inflationary shocks are uncorrelated among emerging market and developing economies (EMDEs) that have relatively small economic size, which is plausible given their limited direct economic linkages. With headline inflation data for a large number of such economies, we can effectively average out these idiosyncratic shocks in our analysis.

To implement our decomposition, we regress the average inflation of small open EMDEs on global economic slack, its lags, and oil price inflation. The regression residual serves as our proxy for the global inflation trend, while the estimated coefficients on global slack and its lags provide another proxy for its impact.

We show that both the global inflation trend and global slack factors have statistically significant impact on headline inflation that is robust to controlling for unemployment rate. Moreover, we find clear patterns to suggest the importance of the delayed impact of global slack in affecting headline inflation dynamics.

To explain why domestic slack inadequately captures global shock impacts, we develop a New Keynesian Phillips Curve (NKPC) with cross-border input-output linkages, extending the work of Gali and Gertler (1999), Gali and Monacelli (2005), and Hazell et al. (2021).[5] Our derived structural equation shows headline inflation is affected by domestic and global slack, including their lags, and technological shocks that alter the relative prices of tradable goods.[6]

[4] We leave it for future research to capture non-oil global supply shocks and elaborate below why our results should not be driven by omitting such shocks. The intuition is that non-oil supply shocks at the global level are rare "and" seem to have a small impact on global slack.

[5] For recent discussion on sectoral shocks, see Baqaee and Farhi, 2022; Guerrieri et al. 2022; di Giovanni et al. 2024, among others.

[6] Annex B shows empirical patterns to suggest that the relative price of tradable goods appeared to be active during all inflation puzzles, suggesting a potential role of its underlying forces.

We have three key empirical findings. First, the global inflation trend significantly impacts long-term inflation expectations in advanced economies. Its effect on 6-10 year expectations is about half its impact on 2-year expectations. While this pattern resembles the oil price level's impact on expectations, a one-standard deviation change in the global inflation trend has a much stronger effect than a similar change in oil prices. This finding, combined with our global slack results, reveals two important persistent forces affecting inflation beyond domestic slack that were previously ignored.

Second, including global trend and global slack factors resolves both the missing disinflation and missing reflation puzzles in the pre-COVID-19 period. While Hazell et al. (2021) attribute these puzzles to a very flat Phillips curve, our results demonstrate the importance of these two global forces. Global slack played a dominant role in the missing disinflation episode following the GFC, while the global trend was more important in explaining the missing reflation puzzle throughout the 2010s. As a contrast with the next finding, we achieve this result by assuming constant coefficients of inflation drivers over time.

Finally, after considering structural changes in the inflation process, our model jointly explains three global inflation puzzles almost perfectly. We demonstrate this by documenting the changing inter-quartile ranges of inflation equation residuals over time and compare across specifications regarding this pattern. Our framework accommodates structural changes in both Phillips curve slope and global variable coefficients. We find limited evidence of Phillips curve steepening during COVID-19, but strong evidence of increased domestic inflation sensitivity to global factors. We also observe distinct patterns when comparing G7 and non-G7 advanced economies.

We extend Hazell et al.'s (2021) empirical framework by analyzing global drivers of inflation movements not well captured by domestic slack or monetary policy regime shifts. While Hazell et al. (2021) categorize these unexplained inflation movements as cost-push shocks, we find that they contain two distinct components with potentially persistent effects. This difference is critical and has profound policy implications, as cost-push shocks are traditionally considered transitory forces.

Our study relates closely to Ciccarelli and Mojon (2010), a seminal paper highlighting the strong co-movement of inflation across countries. A key difference is that we identify the global inflation trend—a latent variable—through an identification assumption based on global variables. This requires the elimination of idiosyncratic shocks through a large number of non-industrial economies that were not included in their sample.

The rest of the paper is organized as follows. Section II presents the empirical strategy. Section III documents key stylized facts to further support the strategy. Section IV constructs the global factors and explores their properties. Section V develops the NKPC with cross-border input and output linkages.

Section VI uses the Phillips curve with three global factors to explain inflation puzzles. Section VII concludes.

II. The Empirical Model

2.1 An Inflation Model with Three Global Factors

A key difference between our inflation model and the conventional framework is the treatment of cost-push shocks, denoted by $\varepsilon_{i,t}$ and defined as:

$$\varepsilon_{i,t} \triangleq \pi_{i,t} - \gamma_i \pi_{i,t}^{e} - \beta_i u_{i,t}, \tag{1}$$

where $\pi_{i,t}$ is headline inflation, γ_i is the discount rate reflecting price stickiness (Gali and Gertler, 1999), $\pi_{i,t}^{e}$ is the expectation of price setters, β_i is the slope of the Phillips curve, and $u_{i,t}$ is unemployment rate.

In the conventional framework, cost-push shocks are typically assumed to have transitory effects, and persistent inflation movements reflect either incompletely anchored inflation expectations or changes in domestic economic slack. Accordingly, one challenge in explaining persistent inflation movements through changes in unemployment rates may stem from poorly measured shifts in price setters' inflation expectations, which some researchers argue are sensitive to energy price levels (Coibion and Gorodnichenko (2015) and Hasenzagl et al. (2019), among others). Another challenge may reflect the unemployment rate's limitations in accurately capturing true economic slack (Hong et al. (2018) and Shapiro (2024) among others).[7]

In this paper, we treat $\varepsilon_{i,t}$, the residual factor in equation (1), differently. Instead of categorizing it as transitory cost-push shocks, we assume that it may contain persistent forces:

$$\varepsilon_{i,t} = \tau_{i,t} + \sum_{j=0}^{J} \theta_{ij} Y_{t-j}^{Gap} + \gamma_i \Delta P_t^{Oil} + \lambda_i G_t, \tag{2}$$

where $\tau_{i,t}$ captures the impact of idiosyncratic shocks specific to economy i, Y_{t-j}^{Gap} denotes the global economic slack in period $t-j$, ΔP_t^{Oil} is oil price inflation, G_t is a force common across all economies.

[7] Another strand of the NKPC literature tries to understand persistent inflation puzzles by examining whether the "true" slope of the Phillips curve has flattened over time. Hazell et al. (2021) find that the true slope has been small since the 1980s. Their analysis suggests that the apparently weakening relationship between economic slack and headline inflation in the United States since the 1980s partially stems from an upward bias in estimating the Phillips curve slope. This bias occurs because simple Phillips curve estimations fail to account for monetary policy regime switching shocks in the 1980s, when disinflation occurred due to policy changes rather than as a causal response to changes in unemployment.

Let $v_{i,t}$ denote the impact of idiosyncratic shocks on headline inflation, which can go through domestic slack, or inflation expectations of economic agents. In this sense, it is broader than $\tau_{i,t}$. We re-define G_t as:

$$\lambda_i G_t = \pi_{i,t} - g_i\left(\overrightarrow{Y_t^{Gap}}\right) - \gamma_i \Delta P_t^{Oil} - v_{i,t}, \quad (3)$$

where $g_i\left(\overrightarrow{Y_t^{Gap}}\right) = \sum_{j=0}^{J} \theta_{ij} Y_{t-j}^{Gap}$. We refer to G_t as the global inflation trend, which excludes the impact of idiosyncratic shocks and cyclical global factors such as global economic slack and oil price inflation.

2.2 Econometric Assumptions

To make the model tractable, we introduce several assumptions:

Assumption 1. Global factors and idiosyncratic variable $v_{i,t}$ are uncorrelated with each other.

Assumption 1 is standard in the global inflation literature (Ciccarelli and Mojon, 2010; Mumtaz and Surico, 2012; Ha et al., 2024, among others).

Assumption 2. G_t is uncorrelated with cyclical factors including $\overrightarrow{Y_t^{Gap}}$ and ΔP_t^{Oil}.

Assumptions 2 captures the idea that trend and cyclical forces are independent of each other.

We assume that

$$G_t = h\left(\overrightarrow{T_t}, S_t^*\right),$$

where h is a linear function, $\overrightarrow{T_t}$ captures global inflation trend forces and S_t^* denotes supply shocks not captured by $\overrightarrow{Y_t^{Gap}}$, ΔP_t^{Oil}, or $v_{i,t}$.

A potential concern is whether cyclical forces omitted in S_t^* can significantly affect the correlation between G_t and $g_i\left(\overrightarrow{Y_t^{Gap}}\right)$? Two factors mitigate this concern: (i) S_t^* tends to be rare, and (ii) S_t^* typically has limited impact on shifting global output. For example, consider the Global Supply Chain Pressure Index constructed by the New York Fed. Between January 1998 and December 2024, the index's standard deviation was 1.04. Before the COVID-19 pandemic, only 4.5% of months exceeded this threshold, rising to 88% during the pandemic, before returning to zero after August 2023. Even for prominent supply shocks like the chip shortage during COVID, the semiconductor industry accounts for less than 1% of the

global GDP.[8] Such rare and relatively small shocks should not have a significant impact on the average correlation highlighted in Assumption 2.

Assumption 3 $v_{i,t}$ is independent of each other among small open economies with weak trade and financial ties.

This assumption allows regional factors to result in correlated shocks, and idiosyncratic shocks to be correlated among AEs.

2.3 Empirical Strategy

Let $\Lambda_t^1(\{\mu_j\}, \eta, \beta)$ be a weighted average of the three global variables in equation (3):

$$\Lambda_t^1(\{\mu_j\}, \eta, \beta) = \sum_{j=0}^{J} \mu_j Y_{t-j}^G + \eta P_t^{Oil} + \beta G_t. \quad (4)$$

Suppose Λ_t^1, $\{Y_{t-j}^G\}_{j=0}^{+\infty}$, and P_t^{Oil}, but not G_t, are observed. Under Assumption 2, a proxy of G_t can be constructed as the residual from the regression of Λ_t^1 on $\{Y_{t-j}^G\}_{j=0}^{J}$ and P_t^{Oil}.

This way of identifying the global inflation trend is different from the conventional practice of extracting inflation trend at the individual country level (Iceland, 2004; Stock and Watson, 2007; Cogley and Sbordone, 2008; Mertens, 2014; Ascari and Sbordone, 2014; Kamber and Wong, 2020; Ascari and Fosso, 2022; among others), which critically relies on the assumption that the trend contains unit roots, as well as other assumptions about trend and cyclical shocks. In our strategy, the key is to construct $\Lambda_t^1(\{\mu_j\}, \eta, \beta)$.

The first step of our empirical strategy is to construct a metric Λ_t^1.

Step 1. *Calculate the average inflation of a large number of economies that have weak economic ties and are not advanced economies to obtain* $\Lambda_t^{1,*}$.

Interestingly, Step 1 suggests that our empirical strategy cannot be implemented without a global sample and highlights the focus on inflation trends at the global level, as this step may eliminate inflation trend driven by country-specific idiosyncratic factors.

The regression of $\Lambda_t^{1,*}$ on $\{Y_{t-j}^G\}_{j=0}^{+\infty}$ and P_t^{Oil} not only helps create a proxy for G_t, but also a proxy for $g_i\left(\overrightarrow{Y_t^{Gap}}\right)$ for any country i.

[8] See, for example, https://www.semiconductors.org/policies/tax/market-data/?type=post.

In Section III, we show that if the production technology is symmetric across countries, there exist a_i and $\{b_j\}_{j=0}^{J}$, such that $g_i\left(\overrightarrow{Y_t^{Gap}}\right) = a_i \sum_{j=0}^{J} b_j Y_{t-j}^{G}$. Consequently, there exists φ, such that

$$\Lambda_t^{1,*} = \varphi \sum_{j=0}^{J} b_j Y_{t-j}^{G} + \eta P_t^{Oil} + \beta G_t.$$

The regression of $\Lambda_t^{1,*}$ on $\{Y_{t-j}^{G}\}_{j=0}^{+\infty}$ and P_t^{Oil} yields coefficients of $\{Y_{t-j}^{G}\}_{j=0}^{J}$, which can be used to construct a proxy for $g_i\left(\overrightarrow{Y_t^{Gap}}\right)$. We summarize these as the Step 2 of our empirical strategy.

Step 2. *Regress $\Lambda_t^{1,*}$ on $\{Y_{t-j}^{G}\}_{j=0}^{+\infty}$ and P_t^{Oil}, to create the proxies for $g_i\left(\overrightarrow{Y_t^{Gap}}\right)$ and G_t.*

The construction of the proxy for $g_i\left(\overrightarrow{Y_t^{Gap}}\right)$ reveals another interesting difference between our empirical strategy and the previous studies examining the role of global output gap (Borio and Filardo, 2007). Likely reflecting a limited degree of freedom in the data and the ambiguity about the number of lags that should be included in the analysis, the lagged impact of global slack is not explored previously. By contrast, we can include a large number of lags for the global slack in Step 2.

Step 3. *Regress $\pi_{i,t}$ on the unemployment rate, oil price inflation, and the proxies of $g_i\left(\overrightarrow{Y_t^{Gap}}\right)$ and G_t.*

Assumption 1 alleviates potential concerns about the endogeneity issue in this regression.

III. Key Stylized Facts

This section document salient empirical patterns to support the focus of this paper on the role of global factors in explaining inflation puzzles.

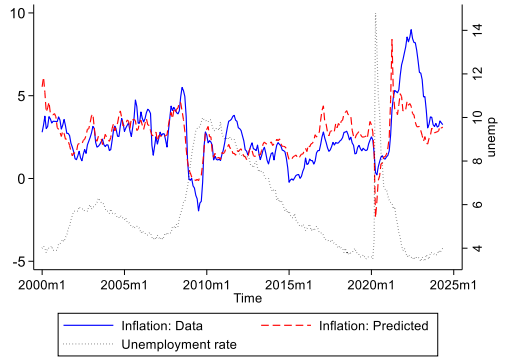
Figure 1 illustrates the limitation of a Phillips curve augmented with oil price inflation. We compare actual headline inflation of the United States with values predicted by the following model:

$$\pi_{i,t} = \varphi_i u_{i,t} + \theta_i \Delta P_t^{Oil} + \varepsilon_{i,t}^{1}, \quad (1)$$

with $u_{i,t}$ denotes the unemployment rate, and ΔP_t^{Oil} represents oil price inflation.

As shown in Figure 1, actual inflation was elevated around 2010 despite high unemployment rates. It then fell significantly below predicted values throughout the 2010s, showing little improvement despite steadily declining unemployment rates that reached historically low levels. During the COVID-19 pandemic, headline inflation exhibited strong volatility, while the model predicted only a milder and more transitory rise.

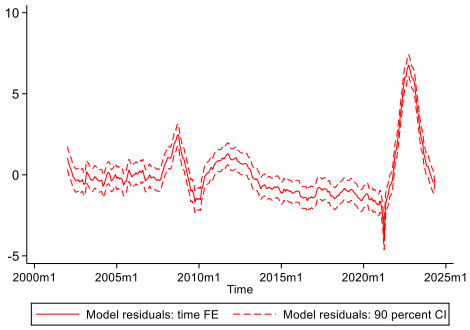
Figure 1 Inflation Patterns in AEs



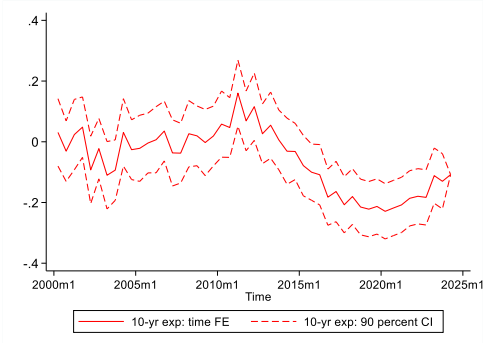
These inflation puzzles observed in the United States are also evident across other AEs. In Figure 2, we present two key patterns. The left panel shows the model residual $\varepsilon_{i,t}^{1}$ for AEs, representing inflation movements unexplained by unemployment and oil prices. The right panel presents long-term inflation expectations (LTIE) of professional forecasters for AEs.[9]

Figure 2 Inflation Patterns in AEs

2a. Co-movement of Inflation Residuals across AEs



2b. Co-movement of LTIEs across AEs



Note: The left panel plots θ_t from $\varepsilon_{i,t} = \eta_i + \theta_t + \xi_{it}$, where $\varepsilon_{i,t}$ is from the residual from $\pi_{i,t} = \alpha_i + \beta_i u_{i,t} + \gamma_i \Delta p_{oil,t} + \varepsilon_{i,t}$. The equation is estimated for 33 advanced economies (all AEs based on the IMF classification, excluding Australia, Hong Kong, and Singapore due to data availability issues). The right panel plots the time fixed effects from a similar regression with $\varepsilon_{i,t}$ replaced by the LTIE.

Four interesting patterns emerge from Figure 2. First, the residual $\varepsilon_{i,t}^{1}$ displayed strong co-movement across AEs, both before and during the COVID-19 pandemic. Second, these residuals and the LTIEs also co-moved, both rising between 2000 and 2011 before declining afterward. Third, during these co-movement phases, the residual $\varepsilon_{i,t}^{1}$ exhibited stronger fluctuations than the LTIEs, suggesting that mean-

[9] We use the LTIEs of forecasters to proxy the LTIEs of price setters due to data limitations. Figure 1 uses the 6th-10th year forecast of headline inflation from the Consensus Economics.

reverting rather than permanent shocks are the primary forces. Finally, the co-movement between residuals and LTIEs weakened during both the Global Financial Crisis and the COVID-19 pandemic episode, consistent with global slack playing a more significant role during these episodes.

IV. Empirical Analysis: New Global Factors

4.1 Construction of Global Factors

To construct global factors to capture the impact of global slack and global inflation trend, we first calculate the average inflation of a group of economies deemed to have limited direct financial and trade linkages (See s*tep 1 in Section 2.2*).

To construct this group, we start from those classified as emerging market and developing economies by the World Economic Outlook and having monthly CPI data available in the Haver analytics.[10] Next, we use the following criteria to exclude large economies and those with hyperinflation episodes: (i) any economy whose GDP in USD based on the market exchange rate in 2024 was larger than Poland's is excluded; (ii) any economy experiencing year-on-year inflation that was larger than 30 percent in any month between January 2000 and December 2024 is excluded; (iii) any economy with missing observation in any month between January 1999 and December 2024 is excluded. Based on these criteria, the following 41 economies remain in the EMDE sample: Albania, Armenia, Bangladesh, Benin, Bolivia, Botswana, Bulgaria, Burkina Faso, Chile, Colombia, Costa Rica, Croatia, El Salvador, Fiji, Georgia, Guatemala, Honduras, Hungary, Israel, Jamaica, Jordan, Kenya, Macao, Malaysia, Maldives, Mali, Mauritius, Moldova, Niger, North Macedonia, Panama, Paraguay, Peru, Philippines, Poland, Senegal, South Africa, Thailand, Togo, Trinidad & Tobago, Tunisia, and Uruguay.

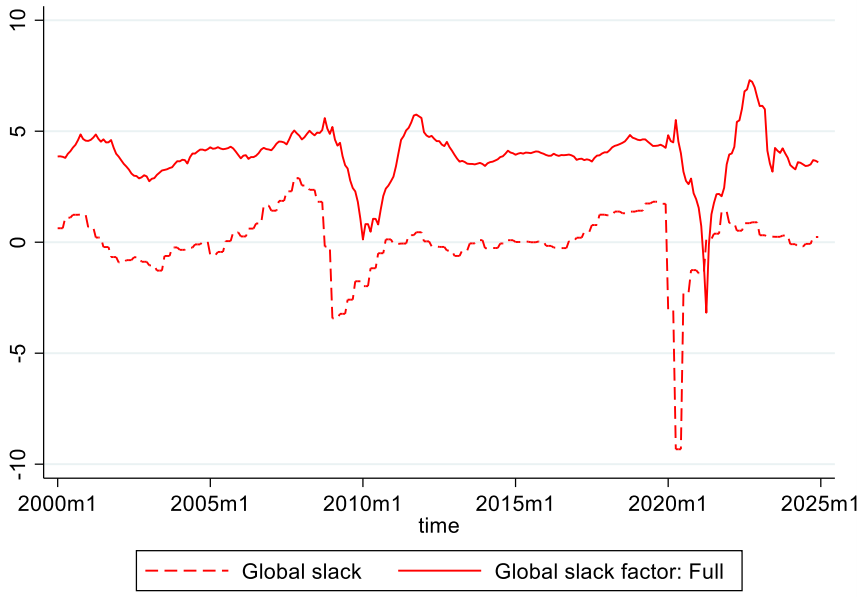
We regress the average inflation of these economies on the global output gap and its lags, as well as oil price inflation. As the benchmark exercise, we choose to have 36 lags and the sample period as from

[10] The 41 economies include: Albania, Algeria, Angola, Argentina, Armenia, Azerbaijan, Bahrain, Bangladesh, Belarus, Belize, Benin, Bhutan, Bolivia, Bosnia and Herzegovina, Botswana, Brazil, Brunei, Bulgaria, Burkina Faso, Cambodia, Cameroon, Central African Republic, Chad, Chile, China, Colombia, Congo Rep, Costa Rica, Cote d'Ivoire, Croatia, Dominican Republic, Ecuador, Egypt, El Salvador, Equatorial Guinea, Ethiopia, Fiji, Gabon, Georgia, Ghana, Guatemala, Guinea-Bissau, Honduras, Hungary, India, Indonesia, Iran, Iraq, Israel, Jamaica, Jordan, Kenya, Kosovo, Kuwait, Kyrgyz Republic, Laos, Lebanon, Lesotho, Macao, Malawi, Malaysia, Maldives, Mali, Mauritius, Mexico, Moldova, Mongolia, Montenegro, Morocco, Mozambique, Myanmar, Namibia, Nepal, Nicaragua, Nigeria, Niger, North Macedonia, Oman, Pakistan, Panama, Papua New Guinea, Paraguay, Peru, Philippines, Poland, Qatar, Romania, Russia, Rwanda, Saudi Arabia, Senegal, Serbia, Seychelles, South Africa, Sri Lanka, Sudan, Suriname, Tajikistan, Tanzania, Thailand, Togo, Trinidad & Tobago, Tunisia, Türkiye, Uganda, Ukraine, United Arab Emirates, Uruguay, Uzbekistan, Venezuela, Vietnam, and Zambia.

January 2000 to December 2024. We use the coefficients of the global output gap and its lags to calculate the global slack factor.

Figure 3 compares the global slack factor and the global slack itself to illustrate the delayed impact of global slack. We describe the delayed impact by highlighting five episodes in Table 1. Four of them lasted 10 months, while one 28 months. We divide the change in the global slack factor, a proxied for the impact of global slack on the average inflation of small open EMDEs, by the change in the global slack, and call the ratio the implied slope, which is presented in the last column of the table.

Figure 3 Global Slack Factor vs. Global Slack



Three patterns are clearly seen from Table 1. First, the implied slope is large in magnitude, varying between -7.3 and 6.8. Note that the typical estimation of the slope of Phillips curve for the United States is around 0.3 (Hazell et al. (2021)). The implied slope here is around 24 times larger than that. Second, the implied slope has the wrong sign in two episodes: April 2009 – January 2010, and November 2021 – September 2022. Finally, these episodes shed light on all three inflation puzzles. First, the delayed impact of global slack contributed to upward inflation pressure during the missing disinflation episode, especially between January 2010 – October 2011. During this episode, with the global output gap closing by 2.43 percentage points, the average EMDE inflation that can be attributed to the global slack rose by 5.49 percentage points. Such effects are likely omitted by empirical studies that do not consider the role of global slack or its contemporaneous effects.

Second, the delayed impact of global slack contributed to weak inflation seen by small open EMDEs in the missing reflation episode. While the global output gap contracted mildly between October 2011 and January 2014 by 0.72 percentage point, the average EMDE inflation attributed to the global slack declined by 2.17 percentage points. This decline is sufficient to offset a decline in unemployment gap of 7.2 percentage points if the slope of Phillips curve is 0.3.

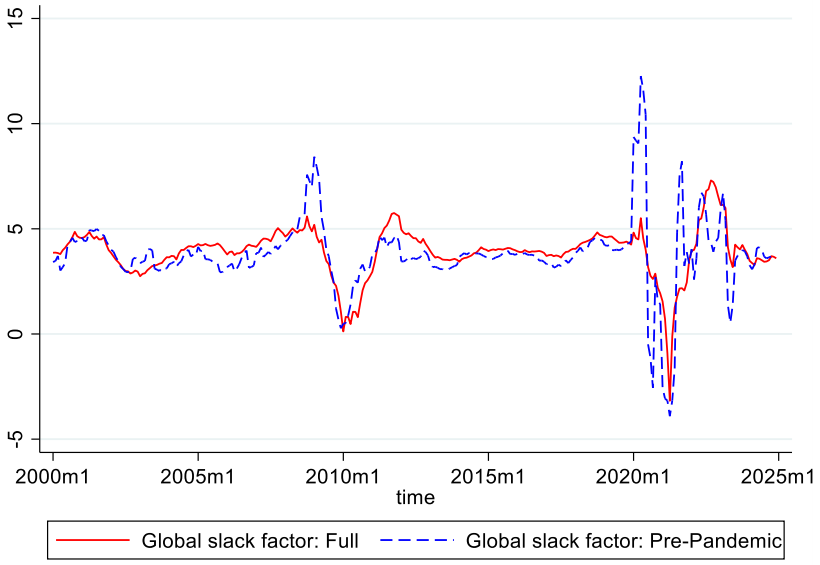
Finally, the delayed impact of global slack played a key role in the inflation surge in 2022 and its reversal after September 2022 for small open EMDEs. Despite a decline of global slack of 0.53 percentage point, the average EMDE inflation attributed to global slack rose by 3.87 percentage points between November 2021 and September 2022. In the following period, with the global slack contracting by only 0.61 percentage point, the average EMDE inflation attributed to global slack fell by 4.12 percentage points. Such a strong disinflation is equivalent to a rise of unemployment of 13.7 percentage points.

Table 1 Inflation Episodes with Strong Delayed Impact of Global Slack

	Length	Output gap at t_0	Output gap at t_1	Δ Output gap	Global slack factor at t_0	Global slack factor at t_1	Δ Global slack factor	Implied slope
(i) April 2009 – January 2010	10	-3.23	-1.98	1.25	4.48	0.12	-4.36	-3.50
(ii) January 2010 – October 2011	10	-1.98	0.45	2.43	0.12	5.60	5.48	2.25
(iii) October 2011 – January 2014	28	0.45	-0.27	-0.72	5.60	3.44	-2.17	3.01
(iv) November 2021 – September 2022	10	1.38	0.86	-0.53	3.44	7.30	3.87	-7.33
(v) September 2022 – June 2023	10	0.86	0.25	-0.61	7.30	3.18	-4.12	6.80

Notably, the exercises here control for oil price inflation, so these effects should not be caused by cost-push effects from oil prices. Figure 4 further suggests that the pattern of the global slack factor is not driven by the average EMDE inflation regression sample period. If we restrict the regression to be the pre-pandemic episode, we get noisier patterns, but the broad trends are the same as having the full sample period. In the rest of the paper, we use the full period as the global slack factor is less noisy.

Figure 4 Global Slack Factor by Estimation Period: Full vs. Pre-Pandemic

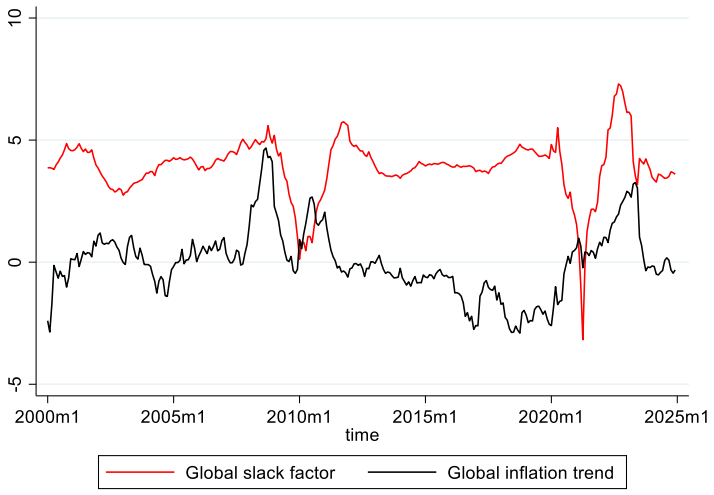


The global inflation trend appears to be quite volatile in some episodes while fluctuating around zero in the long run. Notably, it played an important role in weakening headline inflation in the missing reflation episode, while driving the volatile inflation during 2022-2023. It declined from 2.67 in July 2010 to -2.544 in December 2019, when the global slack improved from -0.497 percentage point to 1.730 percentage points. The difference is 5.21 percentage points or an increase of unemployment gap of 17.4 percentage points if the slope of Philips curve is 0.3.

The strong impact of the global inflation trend is also seen during the COVID-19 pandemic episode. It reinforced the impact of global slack. For example, it increased from 0.549 percentage point to 1.971 percentage points, and the improvement of 1.422 percentage points is equivalent to a decline of unemployment rate by 4.74 percentage points if the slope of Phillips curve is 0.3.

It also contributed to the reversal of headline inflation from the 2022 surge. Between June 2023 and April 2024, it declined from 3.036 percentage points to -0.522. The decline of 3.558 percentage points is equivalent to a rise of unemployment gap by 11.86 percentage points if the slope of Phillips curve is 0.3.

Figure 5 Global inflation trend vs. Global Slack Factor



4.2. The Persistence of Global Factors

To explore the persistence of global factors, we estimate the following equation:

$$\pi_{i,t}^{e,k,k+l} = \alpha_i + \sum_{j=1}^{J} \beta_{j,k} G_{j,t} + \varepsilon_{i,t},$$

where $\pi_{i,t}^{e,k,k+l}$ is the average inflation of country i between period $t+k$ and $t+k+l$ projected in period t. We use the information from the consensus economics database, which provides $k = 2$, 3, and 5 for $l = 1$, and $k = 6$ for $l = 4$. The sample consists of 33 economies classified as advanced economies by World Economic Outlook.[11] The sample period is between January 2000 and December 2024.

We first present the results for global variables that are standard in the literature, which serve as a benchmark to evaluate the new global factors we constructed. Table 2 reports the estimation results for $\{G_{j,t}\} \triangleq \{\text{World outputgap}, \text{oil price}, \text{oil price inflation}\}$. We include both the level and change in oil price to capture the energy price's impact on both the expectation of price setters and the cost of production. Coibion and Gorodnichenko (2015) and Hasenzagl et al. (2022) argue for the importance of the expectation channel.

[11] The 33 economies include: Australia, Austria, Belgium, Canada, Cyprus, Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hong Kong SAR, Ireland, Israel, Italy, Japan, Korea, Latvia, Lithuania, Netherlands, New Zealand, Norway, Portugal, Singapore, Slovak Republic, Slovenia, Spain, Sweden, Switzerland, Taiwan Province of China, United Kingdom, United States.

Table 2 confirms that oil price can have a persistent influence on headline inflation. A 50% change in oil price (2 standard deviations of the log level of oil price) shift 2-year ahead inflation expectation by 0.1 percent, and the effects remain to be statistically significant in the long run. Interestingly, the magnitude weakens by half when forecasters were asked to assess the 3 year-ahead expectation, but and is roughly stable for longer horizons.

Table 2 Inflation Expectations and Global Factors: Global Slack, Oil Price Levels and Chnages

	(1)	(2)	(3)	(4)	(5)	(6)
	2-yr	2-yr	2-yr	3-yr	3-yr	3-yr
VARIABLES	expectation	expectation	expectation	expectation	expectation	expectation
Global slack	0.0305***	0.0442***	0.0347***	0.0150***	0.0225***	0.0179***
	(0.00702)	(0.00694)	(0.00724)	(0.00562)	(0.00555)	(0.00581)
Oil price level	0.00206***		0.00224***	0.000958**		0.00108***
	(0.000504)		(0.000509)	(0.000404)		(0.000408)
Oil price inflation		-0.000384*	-0.000542**		-0.000292	-0.000368*
		(0.000233)	(0.000234)		(0.000186)	(0.000188)
Constant	1.862***	2.000***	1.856***	1.970***	2.036***	1.966***
	(0.0346)	(0.0111)	(0.0347)	(0.0278)	(0.00885)	(0.0278)
Observations	2,033	2,033	2,033	2,033	2,033	2,033
R-squared	0.470	0.466	0.471	0.521	0.520	0.521

	(7)	(8)	(9)	(10)	(11)	(12)
	5-yr	5-yr	5-yr	6-10-yr	6-10-yr	6-10-yr
VARIABLES	expectation	expectation	expectation	expectation	expectation	expectation
Global slack	0.000350	0.00738	0.00212	-0.00453	0.00137	-0.00328
	(0.00456)	(0.00451)	(0.00471)	(0.00425)	(0.00420)	(0.00439)
Oil price level	0.00116***		0.00124***	0.00104***		0.00109***
	(0.000328)		(0.000331)	(0.000306)		(0.000309)
Oil price inflation		-0.000140	-0.000227		-8.38e-05	-0.000161
		(0.000151)	(0.000152)		(0.000141)	(0.000142)
Constant	1.969***	2.046***	1.967***	1.965***	2.033***	1.963***
	(0.0225)	(0.00719)	(0.0226)	(0.0210)	(0.00671)	(0.0211)
Observations	2,031	2,031	2,031	2,029	2,029	2,029
R-squared	0.554	0.551	0.555	0.546	0.544	0.547

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

As a contrast, global slack and oil price inflation have less persistent influence. An increase of global slack of 3 percentage points (around 2 standard deviations in the sample) raises the 2-year ahead inflation expectation and 3-year ahead inflation expectation by around 0.1 percent and 0.06 percent respectively. Such effects become insignificant beyond the 5-year horizon. Finally, oil price inflation has a strong mean-reverting process, and a rise in oil price inflation is expected to have a negative influence on

medium-term inflation expectation, although the effects tend to be insignificant beyond the 2-year horizon.

We now turn to the case of $\{G_{j,t}\} \triangleq \{\text{Global slack factor, global inflation trend, oil price inflation}\}$. Table 3 reports the estimation results. The patterns for global slack and oil price inflation are broadly the same. An increase of global slack factor of 2.4 percentage points (around 2 standard deviations) raises 2-year ahead and 3-year ahead inflation expectation by around 0.16 percentage points and 0.07 percentage point. The oil price inflation has positive impact now, but the effects die down beyond the 3-year horizon.

The global inflation trend factor played a similar role as the oil price level seen in Table 2. The effects beyond 2 year are around half of the impact on the 2-year expectation, and an increase of 2.79 percentage points of global inflation trend (around 2 standard deviations) raises the 2-year expectation by around 0.19 percent. The oil price level effects capture around 63% of the global inflation trend effect at the 2-year horizon but falls to 52% at the 6-10 year horizon.

Table 3 Inflation Expectations and Global Factors: Oil Price Inflation, Global Slack Factor, and Global Inflation Trend

	(1)	(2)	(3)	(4)
VARIABLES	**2-yr expectation**	**3-yr expectation**	**5-yr expectation**	**10-yr expectation**
Oil price inflation	0.00105***	0.000348*	5.51e-05	-7.36e-05
	(0.000252)	(0.000205)	(0.000166)	(0.000154)
Global slack factor	0.0663***	0.0281***	0.00926	0.00121
	(0.00865)	(0.00703)	(0.00569)	(0.00530)
Global inflation trend	0.0691***	0.0391***	0.0361***	0.0360***
	(0.00723)	(0.00587)	(0.00475)	(0.00443)
Constant	1.738***	1.926***	2.016***	2.036***
	(0.0376)	(0.0305)	(0.0247)	(0.0230)
Observations	2,000	2,000	1,998	1,996
R-squared	0.497	0.532	0.565	0.559

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

To summarize, the results in this section suggest that both global slack and the global inflation trend can potentially have persistent effects on headline inflation, as suggested by their significant impact on medium term inflation expectations. The pattern is particularly salient for the global inflation trend. While we find a strong connection with the role of oil price level on the expectation of price setters, we find

patterns to suggest that around half of the medium-term effects of global inflation trend is captured by oil price level effects.

4.3. Domestic Slack vs. Global Factors

We use a simple exercise to argue that global factors capture channels that are missing by domestic slack. We estimate the following equation for each advanced economy:

$$\pi_{i,t} = \alpha_i + \sum_{j=1}^{J} \beta_{j,k} G_{j,t} + \rho_i u_{i,t} + \varepsilon_{i,t},$$

where $\{G_{j,t}\} \triangleq \{\text{Global slack factor, global inflation trend, oil price inflation}\}$ and $u_{i,t}$ is the unemployment rate.

Table 4 presents the estimation results and contrasts them with an alternative specification in which we drop the global slack factor and global inflation trend. There are several patterns to suggest that domestic slack fails to capture the impact of these two global factors. First, both global factors have statistically significant coefficients in the regressions of almost all economies. Second, there is no consistent pattern to suggest that these global factors weaken the coefficient of unemployment rate. If these variables are highly correlated, we may see the inclusion of the global factors weaken the explanatory power of unemployment rate. However, for the Czech Republic, Germany, Israel, Japan, Macao, Malta, Taiwan, and the United Kingdom, we see an increase in the coefficient size of unemployment rate. Since the global slack correlated with unemployment rate during global business cycles, it is not surprising to see that for many cases, the coefficient of unemployment rate does decline after the two additional global factors are controlled for. These patterns overall suggest that the two global factors capture additional inflation drivers omitted by the conventional Phillips curve framework.

4.4 Counter-Cyclicality of Global Factors

A recent strand of literature has noticed that not all CPI components are sensitive to economic slack (Mehdi and Shapiro (2014) and Stock and Watson (2021)). Lian and Freitag (2022) explores this issue in the international context. They highlight the presence of downward trends among non-cyclical CPI components between 2012 and 2019. However, they do not further identify the underlying causes while pointing out they seem to be pervasive across different sectors and exist in both goods and services.

The significant decline of the global inflation trend during the missing reflation episode provides a support for the finding of Lian and Freitag (2022) and suggests that the underlying driver can be forces behind the global inflation trend.

Recognizing the potential counter-cyclical movements of the global inflation trend is important, as it suggests that the common movements of headline inflation across countries are shaped by both cyclical forces such as global slack, and non-cyclical forces. This introduces an additional dimension to assess the mechanism of inflation dynamics: the joint evolution of cyclical and counter-cyclical global forces. We leave this issue for future research as it is beyond the scope of the current paper.

Table 4 Country-Specific Phillips Curves

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
VARIABLES	Austria	Austria	Belgium	Belgium	Canada	Canada	Cyprus	Cyprus	Czech Republic	Czech Republic
Unemployment rate	-0.753***	0.0861	-0.698***	-0.507***	-0.567***	-0.372***	-0.312***	-0.183***	-0.609***	-0.644***
	(0.139)	(0.124)	(0.0874)	(0.0560)	(0.0551)	(0.0552)	(0.0274)	(0.0206)	(0.0830)	(0.0545)
Oil price inflation	0.00534**	0.0157***	0.0132***	0.0215***	0.0120***	0.0162***	0.0221***	0.0335***	0.0139***	0.0279***
	(0.00268)	(0.00227)	(0.00250)	(0.00162)	(0.00156)	(0.00148)	(0.00266)	(0.00192)	(0.00469)	(0.00316)
Global inflation trend		0.626***		0.670***		0.294***		0.659***		1.258***
		(0.0626)		(0.0447)		(0.0385)		(0.0561)		(0.0883)
Global slack factor		0.898***		0.927***		0.378***		0.962***		1.588***
		(0.0820)		(0.0575)		(0.0554)		(0.0638)		(0.109)
Constant	6.417***	-1.684*	7.258***	2.152***	6.034***	3.144***	4.015***	-0.862***	6.257***	0.0768
	(0.751)	(0.862)	(0.641)	(0.522)	(0.393)	(0.540)	(0.240)	(0.327)	(0.484)	(0.566)
Observations	301	300	301	300	301	300	301	300	301	300
R-squared	0.112	0.466	0.240	0.715	0.399	0.556	0.465	0.755	0.165	0.657
	(11)	(12)	(13)	(14)	(15)	(16)	(17)	(18)	(19)	(20)
VARIABLES	Denmark	Denmark	Estonia	Estonia	Finland	Finland	France	France	Germany	Germany
Unemployment rate	-0.499***	0.00151	-0.344***	-0.217***	-0.825***	-0.295***	-0.807***	-0.497***	-0.201***	-0.290***
	(0.101)	(0.0662)	(0.0711)	(0.0394)	(0.0939)	(0.0698)	(0.0595)	(0.0528)	(0.0337)	(0.0220)
Oil price inflation	0.0107***	0.0187***	0.0297***	0.0487***	0.00874***	0.0165***	0.00668***	0.0122***	0.0112***	0.0185***
	(0.00284)	(0.00185)	(0.00600)	(0.00322)	(0.00239)	(0.00171)	(0.00141)	(0.00116)	(0.00217)	(0.00143)
Global inflation trend		0.697***		1.770***		0.674***		0.286***		0.623***
		(0.0456)		(0.0899)		(0.0484)		(0.0347)		(0.0403)
Global slack factor		0.792***		2.311***		0.858***		0.497***		0.718***
		(0.0604)		(0.116)		(0.0623)		(0.0398)		(0.0483)
Constant	3.889***	-1.380***	6.804***	-3.544***	8.628***	0.801	8.703***	3.974***	2.984***	0.625***
	(0.449)	(0.445)	(0.650)	(0.672)	(0.784)	(0.710)	(0.528)	(0.531)	(0.217)	(0.240)
Observations	217	216	300	299	301	300	301	300	301	300
R-squared	0.175	0.715	0.133	0.776	0.236	0.653	0.441	0.671	0.150	0.667
	(21)	(22)	(23)	(24)	(25)	(26)	(27)	(28)	(29)	(30)
VARIABLES	Greece	Greece	Iceland	Iceland	Ireland	Ireland	Israel	Israel	Italy	Italy
Unemployment rate	-0.235***	-0.137***	0.182*	0.194**	-0.371***	-0.307***	-0.0116	-0.0880***	-0.358***	0.0694
	(0.0200)	(0.0175)	(0.103)	(0.0787)	(0.0340)	(0.0242)	(0.0455)	(0.0337)	(0.0618)	(0.0482)
Oil price inflation	0.0176***	0.0288***	0.000985	0.00304	0.0131***	0.0239***	0.0113***	0.0157***	0.00859***	0.0196***
	(0.00325)	(0.00256)	(0.00520)	(0.00386)	(0.00331)	(0.00242)	(0.00316)	(0.00242)	(0.00311)	(0.00216)
Global inflation trend		0.654***		1.600***		0.785***		0.841***		0.823***
		(0.0752)		(0.0992)		(0.0654)		(0.0678)		(0.0642)
Global slack factor		0.928***		0.675***		1.148***		0.446***		0.987***
		(0.0802)		(0.135)		(0.0835)		(0.0817)		(0.0696)
Constant	5.543***	0.200	4.016***	1.325*	4.850***	-0.248	1.494***	0.372	5.129***	-2.786***
	(0.358)	(0.467)	(0.529)	(0.793)	(0.296)	(0.433)	(0.300)	(0.412)	(0.589)	(0.581)
Observations	253	252	265	264	302	300	205	204	253	252
R-squared	0.462	0.707	0.012	0.548	0.335	0.690	0.060	0.522	0.163	0.650
	(31)	(32)	(33)	(34)	(35)	(36)	(37)	(38)	(39)	(40)
VARIABLES	Japan	Japan	Latvia	Latvia	Lithuania	Lithuania	Luxembourg	Luxembourg	Macao	Macao
Unemployment rate	-0.819***	-0.879***	-0.535***	-0.384***	-0.440***	-0.336***	-0.291***	-0.0425	-1.152***	-1.343***
	(0.0601)	(0.0548)	(0.0681)	(0.0294)	(0.0584)	(0.0343)	(0.0499)	(0.0360)	(0.0878)	(0.0754)
Oil price inflation	-0.00158	0.00118	0.0261***	0.0489***	0.0187***	0.0367***	0.0124***	0.0201***	0.00610*	0.0155***
	(0.00150)	(0.00133)	(0.00643)	(0.00276)	(0.00586)	(0.00347)	(0.00172)	(0.00124)	(0.00349)	(0.00304)
Global inflation trend		0.304***		2.091***		1.819***		0.434***		0.647***
		(0.0388)		(0.0764)		(0.0958)		(0.0337)		(0.0850)
Global slack factor		0.300***		2.622***		2.039***		0.624***		0.912***
		(0.0465)		(0.0990)		(0.123)		(0.0418)		(0.102)
Constant	3.574***	2.591***	9.473***	-2.638***	7.500***	-1.723**	3.520***	-0.263	6.167***	3.132***
	(0.237)	(0.309)	(0.767)	(0.585)	(0.637)	(0.693)	(0.266)	(0.285)	(0.314)	(0.478)
Observations	301	300	301	300	301	300	301	300	301	300
R-squared	0.388	0.551	0.208	0.870	0.187	0.746	0.278	0.677	0.367	0.570

Table 4 Country-Specific Phillips Curves (continued)

VARIABLES	(41) Malta	(42) Malta	(43) Netherlands	(44) Netherlands	(45) Norway	(46) Norway	(47) Portugal	(48) Portugal	(49) Slovak Republic	(50) Slovak Republic
Unemployment rate	-0.0996	-0.183***	-0.730***	-0.526***	-0.371***	0.262*	-0.196***	-0.152***	0.115**	0.125***
	(0.0639)	(0.0404)	(0.0776)	(0.0667)	(0.136)	(0.154)	(0.0317)	(0.0214)	(0.0462)	(0.0387)
Oil price inflation	0.00245	0.00893***	0.00396	0.0117***	0.00491**	0.00888***	0.00722***	0.0160***	0.0213***	0.0353***
	(0.00230)	(0.00147)	(0.00281)	(0.00246)	(0.00209)	(0.00208)	(0.00269)	(0.00189)	(0.00531)	(0.00461)
Global inflation trend		0.689***		0.389***		0.389***		0.662***		0.729***
		(0.0416)		(0.0647)		(0.0617)		(0.0511)		(0.128)
Global slack factor		0.749***		0.769***		0.373***		0.923***		1.619***
		(0.0507)		(0.0791)		(0.0786)		(0.0639)		(0.158)
Constant	2.810***	0.276	6.376***	2.119***	3.840***	-0.151	3.907***	-0.228	2.356***	-4.277***
	(0.374)	(0.328)	(0.466)	(0.550)	(0.542)	(0.811)	(0.326)	(0.358)	(0.587)	(0.829)
Observations	301	300	265	264	300	300	301	300	301	300
R-squared	0.012	0.635	0.271	0.515	0.045	0.189	0.152	0.627	0.076	0.371

VARIABLES	(51) Slovenia	(52) Slovenia	(53) Korea	(54) Korea	(55) Spain	(56) Spain	(57) Sweden	(58) Sweden	(59) Switzerland	(60) Switzerland
Unemployment rate	-0.502***	-0.246***	-1.019***	-0.0313	-0.151***	-0.0764***	-0.554***	-0.0173	-0.769***	-0.463***
	(0.0881)	(0.0747)	(0.154)	(0.114)	(0.0180)	(0.0128)	(0.145)	(0.132)	(0.0710)	(0.0586)
Oil price inflation	0.0194***	0.0310***	0.0121***	0.0152***	0.0204***	0.0301***	0.00962***	0.0167***	0.0127***	0.0154***
	(0.00404)	(0.00346)	(0.00171)	(0.00117)	(0.00236)	(0.00169)	(0.00349)	(0.00294)	(0.00109)	(0.000849)
Global inflation trend		0.825***		0.618***		0.575***		0.734***		0.310***
		(0.0963)		(0.0355)		(0.0459)		(0.0774)		(0.0233)
Global slack factor		1.133***		0.456***		0.857***		0.955***		0.317***
		(0.118)		(0.0411)		(0.0571)		(0.108)		(0.0325)
Constant	6.264***	0.0765	5.907***	0.634	4.445***	-0.175	6.009***	-1.804	2.696***	0.536**
	(0.589)	(0.745)	(0.542)	(0.465)	(0.299)	(0.344)	(1.086)	(1.248)	(0.211)	(0.260)
Observations	301	300	302	300	301	300	290	288	302	300
R-squared	0.180	0.468	0.225	0.670	0.388	0.726	0.068	0.422	0.457	0.714

VARIABLES	(61) Taiwan	(62) Taiwan	(63) United Kingdom	(64) United Kingdom	(65) United States	(66) United States
Unemployment rate	-0.643***	-0.640***	-0.180**	-0.216***	-0.325***	-0.260***
	(0.0807)	(0.0765)	(0.0755)	(0.0572)	(0.0385)	(0.0305)
Oil price inflation	0.0128***	0.0153***	0.00470*	0.0105***	0.0229***	0.0285***
	(0.00130)	(0.00115)	(0.00251)	(0.00190)	(0.00187)	(0.00144)
Global inflation trend		0.294***		0.681***		0.457***
		(0.0325)		(0.0536)		(0.0393)
Global slack factor		0.282***		0.673***		0.589***
		(0.0418)		(0.0664)		(0.0516)
Constant	3.647***	2.498***	3.378***	0.872*	4.143***	1.399***
	(0.340)	(0.419)	(0.426)	(0.462)	(0.235)	(0.324)
Observations	301	300	299	299	302	300
R-squared	0.383	0.588	0.032	0.503	0.460	0.727

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

V. The New Keynesian Phillips Curve Model with Cross-Border Input-Output Linkages

This section develops the NKPC that accounts for cross-border input-output linkages, which provides the theoretical foundation for empirical patterns documented in Section IV.

5.1 Model Structure

Small open economies and tradability of intermediate goods. Consider the global economy with N individual economies. N is large, and an individual economy corresponds to a small open economy or a sub-region of a large economy like the United States. Each economy produces a spectrum of intermediate goods that has measure one, and in economy i, only $\omega_T^i < 1$ fraction of intermediate goods are tradable.

Production technology and international production network. Each intermediate good is produced using labor and tradable intermediate goods that are sourced globally. For a firm producing good z and residing in economy i (referred to as firm $I_{i,z}$), its production function can be represented by:

$$Y_{i,z,t} = A_{i,z,t}\left(L_{i,z,t}\right)^{\alpha_{i,z}}\left[\left(\sum_{n=1}^{N}\zeta_n^T\left(\left(\int_{z'\in I_n^T}\left(Y_{i,z,n,z',t}^{F,T}\right)^{\frac{\eta_n^T-1}{\eta_n^T}}\right)^{\frac{\eta_n^T}{\eta_n^T-1}}\right)^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}\right]^{1-\alpha_{i,z}}, \quad (5)$$

where $A_{i,z,t}$ is the total factor productivity, $L_{i,z,t}$ is the labor employed by the firm, $\alpha_{i,z}$ is the firm-specific labor share, ζ_n is a production parameter that can affect the share of tradable intermediate goods purchased from economy n, $Y_{i,z,n,z',t}^T$ represents the amount of intermediate goods purchased from firm z' in economy n that is used by firm $I_{i,z}$, η_n^T is the elasticity of substitution between tradable intermediate goods produced by country n, and η is the elasticity of substitution between tradable goods in different countries. For tractability, we assume production technology has the same parameters for tradable goods across different economies.

Price stickiness. $1-\theta_i$ fraction of firms adjust prices every period, with $0<\theta_i<1$. The price adjustment shock is exogenously given.

Household decision problem. We follow Greenwood, Hercowitz, and Huffman (1988) and Hazell et al. (2021) to consider the following household utility function:

$$u\left(C_{i,t},N_{i,t}\right)=\frac{\left(C_{i,t}-\chi\frac{N_{i,t}^{1+\varphi^{-1}}}{1+\varphi^{-1}}\right)^{1-\sigma^{-1}}}{1-\sigma^{-1}},$$

where

$$C_{i,t}=\left(\sum_{n=1}^{N}\zeta_n^T\left(\left(\int_{z\in I_n^T}\left(Y_{i,n,z,t}^{H,T}\right)^{\frac{\eta_n^T-1}{\eta_n^T}}dz\right)^{\frac{\eta_n^T}{\eta_n^T-1}}\right)^{\frac{\eta-1}{\eta}}+\zeta_i^{NT}\left(\int_{z\in I_i^{NT}}\left(Y_{i,z,t}^{H,NT}\right)^{\frac{\eta_i^{NT}-1}{\eta_i^{NT}}}dz\right)^{\frac{\eta_i^{NT}}{\eta_i^{NT}-1}}\right)^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}$$

where I_n^T represents the tradable intermediate goods produced by economy n, and I_i^{NT} represents the set of non-tradable intermediate goods available in economy i. For tractability, we assume that household preference and firm production technology have the same parameters for tradable goods.

Households maximize the utility function, subject to the budget constraint:

$$\sum_{n=1}^{N}\int_{z\in I_n^T} p_{i,n,z,t}^{H,T} Y_{i,n,z,t}^{H,T}\,dz + \int_{z\in I_i^{NT}} p_{i,z,t}^{H,NT} Y_{i,z,t}^{H,NT}\,dz \le w_{i,t}L_i + \pi_{i,t}.$$

where $w_{i,t}$ denotes the wage of country i in period t, L_i is the labor endowment, and $\pi_{i,t}$ is the profit received by households in country i.

5.2 Optimal Pricing Problem

Firm $I_{i,z}$ adjusts its price in period t, expecting the probability of re-adjusting prices being $1-\theta_i$ for future periods. The optimal choice $P_{i,z,t}^*$ maximizes its expected profit:

$$\max_{P_{i,z,t}^*} E_t \sum\nolimits_{j=0}^{\infty} (\theta_i)^j \{M_{i,t,t+j}\Pi_{i,z,t+j}\}, \tag{6}$$

where $M_{i,t,t+j}$ is the discount rate; and $\Pi_{i,z,t+j}$ is the profit of the firm in period $t+j$ and satisfies:

$$\Pi_{i,z,t+j} = P_{i,z,t}^* Y_{i,z,t+j} - C_{i,z,t+j} Y_{i,z,t+j},$$

where $C_{i,z,t+j}$ is the unit production cost.

The output $Y_{i,z,t+j}$ can be derived as the following function of $P_{i,z,t}^*$:

The optimal solution for tradable goods is:

$$Y_{i,z,t+j} = \sum_{n=1}^{N} Y_{n,i,z,t+j}^{H,T} = \left(\zeta_i^T\right)^{\eta} \sum_{n=1}^{N} \left(\frac{P_{n,i,t+j}^{H,T}}{P_{i,z,t}^*}\right)^{\eta_n^T} \left(\frac{P_{n,t+j}}{P_{n,i,t+j}^{H,T}}\right)^{\eta} \cdot \frac{I_{n,t+j}}{P_{n,t+j}}.$$

For non-tradable goods:

$$Y_{i,z,t}^{NT} = \left(\zeta_i^{NT}\right)^{\eta} \left(\frac{P_{i,t}^{H,NT}}{P_{i,z,t}^*}\right)^{\eta_i^{NT}} \left(\frac{P_{i,t}}{P_{i,t}^{H,NT}}\right)^{\eta} \cdot \frac{I_{i,t}}{P_{i,t}},$$

where

$$I_{i,t} = w_{i,t}L_i + \pi_{i,t},$$

$$P_{i,t} = \left[\sum_{n=1}^{N} (\zeta_n^T)^{\eta} (P_{i,n,t}^{H,T})^{1-\eta} + \left(\zeta_i^{NT}\right)^{\eta} (P_{i,t}^{H,NT})^{1-\eta}\right]^{\frac{1}{1-\eta}},$$

$$P_{i,n,t}^{H,T} = \left[\int_{z\in I_n^T} (p_{i,n,z,t}^{H,T})^{1-\eta_n^T}\,dz\right]^{\frac{1}{1-\eta_n^T}},$$

$$P_{i,t}^{H,NT} = [\int_{z\in I_i^{NT}} (p_{i,z,t}^{NT})^{1-\eta_i^{NT}}\, dz]^{\frac{1}{1-\eta_i^{NT}}}.$$

The unit production cost $C_{i,z,t+j}$ satisfies:

$$C_{i,z,t+j} = \frac{1}{A_{i,z,t+j}}\left(\frac{w_{i,t+j}}{\alpha_{i,z}}\right)^{\alpha_{i,z}} (\frac{P_{i,z,t+j}^{F,T}}{1-\alpha_{i,z}})^{1-\alpha_{i,z}},$$

where

$$P_{i,z,t+j}^{F,T} = [\sum_{n=1}^{N} (\zeta_n^T)^{\eta} \left(P_{i,z,n,t+j}^{F,T}\right)^{1-\eta}]^{\frac{1}{1-\eta}},$$

$$P_{i,z,n,t+j}^{F,T} = [\int_{z'\in I_n^T} (p_{i,z,n,z',t+j}^{F})^{1-\eta_n^T} dz']^{\frac{1}{1-\eta_n^T}}.$$

5.3 Solution to the Optimal Pricing Problem

To solve the optimal pricing problem (6), the first order condition with respect to $P_{i,z,t}^*$ gives:

$$E_t \sum_{j=0}^{\infty} (\theta_i)^j \{M_{i,t,t+j} \mathrm{Y}_{i,z,t+j} (P_{i,z,t}^* - \frac{\eta_{i,z}}{\eta_{i,z}-1} C_{i,z,t+j})\} = 0,$$

where $\eta_{i,z} = \eta_i^T$ for tradable goods, and $\eta_{i,z} = \eta_i^{NT}$.

$P_{i,z,t}^*$ can be solved as:

$$P_{i,z,t}^* = \frac{\eta_{i,z}}{\eta_{i,z}-1} \frac{E_t \sum_{j=0}^{\infty} (\theta_i)^j \{M_{i,t,t+j} \mathrm{Y}_{i,z,t+j} C_{i,z,t+j}\}}{E_t \sum_{j=0}^{\infty} (\theta_i)^j \{M_{i,t,t+j} \mathrm{Y}_{i,z,t+j}\}}. \quad (7)$$

5.4 The *NKPC with global supply chains*

Aggregate price $P_{i,t}$ and aggregate tradable goods price $P_{i,t}^T$ satisfy:

$$(P_{i,t})^{1-\eta} = \sum_{n=1}^{N} (\zeta_n^T)^{\eta} (P_{i,n,t}^{H,T})^{1-\eta} + \left(\zeta_i^{NT}\right)^{\eta} (P_{i,t}^{H,NT})^{1-\eta},$$

where

$$(P_{i,n,t}^{H,T})^{1-\eta_n^T} = \int_{z\in I_n^T} (p_{i,n,z,t}^{H,T})^{1-\eta_n^T}\, dz,$$

$$(P_{i,t}^{H,NT})^{1-\eta_i^{NT}} = \int_{z\in I_i^{NT}} (p_{i,z,t}^{NT})^{1-\eta_i^{NT}}\, dz.$$

For firm $\{i,z\}$ that adjust prices,

$$P_{i,z,t}^{*} = \frac{\eta_{i,z}}{\eta_{i,z}-1}\frac{E_t\sum_{j=0}^{\infty}(\theta_i)^j\{M_{i,t,t+j}\mathrm{Y}_{i,z,t+j}C_{i,z,t+j}\}}{E_t\sum_{j=0}^{\infty}(\theta_i)^j\{M_{i,t,t+j}\mathrm{Y}_{i,z,t+j}\}}.$$

Define $\tilde{x}_t = \ln(X_t) - \ln(X^{ss})$, we have

$$\tilde{p}_{i,z,t}^{*} = (1-\beta\theta)E_t\sum_{j=0}^{\infty}\left\{(\beta\theta)^j\tilde{c}_{i,z,t+j}\right\},$$

$$\tilde{c}_{i,z,t+j} = -\tilde{a}_{i,z,t+j} + \alpha_{i,z}\widetilde{w}_{i,t+j} + \left(1-\alpha_{i,z}\right)\sum_{n=1}^{N} s_{i,z,n}^{F}\,\tilde{p}_{i,z,n,t+j}^{T}.$$

where

$$s_{i,z,n}^{F} = \frac{(\zeta_n^T)^{\eta}\left(P_{i,z,n}^{ss,T}\right)^{1-\eta}}{\sum_{n=1}^{N}(\zeta_n^T)^{\eta}\left(P_{i,z,n}^{ss,T}\right)^{1-\eta}}.$$

We also have

$$\tilde{p}_{i,t} = \sum_{n=1}^{N} s_{i,n}^{T}\tilde{p}_{i,n,t}^{H,T} + s_i^{NT}\tilde{p}_{i,t}^{H,NT},$$

where

$$s_{i,n}^{T} = \frac{(\zeta_n^T)^{\eta}\left(P_{i,n,ss}^{H,T}\right)^{1-\eta}}{\sum_{n=1}^{N}(\zeta_n^T)^{\eta}\left(P_{i,n,ss}^{H,T}\right)^{1-\eta} + \left(\zeta_i^{NT}\right)^{\eta}\left(P_{i,ss}^{H,NT}\right)^{1-\eta}},$$

$$s_i^{NT} = \frac{\left(\zeta_i^{NT}\right)^{\eta}\left(P_{i,ss}^{H,NT}\right)^{1-\eta}}{\sum_{n=1}^{N}(\zeta_n^T)^{\eta}\left(P_{i,n,ss}^{H,T}\right)^{1-\eta} + \left(\zeta_i^{NT}\right)^{\eta}\left(P_{i,ss}^{H,NT}\right)^{1-\eta}},$$

$$\tilde{p}_{i,n,t}^{H,T} = (1-\theta)\tilde{p}_{i,n,t}^{H,T,*} + \theta\tilde{p}_{i,n,t-1}^{H,T},$$

$$\tilde{p}_{i,t}^{H,NT} = (1-\theta)\tilde{p}_{i,t}^{H,NT,*} + \theta\tilde{p}_{i,t-1}^{H,NT}.$$

Through algebra, we get

$$\tilde{p}_{i,t} - \theta\tilde{p}_{i,t-1} = (1-\theta)(\sum_{n=1}^{N} s_{i,n}^{T}\tilde{p}_{i,n,t}^{H,T,*} + s_i^{NT}\tilde{p}_{i,t}^{H,NT,*}).$$

Since

$$\tilde{p}_{i,z,t}^{*} = (1-\beta\theta)E_t\sum\nolimits_{j=0}^{\infty}\{(\beta\theta)^j\tilde{c}_{i,z,t+j}\},$$

Therefore, we have

$$\tilde{p}_{i,t} - \theta\tilde{p}_{i,t-1} = (1-\theta)(1-\beta\theta)E_t\sum_{n=1}^{N} s_{i,n}^{T}\sum\nolimits_{j=0}^{\infty}\{(\beta\theta)^j\tilde{c}_{i,n,t+j}^{H,T,*}\}$$

$$+(1-\theta)(1-\beta\theta)s_i^{NT}E_t\sum\nolimits_{j=0}^{\infty}\{(\beta\theta)^j\tilde{c}_{i,t+j}^{H,NT,*}\}.$$

Which yields:

$$\tilde{p}_{i,t} - \theta\tilde{p}_{i,t-1} = (1-\theta)(1-\beta\theta)\sum_{n=1}^{N} s_{i,n}^{T}\tilde{c}_{i,n,t}^{H,T,*} + (1-\theta)(1-\beta\theta)s_i^{NT}\tilde{c}_{i,t}^{H,NT,*}$$

$$+\beta\theta E_t[\tilde{p}_{i,t+1} - \theta\tilde{p}_{i,t}],$$

from which we obtain the Phillips curve as:

$$\pi_{i,t} = \frac{(1-\theta)(1-\beta\theta)}{\theta}(\sum_{n=1}^{N} s_{i,n}^{T}\{\tilde{c}_{i,n,t}^{H,T,*} - \tilde{p}_{i,t}\} + s_i^{NT}\{\tilde{c}_{i,t}^{H,NT,*} - \tilde{p}_{i,t}\}) + \beta E_t\pi_{i,t+1}.$$

Proposition 1 $\sum_{n=1}^{N} s_{i,n}^{T}\{\tilde{c}_{i,n,t}^{H,T,*} - \tilde{p}_{i,t}\} + s_i^{NT}\{\tilde{c}_{i,t}^{H,NT,*} - \tilde{p}_{i,t}\}$ takes the following form:

$$\sum\nolimits_{k=0}^{+\infty}\phi_k^{1,l}\widetilde{w}_{n,t-k} + \sum\nolimits_{k=0}^{+\infty}\phi_{n,k}^{2,l}\widetilde{w}_{t-k}^{G}$$

$$+\sum\nolimits_{k=0}^{+\infty}\sum\nolimits_{m=1}^{N}\phi_{n,k,m}^{3,l}\tilde{a}_{m,t}^{H,T} + \sum\nolimits_{k=0}^{+\infty}\sum\nolimits_{m=1}^{N}\phi_{n,k,m}^{4,l}\tilde{a}_{m,t}^{H,NT}.$$

Proof: See Appendix A.

VI. Empirical Analysis: A New Phillips Curve and Inflation Puzzles

We construct the two new global factors in the previous section and show that they can be potentially persistent given their statistically significant impact on medium-term inflation expectations and even long-run expectations. Moreover, we show that their impact goes beyond those explored previously,

including domestic slack, and the level of oil price (which can affect the price setters' expectations). Furthermore, we highlight that the global inflation trend can experience counter-cyclical movements to create common inflation puzzles across countries.

This section takes a closer look at the ability of the Phillips curve augmented with the two new global factors and oil price inflation to explain inflation dynamics.

6.1 Power of explaining inflation dynamics

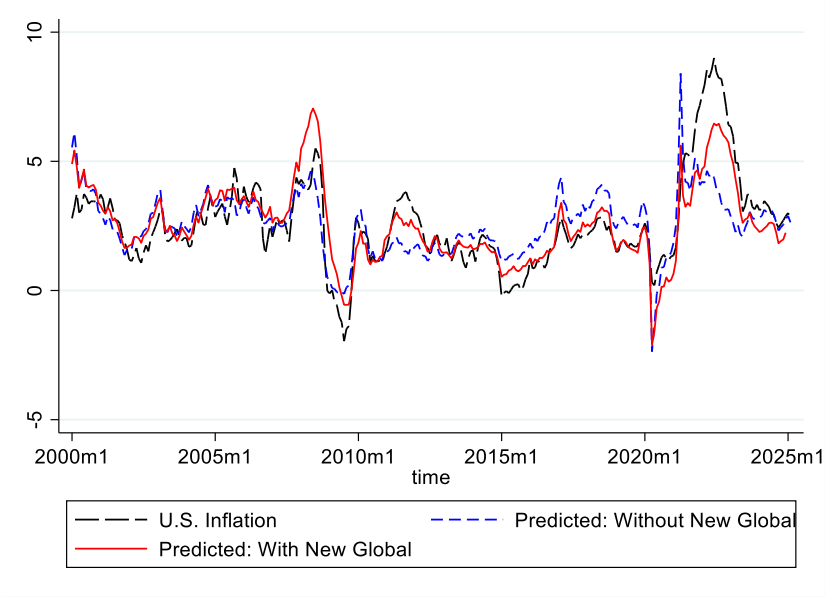
The three-global-factor Phillips curve has substantially higher explanatory power than the oil-price-inflation augmented Phillips curve. Table 4 shows the R-square increases from 46% to 73% for the United States. It is more dramatic for the United Kingdom, rising from 3% to 50%. Such dramatic improvements are also seen for Iceland, Israel, Malta, Norway, Slovak Republic, and Sweden, as their oil price inflation augmented Phillips curve has R-square at single digits, while the three-global-factor Phillips curves have substantially higher explanatory power.

6.2 Explaining Inflation Puzzles

Figure 6 shows how the three-global factor Phillips curve helps resolve inflation puzzles in the United States. It plots the actual inflation as the black long-dash line, and the two predicted values from the oil price inflation augmented Phillips curve and the three global factor augmented Phillips curve as the blue dash line and the red solid line respectively. The gap between the blue dash line and the black long-dash line, as is discussed above, points to three inflation puzzles, and the inclusion of the two new global factors helps resolve the missing disinflation puzzle around 2011 and the missing reflation puzzle in the 2010s very well. While the three-factor Phillips curve only explains a portion of the COVID-19 inflation patterns, it is interesting to see that it captures the turning points around mid-2022 very well.

Figure 7 further demonstrates the ability of the three-global-factor Phillips curve in resolving inflation puzzles on the international level. It plots the distributions of residuals from the oil-price-inflation augmented Phillips curve and those from the three-global-factor augmented Phillips curve, both estimated separately for each advanced economy. We exclude the United States in constructing the patterns in Figure 7 to reinforce the point that inflation puzzles also existed in other advanced economies.

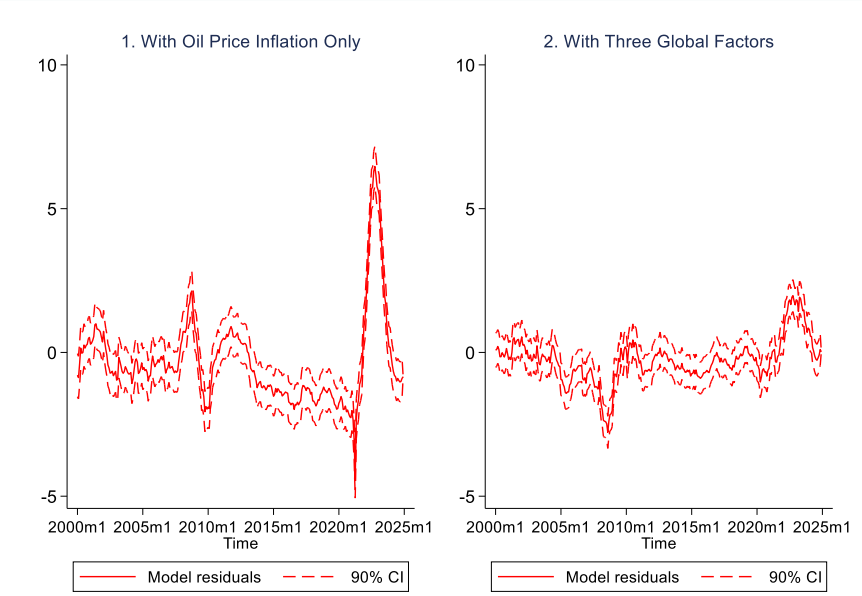
Figure 6 Phillips Curves Performance for United States: Oil Price Only vs. Predicted Values



Note: Predicted without new global factor refers to "oil price only".

Figure 7 shows that after including the two new global factors, in the post-global financial crisis period, inflation residuals have much less volatile movements. In particular, the two inflation puzzles before the COVID-19 pandemic largely disappear. These patterns are consistent with those in Figure 6 for the United States.

Figure 7 Phillips Curve Performance for AEs excluding the United State: Oil Price Only vs. Three Global Factors

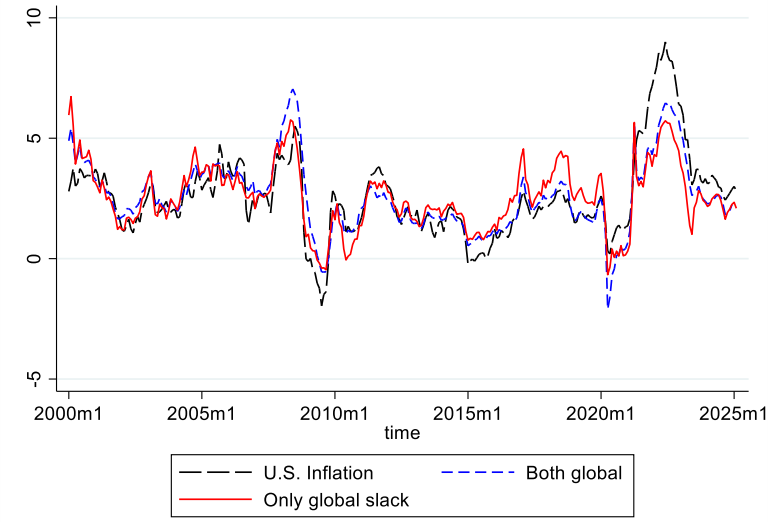


6.3 Distinctive roles of Global Slack and Global Inflation Trend

We explore inflation dynamics in the United States if the global inflation trend is held as constant. We have two options of conducting this thought experiment, with one having the coefficients to be the same as those in the specification with the global inflation rend, and the other re-estimating the coefficients. Given we have a small sample size for the United States, there is not an obvious reason to favor the first option. For simplicity, we go for the second one.

Figure 8 shows that the missing reflation puzzle persists even if the global slack factor is controlled, mainly coming from the post-2015 period (which is consistent with the global inflation trend pattern shown in Figure 5). Moreover, the inflation surge in 2022 predicted by the model is slightly weaker when the global inflation trend is excluded. On the other hand, it is interesting to note that the missing disinflation and the majority of the 2022 inflation surge that is explained by the three global factor model are attributed to the global slack factor.

Figure 8 Phillips Curve Performance for United States: Global Slack vs. Both Factors



6.4 Structural Changes of Inflation Processes

The three-global-factor Phillips curve allows a richer exercise to explore the impact of global shocks on inflation processes, where we allow the coefficients of all three global factors and the unemployment rate to be time-varying:

$$\pi_{i,t} = \alpha_i + \sum_{j=1}^{J} \beta_{j,k,t} G_{j,t} + \rho_{i,t} u_{i,t} + v_{i,t}.$$

We split the sample period into four episodes: (i) the pre-global financial crisis period, which is defined as before September 2008; (ii) the post-GFC and pre-COVID-19-pandemic period, which is between September 2008 and February 2020; (iii) the COVID-19-pandemic period, which is between March 2020 and May 2023; and (iv) the post-COVID-19-pandemic period, which is between June 2023 and December 2024.

This exercise can shed light on several interesting questions: (i) whether the global shocks affect the slope of Phillips curve? (ii) whether the global shocks affect the coefficients of global factors? (iii) Can the three-global-factor Phillips curve explain the inflation patterns during the COVID-19 pandemic better after accounting for the structural changes? (iv) Are these patterns robust if we separate the sample economies into G7 and non-G7 economies?

Table 5 reports the estimation results. There are a rich set of patterns that are consistently found for both G7 and non-G7 economies. First, there was a steepening of reduced-form Phillips curve during the post-GFC-pre-COVID period. Second, the COVID-19 pandemic had actually a flattening of reduced-form

Phillips curve relative to the post-GFC-pre-COVID period. Third, the slope of reduced-form Phillips curve steepened again during the post-COVID period. Fourth, the coefficients of global slack factor increased sharply during the COVID-19 pandemic, and the pattern is even more dramatic for the post-COVID period. Fifth, the sharp rise in the coefficients in the COVID-19 pandemic and in the post-COVID period also occurred for the global inflation trend.

There is also some interesting differences between G7 economies and non-G7 economies. First, the coefficients of global slack and global inflation trend are much smaller for G7 economies than non-G7 economies before the COVID-19 pandemic. For example, the G7 economies' global slack coefficient is around 1/3 of that of non-G7 economies before the global financial crisis, and the ratio increases to 0.65 in the post-GFC and pre-COVID period, and further to 0.69 and 1.01 during the COVID and post-COVID periods. Similarly, the ratio of G7 coefficient over non-G7 coefficient for the global inflation trend is 0.56, 0.42, 0.81, and 0.98. These patterns suggest a new way for inflation expectations to see its anchoring being weakened: the sensitivity of inflation with respect to global factors increases sharply. Intuitively, this may reflect the reluctance of firms in absorbing the cost-push pressure from the large swings in global forces, especially if they are perceived to be persistent, as suggested by the results in Section 5.2.

Figure 9 plots the residuals of the three-global-factor Phillips curve. The pattern suggests that all the puzzles are fully resolved once structural breaks are further considered. Figure 10 confirms this by showing the performance of the Phillips curve with structural breaks, which is a significant improvement than those presented in Figure 6, especially for the COVID-19 pandemic period.

VII. Concluding Remarks

This paper develops a new inflation framework to consider persistent global inflation driving forces. We develop an empirical strategy to identify these forces and show that they significantly affect medium-term inflation expectations.

This framework is shown to be consistent with a New Keynesian Phillips Curve that considers cross-border input-output linkages. A key feature of the inflation structural equation is that both global slack and its lags can be important, and shocks that influence the relative price of tradable goods can influence headline inflation dynamics beyond economic slack.

We use this framework to explain all major inflation puzzles across advanced economies jointly, and show that once we allow for structural breaks in inflation processes, especially changes in the coefficients of global variables across episodes, our model explains these puzzles almost perfectly.

Table 5 Phillips Curve with Structural Changes

VARIABLES	(1) **Full**	(2) **G7**	(3) **Non-G7**
Unemployment rate	-0.0652***	0.0264	-0.0677***
	(0.0118)	(0.0214)	(0.0133)
Oil price inflation	0.0130***	0.00847***	0.0143***
	(0.000931)	(0.000935)	(0.00114)
Global slack	0.702***	0.303***	0.824***
	(0.0556)	(0.0570)	(0.0681)
Global inflation trend	0.407***	0.253***	0.449***
	(0.0308)	(0.0307)	(0.0379)
Unemployment rate · 1{t >= 2008M9 & t <= 2020M2}	-0.115***	-0.173***	-0.109***
	(0.0119)	(0.0227)	(0.0133)
Oil price inflation · 1{t >= 2008M9 & t <= 2020M2}	0.00883***	0.0112***	0.00813***
	(0.00129)	(0.00130)	(0.00158)
Global slack · 1{t >= 2008M9 & t <= 2020M2}	0.0146	0.206***	-0.0469
	(0.0622)	(0.0636)	(0.0761)
Global inflation trend · 1{t >= 2008M9 & t <= 2020M2}	0.136***	0.0105	0.166***
	(0.0360)	(0.0362)	(0.0442)
Unemployment rate · 1{t >= 2020M3 & t <= 2023M5}	-0.00380	-0.0944***	0.00292
	(0.0202)	(0.0288)	(0.0237)
Oil price inflation · 1{t >= 2020M3 & t <= 2023M5}	0.0134***	0.0127***	0.0134***
	(0.00127)	(0.00132)	(0.00155)
Global slack · 1{t >= 2020M3 & t <= 2023M5}	0.419***	0.524***	0.368***
	(0.0615)	(0.0636)	(0.0751)
Global inflation trend · 1{t >= 2020M3 & t <= 2023M5}	0.833***	0.786***	0.841***
	(0.0522)	(0.0551)	(0.0634)
Unemployment rate · 1{t >= 2023M6}	-0.172***	-0.392***	-0.143***
	(0.0313)	(0.0451)	(0.0360)
Oil price inflation · 1{t >= 2023M6}	0.0193**	0.0270***	0.0172*
	(0.00785)	(0.00831)	(0.00951)
Global slack · 1{t >= 2023M6}	1.244***	1.652***	1.121***
	(0.231)	(0.246)	(0.280)
Global inflation trend · 1{t >= 2023M6}	0.947***	1.079***	0.909***
	(0.133)	(0.141)	(0.162)
1{t >= 2008M9 & t <= 2020M2}	0.596**	0.370	0.754**
	(0.271)	(0.314)	(0.328)
1{t >= 2020M3 & t <= 2023M5}	-1.111***	-0.654*	-1.031***
	(0.292)	(0.337)	(0.352)
1{t >= 2023M6}	-2.552***	-2.408**	-2.347**
	(0.868)	(0.942)	(1.049)
Constant	-0.192	0.0921	-0.471
	(0.248)	(0.292)	(0.300)
Observations	9,732	2,051	7,681
R-squared	0.594	0.789	0.581

Standard errors in parentheses
*** p<0.01, ** p<0.05, * p<0.1

Figure 9 Phillips Curve Performance for AEs: Oil Price only vs. Three Global Factors and Structural Breaks



Figure 10 Phillips Curve Performance for G7 Economies

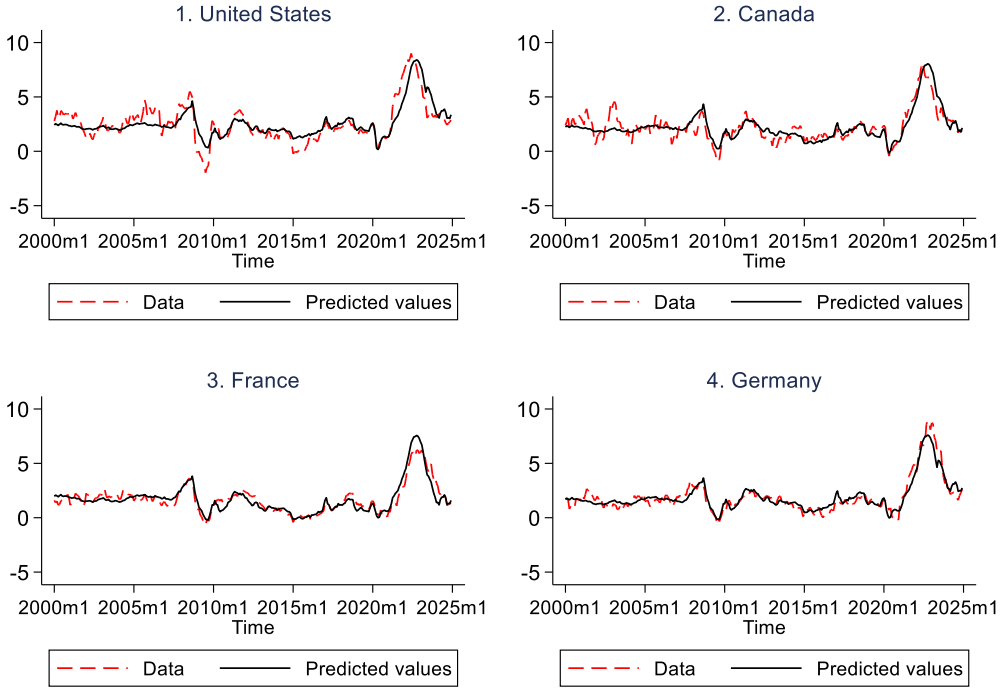
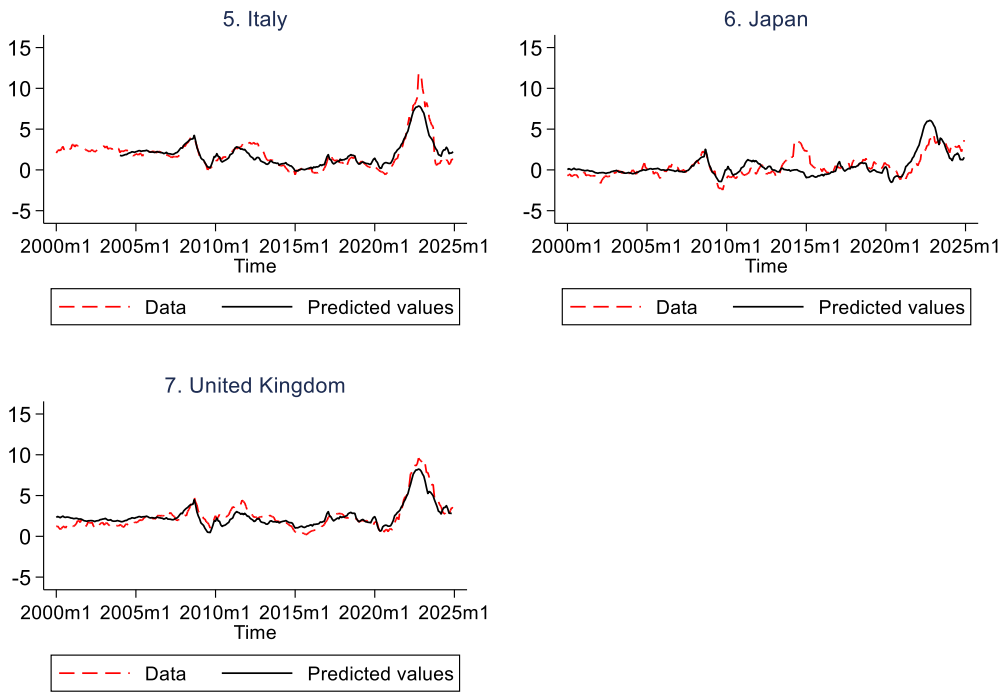


Figure 10 Phillips Curve Performance for G7 Economies (continued)



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Appendix A

A.1 Unit Production Cost

To ease notation, we suppress country and time when deriving the unit cost of production.

Lemma A.1 The optimization problem of firms is:

$$C_{i,z,t} = \min \left(w_{i,t}L_{i,z,t} + \sum\nolimits_{n=1}^{N} \int_{z\prime \in I_n^T} p_{i,z,n,z',t}^{F} Y_{i,z,n,z',t}^{F,T}\right)$$

such that

$$A_{i,z,t}\left(L_{i,z,t}\right)^{\alpha_{i,z}} \left[\left(\sum_{n=1}^{N} \zeta_n^T \left(\left(\int_{z\prime \in I_n^T} \left(Y_{i,z,n,z',t}^{F,T}\right)^{\frac{\eta_n^T-1}{\eta_n^T}}\right)^{\frac{\eta_n^T}{\eta_n^T-1}}\right)^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}\right]^{1-\alpha_{i,z}} \geq 1.$$

The unit production cost $C_{i,z,t}$ satisfies:

$$C_{i,z,t} = \frac{1}{A_{i,z,t}}\left(\frac{w_{i,t}}{\alpha_{i,z}}\right)^{\alpha_{i,z}} \left(\frac{P_{i,z,t}^{F,T}}{1-\alpha_{i,z}}\right)^{1-\alpha_{i,z}},$$

where

$$P_{i,z,t}^{F,T} = \left[\sum_{n=1}^{N} \left(\zeta_n^T\right)^{\eta} \left(P_{i,z,n,t}^{F,T}\right)^{1-\eta}\right]^{\frac{1}{1-\eta}},$$

$$P_{i,z,n,t}^{F,T} = \left[\int_{z\prime \in I_n^T} \left(p_{i,z,n,z',t}^{F}\right)^{1-\eta_n^T} dz'\right]^{\frac{1}{1-\eta_n^T}}.$$

Proof: We solve the first order conditions of the Lagrange function:

$$L = w_{i,t}L_{i,z,t} + \sum_{n=1}^{N}\int_{z'\in I_n^T} p^F_{i,z,n,z',t}Y^{F,T}_{i,z,n,z',t}$$

$$-\lambda\left(A_{i,z,t}\left(L_{i,z,t}\right)^{\alpha_{i,z}}\left[\left(\sum_{n=1}^{N}\zeta_n^T\left(\left(\int_{z'\in I_n^T}\left(Y^{F,T}_{i,z,n,z',t}\right)^{\frac{\eta_n^T-1}{\eta_n^T}}\right)^{\frac{\eta_n^T}{\eta_n^T-1}}\right)^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}\right]^{1-\alpha_{i,z}} - 1\right).$$

Moreover, the optimal solution

$$Y^{F,T}_{i,z,n,z',t} = \left(1-\alpha_{i,z}\right)\frac{C_{i,z,t}}{P_{i,z,t}}\cdot(\zeta_n^T)^{\eta}\left(\frac{P^{F,T}_{i,z,n,t}}{P^{F,T}_{i,z,t}}\right)^{-\eta}\left(\frac{p^F_{i,z,n,z',t}}{P^{F,T}_{i,z,n,t}}\right)^{-\eta_n^T},$$

Lemma A.2 Households maximize

$$C_{i,t} = \left(\sum_{n=1}^{N}\zeta_n^T\left((\int_{z\in I_n^T}(Y^{H,T}_{i,n,z,t})^{\frac{\eta_n^T-1}{\eta_n^T}}dz)^{\frac{\eta_n^T}{\eta_n^T-1}}\right)^{\frac{\eta-1}{\eta}} + \zeta_i^{NT}(\left(\int_{z\in I_i^{NT}}\left(Y^{H,NT}_{i,z,t}\right)^{\frac{\eta_i^{NT}-1}{\eta_i^{NT}}}dz\right)^{\frac{\eta_i^{NT}}{\eta_i^{NT}-1}})^{\frac{\eta-1}{\eta}}\right)^{\frac{\eta}{\eta-1}}$$

subject to:

$$\sum_{n=1}^{N}\int_{z\in I_n^T} p^{H,T}_{i,n,z,t}Y^{H,T}_{i,n,z,t}\,dz + \int_{z\in I_i^{NT}} p^{H,NT}_{i,z,t}Y^{H,NT}_{i,z,t}dz \le w_{i,t}L_i + \pi_{i,t}.$$

The optimal solution for tradable goods is:

$$Y^{H,T}_{i,n,z,t} = (\zeta_n^T)^{\eta}\left(\frac{P^{H,T}_{i,n,t}}{p^{H,T}_{i,n,z,t}}\right)^{\eta_n^T}(\frac{P_{i,t}}{P^{H,T}_{i,n,t}})^{\eta}\cdot\frac{I_{i,t}}{P_{i,t}}.$$

For non-tradable goods:

$$Y^{NT}_{i,z,t} = \left(\zeta_i^{NT}\right)^{\eta}(\frac{P^{H,NT}_{i,t}}{p^{NT}_{i,z,t}})^{\eta_i^{NT}}(\frac{P_{i,t}}{P^{H,NT}_{i,t}})^{\eta}\cdot\frac{I_{i,t}}{P_{i,t}},$$

where

$$I_{i,t} = w_{i,t}L_i + \pi_{i,t},$$

$$P_{i,t} = [\sum_{n=1}^{N} (\zeta_n^T)^{\eta} (P_{i,n,t}^{H,T})^{1-\eta} + (\zeta_i^{NT})^{\eta} (P_{i,t}^{H,NT})^{1-\eta}]^{\frac{1}{1-\eta}},$$

$$P_{i,n,t}^{H,T} = [\int_{z \in I_n^T} (p_{i,n,z,t}^{H,T})^{1-\eta_n^T} \, dz]^{\frac{1}{1-\eta_n^T}},$$

$$P_{i,t}^{H,NT} = [\int_{z \in I_i^{NT}} (p_{i,z,t}^{NT})^{1-\eta_i^{NT}} \, dz]^{\frac{1}{1-\eta_i^{NT}}}.$$

Proof: It is straightforward to solve the Lagrange problem.

Proposition 1 $\sum_{n=1}^{N} s_{i,n}^T \{\tilde{c}_{i,n,t}^{H,T,*} - \tilde{p}_{i,t}\} + s_i^{NT} \{\tilde{c}_{i,t}^{H,NT,*} - \tilde{p}_{i,t}\}$ takes the following form:

$$\sum_{k=0}^{+\infty} \phi_k^{1,l} \widetilde{w}_{n,t-k} + \sum_{k=0}^{+\infty} \phi_{n,k}^{2,l} \widetilde{w}_{t-k}^G$$

$$+ \sum_{k=0}^{+\infty} \sum_{m=1}^{N} \phi_{n,k,m}^{3,l} \tilde{a}_{m,t}^{H,T} + \sum_{k=0}^{+\infty} \sum_{m=1}^{N} \phi_{n,k,m}^{4,l} \tilde{a}_{m,t}^{H,NT}.$$

Proof of Proposition 1: We have the following equation for the price of tradable goods:

$$\tilde{p}_{i,n,t}^{H,T} = \theta \tilde{p}_{i,n,t-1}^{H,T} + (1-\theta)(1-\beta\theta) E_t \sum_{j=0}^{\infty} \{(\beta\theta)^j \tilde{c}_{i,m,t+j}^{H,T,*}\}$$

$$= \theta \tilde{p}_{i,n,t-1}^{H,T} + (1-\theta)(1-\beta\theta) E_t \sum_{j=0}^{\infty} \left\{(\beta\theta)^j \{-\tilde{a}_{i,n,t+j}^{H,T} + \alpha_n \widetilde{w}_{n,t+j} + (1-\alpha_n) \sum_{m=1}^{N} s_{n,m}^F \tilde{p}_{i,m,t+j}^T\}\right\}.$$

To solve this equation, we use the following iteration approach:

$$\tilde{p}_{i,n,t}^{H,T,0} = 0,$$

$$\tilde{p}_{i,n,t}^{H,T,l+1} = \theta \tilde{p}_{i,n,t-1}^{H,T,l}$$

$$+(1-\theta)(1-\beta\theta) E_t \sum_{j=0}^{\infty} \left\{(\beta\theta)^j \{-\tilde{a}_{i,n,t+j}^{H,T} + \alpha \widetilde{w}_{n,t+j} + (1-\alpha) \sum_{m=1}^{N} s_{n,m}^F \tilde{p}_{i,m,t+j}^{T,l}\}\right\}$$

We can guess and verify that $\tilde{p}_{i,n,t}^{H,T,l}$ has the following form:

$$\tilde{p}_{i,n,t}^{H,T,l} = \sum_{k=0}^{+\infty} \phi_k^{1,l} \widetilde{w}_{n,t-k} + \sum_{k=0}^{+\infty} \phi_{n,k}^{2,l} \widetilde{w}_{t-k}^G$$

$$+\sum_{k=0}^{+\infty}\sum_{m=1}^{N}\phi_{n,k,m}^{3,l}\tilde{a}_{m,t}^{H,T}+\sum_{k=0}^{+\infty}\sum_{m=1}^{N}\phi_{n,k,m}^{4,l}\tilde{a}_{m,t}^{H,NT},$$

where $\widetilde{w}_{t-k}^{G}=\frac{1}{N}\sum_{n=1}^{N}s_{n,m}^{F}\widetilde{w}_{m,t-k}$.

Note that we utilize the symmetry of technology to assume that $\phi_{k}^{1,l}$ only depends on k but not n.

Define $\phi_{n,k}^{1}=\lim_{l\to\infty}\phi_{n,k}^{1,l}$, $\phi_{n,k}^{2}=\lim_{l\to\infty}\phi_{n,k}^{2,l}$, $\phi_{n,k,m}^{3}=\lim_{l\to\infty}\phi_{n,k,m}^{3,l}$, $\phi_{n,k,m}^{4}=\lim_{l\to\infty}\phi_{n,k,m}^{4,l}$. Please derive $\phi_{n,k}^{1}$, $\phi_{n,k}^{2}$, $\phi_{n,k,m}^{3}$, and $\phi_{n,k,m}^{4}$.

Through iterations, we can solve:

$$\phi_{0}^{1}=\frac{\alpha\frac{(1-\theta)(1-\beta\theta)}{1-\beta\theta\rho_{w}}}{1-(1-\theta)(1-\alpha)\sum_{m=1}^{N}s_{n,m}^{F}},\text{and }\phi_{0}^{k}=\gamma^{k}\phi_{0}^{1}.$$

Global wage coefficients ϕ_{n}^{2}, define $\Omega=\theta[I-(1-\theta)(1-\alpha)S]^{-1}$, then $\phi_{k}^{2}=\Omega^{k}\phi_{0}^{2}e_{N}$, where e_{N} is a vector of 1s, and $\phi_{0}^{2}=N(1-\alpha)\alpha\frac{(1-\theta)^{2}(1-\beta\theta)}{(1-\beta\theta\rho_{w})(1-\beta\theta)\left(1-(1-\theta)(1-\alpha)\sum_{p=1}^{N}s_{n,p}^{F}\right)}$.

For technology shocks for tradable goods sectors, we can derive the $N\times 1$ vector $\Phi_{m,0}^{3}$ as

$$\Phi_{m,0}^{3}=-\frac{(1-\theta)(1-\beta\theta)}{1-\beta\theta\rho_{a}}[I-(1-\theta)(1-\alpha)S]^{-1}e_{m},$$

where e_{m} is a unit vector with 1 in position m and 0 elsewhere, and $\Phi_{m,k}^{3}=\Omega^{k}\Phi_{m,0}^{3}$.

For technology shocks for non-tradable goods sectors, we can derive the $N\times 1$ vector Φ_{m}^{4} as

$$\Phi_{m}^{4}=-\frac{(1-\theta)(1-\beta\theta)}{1-\beta\theta\rho_{a}}[I-(1-\theta)(1-\alpha)S]^{-1}e_{m},$$

where e_{m} is a unit vector with 1 in position m and 0 elsewhere, and $\Phi_{m,k}^{4}=\Omega^{k}\Phi_{m,0}^{4}$.

Appendix B Additional Stylized Facts

Figure B.1 plots the price of goods relative to services in the United States. It was resilient after the global financial crisis, weakened significantly during the missing reflation episode, and had volatile movements during the COVID-19 pandemic. These patterns suggest an active role of the forces behind the relative tradable goods prices in affecting all three inflation puzzles.

Figure B.1 The Price of Goods Relative to Services in the United States

The price of goods relative to services

