Relative-Price Changes as Aggregate Supply Shocks Revisited: Theory and Evidence*

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1 Introduction

Commodity price increases and supply chain disruptions have recently been at the forefront of discussions about possible drivers of *high and persistent* inflation worldwide. For instance, the top panel of Figure 1 shows that following the Covid pandemic, supply chain pressures and commodity prices increased substantially. The bottom panel of Figure 1 shows that this in turn coincided with an increase in import inflation and headline inflation in the U.S. In addition, the bottom panel of Figure 1 highlights that both core inflation and import inflation, excluding petroleum, also rose persistently and have remained high in the U.S.

But how can relative price changes cause aggregate inflation? This is especially puzzling because in simple multi-sector models such shocks, which cause "relative price" changes across sectors, do not affect aggregate inflation. In particular, aggregate inflation dynamics in these models is determined through a Phillips curve that involves only aggregate GDP gap. In other words, once aggregate GDP gap dynamics is taken into account, these models predict *no additional role for relative price movements* in determining aggregate inflation.

We present both theoretical and empirical evidence that questions this narrative. We set up a multi-sector monetary model with input-output linkages where sectors use one anothers' output as production inputs, and where sectors differ in the duration of nominal price changes. We show that in such an environment, aggregate inflation dynamics is determined through a Phillips curve that involves not just the aggregate GDP gap, but also relative (across sectors) price gaps.

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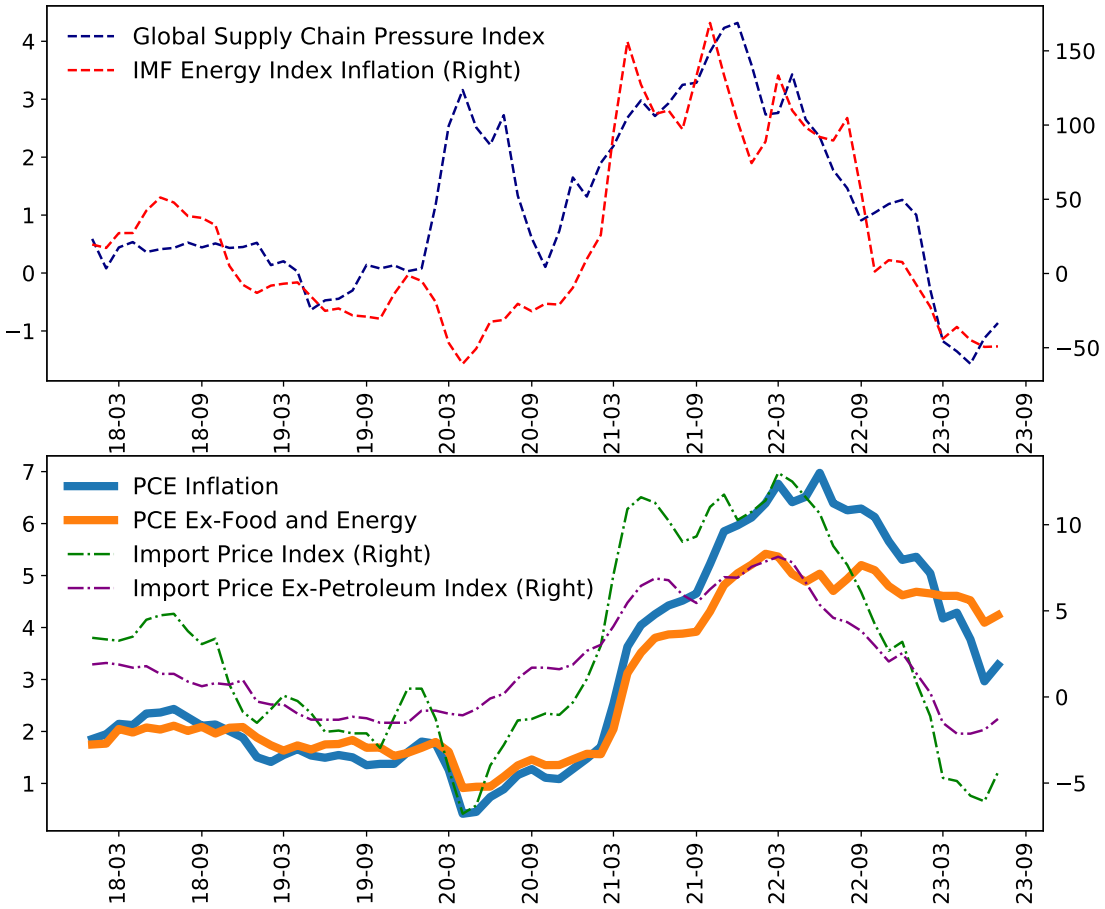


Figure 1: Recent evolution of consumer prices, energy prices, and supply chain pressures

Notes: This figure plots consumer headline and core inflation in the U.S. using the PCE index, import and import excluding petroleum inflation in the U.S. using the BLS import price index, energy inflation using the IMF energy index, and the New York Fed index of global supply chain pressure. The time period is 2018:01-2023:07. The units are percentages for inflation measures. The global supply chain pressure measure is normalized such that a value of zero represents the index's average value and a positive value represents how many standard deviations the index is above the average value.

We analytically decompose how this additional role for relative price changes comes about due to two forces: production linkages and heterogeneous price stickiness across sectors. In particular, both model ingredients are sufficient on their own to generate such a new role for relative price changes. When both features are present, they interact in non-trivial ways, but this interaction can nevertheless still be understood in terms of economic mechanisms driven by model primitives. Viewed in this way, relative price changes in our model are indeed akin to aggregate supply shocks (Ball and Mankiw (1995)) as they affect aggregate inflation even while holding aggregate GDP gap constant.[1]

Empirically, we use the theoretical results as a guiding framework to investigate how recent inflation dynamics were affected by relative price changes. First, we show that exogenous oil price shocks that drive up consumer prices in the energy sector in the U.S. have a significant positive effect not only on headline inflation, but also on core inflation. That is, such shocks pass through to aggregate inflation even after removing their direct and mechanical own-sector effect, as predicted by our model with production networks. Moreover, the pass-through of these shocks to aggregate inflation is fairly quick, as predicted by our model for a shock originating in a relatively flexible price sector. These same shocks cause a contraction in real activity as they increase the unemployment rate and decrease consumption. The evidence thus clearly suggests that relative price changes originating from global oil commodity markets act as negative aggregate supply shocks in the U.S.[2]

Second, we show that innovations to the global supply chain pressure index also have a positive effect on both aggregate and sectoral inflation in the U.S. In particular, these shocks affect import inflation the most, followed by (non-durable and durable) goods inflation and services inflation. The effects on import inflation are present even after excluding petroleum imports while the effects on non-durable and durable goods inflation are comparable. These inflationary effects build up over time and peak after a delay, as predicted by our model with production networks where such disruptions in an upstream sector would work its way over time through input-output linkages.[3]

We discuss further theoretical and empirical analysis we plan to undertake, building on these preliminary results, at the end of this proposal.

[1] Aoki (2001) and Benigno (2004) in two-sector models showed how heterogeneous price stickiness across sectors leads to such a role for relative price changes and analyzed optimal monetary policy implications. Chapter 6 in Woodford (2003) has a detailed discussion of inflation dynamics and optimal policy in two-sector sticky price models.

[2] As we show in detail later, these broad patterns are qualitatively present even if exclude two time periods with large oil price shocks: the 1970s and post-2020 period. Excluding these periods leads to slightly smaller effects on core inflation and real economic activity.

[3] As we show in detail later, these broad patterns are qualitatively present even if we exclude the the post-2020 period that has large large supply chain disruption shocks. Excluding this period leads to slightly smaller effects on durable goods inflation and no effect on services inflation.

2 Theory

We base our analysis on a discrete-time representation of the aggregate Phillips curve in Afrouzi and Bhattarai (2023), which is derived in a multi-sector New Keynesian model with arbitrary production linkages, heterogeneous price stickiness across sectors, and both aggregate and sectoral shocks.[4] We show that the aggregate Phillips curve in this model can be written as

$$\pi_t = \rho \mathbb{E}_t[\pi_{t+1}] - \boldsymbol{\beta}^\intercal \boldsymbol{\Gamma}(\mathbf{q}_t - \mathbf{q}_t^f) + \boldsymbol{\beta}^\intercal \boldsymbol{\Gamma} \mathbf{1} \tilde{y}_t \tag{1}$$

where ρ is the household's discount factor, π_t is the *aggregate* inflation rate in consumer price index (CPI), $\boldsymbol{\beta}$ is the vector of the household's expenditure shares from sectoral goods, $\mathbf{q}_t$ is the vector of *sectoral prices relative to the CPI*, $\mathbf{q}_t^f$ is the vector of equilibrium relative prices in a counterfactual economy with fully flexible prices, $\tilde{y}_t$ is the aggregate GDP gap, and $\boldsymbol{\Gamma}$ is a matrix of parameters described below.

In the rest of this section, we briefly describe the precise environment in which Equation (1) is derived, and then discuss the economic mechanisms that drive the role of the relative price change gap, $\mathbf{q}_t$ - $\mathbf{q}_t^f$, in determining aggregate inflation, π_t.[5]

2.1. Short description of the model

Time is discrete and runs forever. The economy consists of a representative household that consumes an aggregate basket of goods produced by n sectors. The aggregate consumption of this household is defined by an aggregation of these products, denoted by $C_t = \Phi(C_{1,t}, \ldots, C_{n,t})$. Given a vector of prices for the sectoral goods, with a homogeneous of degree one $\Phi(.)$ function, the aggregate consumption bundle is priced at P_t which is only a function of sectoral prices. P_t is therefore the CPI of this economy. The household also supplies labor in a competitive labor market at nominal wage W_t. Similar to baseline New Keynesian models, labor is the only primary factor of production.

The household's utility over consumption and leisure is given by $\ln(C_t) - L_t$. These preferences imply that the nominal wage is proportional to the aggregate nominal demand $W_t = M_t \equiv P_t C_t$. Assuming that the central bank controls the path of nominal GDP, M_t, this implies that nominal wages are directly determined by monetary policy.[6] Moreover, with no investment, government

[4] This discrete time model is similar to the one in Rubbo (2023), with some differences in the details of labor market and monetary policy specification. Our Phillips curve formulation is however, different, as we mention later.

[5] For a detailed description of the continuous-time analog of this model, see Afrouzi and Bhattarai (2023).

[6] As we discuss in Afrouzi and Bhattarai (2023), this does not restrict the model significantly and the main insights derived under this assumption extend to alternative policy specifications such as a Taylor rule or an economy with finite elasticity of labor supply.

spending or imports and exports, the aggregate GDP of this economy is given by $Y_t \equiv C_t$.

On the firm side, each sector $i \in [n]$ consists of a unit measure of monopolistically competitive firms with Calvo-type sticky prices, where firms change their prices at each period with an i.i.d. probability of $1-\theta_i$. Importantly, θ_i can be different across sectors. These intermediate firms use labor and final goods of other sectors to produce and meet the demand of a final good producer in their sector. In sector $i \in [n]$, this final good producer uses a CES production function to exclusively demand the product of the intermediate firms within its sector and produce its final product. These final goods are then used by the household for consumption or by intermediate goods producers of all sectors as inputs, forming an arbitrary production network.

We do not restrict the structure of this network in any way and let a_{ij} denote the expenditure share of firms in sector i on the final good of sector j. With constant returns to scale production functions, it follows that the log-linearized deviation of the marginal cost of firms in sector i from its level in an efficient steady-state is only a function of prices and the nominal wage given by

$$mc_{i,t} = \alpha_i m_t + \sum_{k \in [n]} a_{ik} p_{k,t} - z_{i,t} \tag{2}$$

where small letters denote deviations from the log-linearized steady-state and $z_{i,t}$ is a sector-specific Hicks-neutral productivity shock. Moreover, α_i is the share of labor in sector i's production function, w_t is the nominal wage, and $p_{k,t}$ is the price of sector k's final good. Constant returns to scale implies $\alpha_i + \sum_{k \in [n]} a_{ik} = 1$ for all $i \in [n]$.

In the spirit of a standard New Keynesian model, we can also define the counterfactual concept of a "desired" price for firms, which captures the linearized best response function of a firm in sector i under flexible prices. Letting $p^*_{i,t}$ denote this desired price, it follows that

$$p^*_{i,t} = \omega_{i,t} + mc_{i,t} \tag{3}$$

where $\omega_{i,t}$ is a sector-specific markup shock. Thus, $p^*_{i,t}$ captures the fact that if *if* firms had flexible prices they would set their prices equal to their marginal cost plus a term that captures the deviation of their markups from the steady state. However, prices are not flexible and firms that do get to reset their prices at each period, choose them in a forward-looking manner to maximize the present discounted value of their profits in the histories of events where they are stuck with their prices in the future. The result of this optimization problem, in log-linearized term, is that firms that reset their prices target a weighted average of their expected future desired prices, weighted by the

probability of price adjustment. Denoting these reset prices by $p^{\#}_{i,t}$, this object is given by

$$p^{\#}_{i,t} = (1-\rho\theta_i)\mathbb{E}_t\left[\sum_{h=0}^{\infty}(\rho\theta_i)^h p^*_{i,t+h}\right] = (1-\rho\theta_i)mc_{i,t} + \rho\theta_i\mathbb{E}_t[p^{\#}_{i,t+1}] \tag{4}$$

Finally, since price changes are staggered, aggregate sectoral prices are simply an average of all past reset prices, weighted by the probability of price adjustment. Denoting the aggregate price of sector i by $p_{i,t}$, it is given by

$$p_{i,t} = (1-\theta_i)p^{\#}_{i,t} + \theta_i p_{i,t-1} \tag{5}$$

2.2. Sectoral and aggregate Phillips curves

Together, Equations (2) to (5) across all sectors characterize the supply side of the economy in terms of a set of sectoral Phillips curves. To see this, it helps to consider the vectorized analogs of these equations:

$$\mathbf{p}^*_t = m_t\boldsymbol{\alpha} + \mathbf{A}\mathbf{p}_t + \boldsymbol{\omega}_t - \boldsymbol{z}_t \tag{6}$$

$$\mathbf{p}^{\#}_t = (\mathbf{I}-\rho\boldsymbol{\Theta})\mathbf{p}^*_t + \rho\boldsymbol{\Theta}\mathbb{E}_t[\mathbf{p}^{\#}_{t+1}] \tag{7}$$

$$\mathbf{p}_t = (\mathbf{I}-\boldsymbol{\Theta})\mathbf{p}^{\#}_t + \boldsymbol{\Theta}\mathbf{p}_{t-1} \tag{8}$$

where $\mathbf{p}^*_t \in \mathbb{R}^n$ is the vector of desired prices across sectors, $\boldsymbol{\alpha}$ is the vector of labor shares, $\mathbf{A} = [a_{ij}] \in \mathbb{R}^{n\times n}$ is the input-output matrix, $\boldsymbol{\omega}_t$ is the vector of markup shocks, $\boldsymbol{z}_t$ is the vector of productivity shocks, $\mathbf{p}^{\#}_t$ is the vector of reset prices, $\boldsymbol{\Theta} = \text{diag}(\theta_i) \in \mathbb{R}^{n\times n}$ is the diagonal matrix of price stickiness across sectors, and $\mathbf{p}_t$ is the vector of aggregate prices.

Combining these equations, we can write everything in terms of shocks and the inflation rates in the vector of aggregate sectoral prices:

$$\boldsymbol{\pi}_t = \rho\mathbb{E}_t[\boldsymbol{\pi}_{t+1}] + \boldsymbol{\Gamma}(\mathbf{p}^f_t - \mathbf{p}_t), \qquad \mathbf{p}^f_t \equiv m_t\mathbf{1} + (\mathbf{I}-\mathbf{A})^{-1}(\boldsymbol{\omega}_t - \boldsymbol{z}_t), \qquad \boldsymbol{\Gamma} \equiv (\boldsymbol{\Theta}^{-1}-\mathbf{I})(\mathbf{I}-\rho\boldsymbol{\Theta})(\mathbf{I}-\mathbf{A}) \tag{9}$$

where $\mathbf{p}^f_t$ is the vector of equilibrium prices in a counterfactual economy with fully flexible prices with the same monetary policy and $\boldsymbol{\Gamma}$ is a matrix of parameters that is a function of the input-output matrix $\mathbf{A}$ and the price stickiness matrix $\boldsymbol{\Theta}$. Note that $\mathbf{p}^f_t$ is affected by sector specific shocks, $\boldsymbol{\omega}_t - \boldsymbol{z}_t$.

We can interpret Equation (9) as the system of sectoral Phillips curves in the economy. To further illustrate this, noting that the CPI index is the expenditure-weighted average of the vector $\mathbf{p}_t$; i.e., $p_t = \boldsymbol{\beta}^\intercal\mathbf{p}_t$, we can write Equation (9) Phillips curve as

$$\boldsymbol{\pi}_t = \rho\mathbb{E}_t[\boldsymbol{\pi}_{t+1}] - \boldsymbol{\Gamma}(\mathbf{q}_t - \mathbf{q}^f_t) + \boldsymbol{\Gamma}\mathbf{1}\tilde{y}_t \tag{10}$$

where $\mathbf{q}_t \equiv \mathbf{p}_t - p_t\mathbf{1}$ is the vector of sectoral prices relative to CPI, and $\mathbf{q}^f_t$ is its analog in the

counterfactual economy with fully flexible prices.

Finally, multiplying this equation by $\boldsymbol{\beta}^\intercal$ from the left gives us the aggregate Phillips curve that we presented in Equation (1)

$$\pi_t = \rho \mathbb{E}_t[\pi_{t+1}] - \boldsymbol{\beta}^\intercal \boldsymbol{\Gamma}(\mathbf{q}_t - \mathbf{q}_t^f) + \boldsymbol{\beta}^\intercal \boldsymbol{\Gamma} \mathbf{1} \tilde{y}_t \tag{11}$$

which shows a key theoretical property of our model: aggregate inflation dynamics are not solely determined by the aggregate GDP gap, but also depend on relative price changes, and specifically, they depend on the relative price gap, $\mathbf{q}_t$ - $\mathbf{q}_t^f$.[7] We next discuss the *economic reasons* for why the relative price gap shows up in the aggregate Phillips curve, Equation (11), of our economy and also elaborate on the implications.

2.3. Discussion of why relative price gaps appear in the Phillips curves

Equation (10) shows that in our network economy with potentially heterogeneous price stickiness across sectors, relative price distortions affect sectoral inflation dynamics independently of the GDP gap. For instance, even if monetary policy were to fully stabilize the GDP gap ($\tilde{y}_t = 0$), inflation rates across sectors would still vary until *relative prices* are at their flexible levels.

The $\boldsymbol{\Gamma}$ matrix determines the effect of relative price distortions on inflation dynamics. Moreover, this implies that any two economies with the same $\boldsymbol{\Gamma}$ matrix deliver the same inflation dynamics, irrespective of whether it reflects heterogeneous price stickiness as in Aoki (2001), Benigno (2004) or production linkages across sectors as in our model. Equation (10) also clarifies the new forces that are introduced through production networks. Multi-sector models without production linkages restrict $\boldsymbol{\Gamma}$ to be a diagonal matrix, implicitly assigning the most sticky sectors as the drivers of inflation persistence. With production linkages, $\boldsymbol{\Gamma}$ can be non-diagonal, which captures the indirect effects of price stickiness across sectors on inflation persistence through production linkages.

On implications for aggregate inflation dynamics, which is given in Equation (11), note that since $\boldsymbol{\Gamma}$ is invertible, the only model where the aggregate Phillips curve can be written with just inflation and output gap is one where the expenditure share $\boldsymbol{\beta}$ is a left eigenvector of the $\boldsymbol{\Gamma}$ matrix. This represents a very stringent restriction on price stickiness and production linkages across sectors. Two clear examples of such economies are (a) the one-sector economy and (b) multi-sector economies with *both* no production linkages ($\mathbf{A} = \mathbf{0}$) *and* homogeneous price stickiness ($\boldsymbol{\Theta} = \bar{\theta}\mathbf{I}$).

[7] Equation (10) and Equation (11) are a different representation compared to the corresponding ones in Rubbo (2023), which are Equation (22) and Equation (23) in that paper. The key differences are first, in both Equation (10) and Equation (11), we write in terms of the relative price gap, $\mathbf{q}_t$ - $\mathbf{q}_t^f$, and second, Equation (11) is written in terms of the same aggregate inflation measure, the rate of change of the CPI index, on both sides of the expression.

3 Empirics

We now present some empirical evidence on relative price changes affecting aggregate inflation and real activity in the U.S. We start with relative price of energy shocks and then move on to global supply chain shocks.

3.1. Effects of relative price of energy shocks

3.1.1. Specification. Our empirical approach, which we describe in detail in the Appendix, employs a local projection instrumental variables (LP-IV) technique. We instrument relative PCE energy prices (which are PCE energy prices relative to PCE core prices) in the U.S. with the oil supply news shock of Kanzig (2021) and estimate dynamic effects of these exogenous changes in relative PCE energy prices on PCE headline and core inflation. In addition, we also estimate effects on measures of real activity such as the unemployment rate and (real) consumption.

3.1.2. Results. The first row of Figure 2 shows impulse responses of U.S. headline inflation and core inflation to an exogenous increase in the relative price of energy, where the oil supply news shock of Kanzig (2021) is the IV.[8] We observe that relative energy price shocks lead to an increase in not just headline inflation, but also core inflation. The positive effects on core inflation depict how these shocks have second-round pass-through effects on various sectors in the economy since measures of core inflation deliberately exclude the direct effect of energy prices. The peak effects of these relative energy price shocks happen fairly quickly, even on core inflation. Moreover, the initial effects are also significant. This is indeed what our model predicts given that the oil and energy sector is a relatively flexible price sector, which leads to immediate, but transient, effects on prices.

The second row of Figure 2 shows that these shocks cause a contraction in economic activity, as after some delay, the unemployment rate increases while (real) consumption expenditure decreases. The effects build up slowly and peak around 24 months. Taken together, the two rows of Figure 2 show that relative price of energy shocks act like negative aggregate supply shocks.

Figure 2 is based on using data for the full sample period, 1975:01-2022:12.[9] Figures 3 and 4 below shows results for two alternate sample periods, from 1981:01-2020:01 and 2008:01-2022:12 respectively. These show that the results, both on inflationary effects as well as on an eventual economic contraction, are robust to excluding the large oil price shocks of the 1970s and the pandemic period and to focusing only on the time period following the financial crisis.

[8] The responses are of the inflation rate in the future compared to the initial period for a one percent initial period increase in the relative price of energy.

[9] Our estimation sample starts at 1975:01 because the oil news supply shock from Kanzig (2021) that we use as an IV starts in 1975:01.

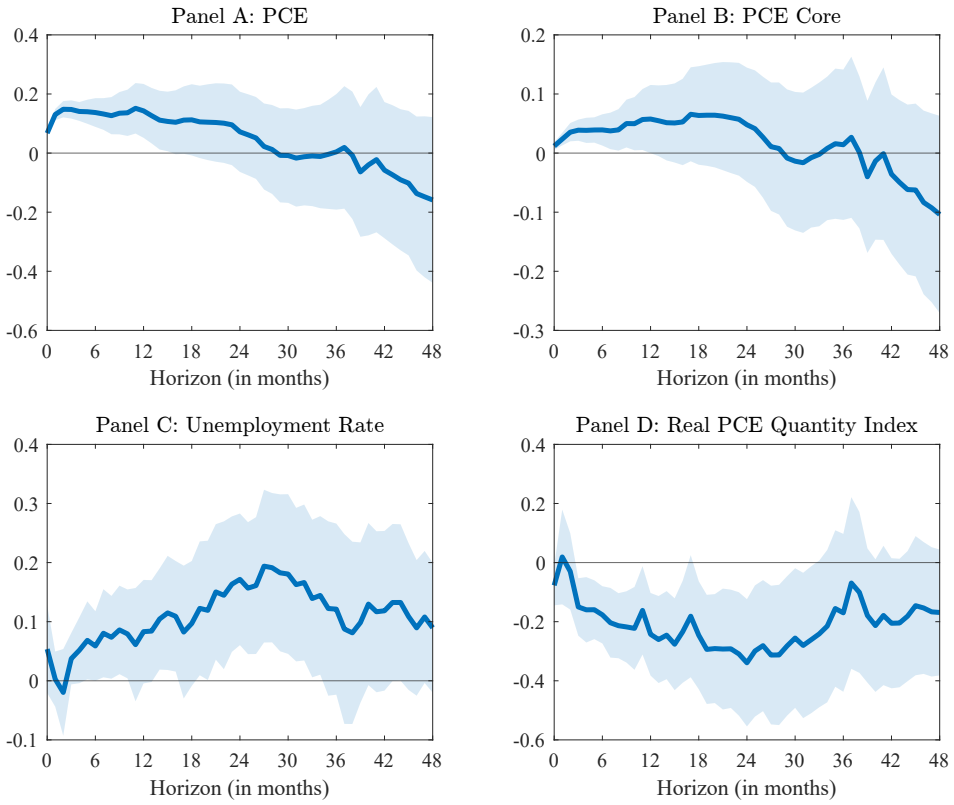


Figure 2: Impulse responses to a shock to the relative price of energy

Notes: This figure plots impulse responses of PCE headline inflation, PCE core inflation, the unemployment rate, and the real PCE quantity index. The shock is to the relative price of energy. Sample period: 1975:01 - 2022:12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

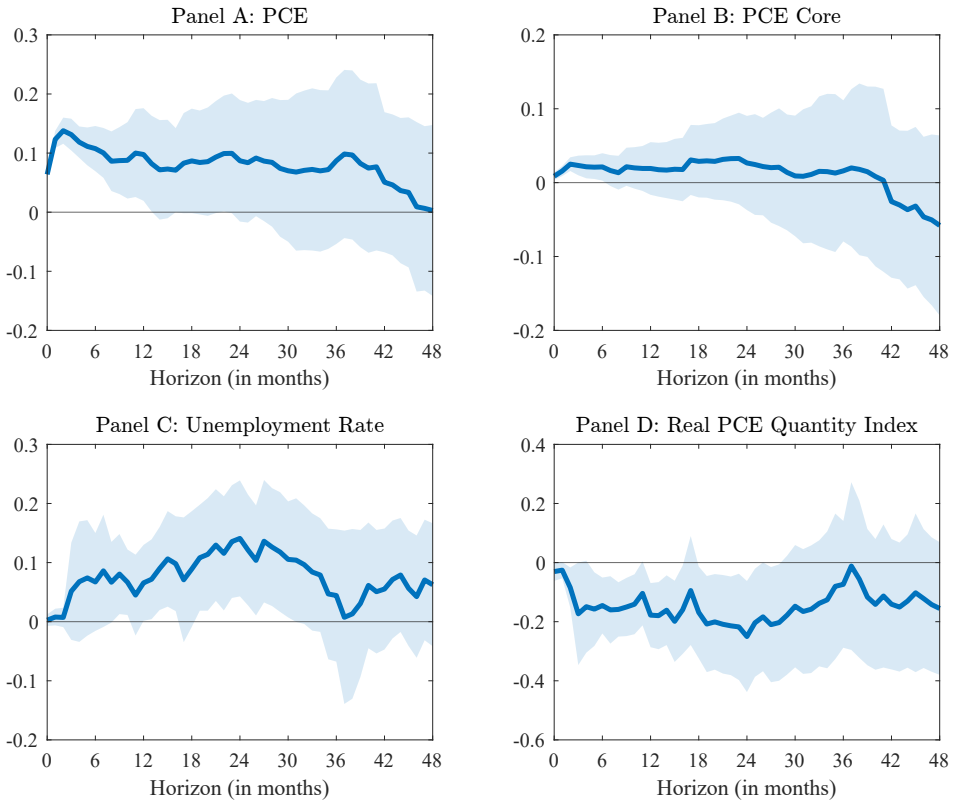


Figure 3: Impulse responses to a shock to the relative price of energy

Notes: This figure plots impulse responses of PCE headline inflation, PCE core inflation, the unemployment rate, and the real PCE quantity index. The shock is to the relative price of energy. Sample period: 1981:01 - 2020:01. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

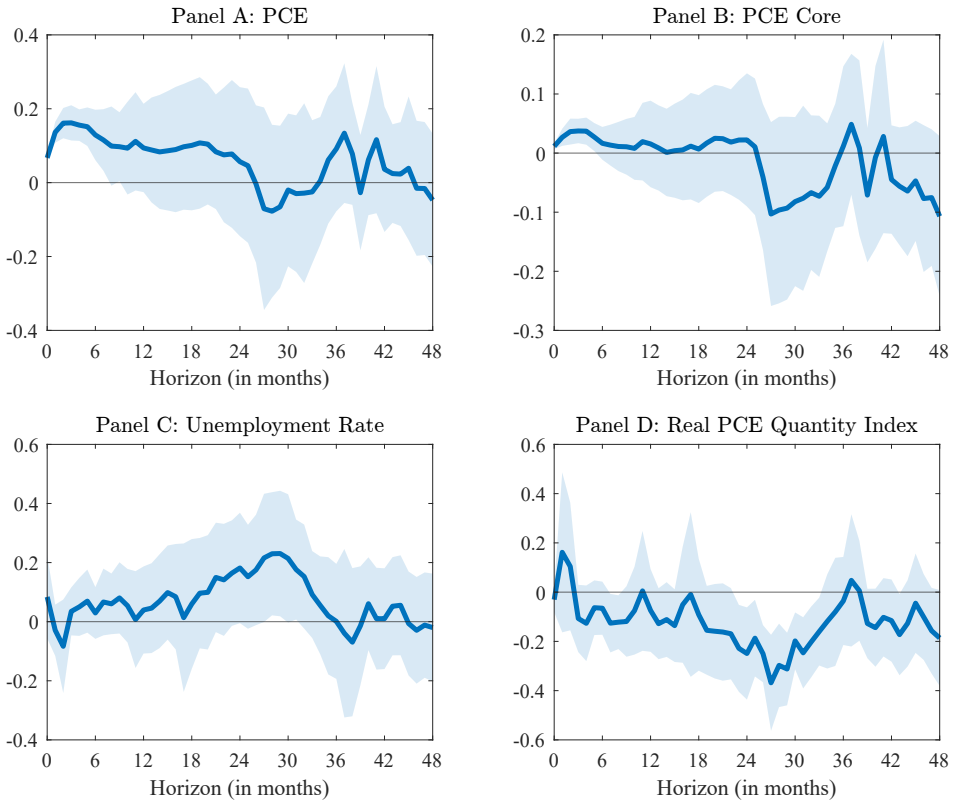


Figure 4: Impulse responses to a shock to the relative price of energy

Notes: This figure plots impulse responses of PCE headline inflation, PCE core inflation, the unemployment rate, and the real PCE quantity index. The shock is to the relative price of energy. Sample period: 2008:01 - 2022:12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

In addition, Figure 2 is based on a specification that does not use additional variables as controls. Figure A1 in the Appendix reports results where we use lagged real wages as controls. Comparing Figure 2 with Figure A1 shows that the results are robust.

3.2. Effects of global supply chain shocks

3.2.1. Specification. Our empirical approach, which we describe in detail in the Appendix, employs a local projection (LP) technique. We estimate dynamic effects of innovations to the global supply chain pressure index on import inflation, PCE goods and services inflation, the unemployment rate, and various measures of (real) consumption.

3.2.2. Results. The first row of Figure 5 shows impulse responses of import price inflation, for total imports and excluding petroleum imports, to an exogenous increase in the global supply chain pressure index.[10] Import prices go up even when excluding petroleum imports. The second and third row of Figure 5 present impulse responses of various PCE inflation measures and they show that global supply chain shocks lead an increase in various consumer prices. These shocks have a particularly strong effect on PCE goods price inflation, for both non-durables and durables. Finally, these shocks also increase PCE service prices after a delay.

Comparing the economic magnitudes, as is intuitive, the effects in Figure 5 are largest on import prices followed by goods and service prices. The effects on non-durables and durables good inflation are comparable in magnitude with the main difference that the peak effect on durables good inflation occurs a bit later than that on non-durables good inflation, as expected. Moreover, the peak effects in all cases happen after a delay, as supply chain pressures work through the production network of the economy. Thus price increases build up over time and peak around 24 months or later. This contrasts with the immediate, but more transient, effect on prices for the case of the relative price of energy shock that we presented earlier in Figure 2.

Figure 6 shows the responses of various measures of real economic activity to the global supply chain shock. The results are noisy, but after some delay, there is a mild contraction in real consumption, in particular of service consumption. The responses of inflation and consumption together show that these global supply chain shock also do act like negative aggregate supply shocks.

Figures 5 and 6 are based on using data for the full sample period, 1998:01 - 2022:12. Figures 7 and 8 below shows results for an alternate time period, 1998:01 - 2020:01. These show that the results are robust to excluding the large supply chain disruptions of the Covid period. One interesting

[10]The responses are of the inflation rate in the future compared to the initial period for a one unit initial period increase in the global supply chain pressure index. Note that one unit increase in the global supply chain pressure index represents a one standard deviation increase from the mean.

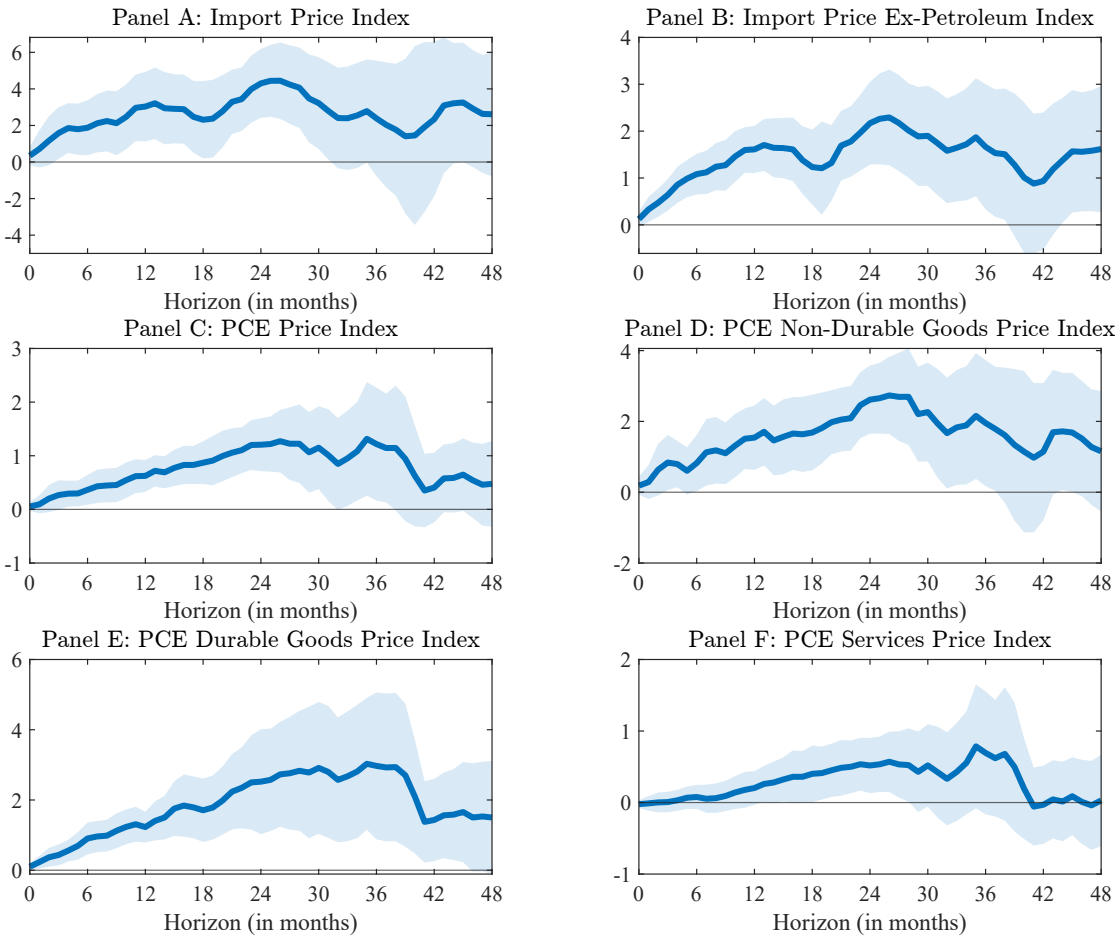


Figure 5: Impulse responses to a shock to the global supply chain pressure index

Notes: This figure plots impulse responses of import price index (total and excluding petroleum) inflation, PCE inflation, PCE (non-durable and durable) goods inflation, and PCE services inflation. The shock is to the global supply chain pressure index. Sample period: 1998:01 - 2022:12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

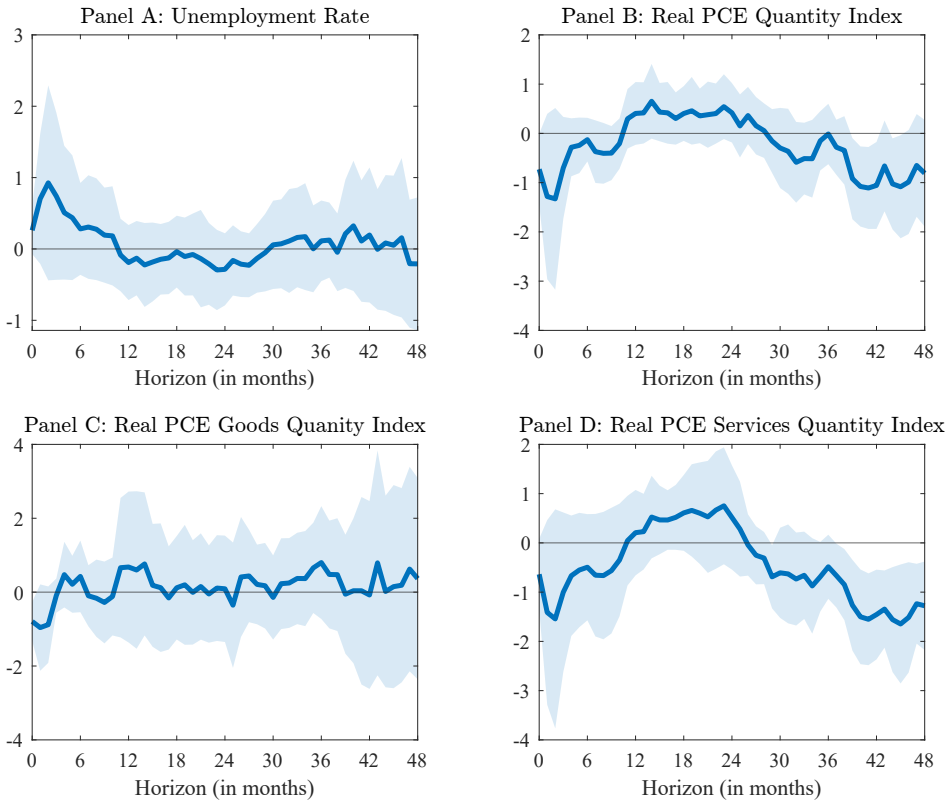


Figure 6: Impulse responses to a shock to the global supply chain pressure index

Notes: This figure plots impulse responses of the unemployment rate, the real PCE quantity index, the real PCE goods quantity index, and the real PCE services quantity index. The shock is to the global supply chain pressure index. Sample period: 1998:01 - 2022:12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

qualitatively different result to note is that now in Figure 7, the effects on service inflation are not statistically significant. Given that the service sector has more sticky prices, this reflects the limited pass-through of smaller shocks that occur during this sub period. Quantitatively, the effects on durable goods inflation are slightly smaller in magnitude in Figure 7 compared to Figure 5. Moreover, quantitatively, the negative effects on real consumption are stronger and more robust in Figure 8 compared to Figure 6.

In addition, Figures 5 and 6 are based on a specification that does not use additional variables as controls. Figures A2 and A3 in the Appendix reports results where we use lagged real wages as controls. Comparing Figures 5 and 6 with Figures A2 and A3 shows that the results are robust.

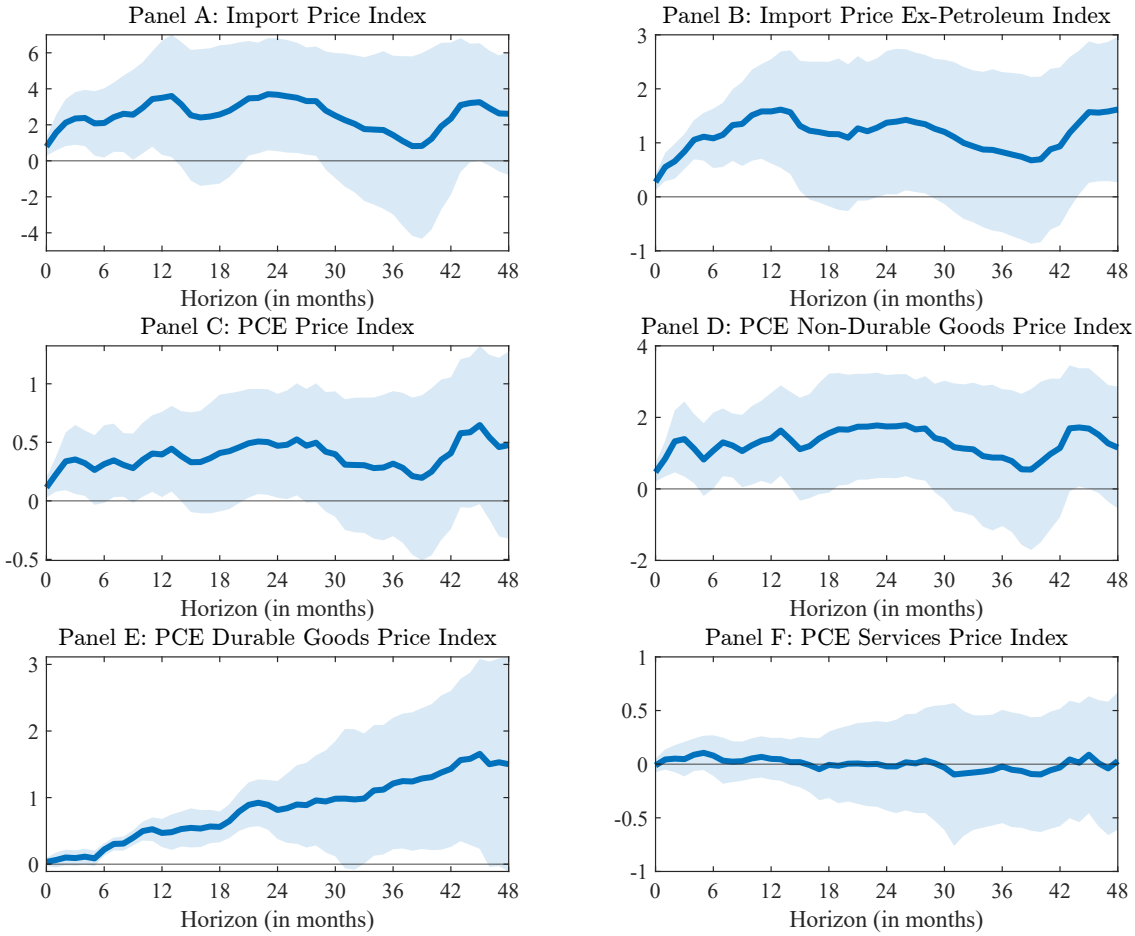


Figure 7: Impulse responses to a shock to the global supply chain pressure index

Notes: This figure plots impulse responses of import price index (total and excluding petroleum) inflation, PCE inflation, PCE (non-durable and durable) goods inflation, and PCE services inflation. Sample period: 1998:01 - 2020:01. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

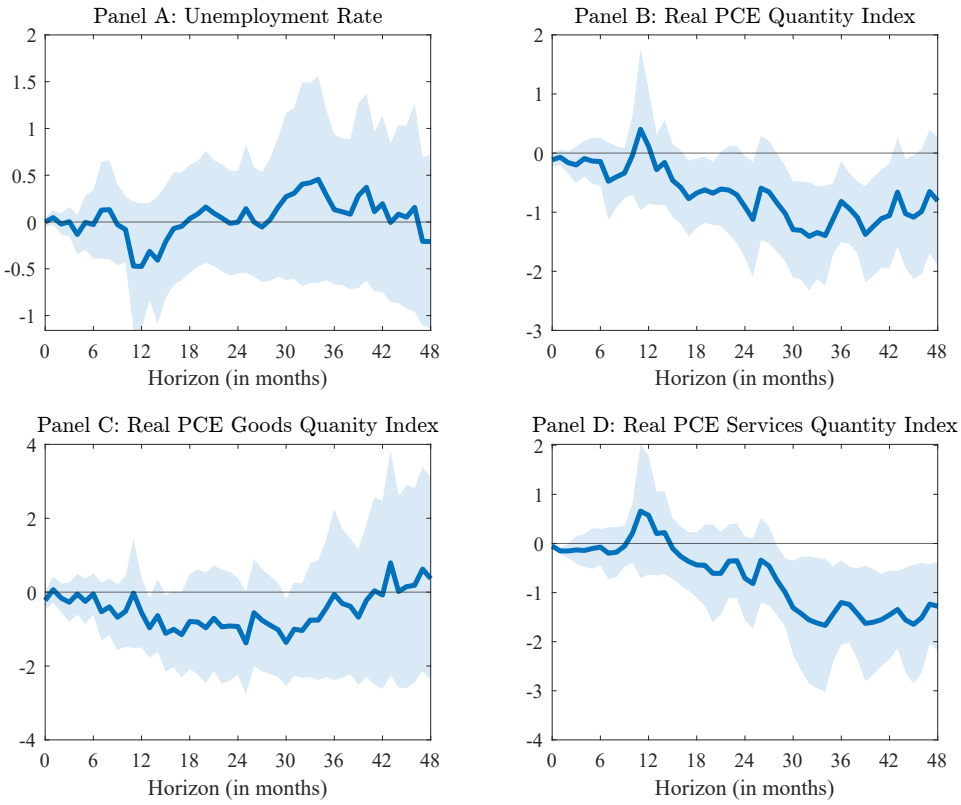


Figure 8: Impulse responses to a shock to the global supply chain pressure index

Notes: This figure plots impulse responses of the unemployment rate, the real PCE quantity index, the real PCE goods quantity index, and the real PCE services quantity index. The shock is to the global supply chain pressure index. Sample period: 1998:01 - 2020:01. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

4 Further Analyses

Building on these preliminary results, we will undertake several detailed additional analyses in the final version of the paper. Theoretically, we will solve in closed-form a simplified two sector model with production networks and heterogeneous price stickiness to show the general equilibrium implications of relative price shocks. For instance, one determinant of general equilibrium effects will be the monetary policy rule. These will include predictions not just for sectoral inflation, but also for sectoral consumption or GDP. This latter component will be one of the distinctions from the analysis in Afrouzi and Bhattarai (2023). We will then use the model solution and impulse responses to interpret the empirical impulse responses to relative price of energy and supply chain shocks.

Empirically, we will assess the effects of the two shocks on much more dis-aggregated (by sectors) prices and consumption, which will help test more precisely the model mechanisms. In addition, we will investigate how sectoral characteristics, such as its intermediate input share and price stickiness, determine the extent of pass-through to sectoral inflation of oil price shocks and supply chain disruptions. That is, we will use the model predictions to investigate what determines heterogeneous pass-through across sectors of these shocks. Finally, we will use empirical estimates from the pre-Covid time period to predict and account for aggregate and sectoral inflation dynamics in the post-Covid time period.

References

Afrouzi, H. and S. Bhattarai (2023). Inflation and GDP Dynamics in Production Networks: A Sufficient Statistics Approach. *NBER Working Paper No. 31218*.

Aoki, K. (2001). Optimal Monetary Policy Responses to Relative-Price Changes. *Journal of Monetary Economics 48*(1), 55–80.

Ball, L. and N. G. Mankiw (1995, 02). Relative-Price Changes as Aggregate Supply Shocks. *The Quarterly Journal of Economics 110*(1), 161–193.

Benigno, P. (2004). Optimal Monetary Policy in a Currency Area. *Journal of International Economics 63*(2), 293–320.

Kanzig, D. R. (2021, April). The Macroeconomic Effects of Oil Supply News: Evidence from OPEC Announcements. *American Economic Review 111*(4), 1092–1125.

Rubbo, E. (2023). Networks, Phillips curves, and Monetary policy. *Econometrica 91*(4), 1417–1455.

Woodford, M. (2003). *Interest and Prices: Foundations of a Theory of Monetary Policy*. Princeton, NJ: Princeton University Press.

5 Appendix

5.1. Data and sources

Variable	Source	Series Code
PCE Price Index	St. Louis FRED	PCEPI
PCE Core Price Index	St. Louis FRED	PCEPILFE
PCE Energy Price Index	St. Louis FRED	DNRGRG3M086SBEA
Unemployment Rate	St. Louis FRED	UNRATE
Real PCE Quantity Index	St. Louis FRED	DPCERA3M086SBEA
Import Price Index	St. Louis FRED	IR
Import Price Ex-Petroleum Index	St. Louis FRED	IREXPET
Average hourly earnings	St. Louis FRED	AHETPI
PCE Durable Goods Price Index	St. Louis FRED	DDURRG3M086SBEA
PCE Non-Durable Goods Price Index	St. Louis FRED	DNDGRG3M086SBEA
PCE Goods Price Index	BEA: Table 2.4.4U.	
PCE Services Price Index	BEA: Table 2.4.4U.	
Real PCE Goods Quantity Index	BEA: Table 2.8.3.	
Real PCE Services Quantity Index	BEA: Table 2.8.3.	
Oli Supply News Shock	https://github.com/dkaenzig/oilsupplynews	
Global Supply Chain Pressure Index	https://www.newyorkfed.org/research/policy/gscp...	

Table A1: Variables and data used in the regressions.

5.2. Details of the local projection specification

To uncover the effect of relative price changes on aggregate inflation in the U.S., we employ a local projection instrumental variables (LP-IV) technique. We consider the effect of changes of PCE energy prices relative to PCE core prices on U.S. aggregate outcomes, instrumenting it using the oil supply news shock of Kanzig (2021).

More specifically, we run

$$\log(Y_{t+h}) - \log(Y_{t-1}) = \alpha^{(h)} + \beta^{(h)} \times \left(\log(\frac{\text{PCE energy}_t}{\text{PCE core}_t}) - \log(\frac{\text{PCE energy}_{t-1}}{\text{PCE core}_{t-1}}) \right) \tag{12}$$

$$+ \sum_{k=1}^{K} \gamma_k^{(h)} \left(\log(Y_{t-k}) - \log(Y_{t-k-1}) \right) \tag{13}$$

$$+ \sum_{k=1}^{J} \zeta_k^{(h)} \left(\log(\frac{\text{PCE energy}_{t-k}}{\text{PCE core}_{t-k}}) - \log(\frac{\text{PCE energy}_{t-k-1}}{\text{PCE core}_{t-k-1}}) \right) + \varepsilon_t \tag{14}$$

where Y_t is the outcome of interest and $\beta^{(h)}$ is the parameter of interest. We use the following outcome variables: headline PCE, PCE core, Unemployment Rate, and (real) PCE consumption. We retrieve these data from the St. Louis FRED. For the unemployment rate, we did not take its log. We use $K = 12, J = 12$. We instrument $\log(\frac{\text{PCE energy}_t}{\text{PCE core}_t}) - \log(\frac{\text{PCE energy}_{t-1}}{\text{PCE core}_{t-1}})$ with Kanzig (2021) oil news supply shock. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area in the Figures in the text corresponds to 90% confidence intervals. The results are robust when

we also control for lagged real wages, measured as the ratio between average hourly earnings of production and nonsupervisory employees, total private and PCE core.

When we consider the global supply chain shocks, we use the New York Fed Global Supply Chain Pressure Index in level instead of $\log(\frac{\text{PCE energy}_t}{\text{PCE core}_t}) - \log(\frac{\text{PCE energy}_{t-1}}{\text{PCE core}_{t-1}})$ as the independent variable. Also in this case, we run the standard local projections without any instrument. More specifically, we run

$$100 \times \log(Y_{t+h}) - 100 \times \log(Y_{t-1}) = \alpha^{(h)} + \beta^{(h)} \times \text{GSCPI}_t \tag{15}$$

$$+ \sum_{k=1}^{K} \gamma_k^{(h)} \Big(\log(Y_{t-k}) - \log(Y_{t-k-1}) \Big) \tag{16}$$

$$+ \sum_{k=1}^{J} \zeta_k^{(h)} \text{GSCPI}_{t-k} + \varepsilon_t \tag{17}$$

where Y_t is the outcome of interest and $\beta^{(h)}$ is the parameter of interest. We use the following outcome variables: import price index, PCE headline, PCE price index, PCE goods price index, PCE services price index, unemployment rate, real PCE quantity index, real PCE goods quantity index, and real PCE services quantity index. For the unemployment rate, we did not take its log. We use $K = 12, J = 12$. The results are robust when we also control for lagged real wages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area in the Figures in the text corresponds to 90% confidence intervals.

5.3. Additional results

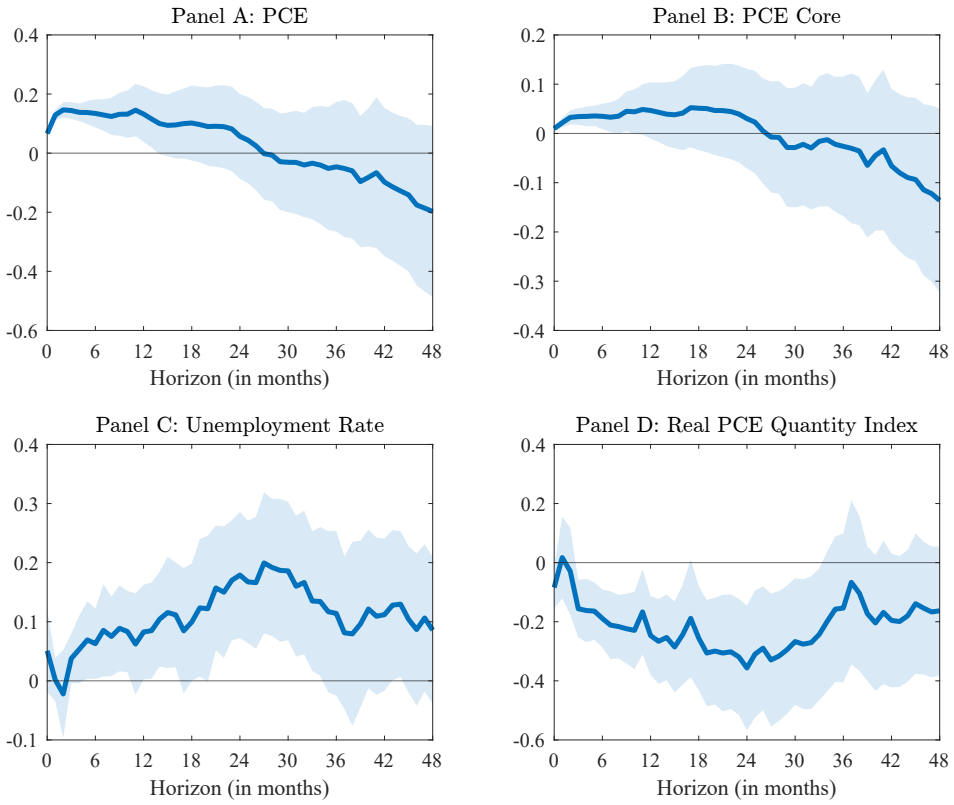


Figure A1: Impulse responses to a shock to the relative price of energy

Notes: This figure plots impulse responses of PCE headline inflation, PCE core inflation, the unemployment rate, and the real PCE quantity index. The shock is to the relative price of energy. The specification uses lagged real wages as controls. Sample period: 1975M01 - 2022M12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

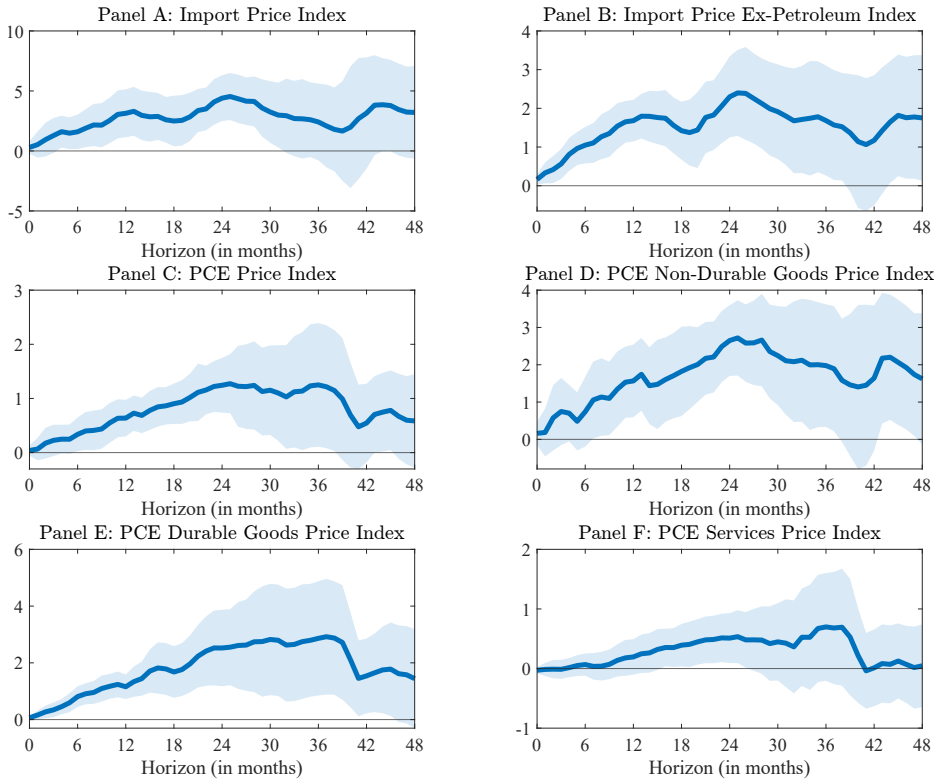


Figure A2: Impulse responses to a shock to the global supply chain pressure index

Notes: This figure plots impulse responses of import price index (total and excluding petroleum) inflation, PCE inflation, PCE (non-durable and durable) goods inflation, and PCE services inflation. The shock is to the global supply chain pressure index. The specification uses lagged real wages as controls. Sample period: 1998:01 - 2022:12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.

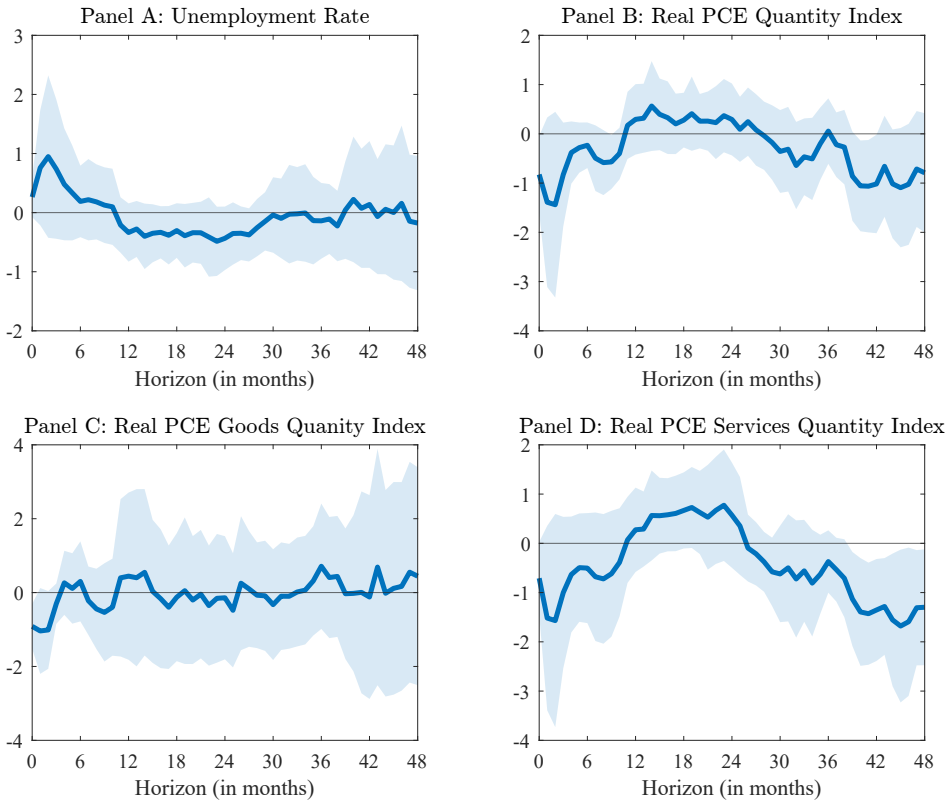


Figure A3: Impulse responses to a shock to the global supply chain pressure index

Notes: This figure plots impulse responses of the unemployment rate, the real PCE quantity index, the real PCE goods quantity index, and the real PCE services quantity index. The shock is to the global supply chain pressure index. The specification uses lagged real wages as controls. Sample period: 1998:01 - 2022:12. The units are percentages. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 90% confidence intervals.