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

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This Version: April 30, 2024

Abstract

We provide theory and evidence that relative price shocks can lead to aggregate inflation and act like aggregate supply shocks. We show empirically that exogenous and positive oil price shocks have a positive impact not only on headline U.S. inflation but also on core U.S. inflation and a negative impact on U.S. real activity. We use a multi-sector monetary model with arbitrary input-output linkages and heterogeneity in price stickiness and analytically characterize how sectoral shocks propagate to the aggregate economy and across sectors. We empirically validate our analytical characterization using panel IV local projections, by showing that the responsiveness of sectoral prices to oil price shocks is in line with what is predicted by our analytical results. To highlight the importance of input-output linkages and heterogeneity of price stickiness in the dynamics and persistence of aggregate inflation, we perform an experiment in our model using the aftermath of COVID-19 to show that even in the absence of aggregate slack, relative price changes can generate persistent aggregate inflation movements and match the behavior of headline and core inflation. We also show the critical role played by monetary policy in the transmission of these relative price changes to the aggregate economy.

JEL Codes: E32, E52, C67
Key Words: Relative Price Changes, Aggregate Supply Shocks, Oil Price Shocks, Input-Output Linkages, Core Inflation, Post-Covid Inflation

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[*] We thank Larry Ball and Felipe Schwartzman for very helpful comments. We thank Raphael Schoenle for generously sharing data on frequency of price adjustment across U.S. sectors.

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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 middle 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 middle 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. Finally, the bottom panel of Figure 1 shows how monetary policy kept interest rates low and stable for an extended period during the run-up of inflation and that after raising it, the unemployment rate, one of the most important measures of aggregate slack in the economy, remained remarkably stable.

But how can relative price changes cause aggregate inflation? This is especially puzzling because in simple multi-sector models (with no cross-sector input-output linkages and no heterogeneity in price stickiness), 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 only involves the 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 two-sector monetary model with input-output linkages where a downstream sector uses the other sector's output as a production input, and where sectors differ in the duration of nominal price changes. We show that in such an environment, aggregate inflation dynamics are determined through a Phillips curve that involves not just the aggregate GDP gap, but also relative (across sectors) price gaps.

We show analytically that 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

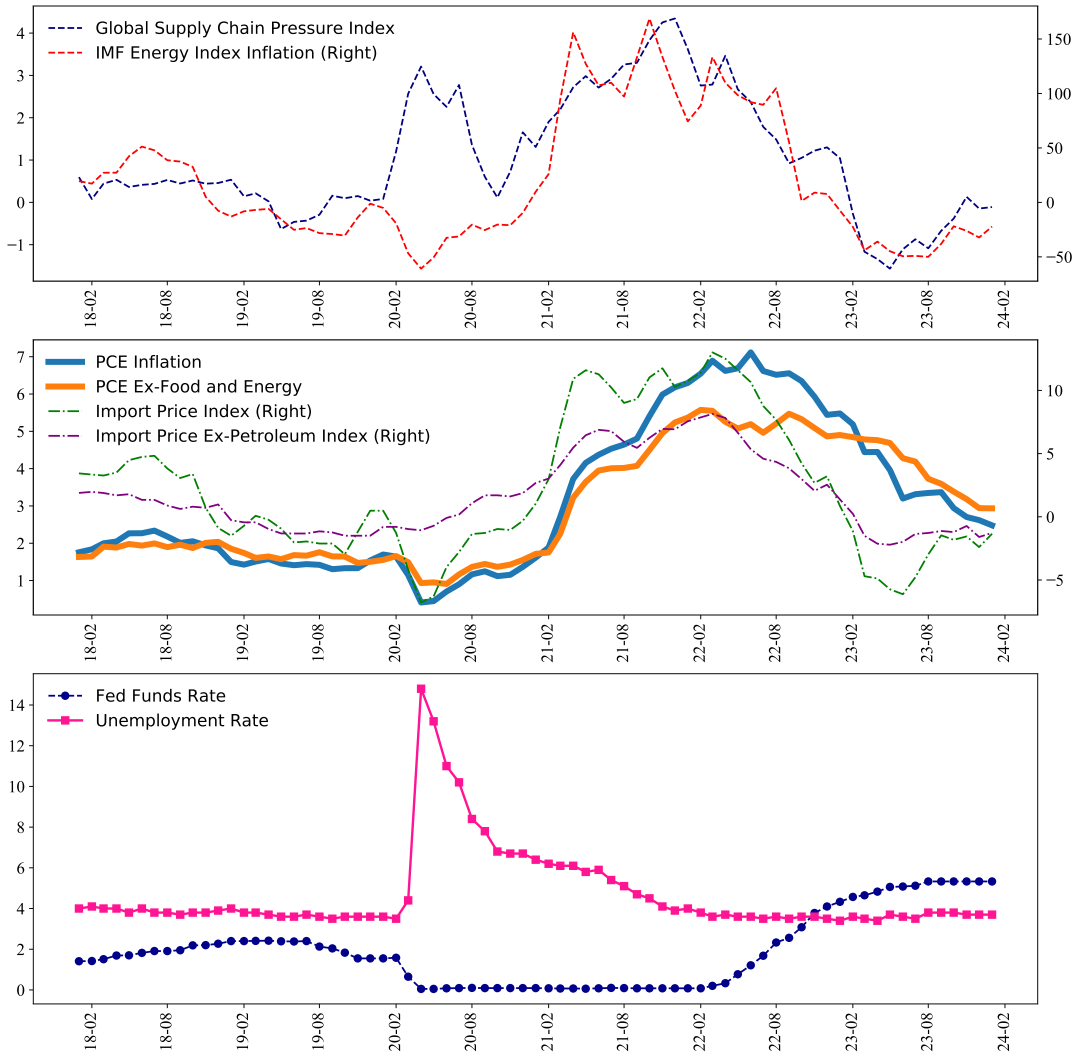

Figure 1: Recent evolution of prices, interest rates, and unemployment rate

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. It also plots the Federal funds rate and the unemployment rate. The time period is 2018:01-2024:01. The units are percentages for inflation measures and for unemployment rate. 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.

constant.[1]

We solve our two-sector model in closed form to further illustrate how shocks to the upstream sector propagate to aggregate and sectoral inflation. While solving for equilibrium, it is essential to take a stance on monetary policy reaction and we provide results that can accommodate various monetary policy rules. Our key result is that an exogenous increase in relative price of the upstream sector passes through to the downstream sector and generates inflation due to input output linkages. Moreover, this inflationary pass-through to the downstream sector is greater if the input share of the upstream sector is larger and it is more persistent (compared to the inflation persistence in the upstream sector) if the downstream sector has greater price stickiness.

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 producer prices in the energy sector in the U.S. have a significant positive effect not only on headline inflation, but also on core inflation.[2] 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.These same shocks cause a contraction in real activity as they decrease real consumption and increase the unemployment rate. 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.[3]

Second, we show that exogenous oil price shocks that drive up producer prices in the energy sector in the U.S. have heterogeneous effects on consumer prices across various sectors. Our empirical framework is a panel local projection with instrumental variables. Using the predictions from the model on a sufficient statistic for sectoral characteristics that drive such heterogeneous effects, we show that indeed our empirical results are consistent with the theoretical predictions. In particular, the pass-through of relative price of energy to consumer prices is higher for sectors that have a greater input share of energy and lower for sectors that have more rigid prices.

Finally, to highlight the importance of input-output linkages and heterogeneity of price stickiness in the dynamics and persistence of aggregate inflation, we perform an experiment in a calibrated version of our model using the aftermath of COVID-19 to show that even in the absence of aggregate slack, relative price changes can generate persistent aggregate inflation movements.

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[1] The mechanism in Ball and Mankiw (1995) is however, different from the one in our paper.

[2] We isolate exogenous variation in producer prices of the energy sector in the U.S. using the oil supply news shock of Kanzig (2021) as an instrumental variable.

[3] As we show in detail later, these broad patterns are qualitatively present even if exclude the recent time period with large oil price shocks, the post-Covid period.

Moreover, our calibrated model matches well the behavior of headline and core inflation, generating patterns similar to those in the middle panel of Figure 1. Using counterfactual exercises we show how the monetary policy rules, the role of the upstream sector as a production input for the downstream sector, as well as higher price flexibility in the upstream sector all contribute to the quantitative results that enable us to match the patterns in Figure 1.

Our paper builds on multi-sector sticky price models where price stickiness is heterogeneous across sectors. Aoki (2001) and Benigno (2004) in two-sector models showed how heterogeneous price stickiness across sectors leads to a role for relative price changes on aggregate inflation 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. Moreover, in models with both sticky prices and wages (Erceg, Henderson, and Levin, 2000, Blanchard and Gali, 2007, Gali, 2008, Lorenzoni and Werning, 2023), the real wage gap plays a similar role to that played by the relative price gap in our model. The continuous time sticky price and wages model in Lorenzoni and Werning (2023) has a particularly similar structure to our model. We do not model sticky wages or multiple production factors, but instead focus on understanding the role of across sector input-output linkages in a simple model where analytical results are derived under various monetary policy rules.

Some recent papers study quantitative implications of sectoral shocks in multi-sector models. For instance, Ruge-Murcia and Wolman (2022) considers a multi-sector model with sectoral shocks and assesses the role of relative price changes in a model without input-output linkages while Carvalho, Lee, and Park (2021) study propagation of sectoral shocks in a model with sectoral heterogeneity in price stickiness and a round-about production structure. Our focus in this paper is on how transition dynamics of relative prices can lead to aggregate and sectoral inflation dynamics similar to what we observed in the post-Covid period after we allow for the roles of both heterogeneous price stickiness and a distinct upstream sector.

Our paper is also closely related to previous work on multi-sector models with production networks and nominal rigidities, such as Pasten, Schoenle, and Weber (2020), La'O and Tahbaz-Salehi (2022), Rubbo (2023), and Afrouzi and Bhattarai (2023). Our model in this paper is simpler, with two sectors, as it is specifically tailored to understanding post-Covid inflation dynamics in a highly transparent set-up. Our theoretical contribution is the focus on the interaction of transition dynamics of relative prices and monetary policy in generating differential aggregate and sectoral inflation dynamics. We also provide empirical support for the model predictions, especially with regards to heterogeneous effects across sectors of a relative price of energy shock, using dis-aggregated sectoral price data.

On the empirical front, our paper is also related to Minton and Wheaton (2023) who explore the effects of oil shocks on sectoral *producer* prices using the Kanzig (2021) shock as an IV for oil prices and estimate how the heterogeneous effects are governed by sectoral characteristics. Our analysis is different, and is thus complementary to their results, in three dimensions. First, we specifically use the closed-form solution for the sectoral statistic that should be the determinant of this pass-through according to our model, which is a specific interaction of price stickiness and input-output linkages. Second, we use the Kanzig (2021) shock as an IV for (relative) *producer prices of energy*. Third, using this IV strategy, we estimate the pass-through from (relative) producer price of energy to *consumer prices*.

2 Model and Theoretical Results

We base our analysis on the theoretical model of Afrouzi and Bhattarai (2023), which is a multi n-sector New Keynesian model with arbitrary production linkages, heterogeneous price stickiness across sectors, and both aggregate and sectoral shocks. Here, we consider a special case with two sectors: "Upstream" (e.g., energy) and "Downstream" (e.g., core) where, in particular, the core sector uses the upstream sector's output as an input.

Thus, the model we consider here is a very special case of the model in Afrouzi and Bhattarai (2023); however, this special case allows us to go much further in deriving analytical representations for the particular set of questions that motivate this study. In particular, we use this special framework to rigorously study (1) the mechanisms for how shocks to upstream but flexible sectors can cause persistent spillover inflation in downstream but sticky sectors, and (2) how different monetary policies can accommodate or mitigate such inflationary pressures.

In the rest of this section, we briefly describe the precise environment of our model, and then discuss the economic mechanisms that drive the role of the relative price changes in determining aggregate inflation.[4]

2.1. Short description of the model

Time is continuous and runs forever. The economy consists of a representative household that consumes an aggregate basket of goods produced by two sectors: "upstream" (Sector 1) and "downstream" (Sector 2). The aggregate consumption of this household is defined by an aggregation of

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[4] For a detailed description of this model in a general set-up, see Afrouzi and Bhattarai (2023).

these products, denoted by

$$C_t = \left(\frac{C_{1,t}}{\beta}\right)^{\beta}\left(\frac{C_{2,t}}{1-\beta}\right)^{1-\beta}$$

Given a vector of prices $(P_{1,t}, P_{2,t})$ for the sectoral goods, the aggregate consumption bundle is priced at

$$P_t = P_{1,t}^{\beta} P_{2,t}^{1-\beta}$$

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 $W_t = M_t \equiv P_t C_t$. In log-linearized terms, this implies that, with perfect foresight, the household's inter-temporal Euler equation can be written as

$$i_t = \dot{c}_t + \pi_t = \dot{m}_t \tag{1}$$

where $\pi_t = \partial_t \ln(P_t)$ is the instantaneous inflation rate, i_t is the nominal interest rate, and $\dot{c}_t$ and $\dot{m}_t$ are the growth rate of log consumption and log nominal demand, respectively. Moreover, with no investment, government 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 $i \in \{1,2\}$ 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. Poisson rate of $\theta_i > 0$. 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 $i \in \{1,2\}$, 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.

For any $i, j \in \{1,2\}$, we let a_{ij} denote the expenditure share of firms in sector i on the final good of sector j. In our two-sector economy with only one upstream sector, this structure is summarized by three shares: a_{11} and a_{22}, which capture the expenditure shares of firms from their own sectors' final good, and importantly, a_{21}, which captures the expenditure share of firms in the downstream sector from the final good of the upstream sector.

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

$$mc_{i,t} = \alpha_i m_t + a_{ii} p_{i,t} + a_{i,-i} p_{-i,t} - z_{i,t} \tag{2}$$

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, $m_t = w_t$ is the nominal wage coinciding with nominal aggregate demand, $a_{i,-i}$ is the expenditure share of sector i from the other sector (a_{21} for $i = 2$ and 0 for $i = 1$), $p_{i,t}$ is the sector i's own final good price, and $p_{-i,t}$ is the final good price of the other sector. Constant returns to scale implies $\alpha_i + a_{i,-i} = 1$ for $i \in \{1,2\}$.

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* 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 terms, 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 the following (forward-looking) differential equation under perfect foresight

$$\dot{p}^{\#}_{i,t} = (\rho + \theta_i)(p^*_{i,t} - p^{\#}_{i,t}) \tag{4}$$

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 evolves according to the following (backward-looking) differential equation

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

with the initial price level at time 0, $p_{i,0^-}$, given. Going forward, for analytical convenience we will consider the limit where $\rho/\theta_i \to 0, \forall i \in \{1,2\}$.

2.2. Sectoral and aggregate Phillips curves

Together, Equations (2) to (5) across the two sectors characterize the supply side of the economy in terms of two *sectoral* Phillips curves:

$$\dot{\pi}_{1,t} = (1-a_{11})(1-a_{22})\lambda_2\theta_1^2 r_t - \alpha_1\theta_1^2 x_t \tag{6}$$

$$\dot{\pi}_{2,t} = -(1-a_{11})(1-a_{22})\lambda_1\theta_2^2 r_t - \alpha_2\theta_2^2 x_t \tag{7}$$

where λ_1 and λ_2 are the Domar weights of sectors 1 and 2, respectively, in the zero-inflation efficient steady-state, and are given by:

$$\begin{aligned} \lambda_1 &= \frac{1}{1-a_{11}}\left(\beta + (1-\beta)\frac{a_{21}}{1-a_{22}}\right) \\ \lambda_2 &= \frac{1-\beta}{1-a_{22}} \end{aligned} \tag{8}$$

Moreover, $r_t \equiv (p_{1,t}-p_{2,t}) - (p_{1,t}-p_{2,t})^f$ is the *relative price gap* of sector 1 to sector 2, which measures the gap between the current relative price and the flexible level of this relative price at time t, and $x_t \equiv y_t - y_t^f$ is the GDP gap of this economy. It it worth recognizing that both the flexible level of output, y_t^f, and the flexible relative price, $(p_{1,t}-p_{2,t})^f$, are independent of monetary policy due to classical dichotomy in the flexible price economy. They are given by:

$$\begin{aligned} \left(p_{1,t}-p_{2,t}\right)^f &= \frac{1}{1-a_{11}}\left(1-\frac{a_{21}}{1-a_{22}}\right)\left(\omega_{1,t}-z_{1,t}\right) - \frac{1}{1-a_{22}}\left(\omega_{2,t}-z_{2,t}\right) \\ y_t^f &= \lambda_1(z_{1,t}-\omega_{1,t}) + \lambda_2(z_{2,t}-\omega_{2,t}) \end{aligned}$$

Finally, we can combining our sectoral Phillips curves, we can also derive the *aggregate* Phillips curve of this economy as

$$\dot{\pi}_t = \underbrace{(1-a_{11})(1-a_{22})(\beta\lambda_2\theta_1^2 - (1-\beta)\lambda_1\theta_2^2)r_t}_{\text{Inflation due to relative price gaps}} - \underbrace{(\beta\alpha_1\theta_1^2 + (1-\beta)\alpha_2\theta_2^2)x_t}_{\text{Inflation due to aggregate slack}} \tag{9}$$

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, r_t. We next discuss the *economic reasons* for why the relative price gap shows up in the aggregate Phillips curve, Equation (9), of our economy and also elaborate on the implications.

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

Equations (6) and (7) show 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 ($x_t \equiv y_t - y_t^f$), inflation rates across sectors would still vary until *relative prices* are at their flexible levels.

The terms that multiply r_t determine the effect of relative price distortions on inflation dynamics, which resemble similar terms in multisector New Keynesian models as in Aoki (2001), Benigno (2004), Woodford (2003) that do not feature production networks. Equations (6) and (7) also clarify that in this simple framework, the network *amplifies* the importance of these relative price gaps as the Domar weight of each sector multiplies r_t in the sectoral Phillips curve of the *other* sector. To see why this amplifies the inflationary effects of sectoral shocks on other sectors, note that Domar weights are bounded below by the expenditure share of their sector with this inequality binding when there are no input-output linkages; i.e.,

$$\lambda_i \geq \beta_i, \forall i, \text{ with equality if } a_{i,j} = 0, \forall i, j \tag{10}$$

Thus, we see that with input-output linkages the impact of relative price gaps increases for all sectoral inflation dynamics.

Moreover, on implications for aggregate inflation dynamics shown in Equation (9), note that relative price gaps are also generally relevant except for the knife-edge case where

$$\beta \lambda_2 \theta_1^2 = (1-\beta)\lambda_1 \theta_2^2 \tag{11}$$

One special case under which this condition holds is when there are no input-output linkages $a_{i,j} = 0$, *and* all sectors have the same price stickiness $\theta_1 = \theta_2$. This is the familiar case of the standard New Keynesian model where this multi-sector economy aggregates to a single-sector economy, and where aggregate inflation is only affected by the aggregate slack in that economy.

2.4. Spillover Inflationary Effects of Relative Price Shocks

One key feature of this model is that the relative price of different sectors at time zero, r_0, is a state variable of this economy. Thus, when initial relative prices are distorted—i.e. when r_0 deviates from its steady-state level—inflation is inherently and endogenously persistent, even without any shocks.

In this section, we study this endogenous persistence within our simple two-sector input-output economy. To this end, we study this economy for a distorted value of r_0—that could stem from previous shocks that happened before time 0—and characterize the transition path of sectoral and aggregate inflation rates back to the steady state under different monetary policy regimes.

More precisely, we will generate such distortions in relative prices by considering a one-time permanent shock to the productivity of the upstream sector. To see why this constitutes a disturbance in r_0, suppose the economy is in a zero-inflation steady state at time 0, so that nominal prices are constant over time and the deviations of all objects, including r, from their steady-state values are zero. We then consider a one-time permanent, unanticipated, and negative shock to the productivity of the upstream sector. Such a shock would increase the price of the upstream sector's final good and would eventually lead to a new steady state where relative prices are different from the initial steady state. But note that from the perspective of this new steady-state, where there have been no shocks since time 0, the initial relative price gap at time 0, r_0, is distorted.

2.4.1. No Monetary Response. We start by considering a monetary policy regime that does not respond to the shock, that is, it keeps nominal demand constant ($\dot{m}_t = 0$), which implies that nominal interest rates are fixed over time, as seen from Equation (1).

Proposition 1. Suppose the economy is in a zero inflation steady state at time $t = 0$ and consider a one-time permanent shock to the productivity or the wedge of the upstream sector at that time. In the absence of any monetary policy response after the shock,

1. Inflation in the upstream sector decays at the rate of $\xi_1 = \theta_1 \sqrt{1 - a_{11}}$:

$$\left.\frac{\partial \pi_{1,t}}{\partial \pi_{1,0}}\right|_{z_1} = e^{-\xi_1 t}$$

2. Spillover inflation in the downstream sector is proportional to the input share of that sector from the upstream sector, a_{21}, positive along the whole transition path, and more persistent than inflation in the upstream sector if and only if $\xi_1 > \xi_2 \equiv \theta_2 \sqrt{1 - a_{22}}$:

$$\left.\frac{\partial \pi_{2,t}}{\partial \pi_{1,0}}\right|_{z_1} = \frac{a_{21}}{1 - a_{22}} \frac{\xi_2}{\xi_2 + \xi_1} \left(\frac{\xi_2 e^{-\xi_1 t} - \xi_1 e^{-\xi_2 t}}{\xi_2 - \xi_1} \right)$$

Proof. Considering the deviations of prices from the new steady-state after a shock to relative prices, let $p_{1,0}$ and $p_{2,0}$ denote these log-deviations of prices in sectors 1 and 2 at time 0, right after the shock. Assuming that prior to the shock to sector 1's productivity or wedge, the economy was in a steady state with zero inflation, the relationship between $p_{1,0}$ and $p_{2,0}$ is given by the input-output matrix as:

$$p_{2,0} = \frac{a_{21}}{1 - a_{22}} p_{1,0} \tag{12}$$

Given that prices are sticky, we are interested in how prices in sectors 1 and 2 start from these values and converge to the steady state. Assuming that monetary policy does not respond along the transition path; i.e., $m_t = 0, \forall\, t \geq 0$ (which also implies that $i_t = 0, \forall\, t \geq 0$), we note that

$$0 = m_t = \beta p_{1,t} + (1-\beta) p_{2,t} + y_t \tag{13}$$

Noting that $(p_{1,t} - p_{2,t})^f = y_t^f = 0$ along the path as well (because there are no shocks after time 0), we have

$$\begin{aligned} r_t &= p_{1,t} - p_{2,t} \\ x_t &= y_t - y_t^f = y_t = -p_{1,t} + (1-\beta) r_t \end{aligned}$$

Plugging these into Equation (6), we have

$$\begin{aligned} \ddot{p}_{1,t} = \dot{\pi}_{1,t} &= (1-a_{11})(1-\beta)\theta_1^2 r_t - (1-a_{11})\theta_1^2(-p_{1,t} + (1-\beta) r_t) \\ &= (1-a_{11})\theta_1^2 p_{1,t} \end{aligned} \tag{14}$$

which is second order differential equation only in terms of $p_{1,t}$ with the initial condition that $p_{1,0}$ is given as well as the boundary condition that $p_{1,t}$ should converge back to its steady state at $p_{1,t} = 0$. It follows that

$$p_{1,t} = p_{1,0} e^{-\xi_1 t}, \qquad \xi_1 = \theta_1 \sqrt{1 - a_{11}} \tag{15}$$

Now, plugging the expression for r_t and x_t, as well as the solution to $p_{1,t}$ into Equation (7), we have

$$\ddot{p}_{2,t} = \dot{\pi}_{2,t} = \xi_2^2 p_{2,t} - \frac{a_{21}}{1 - a_{22}} \xi_2^2 p_{1,0} e^{-\xi_1 t} \tag{16}$$

which is a second order differential equation in $p_{2,t}$ with the initial condition that $p_{2,0}$ is given as well as the boundary condition that $p_{2,t}$ should converge back to its steady state at $p_{2,t} = 0$. It follows that

$$p_{2,t} = \frac{a_{21}}{1 - a_{22}} \frac{p_{1,0}}{\xi_2^2 - \xi_1^2} \left(\xi_2^2 e^{-\xi_1 t} - \xi_1^2 e^{-\xi_2 t} \right) \tag{17}$$

where $p_{1,0}$ captures the initial distortion in relative prices caused by the shock to sector 1. Differentiating the solutions for $p_{1,t}$ and $p_{2,t}$, we have:

$$\left.\frac{\partial \pi_{1,t}}{\partial \pi_{1,0}}\right|_{z_1} = e^{-\xi_1 t} \tag{18}$$

$$\left.\frac{\partial \pi_{2,t}}{\partial \pi_{1,0}}\right|_{z_1} = \frac{a_{21}}{1 - a_{22}} \frac{\xi_2}{\xi_2 + \xi_1} \left(\frac{\xi_2 e^{-\xi_1 t} - \xi_1 e^{-\xi_2 t}}{\xi_2 - \xi_1} \right) \tag{19}$$

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To provide a sense of how the solution looks like, Figure 2 plots these impulse responses for illustrative numerical values that assign a higher stickiness to the downstream sector. As is clear, inflation in the downstream sector is more muted on impact but persists much longer.

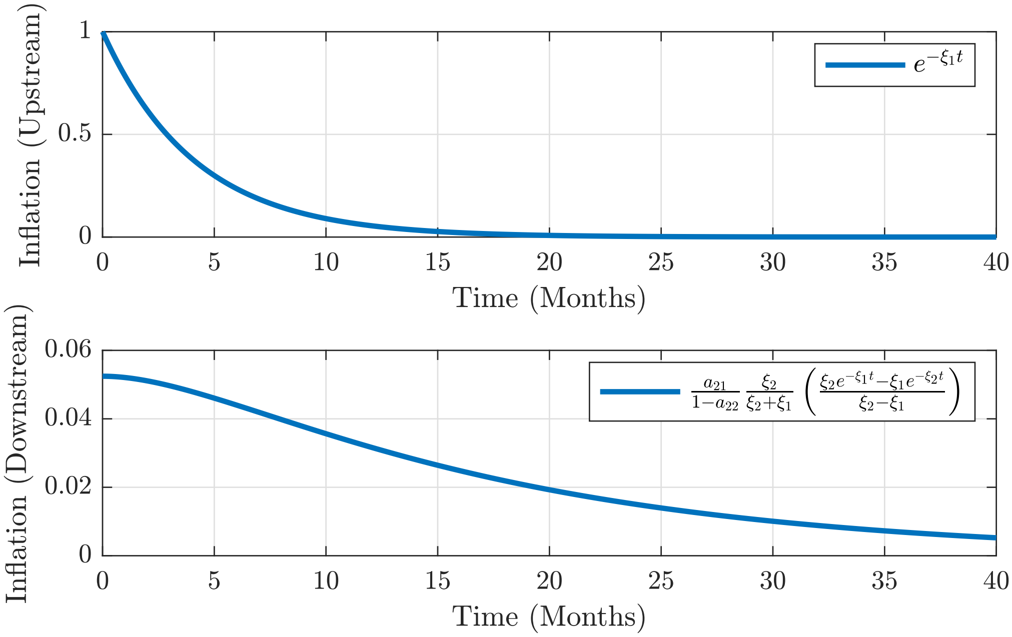

Figure 2: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The figure shows the response of each sector's inflation rate to a permanent shock to the relative price of the upstream sector in the absence of any monetary policy response. The shock is normalized such that inflation in the upstream sector increases by one percent on impact.

To examine Proposition 1 further analytically, let us consider the "cumulative response of inflation (CIR)" generated by the shock in each sector, defined as the area under the impulse response of inflation in each sector. The CIR in the upstream sector is given by ξ_1^{-1} (by design, as we have normalized the shock to generate a one percent increase in inflation on impact). The more interesting case is the CIR in the downstream sector, which is given by

$$\text{CIR}_2^{\pi} = \frac{a_{21}}{1-a_{22}} \times \text{CIR}_1^{\pi} \tag{20}$$

which shows that, in the absence of any monetary response, the total spillover of inflation from the upstream to the downstream sector is proportional to the input share of the downstream sector from the upstream sector, a_{21}, multiplied by the cumulative expenditure share of the downstream sector by itself, $\frac{1}{1-a_{22}} = \sum_{n=0}^{\infty} a_{22}^n$. This is a key result that shows how relative price shocks can generate persistent spillover inflation in downstream sectors. In particular, note that without the input-output linkages, the spillover effect is zero. Moreover, in the absence of price stickiness, the spillover effect is also zero, since relative prices would adjust immediately to the shock.

Moreover, to understand the short-run effects of this inflationary shock, we can also consider the impact pass-through of inflation in the upstream sector to the downstream sector, which is given by

$$\left.\frac{\partial \pi_{2,0}}{\partial \pi_{1,0}}\right|_{z_1} = \frac{a_{21}}{1-a_{22}} \times \frac{\xi_1^{-1}}{\xi_2^{-1}+\xi_1^{-1}} \tag{21}$$

We see that this pass-through is proportional to the long-run pass-through above, but is now adjusted by the term $\frac{\xi_1^{-1}}{\xi_2^{-1}+\xi_1^{-1}}$. This new term captures the relative duration of price stickiness in the two sectors. In particular, if the upstream sector is more flexible than the downstream sector, then this immediate pass-through is dampened, as it would take longer for the downstream firms to get the opportunity to increase their prices in response.

2.4.2. Spillover Effects with Soft Landing. We now move to considering a monetary policy regime that engineers a soft landing, that is, it keeps GDP gap at zero ($x_t = 0, \forall t \geq 0$).

Proposition 2. Consider a one-time permanent shock to relative prices at time zero so that $r_0 \neq 0$. Conditional on monetary policy engineering a perfect soft-landing by setting $x_t = 0, \forall t \geq 0$:

1. The relative price converges back to its steady state exponentially:

$$r_t = r_0 e^{-\bar{\xi} t} \quad \text{where} \quad \bar{\xi} = \sqrt{(1-a_{11})(1-a_{22})(\lambda_2\theta_1^2 + \lambda_1\theta_2^2)} \tag{22}$$

   with the nominal prices of each sector evolving according to:

$$p_{1,t} = \frac{\lambda_2\theta_1^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2} r_0 e^{-\bar{\xi}t}, \qquad p_{2,t} = -\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2} r_0 e^{-\bar{\xi}t} \tag{23}$$

2. The relative price shock causes endogenously persistent aggregate inflation on the path, proportional to r_t:

$$\pi_t = \bar{\xi}\left(\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2} - \beta\right) r_t \tag{24}$$

Proof. **Part 1.** On a path where monetary policy engineers $x_t = 0, \forall t \geq 0$, we can add and subtract the sectoral Phillips curves in Equations (6) and (7) to re-write them as:

$$\ddot{r}_t = (1-a_{11})(1-a_{22})(\lambda_2\theta_1^2 + \lambda_1\theta_2^2) r_t$$
$$\frac{\dot{\pi}_{1,t}}{\lambda_2\theta_1^2} + \frac{\dot{\pi}_{2,t}}{\lambda_1\theta_2^2} = 0$$

These are both second-order differential equations, which, subject to the boundary conditions r_0 given and stability of prices uniquely characterize the path of both price indices over time. To see this note that, subject to these boundary conditions, the first equation implies:

$$r_t = r_0 e^{-\bar{\xi}t}, \quad \bar{\xi} \equiv \sqrt{(1-a_{11})(1-a_{22})(\lambda_2\theta_1^2 + \lambda_1\theta_2^2)}$$

while the second one implies:

$$\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2}p_{1,t}+\frac{\lambda_2\theta_1^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2}p_{2,t}=0, \forall t\geq 0 \tag{25}$$

$$\Longrightarrow p_{1,t}=\frac{\lambda_2\theta_1^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2}r_0e^{-\bar{\xi}t}, \quad p_{2,t}=-\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2}r_0e^{-\bar{\xi}t}$$

Part 2. Having specified the path of sectoral prices, we can now calculate the aggregate price level and inflation rate as

$$p_t=\beta p_{1,t}+(1-\beta)p_{2,t}=\left(\beta-\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_2^2}\right)r_t$$

$$\Longrightarrow \pi_t=-\bar{\xi}\left(\beta-\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_2^2}\right)r_t$$

■

The first takeaway from Proposition 2 is that relative price distortions at an initial period can indeed cause fluctuations in aggregate inflation, even in the absence of any further shocks *and* any fluctuations in aggregate slack in the economy. Note that this is a *key* feature of our multi-sector economy because in the standard New Keynesian model, divine coincidence holds, such that in the face of technology shocks, closing the aggregate slack of that economy eliminates any inflationary effects of such shocks.

The second takeaway is that given the positive relative price response along the path (i.e., $r_t>0$), whether the shock is inflationary or deflationary in terms of the *CPI* inflation rate along the path depends on the sign of the term $\beta-\zeta$ where $\zeta\equiv\frac{\lambda_1\theta_2^2}{\lambda_1\theta_2^2+\lambda_2\theta_1^2}$. To see why, note that a GDP gap stabilization policy is essentially a price targeting rule that fully stabilizes a certain price index.[5] In our case, this price index is $\zeta p_{1,t}+(1-\zeta)p_{2,t}=0$ as shown in Equation (25). Subtracting this price index from the CPI index, we can then see that along the transition path

$$p_t=\beta p_{1,t}+(1-\beta)p_{2,t}=(\beta-\zeta)r_t \Longrightarrow \pi_t=\bar{\xi}(\zeta-\beta)r_t \tag{26}$$

So an increase in the relative price of the upstream sector leads to aggregate inflation if and only if $\zeta>\beta$. This is a central point to our analysis as we can prove the following result.

Proposition 3. Suppose prices are more flexible in the upstream sector in the sense that its network-adjusted frequency is larger ($\xi_1=\theta_1\sqrt{1-a_{11}}>\xi_2=\theta_2\sqrt{1-a_{22}}$). Then, an increase in the relative price of the upstream sector caused by a permanent shock as in Proposition 2 is *CPI inflationary* if

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[5] Earlier versions of this result were shown in Galí (2015) and Woodford (2003) in the context of sticky price-sticky wage economies as well as two sector sticky price economies with no input-output linkages. More recently, Rubbo (2023) proved this in multi-sector sticky price economies with arbitrary input-output linkages.

and only if

$$\zeta > \beta \iff a_{21} > \frac{\beta}{\lambda_2} \times \left(\frac{\xi_1^2}{\xi_2^2} - 1 \right) \tag{27}$$

Proof. Follows from definition of ζ and the expression for the the Domar weights λ_1 and λ_2. ■

Equation (27) shows the importance of input-output linkages in this simple economy for generating inflation at the aggregate level due to relative price shocks to more flexible sectors. In particular, note that with no across sector input-output linkages; i.e., $a_{21} = 0$, the condition in Equation (27) always fails under the assumptions of the proposition. Thus, even if heterogeneous price stickiness across sectors was present, with no across sector input-output linkages, i.e., $a_{21} = 0$, it would not generate inflation at the aggregate level with GDP gap targeting.

2.5. An Experiment for the Post-COVID-19 Inflation

We finish this section by performing an experiment in a calibrated version of our model to show how relative price changes can generate persistent aggregate inflation movements consistent with our motivating Figure 1. We use the aftermath of COVID-19 as a case study for this experiment. We also do counterfactual analyses to isolate the role of different forces in accounting for post COVID-19 inflation dynamics.

2.5.1. Calibration of a two-sector economy. For this experiment, we first divide the sectors in the data to a flexible upstream group and a sticky downstream group to calibrate the network and the price stickiness parameters of our two-sector stylized model. This calibration is described in detail in Section 6.1.

Parameter	Description	Value
β	Upstream sector consumption share	0.1
θ_1	Upstream sector frequency of price adjustment	0.29
θ_2	Downstream sector frequency of price adjustment	0.09
a_{11}	Cost share of upstream sector on upstream sector	0.31
a_{21}	Cost share of downstream sector on upstream sector	0.13
a_{22}	Cost share of downstream sector on downstream sector	0.47

Table 1: Calibrated parameters and description.

2.5.2. Results. We then shock the relative price of the upstream sector in the model in line with Propositions 1 and 2 and consider the following monetary policy reaction: For the first T periods, monetary policy does not react and keeps interest rates fixed (endogenously), and then for the remaining periods, it sets the interest rate to fully stabilize the GDP gap and engineer a soft-landing.

Figure 3 shows the response of the price of the two sectors for different values of T. The blue lines are the path of prices under no monetary response, in which case both prices rise in response to the inflationary relative price shock. Once the economy reaches a soft-landing T the central bank stabilizes the GDP gap, and the nominal prices of the two sectors converge back to a new steady state that is consistent with this policy per Proposition 2. We see that when monetary policy does not react, both prices rise at a relatively faster rate, but once the soft-landing policy is implemented, one price falls while the other one rises to reach the new steady state.

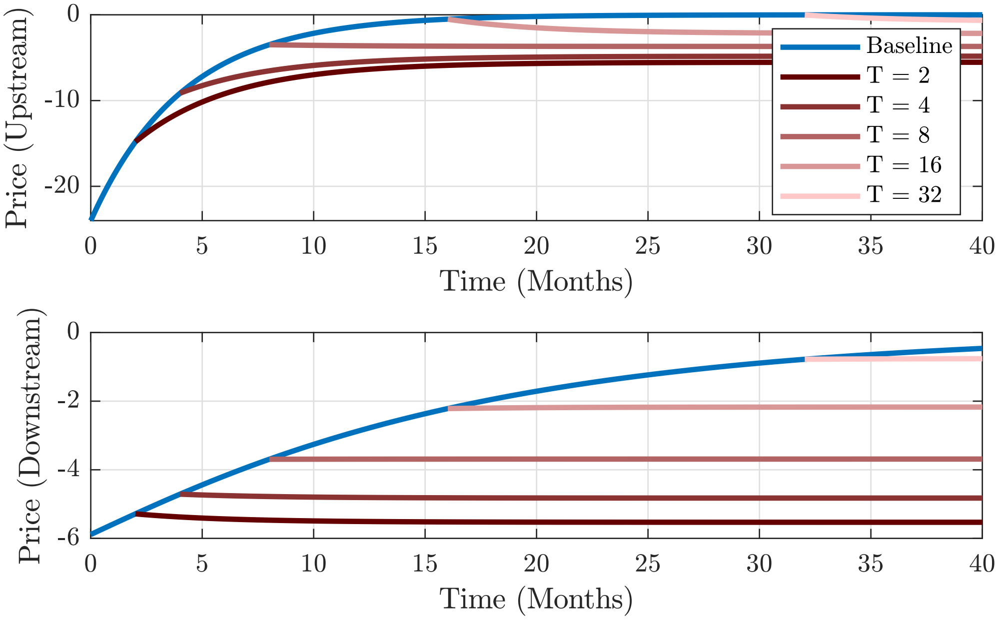

Figure 3: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The figure shows the response of each sector's price level to a permanent shock to the relative price of the upstream sector in absence of a monetary response in blue. Each red line then shows the path of price contingent on monetary policy switching to a soft-landing policy at that time.

Figure 4 shows the response of 12 month inflation in each sector. As expected, inflation in both sectors rise initially due to the base effect of prices being stable before the shock. Once this base effect is gone, prices fall faster in the upstream sector, especially after the soft landing policy is implemented. The consequence is that at some point inflation in the upstream sector decays quickly, while inflation in the downstream sector is more persistent.

Finally, Figure 5 is meant to map the model to the motivating evidence in Figure 1 by showing the responses of aggregate inflation, inflation in the downstream sector (i.e. a sticky sector that is meant to capture the behavior of core inflation), as well as inflation in the relatively flexible upstream sector.

Here, we have chosen the size of the shock to match a peak aggregate inflation of 7 percent, and

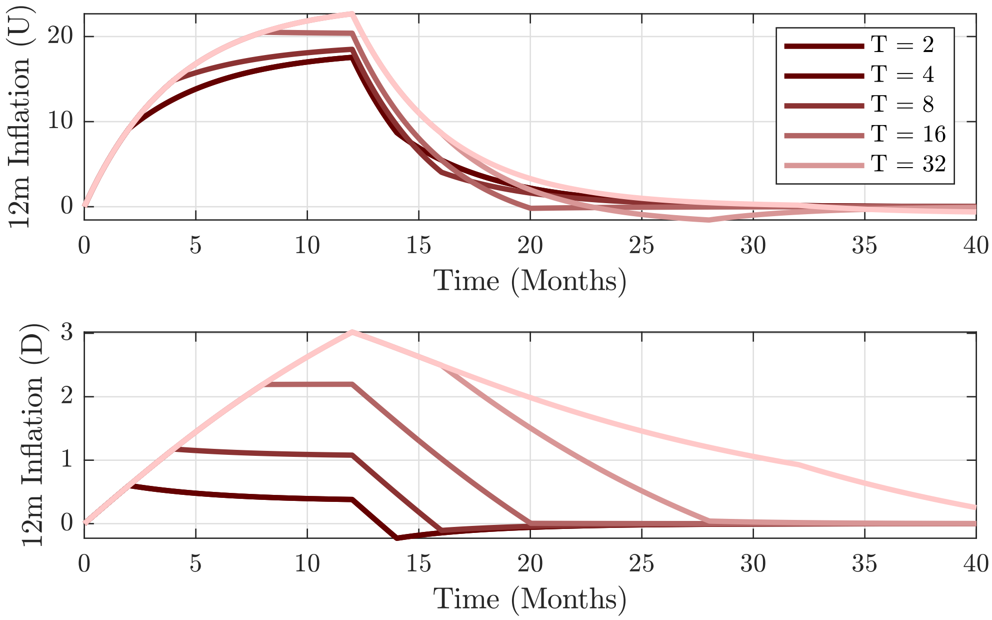

Figure 4: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The figure shows the response of each sector's inflation rate to a permanent shock to the relative price of the upstream sector in the absence of any monetary policy response until some time T, for alternative values of T, after which monetary policy switches to a soft-landing policy.

we have chosen $T = 16$ months so that monetary policy switches to soft-landing 16 months after the shock, in line with the path of interest rates in Figure 1. With these two parameters, this admittedly very stylized model generates the following patterns consistent with Figure 1: the relative price shock generates persistent aggregate inflation movements in the economy; core inflation peaks at around 5 percent and proceeds to cross aggregate inflation at around 20 months after the onset of inflation. Both of these predictions of the model are consistent with the Post-Covid-19 inflation dynamics episode. In particular, the model explains the behavior of the core inflation rate pretty well due to a *one-time* shock to the relative price of the flexible upstream sector.

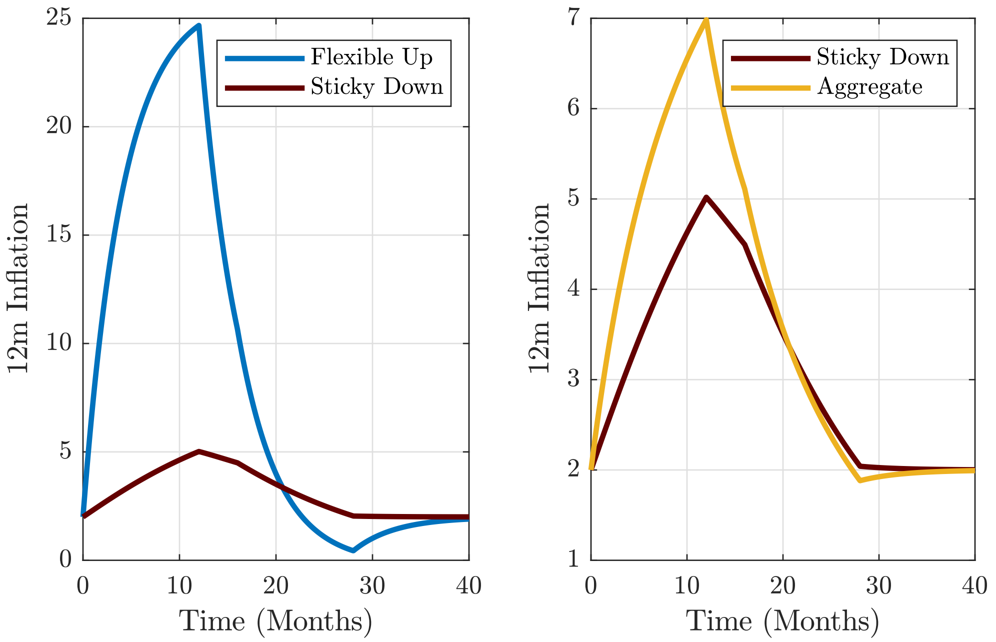

Figure 5: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The left panel shows the impulse responses of inflation rates in the upstream and downstream sectors after a shock to relative price of the upstream sector, where monetary policy does not respond for the first 16 months after the shock and then switches to a soft-landing policy. The right panel shows the response of aggregate inflation along with the downstream sector's inflation to the same shock under the same policy. The shock size is such that aggregate inflation peaks at 7 percent after 12 months.

2.5.3. Counterfactual results.

We now do several counterfactual exercises that illuminate the role of various model features that drive our results.

First, we do a policy counterfactual where the central bank stabilizes the GDP gap from the beginning while keeping the same shocks and model parameters as in our baseline exercise. This exercise will illustrate the extent to which the rise of aggregate inflation in Figure 5 can be attributed to monetary policy keeping interest rates constant. The results are in Figure 6 and they show that aggregate inflation would have peaked at a bit above 3 percent, which is considerably lower than the 7 percent in Figure 5. Moreover, note that under such policy, the inflation in the upstream sector would also have been slightly less pronounced while inflation in the downstream sector would have been negative throughout.

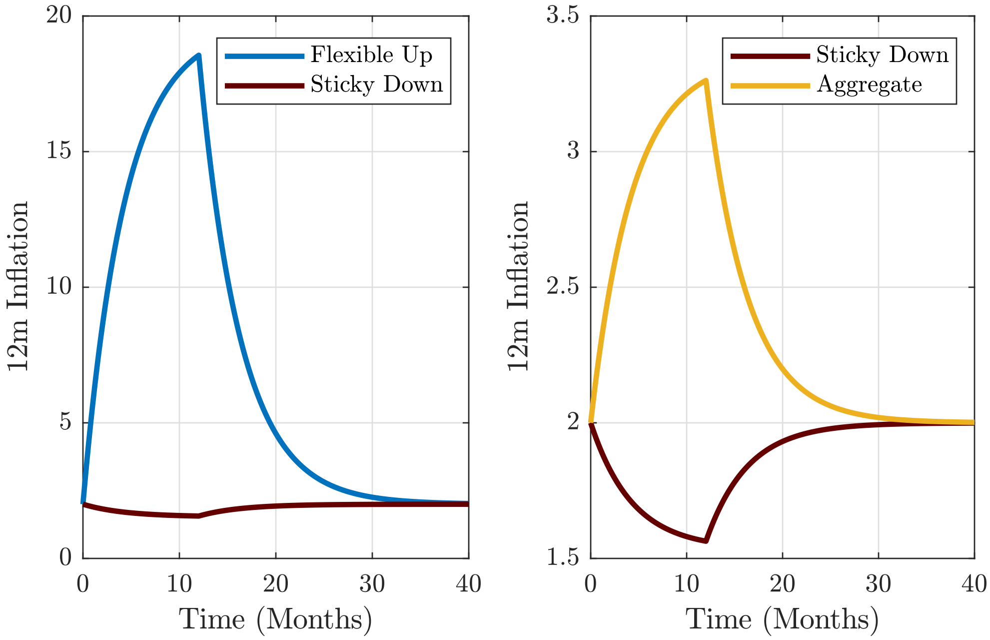

Figure 6: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The left panel shows the impulse responses of inflation rates in the upstream and downstream sectors after a shock to relative price of the upstream sector, where monetary policy does not respond for the first 16 months after the shock and then switches to a soft-landing policy. The right panel shows the response of aggregate inflation along with the downstream sector's inflation to the same shock under the same policy. The shock size is such that aggregate inflation peaks at 7 percent after 12 months in the baseline calibration. Policy rule is GDP gap at zero starting from $t = 0$.

Second, we do a model counterfactual where we shut down the role of upstream sector as a source of intermediate inputs to the downstream sector by setting $a_{21} = 0$. The results are in Figure 7 and show that in such a case, as there is no spillover of upstream sector shock to the downstream sector, there is no inflation in the downstream sector at all. Moreover, aggregate inflation peaks at slightly above 4 percent.

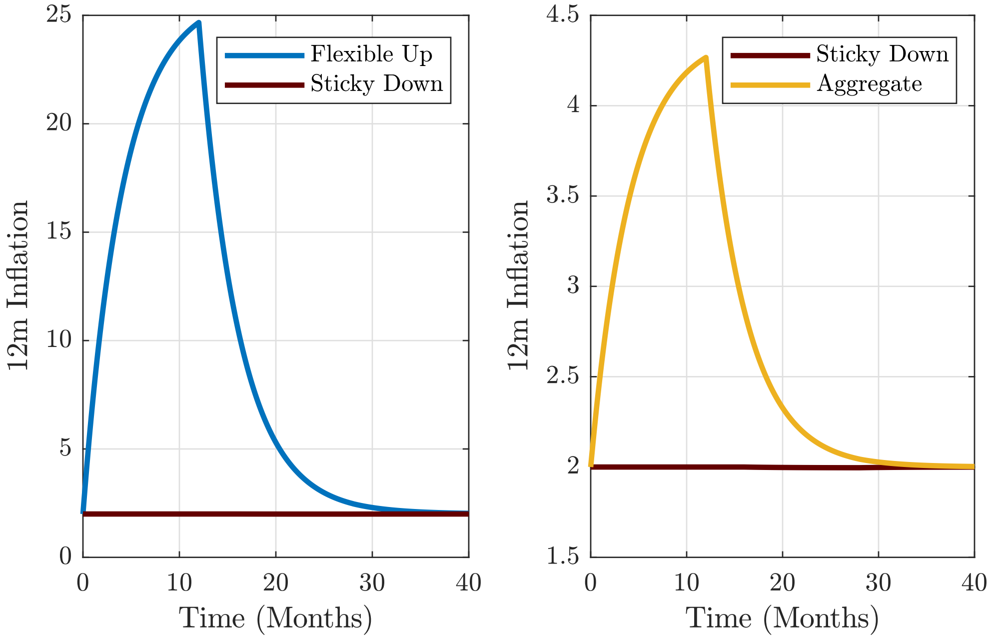

Figure 7: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The left panel shows the impulse responses of inflation rates in the upstream and downstream sectors after a shock to relative price of the upstream sector, where monetary policy does not respond for the first 16 months after the shock and then switches to a soft-landing policy. The right panel shows the response of aggregate inflation along with the downstream sector's inflation to the same shock under the same policy. The shock size is such that aggregate inflation peaks at 7 percent after 12 months in the baseline calibration. Model counterfactuals based on no upstream sector as a production input for the downstream sector: $a_{21} = 0$.

Finally, we do a model counterfactual where we shut down the role of heterogeneous price stickiness across sectors by setting $\theta_2 = \theta_1$. The results are in Figure 8 and show that in such a case, as the downstream sector has a higher price flexibility, inflation increases by more and thus aggregate inflation peaks at above 8 percent, higher than the baseline results of 7 percent in Figure 5. Note however, that as price stickiness is the same across the two sectors now, the dynamics of inflation are identical. As a result, unlike in Figure 5, the inflation is the downstream sector is never higher, and is not more persistent, than aggregate inflation.

Taken together, these counterfactual exercises help highlight how the monetary policy rules, the role of the upstream sector as a production input for the downstream sector, as well as higher price flexibility in the upstream sector all contribute to the results in Figure 5 that enable us to match the patterns in Figure 1.

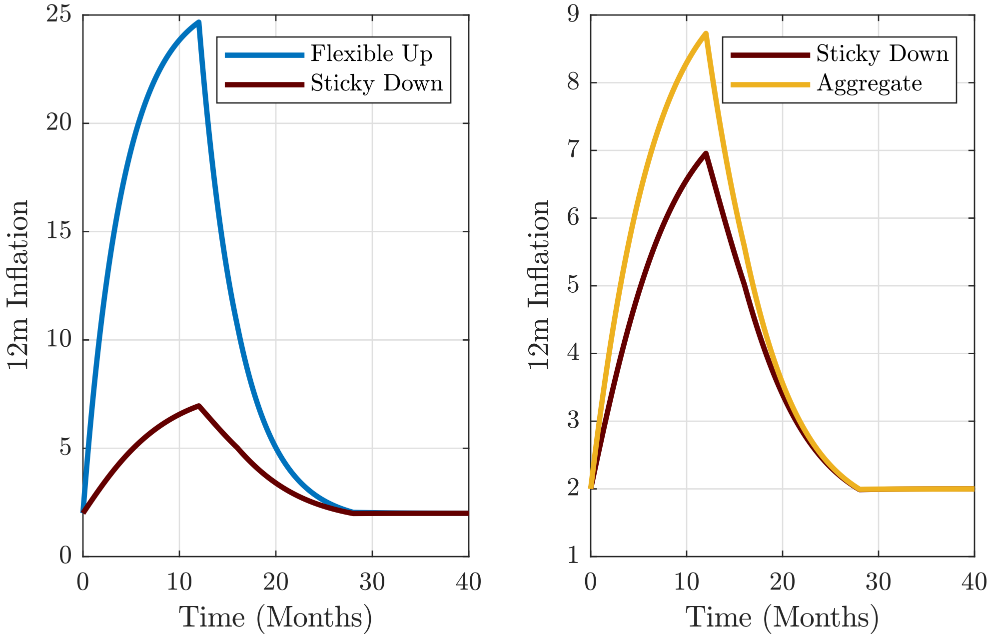

Figure 8: Inflationary effects of a permanent shock to the relative price of the upstream sector

Notes: The left panel shows the impulse responses of inflation rates in the upstream and downstream sectors after a shock to relative price of the upstream sector, where monetary policy does not respond for the first 16 months after the shock and then switches to a soft-landing policy. The right panel shows the response of aggregate inflation along with the downstream sector's inflation to the same shock under the same policy. The shock size is such that aggregate inflation peaks at 7 percent after 12 months in the baseline calibration. Model counterfactual results based on same price stickiness across sectors: $\theta_2 = \theta_1$.

3 Empirical Framework and Results

We now present some empirical evidence on exogenous changes to relative price of energy affecting aggregate inflation and real activity in the U.S. We also present evidence that such exogenous relative price changes affect consumer prices heterogeneously across sectors in the U.S. and that this sectoral heterogeneity is consistent with the predictions of our theoretical model.

3.1. Aggregate effects of relative price of energy shocks

We start by showing aggregate effects of exogenous changes in relative price of energy in the U.S. This allows us to assess empirically whether shocks to relative prices act like negative supply shocks in the aggregate.

3.1.1. Specification. Our empirical approach is a local projection instrumental variables (LP-IV) technique. To isolate exogenous variation, we instrument relative PPI energy prices (which are PPI energy prices relative to aggregate PPI prices) in the U.S. with the oil supply news shock of Kanzig (2021) and estimate dynamic effects of such exogenous changes in relative PPI energy prices on PCE headline and core inflation.[6] In addition, we also estimate effects on measures of real activity such as the unemployment rate and (real) consumption. More specifically, we run

$$\log(Y_{t+h}) - \log(Y_{t-1}) = \alpha^{(h)} + \beta^{(h)} \times \left(\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}})\right) \tag{28}$$

$$+ \sum_{k=1}^{K} \gamma_k^{(h)} \left(\log(Y_{t-k}) - \log(Y_{t-k-1})\right) \tag{29}$$

$$+ \sum_{k=1}^{J} \zeta_k^{(h)} \left(\log(\frac{\text{PPI energy}_{t-k}}{\text{PPI}_{t-k}}) - \log(\frac{\text{PPI energy}_{t-k-1}}{\text{PPI}_{t-k-1}})\right) + \varepsilon_t \tag{30}$$

where Y_t is the outcome of interest and $\beta^{(h)}$ is the parameter of interest that gives us the impulse response coefficient.

We use the following outcome variables: headline PCE, PCE core, unemployment Rate, and (real) PCE consumption.[7] Relative PPI energy price is defined as a simple geometric mean of the relative Oil and gas extraction PPI and Petroleum and coal products manufacturing PPI (relative to aggregate PPI).[8] We use $K = 12, J = 12$. We instrument $\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}})$ with the Kanzig (2021) oil supply news shock. Standard errors are robust to heteroskedasticity and autocorrelation. 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.

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[6] We are thus isolating exogenous variation in wholesale energy prices in the U.S. and estimating its dynamic pass-through to retail prices.

[7] We retrieve these data from FRED. The Appendix provides details on data sources and construction. For the unemployment rate, we do not take its log.

[8] We define it as a simple geometric average of oil and gas extraction and petroleum and coal products PPI. That is, $\text{PPI energy prices}_t \equiv \left(\text{PPI Oil and gas extraction}_t^{\frac{1}{2}}\right)\left(\text{PPI Petroleum and coal products}_t^{\frac{1}{2}}\right)$. A direct PPI energy is not available from the BLS for a long time window.

3.1.2. Results. We show that relative energy price shocks lead to an increase both in headline inflation and core inflation. Furthermore, they also lead to a contraction in economy activity. This evidence is thus consistent with the idea that relative price shocks act like negative aggregate supply shocks.

To establish this result, we first document in Figure 9 that the oil supply news shock of Kanzig (2021) has a positive and significant effect on (relative) PPI energy prices.[9] This effect is present even if we exclude the COVID-19 period, as shown in Panel B of Figure 9. To give a sense of magnitudes, we note that a one unit shock of Kanzig (2021) leads of to a 10.88% increase in Brent oil prices on impact.[10] The pass-through here to PPI prices in the U.S. is thus about half of the effect on Brent oil prices. We then use this shock of Kanzig (2021) as an IV for the relative PPI energy prices to show our main aggregate results. Figure 9 thus serves to show the relevance of the oil supply news shock of Kanzig (2021) as an IV for PPI energy prices.

The first row of Figure 10 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.[11] 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 10 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 10 show that relative price of energy shocks act like negative aggregate supply shocks.

Figure 10 is based on using data for the full sample period, 1986:01-2023:06.[12] Figure 11 below shows results for an alternate sample period, from 1986:01-2020:03. 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 pandemic period.

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[9] The shaded area in the Figures corresponds to 68% and 90% confidence intervals.

[10] Figure A1 shows the impulse response of Brent oil prices after a one unit oil supply news shock.

[11] 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.

[12] Our estimation sample starts at 1986:01 because the Oil and gas extraction PPI and the Petroleum and coal products manufacturing PPI start in 1986:01.

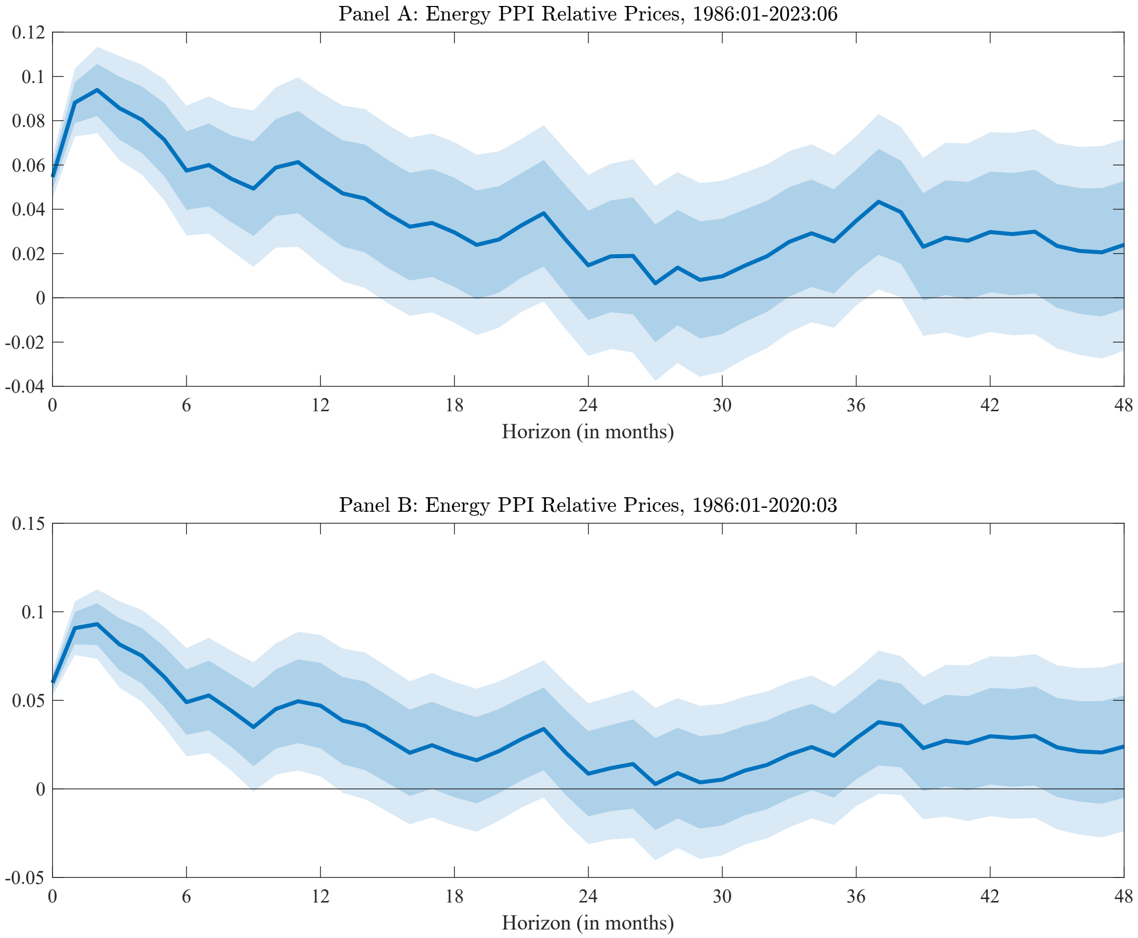

Figure 9: Relative PPI energy prices impulse responses to an oil supply news shock

Notes: This figure plots impulse responses of relative energy PPI. The measure is relative to the aggregate PPI. This measure is defined as the simple geometric average of relative Oil and gas extraction PPI and relative Petroleum and gas extraction PPI. The shock is the oil supply news shock from Kanzig (2021). The dependent variable is measured in log and the independent variable is in units of the shock. The shock is such that a unit shock leads to a 10.88% increase in the Brent oil prices on impact. Sample period: Panel A: 1986:01 - 2023:06. Panel B: 1986:01 - 2020:03. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

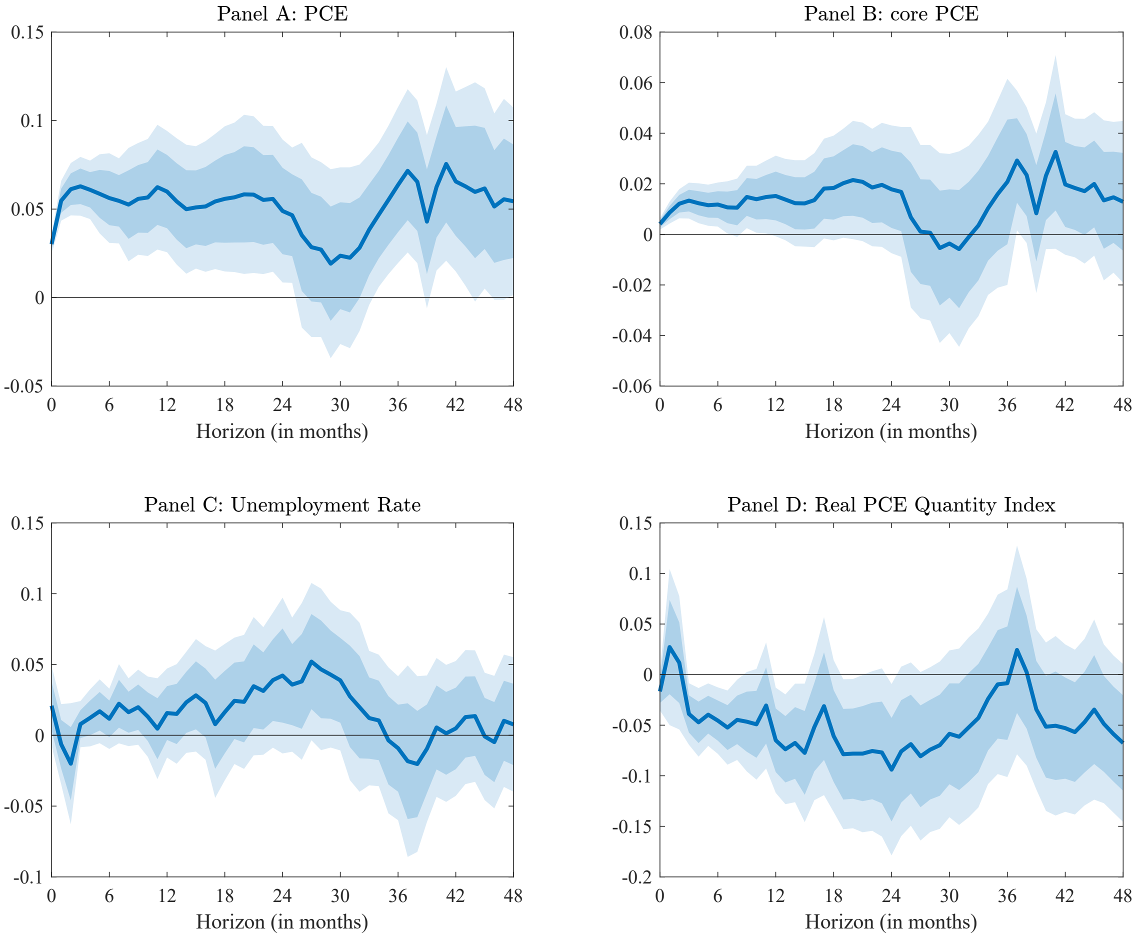

Figure 10: Impulse responses to a shock to the relative price of energy

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 relative price of energy is measured as a simple geometric mean of relative Oil and gas extraction PPI and relative Petroleum and coal products PPI (relative to the aggregate PPI) and is instrumented by the oil supply news shock by Kanzig (2021). Both the dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Sample period: 1986:01 - 2023:06. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals. First stage F-stat: Panel A: 111.0882. Panel B: 105.6962. Panel C: 113.7576. Panel D: 135.4382.

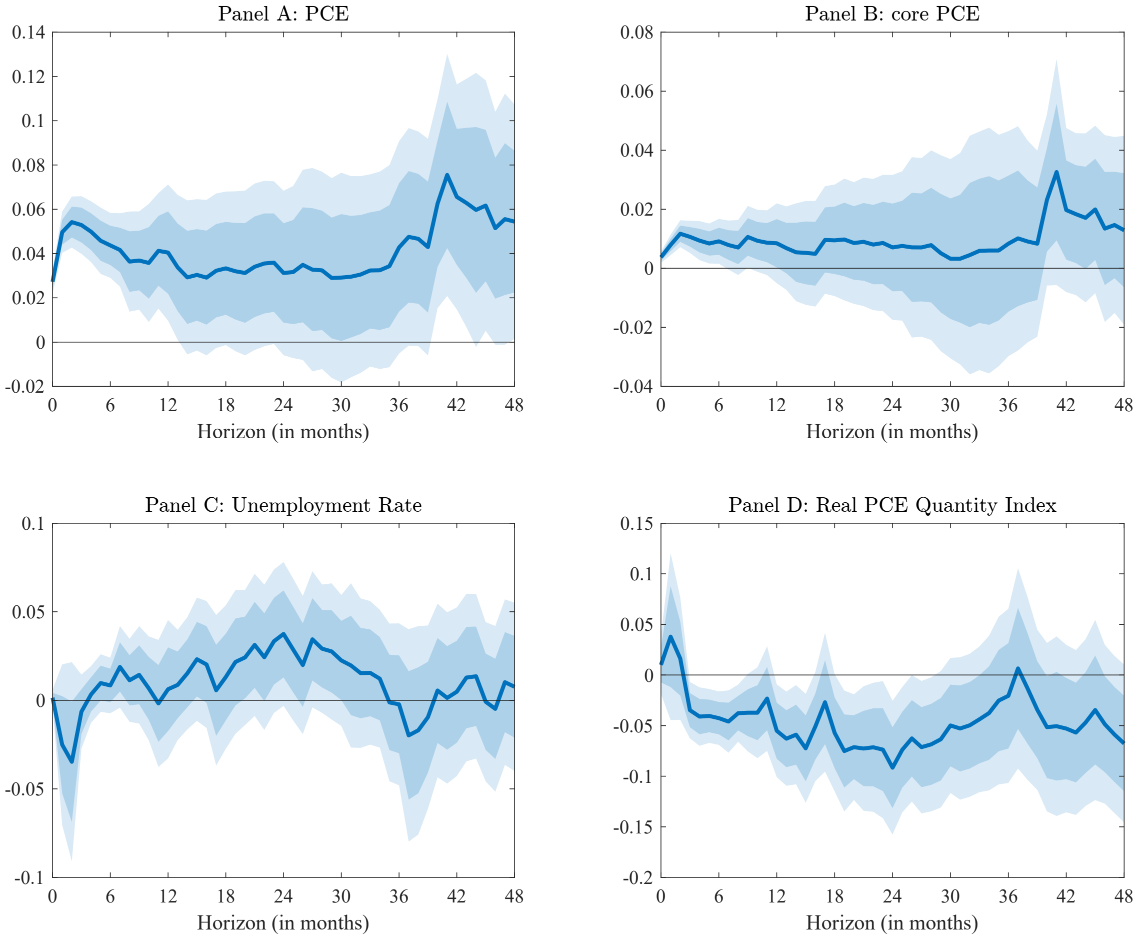

Figure 11: Impulse responses to a shock to the relative price of energy

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 relative price of energy is measured as a simple geometric mean of relative Oil and gas extraction PPI and relative Petroleum and coal products PPI (relative to the aggregate PPI) and is instrumented by the oil supply news shock by Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Sample period: 1986:01 - 2020:03. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

3.1.3. Robustness. We now discuss some results from a sensitivity analysis to our sample period and specification. Figure A2 in the Appendix reports results if we use the sample period of 2008:01-2023:06, thereby focusing only on the time period following the financial crisis. In addition, Figure 10 is based on a specification that does not use additional variables as controls. Figure A3 in the Appendix reports results where we use lagged real wages as controls. Comparing Figure 10 with Figures A2 and A3 shows that the results are robust to these changes in sample period and additional controls.

3.2. Heterogeneous Sectoral Effects of a Relative Price of Energy Shock

Underlying the aggregate inflation response to the relative price of energy shock discussed above is a distribution of sectoral inflation responses. Our model solution revealed sufficient statistics that predict how the sectoral inflation responses should look like, as given in (21)[13]. We now estimate these heterogeneous sectoral inflation responses and show that they align with the predictions of the model in terms of sectoral characteristics that govern such heterogeneity. We use data starting in 1998.

3.2.1. Reduced-form results. We first show that our IV has a positive and significant effect on sectoral PCE prices. More importantly, we show that its interaction with our sufficient statistics does correctly predict the strength of pass-through of oil supply shocks to sectoral PCE prices. These results are thus the “reduced-form” results underlying the IV results we will show next.

We use a panel local projection specification to estimate the effect of the oil supply news shock of Kanzig (2021) on U.S. sectoral PCE prices. More specifically, we run

$$\log P_{jt+h} - \log P_{jt-1} = \beta_0^{(h)} + \beta_1^{(h)} \times \text{Kanzig}_t + \beta_2^{(h)} \times \left(\frac{a_{ji}}{1-a_{jj}} \frac{\theta_j \sqrt{1-a_{jj}}}{\theta_j \sqrt{1-a_{jj}} + \theta_i \sqrt{1-a_{ii}}} \right) \times \text{Kanzig}_t \\ + \sum_{k=1}^{12} \gamma_k^{(h)} (\log P_{jt-k} - \log P_{jt-k-1}) + \sum_{k=1}^{12} \zeta_k^{(h)} \times \text{Kanzig}_{t-k} + \epsilon_{jt}$$

where P_{jt} is the PCE price index of category j at time t and i indexes the IO sector that receives the shock. In our case, i is the total energy sector. The main coefficient of interest is given by $\beta_2^{(h)}$. We compute Driscoll-Kraay standard errors.

In our main results, we exclude PCE categories for which Petroleum and coal products were included in them in 1997.[14] The excluded PCE categories are: Motor vehicle fuels, lubricants, and

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[13] We measure the sufficient statistics in standard deviations.

[14] Oil and gas extraction has zero personal consumption expenditure. Therefore, there is no PCE category that includes Oil and gas extraction.

fluids; Fuel oil and other fuels; and Pharmaceutical and other medical products.[15] The Appendix provides further detail on how we construct the sector specific interaction term using data, where we again note that the expression for that term is guided by our theoretical model that provides the sufficient statistic in (21).

Figure 12 shows that the Kanzig (2021) shock has a positive average effect on sectoral PCE prices that is relatively short-lived.[16] Critically however, when we consider the interaction effect ($\beta_2^{(h)}$) that is guided by the sufficient statistic from the model, we see a significant degree of heterogeneity in sectoral pass-through that impacts both the magnitude and the persistence of the effect of the shock. Moving from the 25th to the 75th percentile of the distribution of the sufficient statistic leads the response to a one-unit Kanzig shock to increase by 0.3 basis points on impact, 1.5 basis points after 3 months, and 3 basis points after 36 months.[17]

To provide a sense of the quantitative differences in effects across sectors, we now report total effects on prices and how they vary across the distribution of the sufficient statistic. The (total) responses on impact of the 25th, 50th, and the 75th percentiles of the distribution of the sufficient statistic are 3.60, 3.69, and 4.00 basis points, respectively. The responses after three months of the 25th, 50th, and the 75th percentiles of the distribution of the sufficient statistic are 11.0, 11.3, and 12.5 basis points, respectively. Finally, the responses after 36 months of the 25th, 50th, and the 75th percentiles of the distribution of the sufficient statistic are 16.0, 16.7, and 19.1 basis points, respectively. The bottom row of Figure 12 shows that results are robust to using a pre-Covid sample period.

3.2.2. IV Results. In this subsection, we argue that the oil supply news shocks affects sectoral PCE prices *through* its impact on relative PPI energy prices. That is, building on the "reduced-form" results we presented in the previous subsection, we now present IV results where we use the oil supply news shock as an IV for relative PPI energy prices.

We employ a panel local projection instrumental variables (panel LP-IV) technique. We consider the effect of changes of PPI energy prices relative to PPI prices on U.S. sectoral prices, instrumenting

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[15] The petroleum and coal products accounted for 43% of the Motor vehicle fuels, lubricants, and fluids purchasers' value ex-transportation cost in 1997. It accounted for 41% of the Fuel oil and other fuels purchasers' value ex-transportation cost in 1997. Finally, it accounted for 0.009% of the Pharmaceutical and other medical products purchasers' value ex-transportation cost in 1997.

[16] The shaded area in the Figures in the text corresponds to 68% and 90% confidence intervals.

[17] The 25 percentile of the distribution of the sufficient statistics is 0.008153 and the 75 percentile is 0.042397. $\beta_2^{(0)} = 0.0011634$, $\beta_2^{(3)} = 0.0044282$, and $\beta_2^{(36)} = 0.0090165$. Then, the difference in response after a one unit shock becomes $\beta_2^{(0)} \times (0.042397 - 0.008153) \times 1 = 0.0000398$ log-points $\approx 0.00398\% \approx 0.3$ basis points, on impact, $\beta_2^{(3)} \times (0.042397 - 0.008153) \times 1 = 0.0001516$ log-points $\approx 0.0151\% \approx 1.5$ basis points after 3 months, and $\beta_2^{(36)} \times (0.042397 - 0.008153) \times 1 = 0.000309$ log-points $\approx 0.0308\% \approx 3$ basis points.

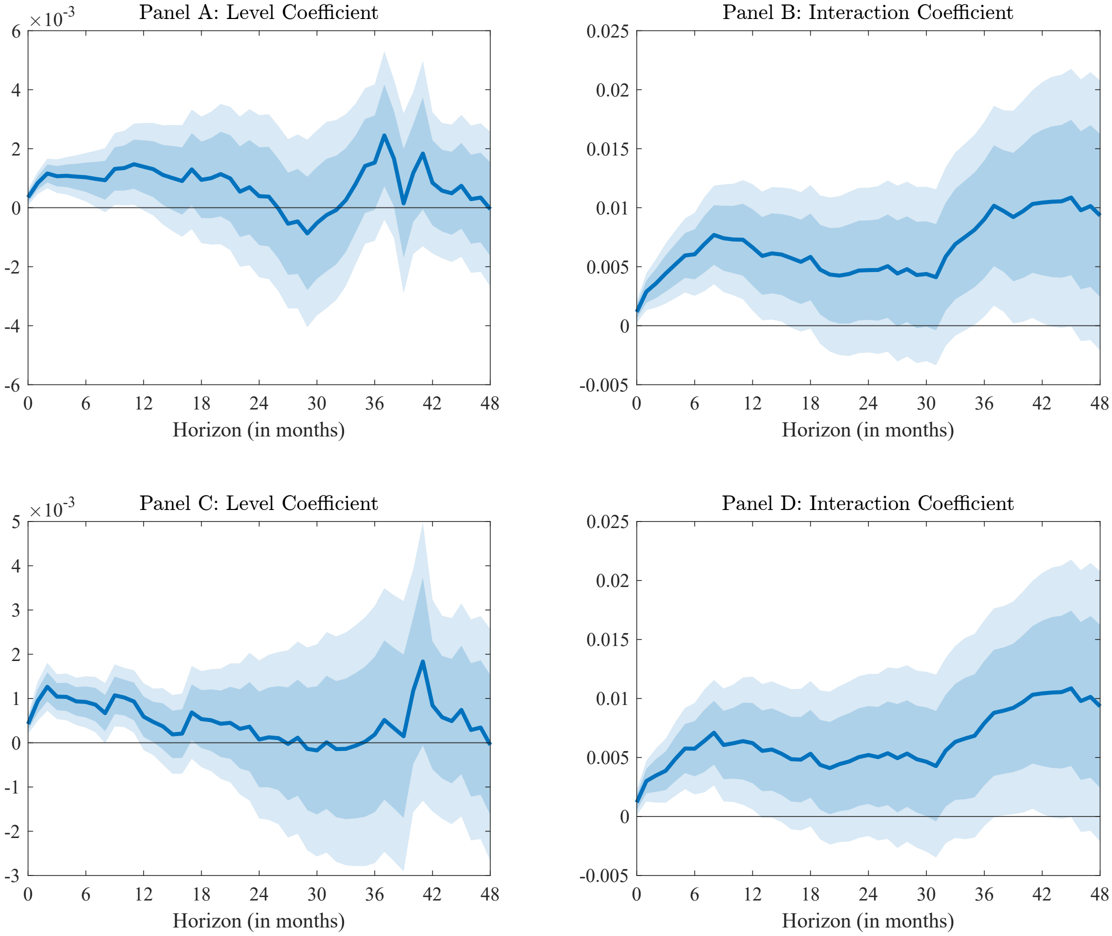

Figure 12: Estimated panel Local Projections coefficients to a Kanzig (2021) shock

Notes: This figure plots the estimated panel Local Projections coefficients to an oil supply news shock, where the dependent variable is the sectoral PCE price index. Reduced form specification. The dependent variable is measured in log and the independent variable is in units of the shock. The shock is such that a unit shock leads to a 10.88% increase in the Brent oil prices on impact. Sample period: Panel A, B: 1998:01 - 2023:06. Panel C, D: 1998:01-2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

it using the oil supply news shock of Kanzig (2021). More specifically, we run

$$
\begin{aligned}
\log P_{jt+h} - \log P_{jt-1} = \beta_0^{(h)} &+ \beta_1^{(h)} \times \left(\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}})\right) \\
&+ \beta_2^{(h)} \times \left(\frac{a_{ji}}{1-a_{jj}} \frac{\theta_j \sqrt{1-a_{jj}}}{\theta_j \sqrt{1-a_{jj}} + \theta_i \sqrt{1-a_{ii}}}\right) \times \left(\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}})\right) \\
&+ \sum_{k=1}^{12} \gamma_k^{(h)} (\log P_{jt-k} - \log P_{jt-k-1}) \\
&+ \sum_{k=1}^{12} \zeta_k^{(h)} \times \left(\log(\frac{\text{PPI energy}_{t-k}}{\text{PPI}_{t-k}}) - \log(\frac{\text{PPI energy}_{t-k-1}}{\text{PPI}_{t-k-1}})\right) + \epsilon_{jt}
\end{aligned}
$$

where P_{jt} is the PCE price index of category j at time t. When we look at the effect of relative energy price changes on sectoral inflation in the U.S., we are mainly interested in how the heterogeneity of response of sectoral inflation depends on our model implied sufficient statistics. Thus, the main coefficient of interest is given by $\beta_2^{(h)}$. We again compute Driscoll-Kraay standard errors.

Figure 13 shows that exogenous changes in the relative price of energy lead to, on average, an increase in sectoral PCE prices. Furthermore, sectors with a higher value of our sufficient statistic indeed respond relatively more to these shocks, as given by the positive estimates for $\beta_2^{(h)}$. Moving from the 25th to the 75th percentile of the distribution of the sufficient statistic leads the response to a one percent increase in the relative price of energy to increase by 0.07 basis points on impact, 0.28 basis points after 3 months, and 0.55 basis points after 36 months[18].

To provide a sense of the quantitative differences in effects across sectors, we now report total effects on prices and how they vary across the distribution of the sufficient statistic. The responses on impact of the 25th, 50th, and the 75th percentiles of the distribution of the sufficient statistic are 0.67, 0.69, and 0.75 basis points, respectively. The responses after three months of the 25th, 50th, and the 75th percentiles of the distribution of the sufficient statistic are 2.16, 2.23, and 2.44 basis points, respectively. Finally, the responses after 36 months of the 25th, 50th, and the 75th percentiles of the distribution of the sufficient statistic are 1.37, 1.50, and 1.93 basis points, respectively. The bottom row of Figure 13 shows that the results are robust to using a pre-Covid sample period.

3.2.3. Robustness and Extensions. In this subection, we show that our result is robust to including time fixed effects or sector fixed effects in the panel local projection specification. Furthermore, we show evidence that our sufficient is indeed informative about the pass-through through placebo

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[18] The 25 percentile of the distribution of the sufficient statistics is 0.008153 and the 75 percentile is 0.042397. $\beta_2^{(0)} = 0.0216634, \beta_2^{(3)} = 0.0820985$, and $\beta_2^{(36)} = 0.163326$. Then, the difference in response after a one percent increase in the relative price of energy becomes $\beta_2^{(0)} \times (0.042397 - 0.008153) \times 1\% = 0.000741841\% \approx 0.07$ basis points on impact, $\beta_2^{(3)} \times (0.042397 - 0.008153) \times 1\% = 0.00281138\% \approx 0.28$ basis points after 3 months, and $\beta_2^{(36)} \times (0.042397 - 0.008153) \times 1\% = 0.005592936\% \approx 0.55$ basis points after 36 months. One percentage point is equal to 100 basis points.

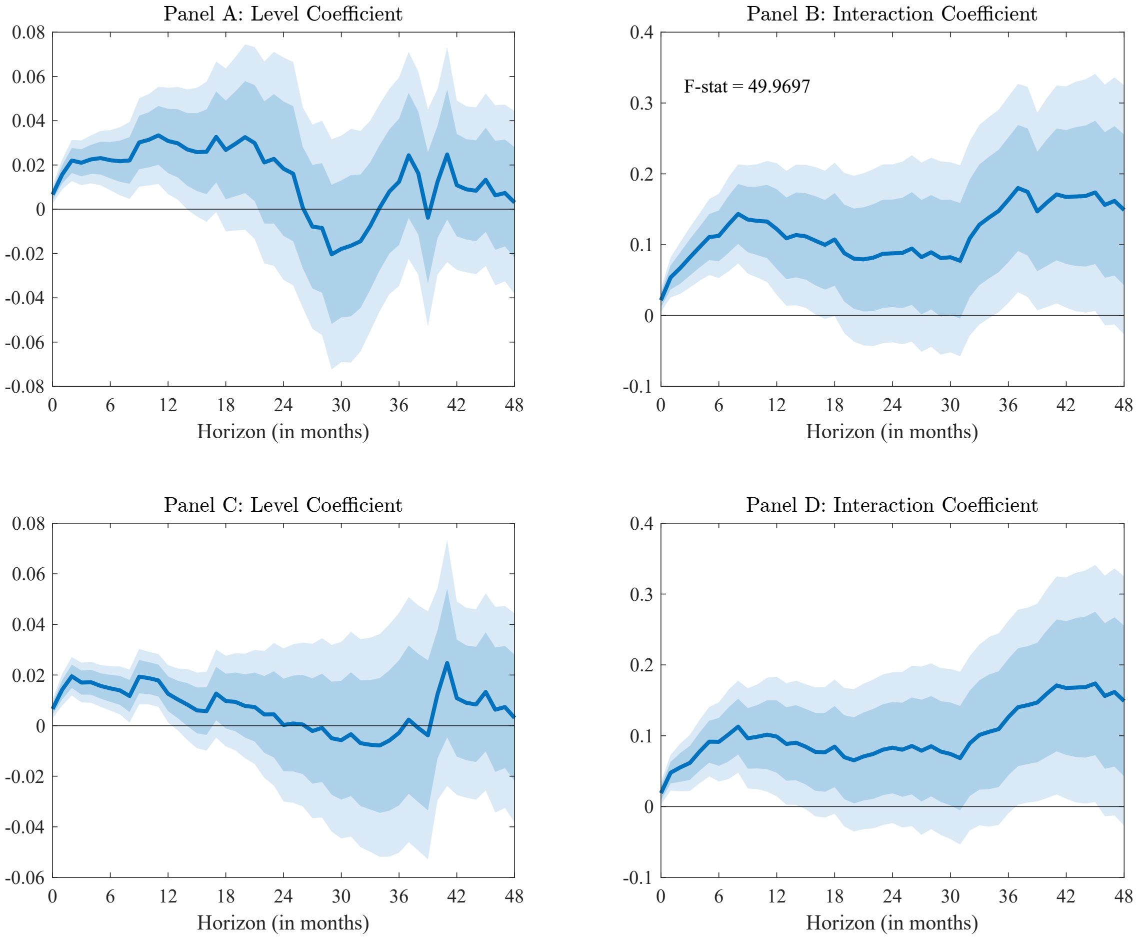

Figure 13: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE price index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Sample period: Panel A, B: 1998:01 - 2023:06. Panel C, D: 1998:01 - 2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals. F-stat: 49.9697.

tests. Finally, we present several extensions.

Placebo Tests. One may be concerned that the significant interaction coefficients we find might be present even if we use the sufficient statistics with relation to sectors that are not directly affected by oil supply shock. To address that, we run the same regression as in the panel local projection IV results subsection constructing the sufficient statistics corresponding to the following IO sectors: Ambulatory health care services, Hospitals, Insurance carriers and related activities, and Legal services[19]. Since oil supply shocks do not affect directly the PPI price in these sectors, we expect the interaction coefficient to be non-positive over the entire horizon. Figure 14 shows the results that are consistent with what we would expect.

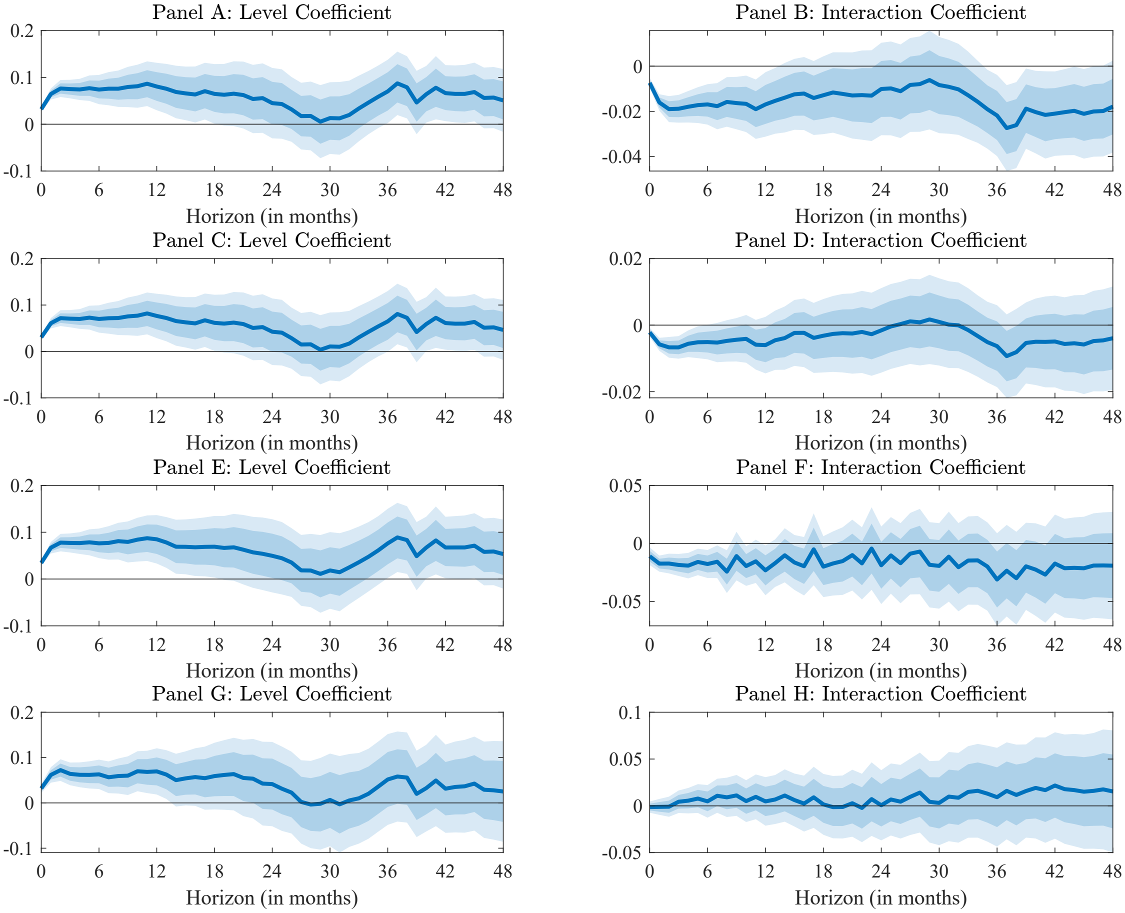

Figure 14: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE price index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Sample period: 1998:01 - 2023:06. Panel A, B: Ambulatory health care services. F-stat: 50.3411. Panel C, D: Hospitals. F-stat: 50.3452. Panel E, F: Insurance carriers and related activities. F-stat: 51.46013. Panel G, H: Legal services. F-stat: 50.496. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

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[19] These are IO sectors with a very small share of cost accounted for Oil and gas extraction (211), Petroleum and coal products (324), and Utilities (22)

Sectoral Quantity Responses. Besides the heterogeneous sectoral price responses, we also present the responses of sectoral quantities, using the same panel local projection IV specification. Thus, we use real PCE quantities of various sectors as the dependent variable. Figure 15 shows the results, which depict negative interaction coefficients, as expected and consistent with the positive interaction coefficients in Figure 13 for sectoral prices.[20] Moving from the 25th to the 75th percentile of the distribution of the sufficient statistic leads the response to a one percent increase in the relative price of energy to decrease by 0.22 basis points on impact and 0.68 basis points after 36 months.[21]

Sensitivity Analysis. We now report results from some important sensitivity analysis. First, we run an alternative specification including time fixed effects, which should account for common shocks that affect all PCE categories. Figure A4 in the Appendix shows the results. Next, we run an alternative specification including sector fixed effects which should account for time invariant sectoral heterogeneity. Figure A5 in the Appendix shows the results. In both cases, the results are similar to our baseline results.

Finally, throughout our analysis, we assumed that the total energy sector was represented by both oil and gas extraction and petroleum and coal products. We now show that our results are robust to considering oil and gas extraction only as the oil sector. For this analysis, we do not exclude any PCE category in the panel regressions. The reason is because the oil and gas extraction sector is not consumed as a final consumption for any category. Therefore, there is no mechanical effect on sectoral PCE prices. Figure A6 in the Appendix shows the results for prices and Figure A7 in the Appendix for quantities. They are similar to our baseline results.

4 Extension

In this section, we present evidence suggesting that changes in global supply chain pressures might also act as negative aggregate supply shocks in the U.S.. We document that increased pressures in global supply chains are linked to increases in domestic inflation and a reduction in economic activity. Moreover, global supply chain pressure first manifests most strongly in import prices of industrial supplies and materials, thereby suggesting a link with intermediate inputs as in our theoretical model.

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[20] See Ghassibe (2021) for an analysis of sectoral consumption responses to a monetary policy shock and an interpretation of the results based on input-output linkages.

[21] The 25th percentile of the distribution of the sufficient statistic is 0.008153 and the 75th percentile is 0.042397. $\beta_2^{(0)} = -0.0668064$, $\beta_2^{(36)} = -0.19911$. Then, the difference in response after a one percent increase in the relative price of energy becomes $\beta_2^{(0)} \times (0.042397 - 0.008153) \times 1\% = -0.00228\% \approx -0.22$ basis points on impact and $\beta_2^{(36)} \times (0.042397 - 0.008153) \times 1\% = -0.00682\% \approx -0.68$ basis points after 36 months.

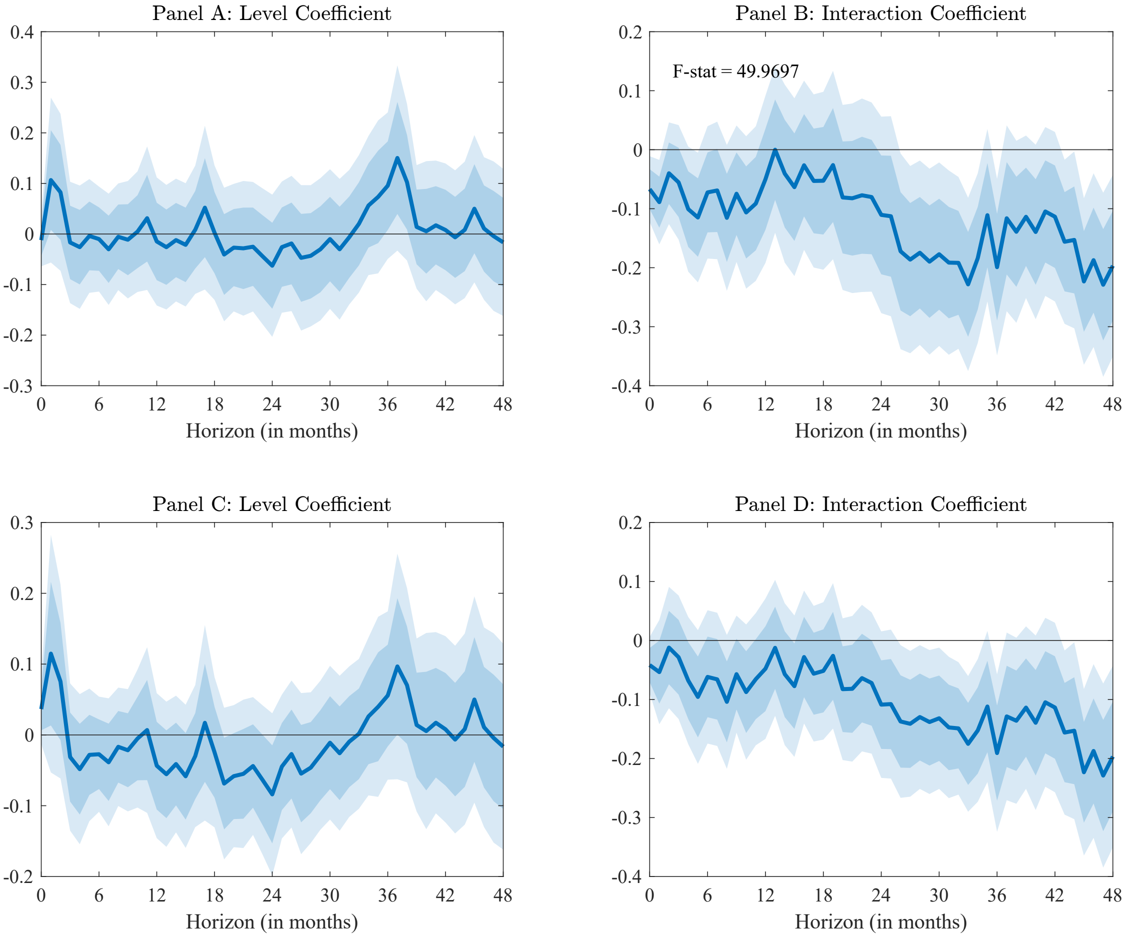

Figure 15: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE quantity index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Sample period: 1998:01 - 2023:06. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

To support this finding, we use the New York Fed Global Supply Chain Pressure Index (GSCPI) as a measure of global supply chain pressures in a local projection framework, as in Subsection 3.1. We focus on the period before the COVID-19 pandemic to ensure that our results are not driven by unusually high shocks or endogenous movements in the GSCPI.

Our analysis first shows that rising global supply chain pressures correlate with higher import prices, which we conjecture is a main channel through which global supply chain pressures affect domestic activity. In particular, as shown in Panel A of Figure 16, a one unit innovation in the GSCPI is associated with approximately 0.15 log-points increase, after 24 months, in import prices of industrial supplies and materials, which serve as inputs for firms. Moreover, more broadly, as shown in Panel B of Figure 16, a one unit innovation in the GSCPI is associated with approximately 0.06 log-points increase, after 24 months, in over import prices. Panels C and D of show results for PCE prices for durables and non-durables, which have a lower pass-through compared to import prices. The effects are nevertheless still significant.

Next we present results related to aggregate prices and economic activity. The first row of Figure 17 shows impulse responses of U.S. headline inflation and core inflation to an innovation in the GSCPI. We observe that innovations in the GSCPI lead to an increase in both headline inflation and core inflation, although the effect on core inflation is less precisely estimated. The second row of Figure 17 shows that innovations in the GSCPI are associated with contraction in economy activity, as after some delay, the unemployment rate increases, while (real) consumption expenditure decreases. Taken together, the two rows of Figure 17 suggest that global supply chain pressures can act as negative aggregate supply shocks.

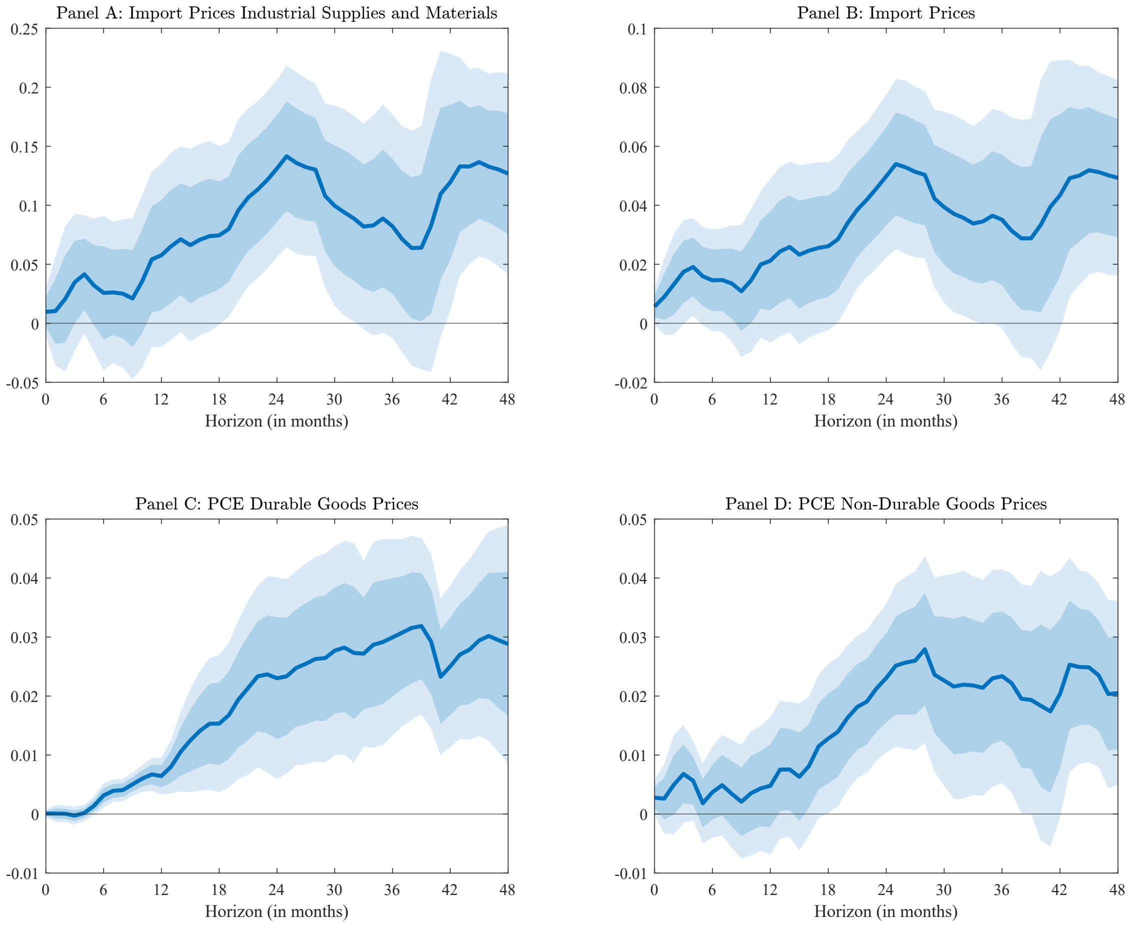

Figure 16: Impulse responses to a global supply chain pressure innovation

Notes: This figure plots impulse responses of import price inflation, import price industrial supplies and materials inflation, PCE durable goods price inflation, and PCE non-durable goods price inflation. The independent variable is the NY Fed Global Supply Chain Pressure Index. The dependent variable is expressed in log, while the independent variable is expressed in units of the index. Controls for 12 lags of log industrial production change, log real wage changes, log PCE changes, log PCE core changes, unemployment changes, and log real personal consumption expenditures. Sample period: 1998:01 - 2020:03. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

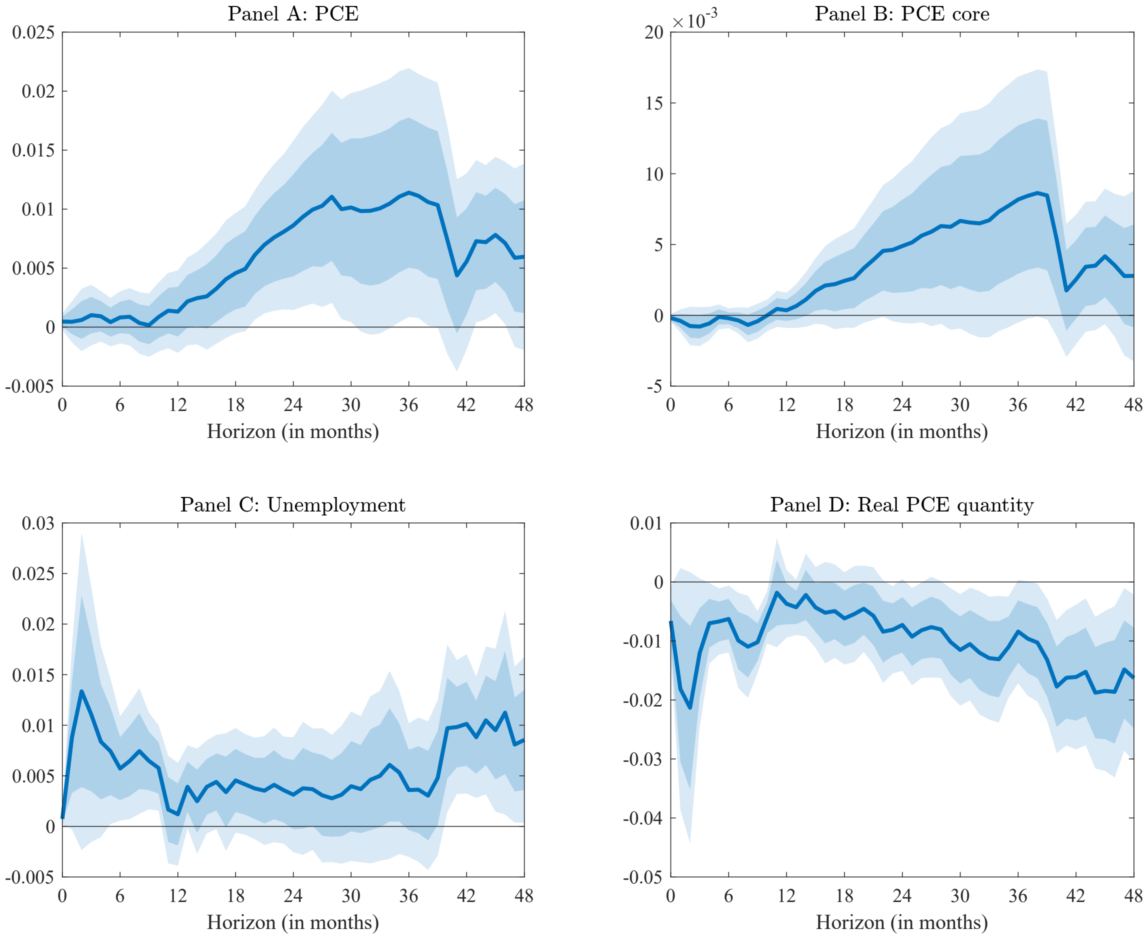

Figure 17: Impulse responses to a global supply chain pressure innovation

Notes: This figure plots impulse responses of PCE headline inflation, PCE core inflation, the unemployment rate, and the real PCE quantity index. The independent variable is the NY Fed Global Supply Chain Pressure Index. The dependent variable is expressed in log, while the independent variable is expressed in units of the index. Controls for 12 lags of log industrial production change, log real wage changes, log PCE changes, log PCE core changes, unemployment changes, and log real personal consumption expenditures. Sample period: 1998:01 - 2020:03. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

5 Conclusion

In this paper, we show how relative price changes cause aggregate inflation in a multi-sector sticky price model with input-output linkages. We present a two-sector calibrated model that can account for recent headline and core inflation dynamics in the U.S., where the shock that drives inflation is a shock to an upstream sector that has a low relative price duration. Empirically, using dis-aggregated PCE price data, we show that exogenous changes to the relative price of energy have heterogeneous pass-through to PCE sectoral prices, as predicted by our model.

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6 Appendix

6.1. Data and sources

Variable	Source	Series Code
PCE Price Index	St. Louis FRED	PCEPI
PCE Core Price Index	St. Louis FRED	PCEPILFE
Unemployment Rate	St. Louis FRED	UNRATE
Real PCE Quantity Index	St. Louis FRED	DPCERA3M086SBEA
PPI	St. Louis FRED	PPIACO
PPI Oil and gas extraction	St. Louis FRED	PCU21112111
PPI Petroleum and Coal Products Mfg	St. Louis FRED	PCU32413241
PCE Price Indices by Type of Product	Table 2.4.4U.	
Real PCE by Type of Product, Quantity Indices	Table 2.4.3U.	
IO Use Table Before Redefinitions PRO	BEA	
PCE Bridge at Summary level	BEA	
Frequency of price adjustment	Pastel et al. (2020)	
Import Matrices Before Redefinitions SUM	BEA	
PCE Energy Price Index	St. Louis FRED	DNRGRG3M086SBEA
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.

PPI energy. We construct a measure of PPI energy by calculating a simple geometric mean between the PPI oil and gas extraction and the PPI petroleum and coal products mfg. That is,

$$\text{PPI energy}_t \equiv \left(\text{PPI oil and gas extraction}_t^{1/2}\right)\left(\text{PPI petroleum and coal products mfg}_t^{1/2}\right)$$

Input-Output table (A) and Personal consumption expenditures (β). We use the 1997 IO use table before redefinition in producers' value at the Summary level disaggregation. We disregard the distinction between commodities and industries and assume that each industry produces only one commodity. Furthermore, we exclude the government sectors (GFGD, GFGN, GFE, GSLG, GSLE), Scrap, used and secondhand goods (Used), Noncomparable imports and rest-of-the-world adjustment (Other)[22]. After this, we end up with 66 sectors. For the empirics, we also perform the following two processes: (1) we collapse the retail summary sectors into a single retail sector. That

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[22] Baqaee and Farhi (2020) adopts a similar procedure.

is, we collapse Motor vehicles and parts dealers (441), Food and beverage stores (445), General merchandise stores (452), and Other retail (4A0) into a single retail sector; (2) we collapse Oil and gas extraction (211) and Petroleum and coal products (324) into a single Total oil sector. We end up with 62 sectors.

Frequency of price adjustment. We use data from Pasten, Schoenle, and Weber (2020). The data comes at a more disaggregated level than the disaggregation we use (Summary level). We aggregate it into our disaggregation level by taking the simple average of frequency of price adjustment among industries within our disaggregation level for which we have data.

Sufficient Statistics for PCE categories. An important component of our analysis is the NIPA PCE bridge table. We use the 1997 PCE bridge table. For each PCE category, the rows of the bridge table shows the commodities included in it, the producers' value of the commodity, and the transportation costs and trade margins required to move the commodity from producer to consumer.

We are interested in $\left[\frac{a_{ji}}{1-a_{jj}}\frac{\theta_j\sqrt{1-a_{jj}}}{\theta_j\sqrt{1-a_{jj}}+\theta_i\sqrt{1-a_{ii}}}\right]_{j \text{ is PCE category}}$ where j is a PCE category. We do not directly observe the cost shares in terms of PCE categories, a_{ji}, their frequency of price adjustment θ_j, or their own category input share a_{jj}. However, we do observe the IO commodities that compose this PCE category, along with its producers' value, transportation costs, and trade margins.

To overcome this limitation, to calculate the sufficient statistic, we take a weighted average of the sufficient statistic for each IO sector that is included in j's PCE category. The weights are given by the share of PCE purchasers' value ex-transportation cost accounted for the respective IO sector. We include wholesale margins and retail margins as rows in the bridge. These would correspond to the Wholesale Trade (42) and the consolidated Retail Sector (441, 445, 452, 4A0). The reason why we exclude transportation cost is because at the Summary level, we cannot assign to which one of the transportation sectors (481, 482, 483, 484, 486, 487) this cost refers to. Similarly, the reason why we collapse the retail sectors into one retail sector is because we cannot assign the margin to the corresponding IO retail sector.

Two sector calibration. In the theory section, we use a two-sector model with an upstream sector and a downstream sector. We define the upstream sector as the Oil and gas extraction (211), Petroleum and coal products (324), Utilities (22), Primary metals (331), Wholesale trade (42), Farms (111CA), Other real estate (ORE), and Federal Reserve banks, credit intermediation, and related activities (521CI) sectors. All other sectors are defined as downstream sectors. For the frequency of price adjustment, we first calculate the continuous time FPA, then we calculate the sectoral duration ${}^{1}/\theta_i$. Then, we take the simple average of the sectoral duration among sectors that belong to the upstream and downstream sectors. Finally, we recover the upstream and downstream FPA by calculating $\theta_j = {}^{1}/\text{duration}_j$, $j \in \{\text{upstream}, \text{downstream}\}$. To construct $\mathbf{A}$ and $\boldsymbol{\beta}$ we use the IO use table, collapsing the IO sectors that belong to upstream and downstream sectors. We end up with the following objects:

$$\boldsymbol{\beta} = \begin{pmatrix} \beta_{\text{upstream}} \\ \beta_{\text{downstream}} \end{pmatrix} = \begin{pmatrix} 0.1003 \\ 0.8996 \end{pmatrix}$$

$$\mathbf{A} = \begin{bmatrix} a_{11} & a_{12} \\ a_{21} & a_{22} \end{bmatrix} = \begin{bmatrix} 0.3102 & 0.3668 \\ 0.1346 & 0.4703 \end{bmatrix}$$

where the sector 1 is the upstream sector, and sector 2 is the downstream sector. Finally,

$$\Theta = \begin{bmatrix} \theta_{\text{upstream}} & 0 \\ 0 & \theta_{\text{downstream}} \end{bmatrix} = \begin{bmatrix} 0.2899 & 0 \\ 0 & 0.0920 \end{bmatrix}$$

6.2. Additional results for aggregate effects

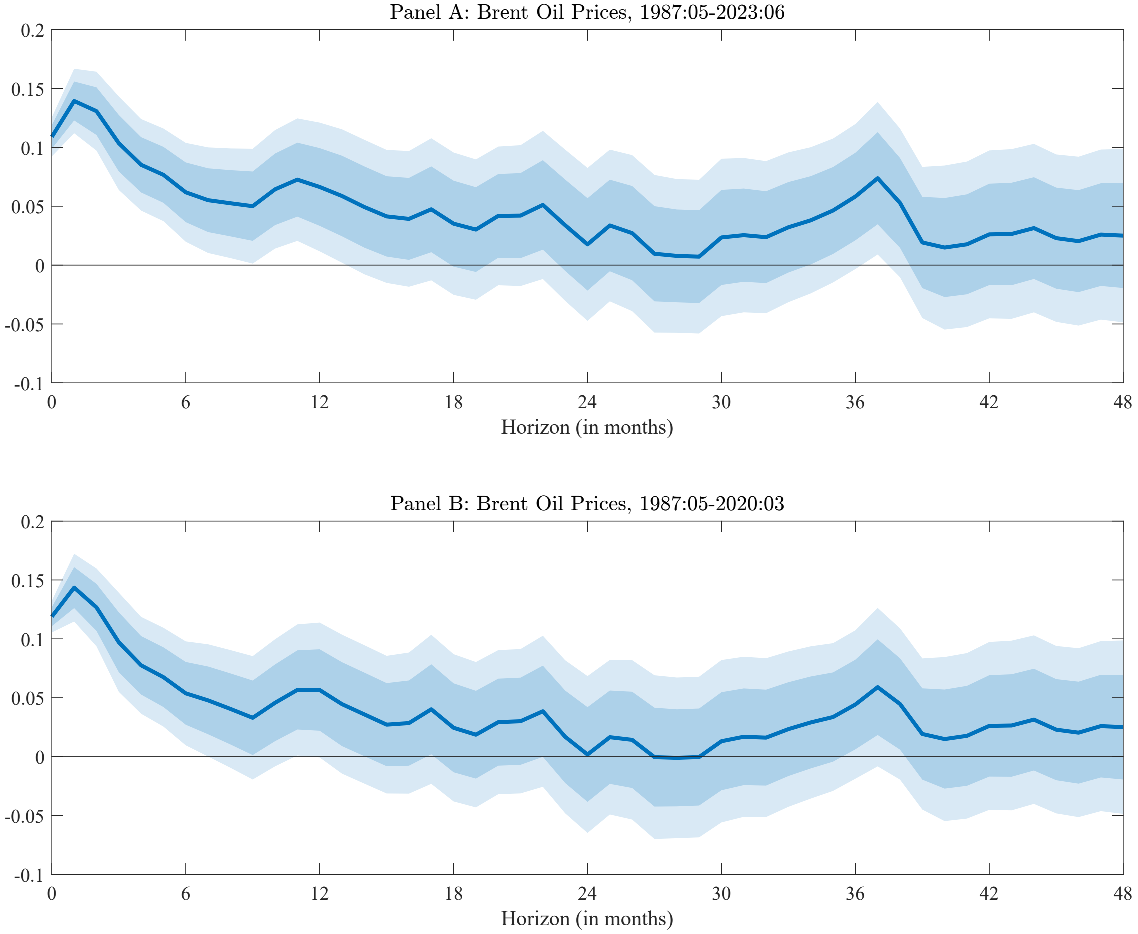

Figure A1: Impulse responses to a Kanzig shock

Notes: This figure plots impulse responses of Brent Oil prices. The shock is the oil supply news shock from Kanzig (2021). The dependent variable is measured in log and the independent variable is in units of the shock. In panel A, a one unit shock leads to a 10.88% increase in oil prices on impact. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

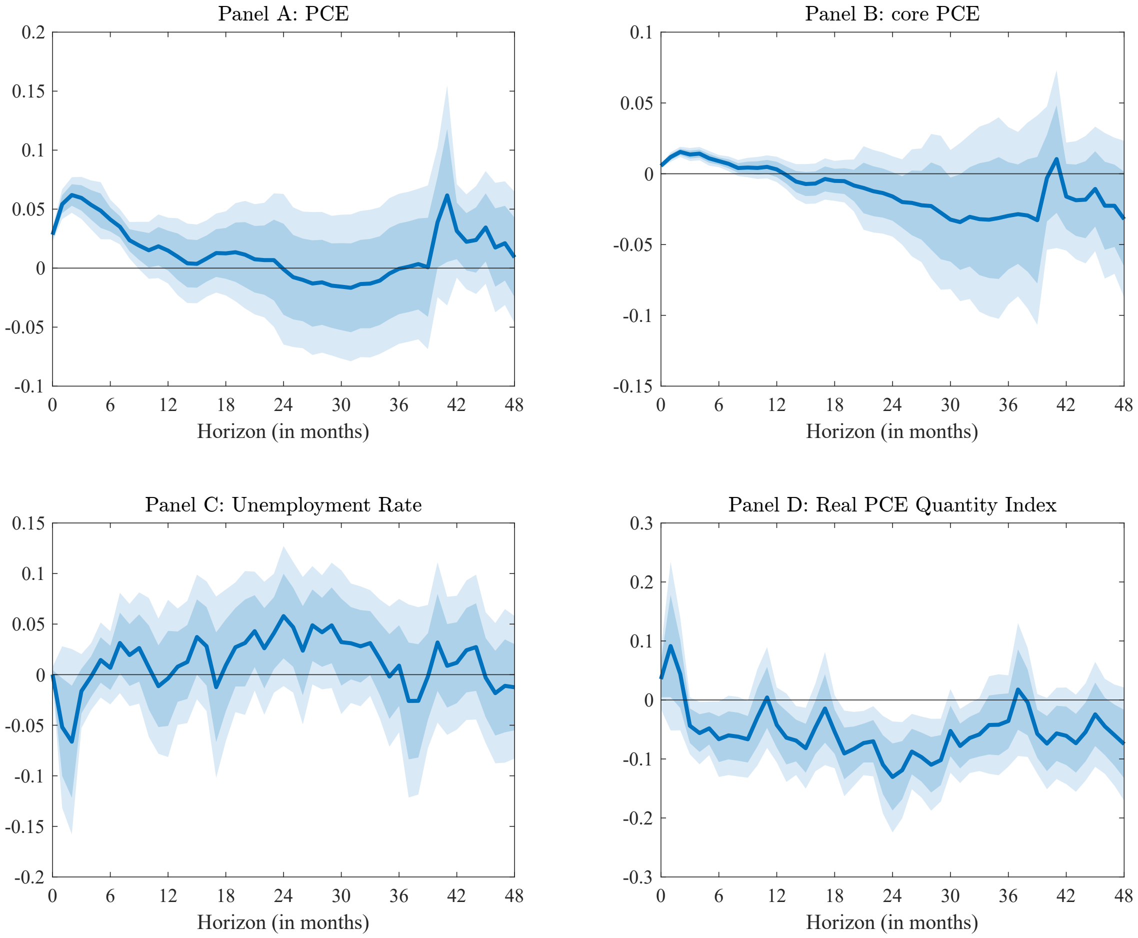

Figure A2: Impulse responses to a shock to the relative price of energy

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 relative price of energy is measured as a simple geometric mean of relative Oil and gas extraction PPI and relative Petroleum and coal products PPI (relative to the aggregate PPI). Sample period: 2008:01 - 2023:06. Both the dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

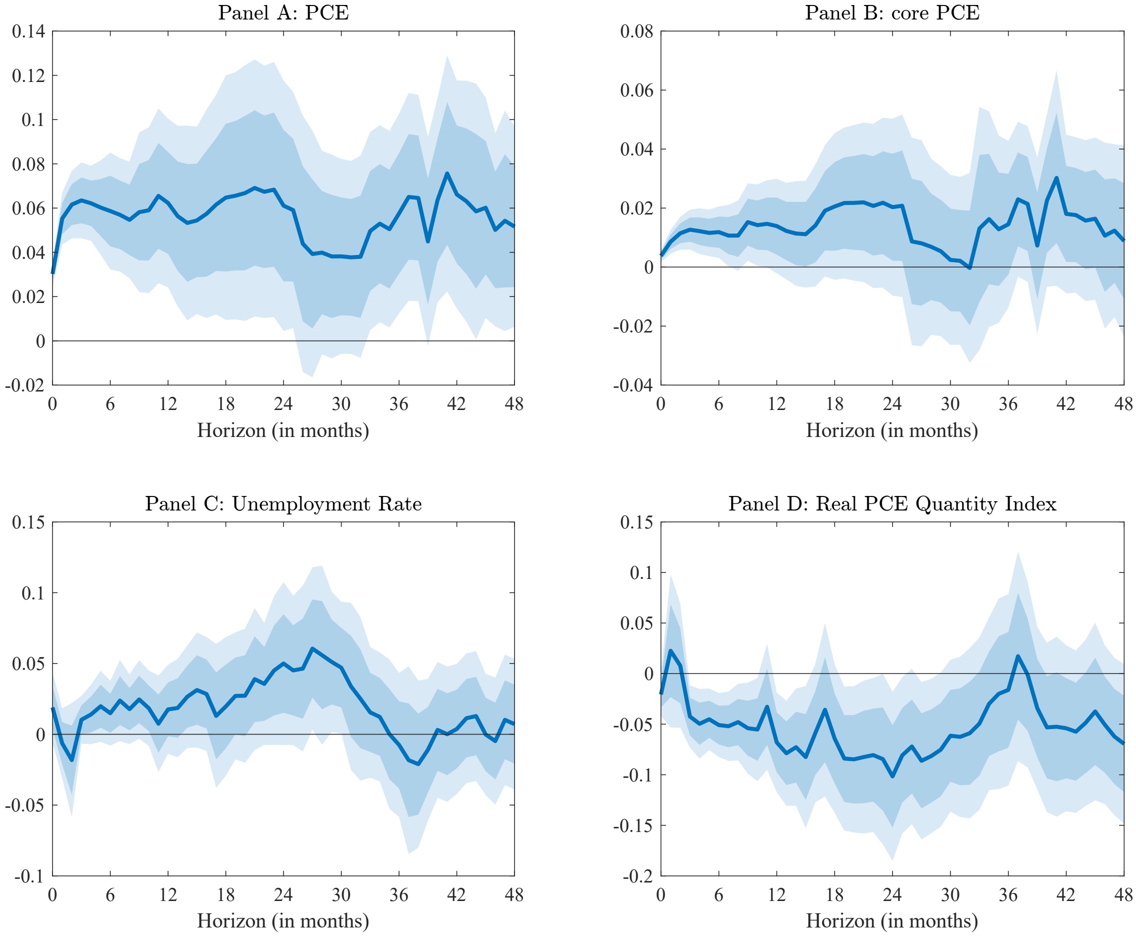

Figure A3: Impulse responses to a shock to the relative price of energy

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 relative price of energy is measured as a simple geometric mean of relative Oil and gas extraction PPI and relative Petroleum and coal products PPI (relative to the aggregate PPI). The specification uses lagged real wages as controls. Both the dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Sample period: 1986:01 - 2023:06. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals. First stage F-stat: Panel A: 84.77. Panel B: 78.55. Panel C: 113.10. Panel D: 116.99.

6.3. Robustness and extensions on sectoral effects

Time Fixed Effects Regressions. In this subsection we run an alternative specification including time fixed effects which should account for common shocks that affect all PCE categories. Figure A4 shows that our sufficient statistics does predict the response of sectoral inflation to oil supply shocks correctly. Finally, we consider robustness in which we add time fixed effects, and in which we add sector fixed effects. That is, in the time fixed effects specification, we run

$$\log P_{jt+h} - \log P_{jt-1} = \beta_1^{(h)} \times \left(\frac{a_{ji}}{1-a_{jj}} \frac{\theta_j \sqrt{1-a_{jj}}}{\theta_j \sqrt{1-a_{jj}} + \theta_i \sqrt{1-a_{ii}}} \right) \times \left(\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}}) \right)$$
$$+ \sum_{k=1}^{12} \gamma_k^{(h)} (\log P_{jt-k} - \log P_{jt-k-1}) + FE_t + \epsilon_{jt}$$

instrumenting the change in the relative prices of energy with the oil supply news shock from Kanzig (2021). FE_t is the time fixed effect.

Sector Fixed Effects Regressions. In this subsection we run an alternative specification including sector fixed effects which should account for time invariant sectoral heterogeneity. Figure A5 shows the result. For the sector fixed effects specification, we run

$$\log P_{jt+h} - \log P_{jt-1} = \beta_1^{(h)} \times \left(\frac{a_{ji}}{1-a_{jj}} \frac{\theta_j \sqrt{1-a_{jj}}}{\theta_j \sqrt{1-a_{jj}} + \theta_i \sqrt{1-a_{ii}}} \right) \times \left(\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}}) \right)$$
$$+ \sum_{k=1}^{12} \gamma_k^{(h)} (\log P_{jt-k} - \log P_{jt-k-1}) + FE_j + \epsilon_{jt}$$

where FE_j is the sector fixed effect.

Oil and gas extraction as the oil sector. Throughout our analysis, we assumed that the total oil sector was represented by both oil and gas extraction and petroleum and coal products. In this subsection, we show that our results are robust to considering oil and gas extraction as the oil sector. For this analysis, we don't exclude any PCE category. The reason why we do this is because the oil and gas extraction sector is not consumed as a final consumption for any category. That is, the personal consumption expenditures for the oil and gas extraction sector is zero. Therefore, there is no mechanical effect on sectoral PCE prices. Figure A6 shows the results for prices and Figure A7 for quantities.

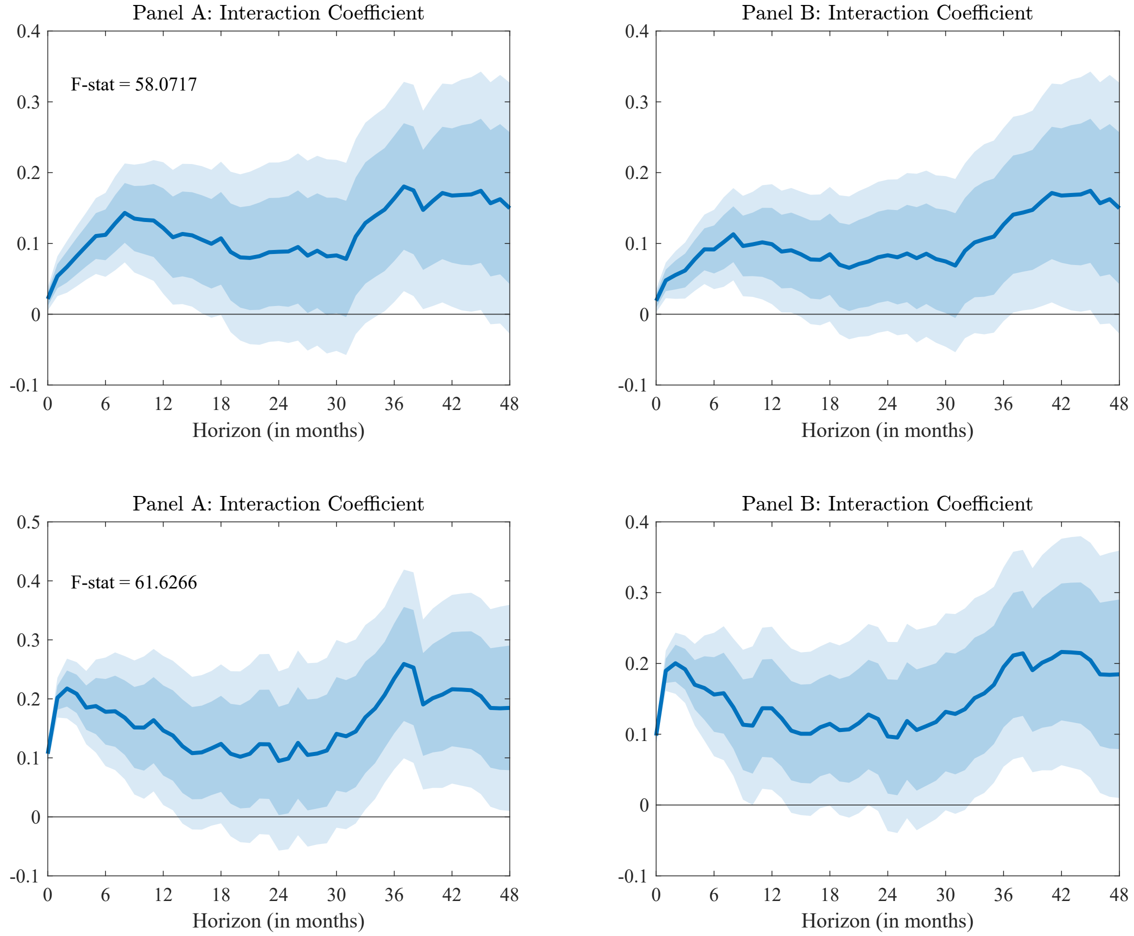

Figure A4: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE price index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Panel A: All PCE categories. 1998:01-2023:06. F-stat: 58.0717. Panel B: All PCE categories. 1998:01-2020:03. Panel C: Ex-PCE categories with positive Petroleum and coal products or Oil and gas extraction producers' value. 1998:01-2023:06. F-stat: 61.6266. Panel D: Ex-PCE categories with positive Petroleum and coal products or Oil and gas extraction producers' value. 1998:01-2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

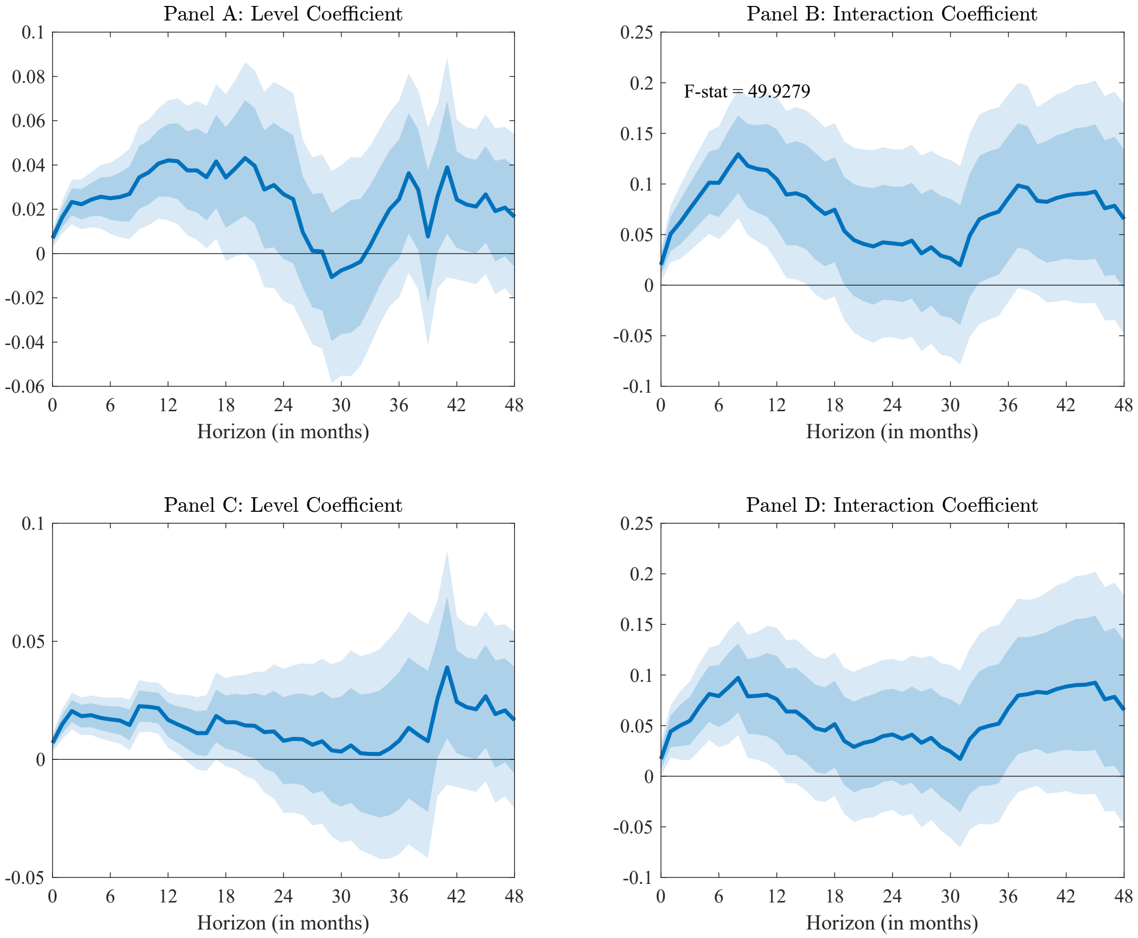

Figure A5: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE price index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. Specification with sector fixed effects. Panel A and B: 1998:01-2023:06. Panel C and D: 1998:01-2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals. F-stat: 49.92

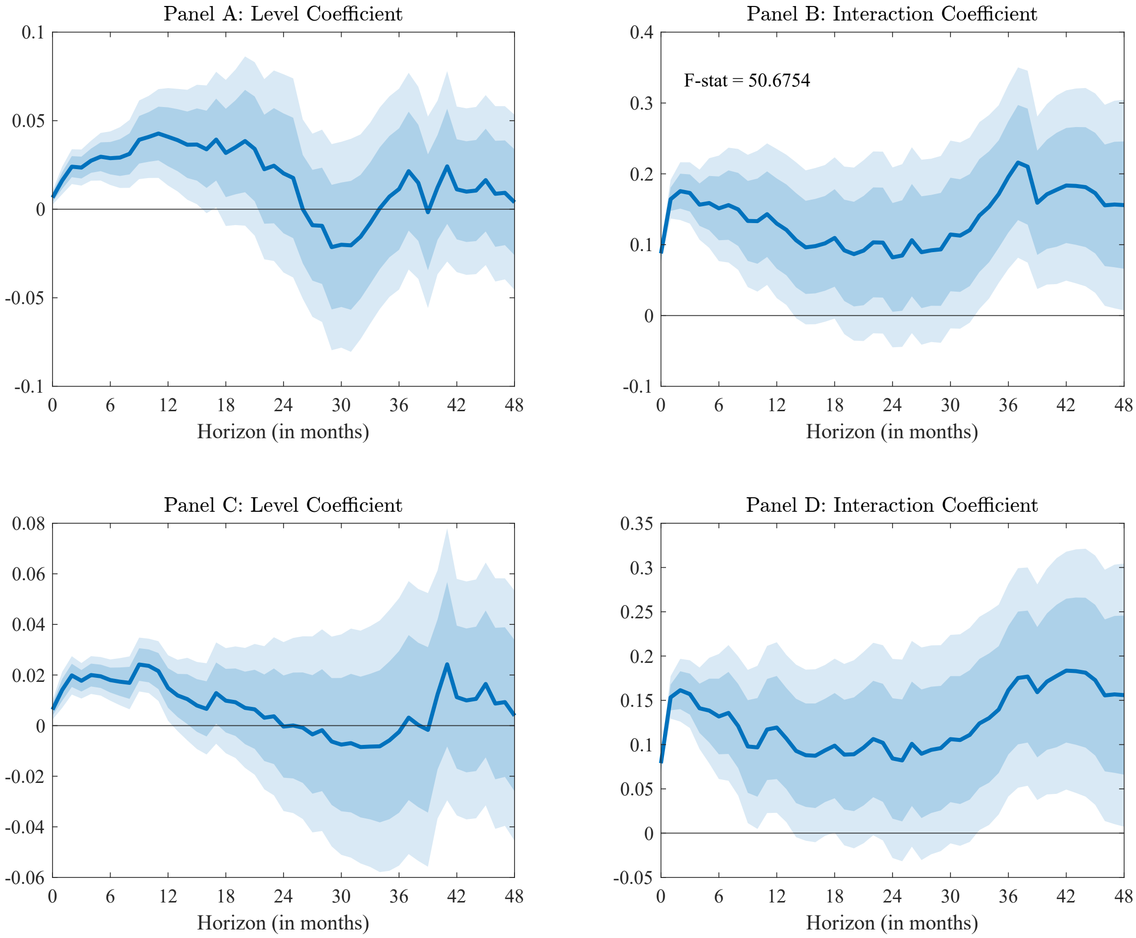

Figure A6: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE price index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. The sufficient statistic is created with relation to Oil and gas extraction sector. Sample: All PCE categories. Panel A, B: 1998:01 - 2023:06. Panel C, D: 1998:01 - 2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals. F-stat: 50.6754

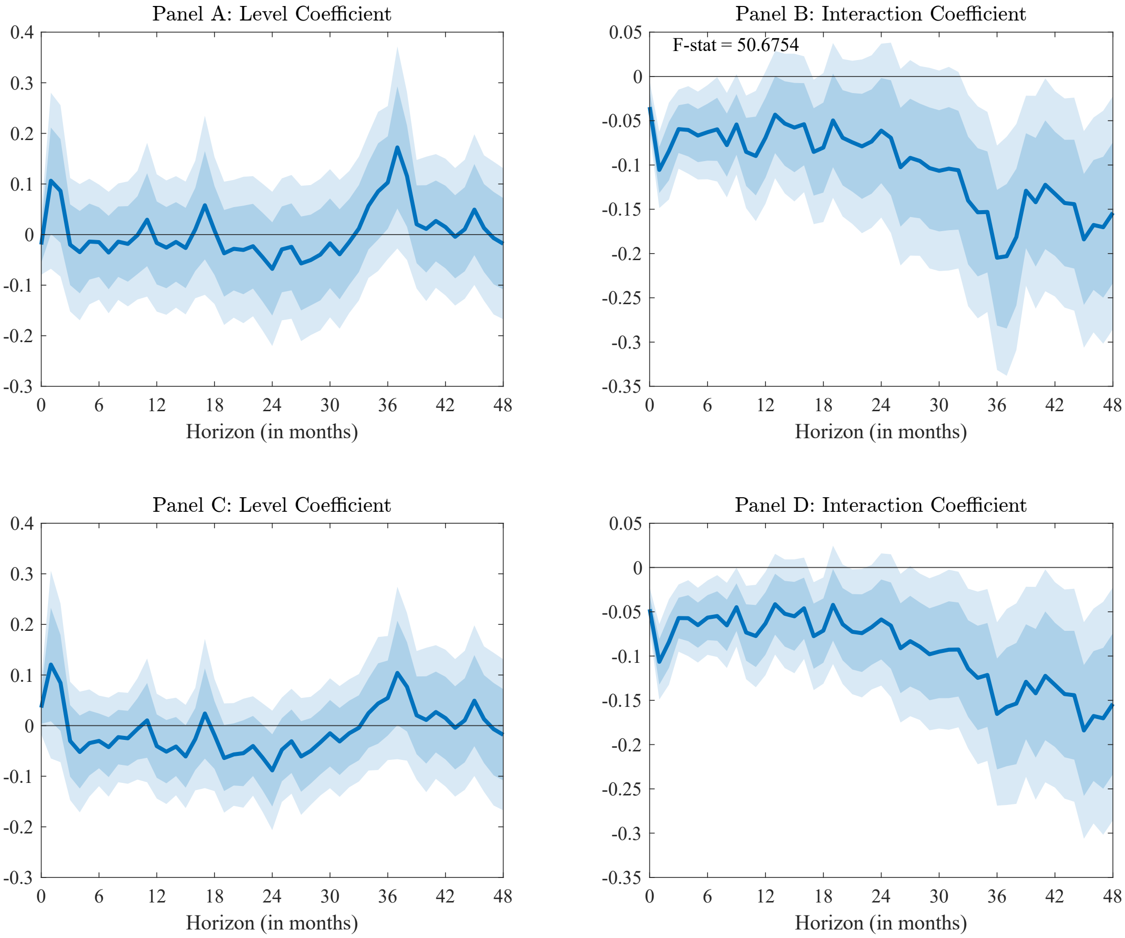

Figure A7: Estimated panel Local Projections coefficients to a shock to the relative price of energy

Notes: This figure plots the estimated panel Local Projections coefficients to a shock to the relative price of energy, where the dependent variable is the sectoral PCE quantity index. The relative price of energy is instrumented by the oil supply news shock from Kanzig (2021). The dependent variable and the independent variable are expressed in log. Hence, the coefficients represent elasticities. The sufficient statistic is created with relation to Oil and gas extraction sector. Sample: All PCE categories. Panel A, B: 1998:01 - 2023:06. Panel C, D: 1998:01 - 2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals. F-stat: 50.6754