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

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Abstract

We provide theory and evidence that relative price shocks can cause aggregate inflation and act as aggregate supply shocks. Empirically, we show that exogenous positive energy price shocks have a positive impact not only on headline but also on U.S. core inflation while depressing U.S. real activity. In a two-sector monetary model with upstream and downstream sectors and heterogeneous price stickiness, we analytically characterize how upstream shocks propagate to prices. Using panel IV local projections, we show that the responsiveness of sectoral PCE prices to energy price shocks is in line with model predictions. Motivated by post-COVID inflation in the U.S., a model experiment shows that a one-time relative price shock generates persistent movements in headline and core inflation similar to those observed in the data, even in the absence of aggregate slack. The model also emphasizes that monetary policy stance plays an important role in propagation of such shocks.

JEL Codes: E32, E52, C67
Key Words: relative price changes, aggregate supply shocks, energy price shocks, input-output linkages, core inflation, post-COVID inflation, sectoral PCE prices

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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 such relative price changes cause aggregate inflation without any aggregate slack? This is especially puzzling because in simple multi-sector models (with no input-output linkages or 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 are taken into account, these benchmark models predict *no additional role for relative price movements* in determining aggregate inflation. This also implies that in the absence of aggregate slack, that is a zero aggregate GDP gap, there should be no aggregate inflation.

In this paper, we present empirical evidence against this prediction. To understand this evidence, 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 price gaps (across sectors).

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. While both these ingredients are sufficient on their own to generate a new role for relative price changes, when both features are present they interact in non-trivial ways and lead to endogenously persistent spillover inflation across sectors. Such interactions can nevertheless still be understood in terms of economic mechanisms driven by the additional role of relative prices. Viewed in this way, relative

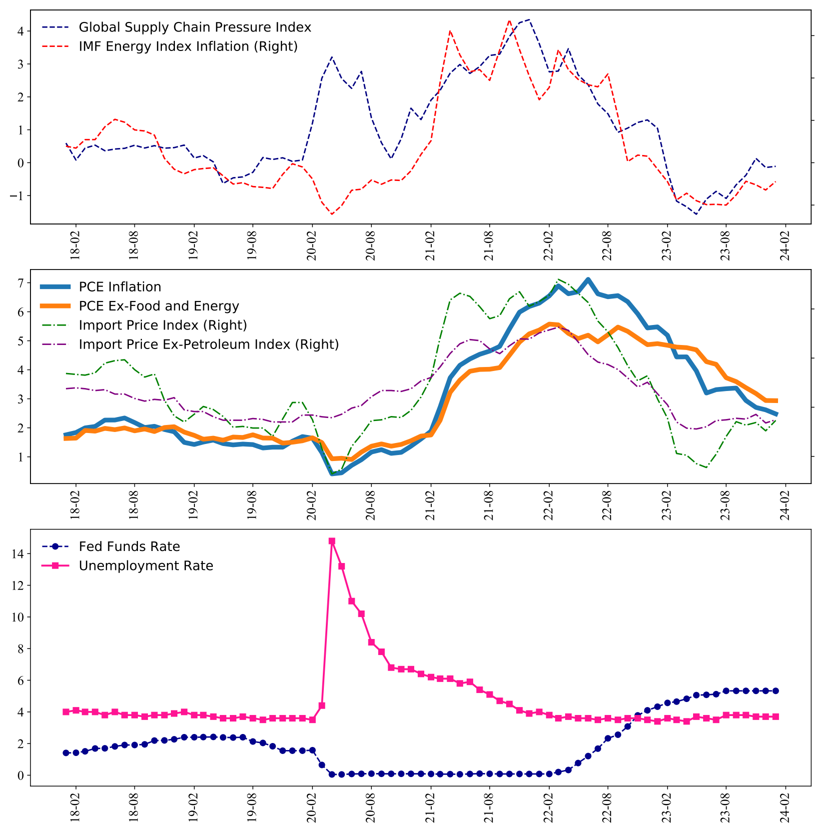

Figure 1: Recent evolution of prices, interest rates, and unemployment rate

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 obtained from St. Louis Fed's FRED. 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 de-meaned and normalized by its standard deviation.

price changes in our model are indeed akin to aggregate supply shocks (Ball and Mankiw, 1995), as they affect aggregate inflation even while holding aggregate GDP gap constant.[1]

We consider and solve in closed-form a two-sector model in order to illustrate how shocks to an upstream sector propagate to aggregate and downstream sectoral inflation in the most minimalist setting. While solving for equilibrium, it is essential to take a stance on monetary policy reaction and we provide results that can accommodate both the no-monetary response observed initially in the post-COVID inflation era, as well as a monetary policy that aims to stabilize aggregate slack.

Our first key analytical result is that in the absence of a monetary policy response, an exogenous increase in relative price of the upstream sector, that arises through a negative productivity shock, passes through to the downstream sector and generates inflation due to input-output linkages.[2] 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 network-adjusted price stickiness.

Our second key analytical result is that if monetary policy responds to the shock in the upstream sector by stabilizing the aggregate GDP gap, then even with no slack, the relative price (the price of the upstream sector relative to the price of the downstream sector) would evolve dynamically along a transition path with an endogenous persistence. Importantly, these dynamics are then inherited by aggregate inflation, which also evolves endogenously in the absence of aggregate slack. Moreover, if input-output linkages are strong enough along the transition path where the relative price is elevated, so would aggregate inflation as long as the upstream sector has higher network-adjusted price stickiness.

Empirically, we use these 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.[3] 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. We also find 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

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

[2]Formally, the no-monetary-policy response entails keeping nominal rates constant endogenously.

[3]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.

negative aggregate supply shocks in the U.S.[4]

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 the following experiment. Motivated by the post-COVID inflation in the U.S., we show that a one-time inflationary shock to the upstream sector in our model can generate persistent aggregate inflation movements, similar to the middle panel of Figure 1, matching well the behavior of both headline and core inflation. We then consider counterfactual exercises that show how monetary policy stance, the role of the upstream sector as a production input for the downstream sector, as well as higher price flexibility in the upstream sector contribute to these 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 hetero-

[4]As we show in detail later, these broad patterns are qualitatively present even if we exclude the post-COVID period.

geneity in price stickiness and a roundabout 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, 2024), La'O and Tahbaz-Salehi (2022), Rubbo (2023, 2024), 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.[5] 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 disaggregated sectoral price data.

On the empirical front, our paper is related to Minton and Wheaton (2023) (MW) who explore the effects of oil shocks on sectoral producer prices as well as aggregate consumer prices. MW use the Kanzig (2021) shock as an IV for oil prices and estimate how the heterogeneous effects are governed by sectoral characteristics. In particular, they employ a general multi-sector network model (similar to the one studied in Afrouzi and Bhattarai, 2023) and structurally estimate the delayed effects of commodity prices on sectoral producer and aggregate consumer inflation.

Our analysis differs from MW in two dimensions. First, in our panel local projection regressions, we estimate the interaction effect of a closed-form expression for a sectoral statistic that should drive the pass-through of relative producer price of energy to those sectors and find evidence in support of this interaction effect predicted by our model. In these regressions, we use the Kanzig (2021) shock as an IV for (relative) sectoral producer prices of energy. Second, using this IV strategy, we estimate the pass-through from (relative) producer price of energy to *quantities* and *sectoral* consumer prices (PCE), as opposed to sectoral producer prices. While the impact of energy price on the latter is important for how shocks propagate through the production network, here, we are instead interested on the bottom line of consumer price indices as they are more relevant for monetary policy objectives. Moreover, using PCE sectoral prices also allows us to empirically assess the effects on PCE sectoral quantities.

Our paper is also related to prior research examining the joint behavior of multiple inflation

[5] Pasten, Schoenle, and Weber (2020) provide analytical solutions for the effects of a monetary shock in a production network model under the assumption of full discounting.

series. Auer, Pedemonte, and Schoenle (2024) finds that a global factor explains much of the headline and core inflation across countries and that it correlates with commodity prices, supporting the idea that relative energy prices might influence global inflation. Schoenle and Smith (2022) shows that disaggregated PCE inflation rates are fat-tailed and granular, with a few sectors having a large impact on inflation in recent times, highlighting the importance of sector-specific shocks.[6] Our two-sector model offers analytical expressions to demonstrate the impact of sectoral shocks on aggregate inflation, albeit at the cost of not capturing the full richness of disaggregated PCE inflation rates. Moreover, on the empirical side, we focus on effects on sectoral prices of an exogenous increase in producer prices of energy and do not consider higher unconditional moments of the distribution, such as skewness, which could be an important avenue for future research.

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. This special case allows us to go much further in deriving analytical representations for the particular set of questions that motivate this study.

2.1. Model description

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 u) and "downstream" (Sector d). The household demands the final goods produced by each industry, supplies labor in a competitive market at nominal wage W_t, and holds nominal bonds B_t with nominal yield i_t that are at zero net supply. Her utility over consumption and leisure is given by $\ln(C_t) - L_t$. Formally, the household solves

$$\max_{\{(C_{i,t})_{i\in\{u,d\}}, L_t, B_t\}_{t\geq 0}} \int_0^\infty e^{-\rho t}[\ln(C_t) - L_t]\mathrm{d}t \tag{1}$$

$$s.t. \quad \sum_{i\in\{u,d\}} P_{i,t}C_{i,t} + \dot{B}_t \leq W_t L_t + i_t B_t + V_t - T_t \tag{2}$$

where $P_{i,t}$ is the price of the final good i, $C_{i,t}$ is consumption of the household from i, V_t is the total profits of all firms in the economy, and T_t is a lump-sum tax by the fiscal authority. Moreover, the

[6] These findings can inform theoretical models of granularity and aggregate fluctuations such as Gabaix (2011).

aggregate consumption C_t is defined as a Cobb-Douglas aggregate of sectoral goods, denoted by

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

It follows that given a vector of prices $(P_{u,t}, P_{d,t})$ for the sectoral goods, the aggregate consumption bundle is priced at

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

The preferences we use imply that the nominal wage is proportional to the aggregate nominal demand $W_t = M_t \equiv P_t C_t$. This implies that, with perfect foresight, the household's inter-temporal Euler equation can be written as

$$i_t - \rho = \frac{\dot{C}_t}{C_t} + \frac{\dot{P}_t}{P_t} = \frac{\dot{M}_t}{M_t} \tag{3}$$

where i_t is the nominal interest rate. 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 $i \in \{u, d\}$ consists of a competitive final good producer and a unit measure of intermediate monopolistically competitive firms. The final good producer of sector i is a price taker, buys from the unit measure of intermediate producers in its sector, and produces a final sectoral good using a CES production function with some substitution elasticity σ. These final goods are then used by the household for consumption or by intermediate goods producers as inputs, forming a production network as depicted in Figure 2.

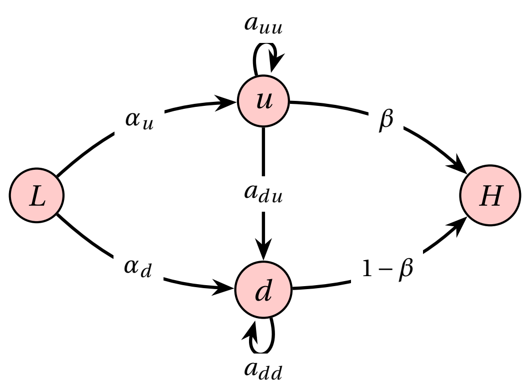

Figure 2: Structure of the production network

Notes: This figure shows the structure of production network considered in our two-sector economy. (u)pstream and (d)ownstream sectors both use labor (L) with shares α_u and α_d, their own output with shares a_{uu} and a_{dd} and the downstream sector also uses upstream sector with share a_{du}. They then sell to the household (H) whose expenditure share from upstream production is β and from downstream sector is $1-\beta$.

Formally, the final good producer of sector i maximizes the net present value of its profits over time, which due to lack of dynamic considerations, collapses to period-by-period maximization of its flow profits:

$$\max_{(Y_t, Y_{ij,t})_{j\in[0,1]}} P_{i,t} Y_{i,t} - \int_0^1 P_{ij,t} Y_{ij,t} \mathrm{d}j \quad \text{s.t.} \quad Y_{i,t} = \left[\int_0^1 Y_{ij,t}^{\frac{\sigma-1}{\sigma}} \mathrm{d}j\right]^{\frac{\sigma}{\sigma-1}}, \forall i \in \{u, d\} \tag{4}$$

where $P_{i,t}$ is the price of the sectoral good in sector i, $Y_{i,t}$ is the firm's production, $P_{ij,t}$ is the price of intermediate producer j in sector i, and $Y_{ij,t}$ is the final good producer's demand for the product of this intermediate firm. This maximization problem yields the standard CES demand function for the intermediate producer j and price index $P_{i,t}$ as a function of intermediate prices:

$$Y_{ij,t} = Y_{i,t} \left(\frac{P_{ij,t}}{P_{i,t}}\right)^{-\sigma}, \forall j \in [0,1], \quad P_{i,t} = \left[\int_0^1 P_{ij,t}^{1-\sigma} \mathrm{d}i\right]^{\frac{1}{1-\sigma}}, \forall i \in \{u, d\} \tag{5}$$

As for the intermediate firms in each sector, they use labor and final sectoral goods to produce with the following Cobb-Douglas production functions (omitting intermediate producer's index j):

$$Y_{u,t}^s = Z_{u,t} \left(\tfrac{L_{u,t}}{\alpha_u}\right)^{\alpha_u} \left(\tfrac{X_{uu,t}}{a_{uu}}\right)^{a_{uu}}, \qquad Y_{d,t}^s = Z_{d,t} \left(\tfrac{L_{d,t}}{\alpha_d}\right)^{\alpha_d} \left(\tfrac{X_{du,t}}{a_{du}}\right)^{a_{du}} \left(\tfrac{X_{dd,t}}{a_{dd}}\right)^{a_{dd}} \tag{6}$$

where all exponents are non-negative, $\alpha_u > 0, \alpha_d > 0$ are strictly positive so both sectors use some labor, and both functions have constant returns to scale so that $\alpha_u + a_{uu} = 1$, $\alpha_d + a_{du} + a_{dd} = 1$. $Z_{i,t}$ is sector i's Hicks-neutral productivity, $L_{i,t}$ is a firm in sector i's labor demand, and $X_{ik,t}$ is a firm in sector i's demand for sector k's final good. Similar to baseline New Keynesian models, labor is the only primary factor of production and these firms are assumed to produce enough to meet the demand of the competitive final good producer in their sector. Formally, given a commitment to supply $Y_{ij,t} = Y^d$ to the final good producer, intermediate firm j in sector i chooses its inputs in order to minimize its total expenditure. Again, omitting the index j and the time subscript t, this cost minimization problem is:

$$\mathscr{C}_i(Y^d) \equiv \min_{\{L_i, X_{i,i}, X_{i,-i}\}} W L_i + P_i X_{i,i} + P_{-i} X_{i,-i} \quad \text{s.t.} \quad Z_i L_i^{\alpha_i} X_{i,i}^{a_{i,i}} X_{i,-i}^{a_{i,-i}} \geq Y^d \tag{7}$$

where $X_{i,i}, X_{i,-i}$ denotes the input of the firm from its own sector's final good and the other sector's input, respectively. Similarly, P_i is the price of sector i's final good and P_{-i} is the final good price of the other sector. $a_{i,i}$ and $a_{i,-i}$ are also defined similarly, and given our specification for production functions above $a_{i,-i} = a_{du}$ for $i = d$ and $a_{i,-i} = 0$ for $i = u$.

Moreover, intermediate producers in each sector set their prices under Calvo (1983) type sticky prices, where price change opportunities arrive according to an i.i.d. Poisson arrival rate of $\theta_i > 0$ for firms in sector i. Importantly, θ_i can be different across sectors. Formally, the problem of firm in sector i that gets to reset its price at time t, omitting the index j, reads:

$$\max_{P^{\#}_{i,t}} \int_0^\infty \theta_i e^{-\int_0^h i_s \mathrm{d}s - \theta_i h} \left((1+\tau_{i,t}) P^{\#}_{i,t} Y_{i,t+h|t} - \mathscr{C}_{i,t+h}(Y_{i,t+h|t}) \right) \mathrm{d}h \quad s.t. \quad Y_{i,t+h|t} = Y_{i,t+h} \left(\frac{P^{\#}_{i,t}}{P_{i,t+h}} \right)^{-\sigma}$$

where $\tau_{i,t}$ denotes a subsidy that can be used to alleviate steady state markup inefficiencies and can vary over time, introducing wedge or markup shocks.

Equilibrium. We give a brief definition of the equilibrium here and refer the reader to Afrouzi and Bhattarai (2023) for a precise definition in a more general set up that nests our model here.

Definition 1. *An equilibrium for this economy is an allocation for households, final good producers, and intermediate firms in each sector as well as monetary and fiscal policies* $\{m_t, \tau_{u,t}, \tau_{d,t}, T_t\}$*, and a set of prices such that (a) given prices and policies, all allocations solve the corresponding decision maker's problem as specified above, (b) the government budget constraint is satisfied such that in each period the lump-sum tax* T_t *finances the subsidies paid to intermediate producers, and (c) labor, goods, and bond markets clear.*

Detailed model derivations, including all proofs, are in the Appendix.

2.2. Characterization

With constant returns to scale Cobb-Douglas production functions, it follows that the log-marginal cost of firms in sector i is only a function of prices and the nominal wage given by

$$mc_{i,t} = \alpha_i m_t + a_{ii} p_{i,t} + a_{i,-i} p_{-i,t} - z_{i,t} \tag{8}$$

where small letters denote logs of their corresponding variables. Moreover, $m_t = w_t$ is the nominal wage coinciding with nominal aggregate demand, $a_{i,-i}$ is the expenditure share of sector i from the other sector (a_{du} for $i = d$ and 0 for $i = u$), $p_{i,t}$ is the sector i's own final good price, and $p_{-i,t}$ is the final good price of the other sector.

Flexible-price benchmark. Before characterizing the evolution of prices with sticky prices, it is useful to characterize output and prices under the flexible-price benchmark, defined as the counterfactual economy in which prices are flexible at all times and in all sectors and monetary policy follows the same path of m_t. In such an economy, with efficient subsidies that alleviate steady state markups, log-price of any firm, and accordingly the resulting sectoral price denoted by $p^f_{i,t}$ in $i \in \{u,d\}$, in a given sector would be equal to their marginal cost:

$$p^f_{i,t} = \omega_{i,t} + mc^f_{i,t}, \forall i \in \{u,d\} \tag{9}$$

where $\omega_{i,t}$ is the log-deviation of markups in sector i at t due to any temporary wedge shocks relative to the steady state, and $mc^f_{i,t}$ is the log marginal cost of the firm under flexible prices. This defines a system of two equations and two unknowns that yield the following solution for sectoral prices when they are fully flexible:

$$p^f_{u,t} = m_t + \frac{1}{1-a_{uu}}(\omega_{u,t} - z_{u,t}) \tag{10}$$

$$p^f_{d,t} = m_t + \frac{1}{1-a_{dd}}(\omega_{d,t} - z_{d,t}) + \frac{a_{du}}{(1-a_{uu})(1-a_{dd})}(\omega_{u,t} - z_{u,t}) \tag{11}$$

which then implies that the flexible log-CPI is given by $p^f_t = \beta p^f_{u,t} + (1-\beta)p^f_{d,t}$ and the flexible log-GDP is given by the difference between log-nominal GDP and log-CPI:

$$y^f_t \equiv m_t - p^f_t = \lambda_u(z_{u,t} - \omega_{u,t}) + \lambda_d(z_{d,t} - \omega_{d,t}) \tag{12}$$

where for $i \in \{u, d\}$, $\lambda_i \equiv \frac{P_i Y_i}{PC}$ denotes the Domar weight of sector i—defined as the ratio of final producers' sales in sector i to the nominal GDP—in the efficient steady state with zero inflation, and can be characterized as functions of equilibrium input and expenditure shares as (see, e.g., Carvalho and Tahbaz-Salehi, 2019):

$$\lambda_u = \frac{\beta}{1-a_{uu}} + \frac{(1-\beta)a_{du}}{(1-a_{uu})(1-a_{dd})}, \quad \lambda_d = \frac{1-\beta}{1-a_{dd}} \tag{13}$$

Log-linearized approximation. To characterize the evolution of prices in the sticky-price economy, we log-linearize the model around the commonly assumed zero inflation efficient steady state. In the spirit of a standard New Keynesian model, we define the counterfactual concept of a "desired" price for firms, which captures the log-linearized best response function of a firm in sector i under flexible prices. Letting $p^*_{i,t}$ denote this desired price, it follows that

$$p^*_{i,t} = \omega_{i,t} + mc_{i,t} \tag{14}$$

where $\omega_{i,t}$ is a sector-specific markup shock and, with slight abuse of notation, $mc_{i,t}$ now represents the log *deviation* of the marginal cost from the zero inflation efficient steady state. 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 history in which they are stuck with the price that they are choosing.

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

$$\dot{p}^{\#}_{i,t} = (\rho + \theta_i)(p^{*}_{i,t} - p^{\#}_{i,t}) \tag{15}$$

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

$$\dot{p}_{i,t} = \theta_i(p^{\#}_{i,t} - p_{i,t}) \tag{16}$$

with the initial price level at time 0, $p_{i,0^-}$, given. Going forward, for analytical convenience we will consider the limit where $\rho \to 0, \forall i \in \{u, d\}$.[7]

2.3. Sectoral and aggregate Phillips curves

Equations (8) and (14) to (16) across the two sectors characterize the supply side of the economy:

Lemma 1. *The evolution of sectoral prices are characterized by the following sectoral Phillips curves:*

$$\dot{\pi}_{u,t} = (1 - a_{uu})(1 - a_{dd})\lambda_d\theta_u^2 r_t - \alpha_u\theta_u^2 x_t \tag{17}$$

$$\dot{\pi}_{d,t} = -(1 - a_{uu})(1 - a_{dd})\lambda_u\theta_d^2 r_t - \alpha_d\theta_d^2 x_t \tag{18}$$

where $\pi_{u,t}$ is the inflation in the upstream sector, $\pi_{d,t}$ is the inflation in the downstream sector, $r_t \equiv (p_{u,t} - p_{d,t}) - (p_{u,t} - p_{d,t})^f$ is the relative price gap *of sector u to sector d, 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 gap between GDP of this economy and the GDP in the flexible price economy.*

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

$$\dot{\pi}_t = \underbrace{(1 - a_{uu})(1 - a_{dd})(\beta\lambda_d\theta_u^2 - (1-\beta)\lambda_u\theta_d^2)r_t}_{\text{Inflation due to relative price gaps}} - \underbrace{(\beta\alpha_u\theta_u^2 + (1-\beta)\alpha_d\theta_d^2)x_t}_{\text{Inflation due to aggregate slack}} \tag{19}$$

where $\pi_t = \beta\pi_{u,t} + (1-\beta)\pi_{d,t}$ is the inflation in the CPI. Equation (19) shows a key theoretical property of this model: aggregate inflation dynamics are not only determined by the aggregate GDP gap but also depend on the relative price gap, r_t.

Accordingly, Equations (17) to (19) show that in our network economy with potentially heterogeneous price stickiness across sectors, relative price distortions affect sectoral and aggregate

[7] This is a fairly reasonable assumption given the very small value of $\rho = -\ln(0.96^{1/12}) = 0.0034$ that would match a yearly interest rate if 4%. One could be concerned about the choice of the time unit which might imply larger ρ at quarterly or yearly levels, but what matters for the dynamics of the model is the ratio of ρ to frequency of each sector, which is independent of time. Thus, this approximation would perform well for dynamics as long as ρ/θ_i is small.

inflation dynamics independently of the GDP gap. For instance, even if monetary policy were to fully stabilize the GDP gap ($x_t \equiv y_t - y_t^f = 0, \forall t \geq 0$), 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 (17) and (18) 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.,

$$\lambda_i \geq \beta_i, \forall i, \text{ with equality if } a_{i,j} = 0, \forall i, j \tag{20}$$

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 (19), note that relative price gaps are also generally relevant except for the knife-edge case where

$$\beta \lambda_d \theta_u^2 = (1-\beta)\lambda_u \theta_d^2 \tag{21}$$

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 $\theta_u = \theta_d$. 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, from their steady state values are zero right before $t = 0$. We then consider a one-time permanent, unanticipated, and negative shock to the productivity of the upstream sector. Such a shock would increase the flexible 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, 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 (3).

Proposition 1. *Suppose the economy is in the efficient 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 $\xi_u = \theta_u \sqrt{1 - a_{uu}}$:*
$$\left.\frac{\partial \pi_{u,t}}{\partial \pi_{u,0}}\right|_{z_u} = e^{-\xi_u t}$$
2. *Spillover inflation in the downstream sector is proportional to the input share of that sector from the upstream sector, a_{du}, and given by:*
$$\left.\frac{\partial \pi_{d,t}}{\partial \pi_{u,0}}\right|_{z_u} = \frac{a_{du}}{1 - a_{dd}} \frac{\xi_d}{\xi_d + \xi_u} \left(\frac{\xi_d e^{-\xi_u t} - \xi_u e^{-\xi_d t}}{\xi_d - \xi_u} \right)$$
which is positive along the whole transition path, where $\xi_d = \theta_d \sqrt{1 - a_{dd}}$.

Proposition 1 confirms that an inflationary shock to the upstream sector would lead to spillover inflation in the downstream sector in absence of a monetary response. Furthermore, we can show that this spillover inflation can be even more persistent in the downstream sector if the adjusted price stickiness of this sector is higher ($\xi_d > \xi_u$), in the sense that is formalized below.

Corollary 1. *Consider the shock in Proposition 1 and suppose $\xi_d > \xi_u$. Then the pass-through to inflation in the downstream sector relative to its impact response is always higher than that of the upstream sector—i.e., if both impulse response functions (IRFs) were normalized by their impact response, the IRF for the downstream sector would always be above the IRF for the upstream sector:*

$$\left.\frac{\partial \pi_{d,t}}{\partial \pi_{d,0}}\right|_{z_u} > \left.\frac{\partial \pi_{u,t}}{\partial \pi_{u,0}}\right|_{z_u}, \quad \forall t > 0 \tag{22}$$

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_u^{-1} (for a normalized shock that generates a one percent increase in this inflation on impact). A more interesting case is the CIR in the downstream sector, which is given by

$$\mathrm{CIR}_d^{\pi} = \frac{a_{du}}{1-a_{dd}} \times \mathrm{CIR}_u^{\pi} \tag{23}$$

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_{du}, multiplied by the cumulative expenditure share of the downstream sector by itself, $\frac{1}{1-a_{dd}} = \sum_{n=0}^{\infty} a_{dd}^n$. 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, 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

$$\left.\frac{\partial \pi_{d,0}}{\partial \pi_{u,0}}\right|_{z_u} = \frac{a_{du}}{1-a_{dd}} \times \frac{\xi_u^{-1}}{\xi_d^{-1}+\xi_u^{-1}} \tag{24}$$

We see that this pass-through is proportional to the long-run pass-through above but is now adjusted by the term $\frac{\xi_u^{-1}}{\xi_d^{-1}+\xi_u^{-1}}$. 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:*

$$r_t = r_0 e^{-\bar{\xi} t} \quad \textit{where} \quad \bar{\xi} = \sqrt{(1-a_{uu})(1-a_{dd})(\lambda_d \theta_u^2 + \lambda_u \theta_d^2)} \tag{25}$$

with the nominal prices of each sector evolving according to:

$$p_{u,t} = \frac{\lambda_d \theta_u^2}{\lambda_u \theta_d^2 + \lambda_d \theta_u^2} r_0 e^{-\bar{\xi} t}, \qquad p_{d,t} = -\frac{\lambda_u \theta_d^2}{\lambda_u \theta_d^2 + \lambda_d \theta_u^2} r_0 e^{-\bar{\xi} t} \tag{26}$$

2. *The relative price shock causes endogenously persistent aggregate inflation on the path, propor-*

tional to r_t:

$$\pi_t = \bar{\xi}\left(\frac{\lambda_u\theta_d^2}{\lambda_u\theta_d^2+\lambda_d\theta_u^2}-\beta\right)r_t \tag{27}$$

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 this two-sector economy because in the standard New Keynesian model, 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 $\zeta \equiv \frac{\lambda_u\theta_d^2}{\lambda_u\theta_d^2+\lambda_d\theta_u^2}$. To see why, note that a GDP gap stabilization policy is essentially a price targeting rule that fully stabilizes a certain price index.[8] In our case, this price index is $\zeta p_{u,t}+(1-\zeta)p_{d,t}=0$ as shown in Equation (A.14). Subtracting this price index from the CPI index, we can then see that along the transition path

$$p_t = \beta p_{u,t}+(1-\beta)p_{d,t} = (\beta-\zeta)r_t \implies \pi_t = \bar{\xi}(\zeta-\beta)r_t \tag{28}$$

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 ($\xi_u = \theta_u\sqrt{1-a_{uu}} > \xi_d = \theta_d\sqrt{1-a_{dd}}$). Then, an increase in the relative price of the upstream sector caused by a permanent shock as in Proposition 2 is* CPI inflationary *if and only if*

$$\zeta > \beta \iff a_{du} > \frac{\beta}{\lambda_d}\times\left(\frac{\xi_u^2}{\xi_d^2}-1\right) \tag{29}$$

Equation (29) 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. This generally reflects a key feature of our model that stabilizing aggregate GDP gap does not automatically stabilize aggregate inflation, as "divine coincidence" does not hold in our set-up. In particular, note that with no across sector input-output linkages; i.e., $a_{du}=0$, the condition in Equation (29) 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., $a_{du}=0$, it would not

[8] 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.

generate inflation at the aggregate level with GDP gap targeting.

2.5. An experiment for the Post-COVID 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 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 Appendix A.3.

Parameter	Description	Value
β	Upstream sector consumption share	0.1
θ_u	Upstream sector frequency of price adjustment	0.29
θ_d	Downstream sector frequency of price adjustment	0.09
a_{uu}	Cost share of upstream sector on upstream sector	0.31
a_{du}	Cost share of downstream sector on upstream sector	0.13
a_{dd}	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 implied by that policy.

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

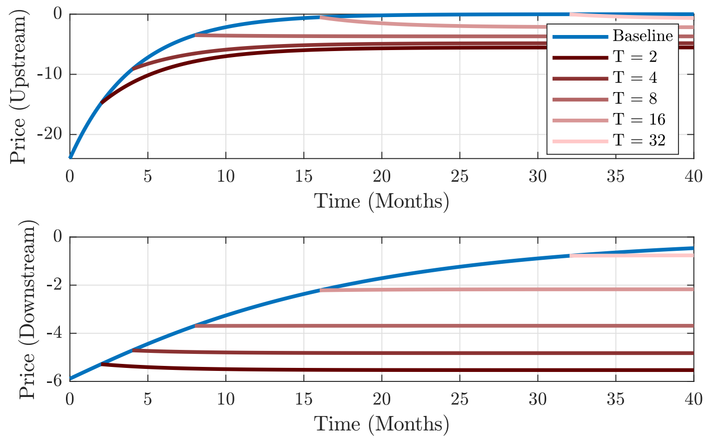

Figure 3: Inflationary effects of a permanent shock to productivity (or wedge) of the upstream sector

Notes: The figure shows the response of each sector's price level to a permanent shock to the productivity/wedge of the upstream sector in absence of a monetary response in blue, where all prices are plotted relative to the new steady state of that economy. Each red line then shows the path of price contingent on monetary policy switching to a soft-landing policy at that time.

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.

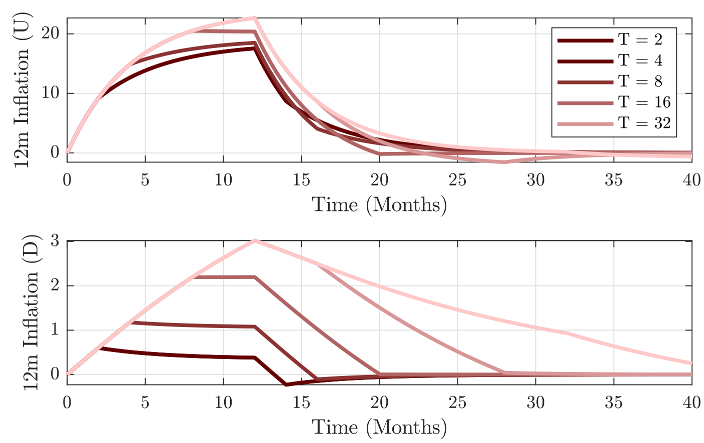

Figure 4: Inflationary effects of a permanent shock to productivity (or wedge) of the upstream sector

Notes: The figure shows the response of each sector's inflation rate to a permanent shock to productivity/wedge 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.

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 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.

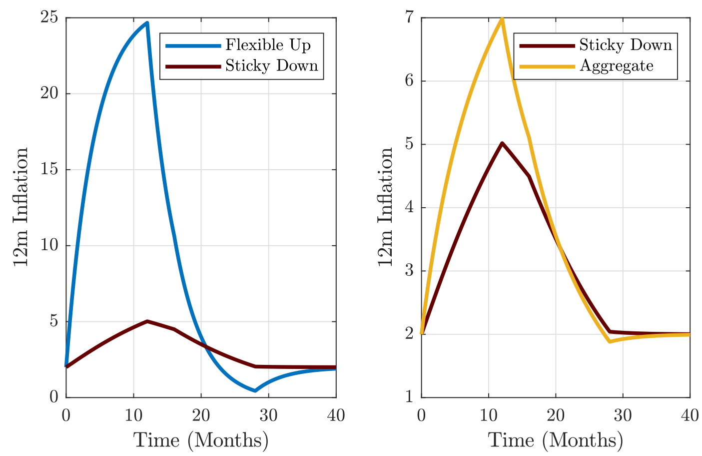

Figure 5: Inflationary effects of a permanent shock to productivity (or wedge) of the upstream sector

Notes: The left panel shows the impulse responses of year on year inflation rates in the upstream and downstream sectors after a shock to productivity (or wedge) 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. The model is log-linearized around a zero steady-state inflation rate, but for comparability of the magnitudes with Figure 1, the y-axes are shifted up by 2%.

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 model counterfactual where we shut down the role of upstream sector as a source of inputs to the downstream sector by setting $a_{du} = 0$. The results are in the left panel of Figure 6 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.

Second, we do a model counterfactual where we shut down the role of heterogeneous price stickiness across sectors by setting $\theta_d = \theta_u$. The results are in the middle panel of Figure 6 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 in the downstream sector is never higher, and is not more persistent, than aggregate inflation.

Finally, 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 the right panel of 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 a 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.

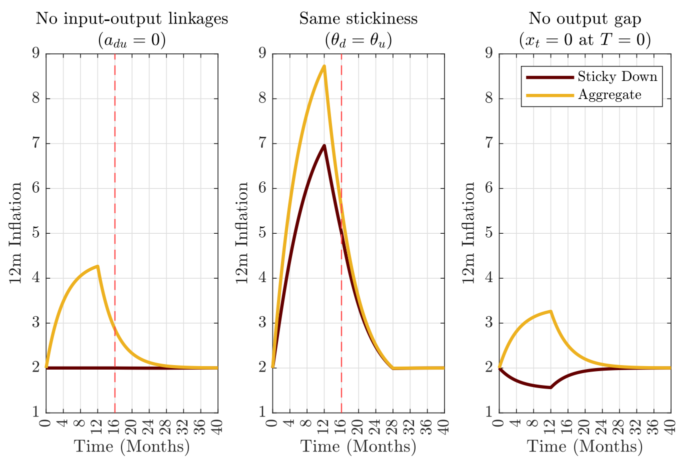

Figure 6: Inflationary effects of a permanent shock to productivity (or wedge) of the upstream sector

Notes: The figures show the response of aggregate inflation along with the sticky downstream sector's inflation to the same shock under different counterfactuals. The left panel considers a counterfactual economy in which the upstream sector is not a production input for the downstream sector: $a_{du} = 0$. The monetary policy does not respond for the first 16 months after the shock and then switches to a soft-landing policy. The middle panel considers a model counterfactual in which both sectors have the same price stickiness: $\theta_d = \theta_u$. The monetary policy does not respond for the first 16 months after the shock and then switches to a soft-landing policy. The right panel considers a counterfactual economy where the central bank stabilizes the GDP gap from the beginning while keeping the same model parameters as in the baseline exercise. The shock size is such that aggregate inflation peaks at 7 percent after 12 months in the baseline calibration. The model is log-linearized around a zero steady-state inflation rate, but for comparability of the magnitudes with Figure 1, the y-axes are shifted up by 2%.

Taken together, the results from these counterfactual exercises in Figure 6 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.

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.[9] In addition, we also estimate effects on measures of real activity such as the unemployment rate and (real) consumption. More specifically, we run

$$\log(Y_{t+h}) - \log(Y_{t-1}) = \alpha^{(h)} + \beta^{(h)} \times \Big(\log(\frac{\text{PPI energy}_t}{\text{PPI}_t}) - \log(\frac{\text{PPI energy}_{t-1}}{\text{PPI}_{t-1}})\Big) \tag{30}$$

$$+ \sum_{k=1}^{K} \gamma_k^{(h)} \Big(\log(Y_{t-k}) - \log(Y_{t-k-1})\Big) \tag{31}$$

$$+ \sum_{k=1}^{J} \zeta_k^{(h)} \Big(\log(\frac{\text{PPI energy}_{t-k}}{\text{PPI}_{t-k}}) - \log(\frac{\text{PPI energy}_{t-k-1}}{\text{PPI}_{t-k-1}})\Big) + \varepsilon_t \tag{32}$$

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.[10] 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).[11] 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

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

[10] 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.

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

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.

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 economic 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 A.1 that the oil supply news shock of Kanzig (2021) has a positive and significant effect on (relative) PPI energy prices.[12] This effect is present even if we exclude the COVID-19 period, as shown in Figure A.2. 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.[13] 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 A.1 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 7 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.[14] 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 7 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 7 show that relative price of energy shocks act like negative aggregate supply shocks.

Figure 7 is based on using data for the full sample period, 1986:01-2023:06.[15] Figure A.4 shows results for an alternate sample period, from 1986:01-2020:03. These show that the results, both on

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

[13] Figure A.3 shows the impulse response of Brent oil prices after a one unit oil supply news shock.

[14] 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.

[15] 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.

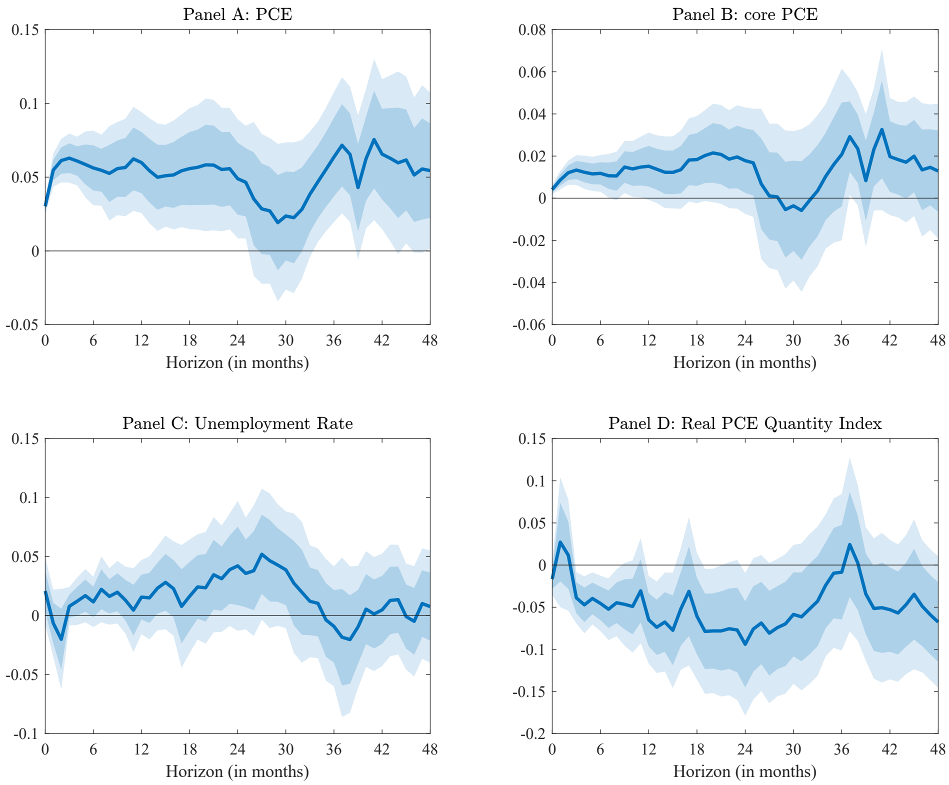

Figure 7: Impulse responses to a shock to the relative price of energy

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.

inflationary effects as well as on an eventual economic contraction, are robust to excluding the large oil price shocks of the pandemic period.

3.1.3. Robustness. We now discuss some results from a sensitivity analysis to our sample period and specification. Figure A.5 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 7 is based on a specification that does not use additional variables as controls. Figure A.6 in the Appendix reports results where we use lagged real wages as controls. Comparing Figure 7 with Figure A.5 and A.6 shows that the results are robust to these changes in sample period and 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. In particular, the model predicts how these heterogeneous responses should depend on underlying parameters. 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 $\beta_2^{(h)}$ that measures the interaction effect of the shock with the statistic implied by the model (which we then normalize by its standard deviation for easier interpretation).[16] We compute Driscoll-Kraay

[16] To see how this specification relates to our two-sector model above, note from Equation (A.7) that for inflationary shock to sector 1, which implies a $p_{u,0} < 0$, we have

$$p_{d,h} - p_{d,0} = \frac{a_{du}}{1-a_{dd}} \left(\frac{\xi_u^2(e^{-\xi_d h} - 1) - \xi_d^2(e^{-\xi_u h} - 1)}{\xi_d^2 - \xi_u^2}\right) |p_{u,0}| = \xi_u \times \frac{\xi_d}{\xi_u + \xi_d} \frac{a_{du}}{1-a_{dd}} h \times |p_{u,0}| + \mathcal{O}(\|\xi_i h\|^2) \qquad (33)$$

where the second equality approximates the exponential functions for small horizons and shows how the interaction standard errors.

In our main results, we exclude PCE categories for which Petroleum and coal products were included in them in 1997.[17] The excluded PCE categories are: Motor vehicle fuels, lubricants, and fluids; Fuel oil and other fuels; and Pharmaceutical and other medical products.[18] The Appendix provides further detail on how we construct the sector specific interaction term using data.

Figure A.7 shows that the Kanzig (2021) shock has a positive average effect on sectoral PCE prices that is relatively short-lived.[19] 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.[20]

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. Figure A.8 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.

term in our regression emerges from our theory. Note that $|p_{u,0}|$ in the model can then be mapped into a relative price of a given sector as in the empirical specification.

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

[18] 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.

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

[20] 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.

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 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 8 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.[21]

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. Figure A.9 shows that the results are robust to using a pre-Covid sample period.

[21] 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.

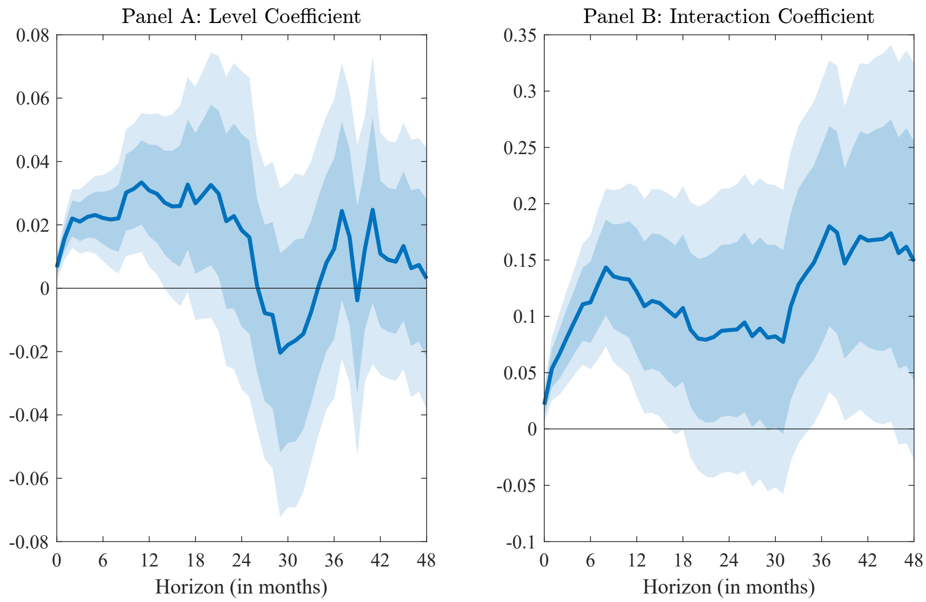

Figure 8: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals. F-stat: 49.9697.

3.2.3. Robustness and extensions. In this subsection, we first present the responses of sectoral quantities to an exogenous increase in relative produce price of energy. We then show that our result is robust to including time 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 tests. Finally, we present some additional evidence relevant for the theory.

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. This exercises thus leverages a key advantage of use PCE data as we have information on both sectoral prices and quantities. In addition, the sectoral quantity results here complement the aggregate quantity results we showed earlier in Figure 7, which had shown evidence for an aggregate contraction following an increase in relative price of energy.

Figure 9 shows the main results, which depict negative interaction coefficients, as expected and consistent with the positive interaction coefficients in Figure 8 for sectoral prices.[22] Moving from the 25th to the 75th percentile of the distribution of the sufficient statistic leads the response to

[22] 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.

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.[23] Figure A.10 shows that the results are robust to using a pre-Covid sample period.

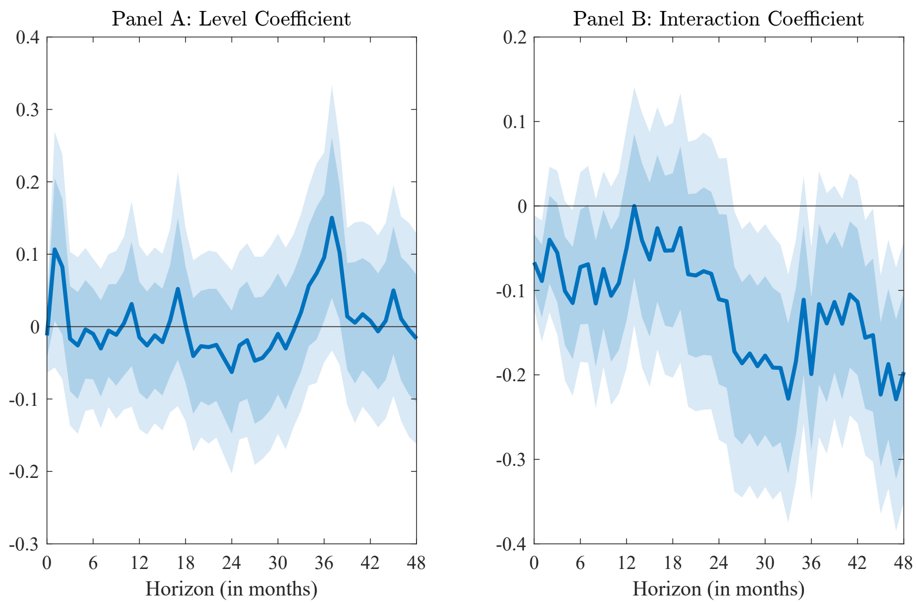

Figure 9: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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.

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.[24] 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 A.11 in the Appendix shows the results that are consistent with what we would expect.

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

[23]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.

[24]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)

shocks that affect all PCE categories. Figure A.12 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 A.13 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 A.14 in the Appendix shows the results for prices and Figure A.15 in the Appendix for quantities. They are similar to our baseline results.

3.2.4. Additional evidence. We provide additional evidence that our sufficient statistics help understanding the heterogeneity of sectoral PCE responses to relative price of energy shocks using the the Iraq invasion of Kuwait in 1990. Furthermore, we use the New York Fed Global Supply Chain Pressure Index (GSCPI) to provide suggestive evidence that changes in global supply chain pressures might also act as negative aggregate supply shocks in the U.S..

Gulf war. In this extension, we explore the Iraq invasion of Kuwait in 1990 in an event-study framework as it was an exogenous reason for energy prices to increase. The Gulf war, which includes the invasion of Kuwait by Iraq in August 1990, started in August of 1990 and came to an end in the end of February of 1991.

We start by showing in Figure A.16 the time path of PPI energy price (relative to PPI), PCE headline, and PCE core inflation around the Gulf War dates. It shows the spike in PPI energy relative prices around that time, and it already suggests a positive correlation between the three variables. We next run a (cross-sectional) regression of changes in sectoral PCE prices on changes in PPI energy relative prices, where we interact the PPI energy relative prices with the sufficient statistic from the model in a way analogous to the baseline empirical specification in the paper.[25] The results are in Table A.2 and show that even excluding the PCE sectors that are directly in the energy sector (as defined by being PCE categories with Oil and Gas Extraction or Petroleum and Coal products commodities in its composition) in Column 2, the interaction term is positive in line with our model prediction.

[25]Specifically, we run the following regression: $100 \times (\log P_{i,1991:03} - \log P_{i,1990:07}) = \beta_0 + \beta_1 \times \text{Suff. Stat.}_i \times 100\big(\log\big(\frac{\text{PPI energy}}{\text{PPI}}\big)_{1991:03} - \log\big(\frac{\text{PPI energy}}{\text{PPI}}\big)_{1990:07}\big) + \varepsilon_i$ where $P_{i,t}$ is the PCE index of category i in period t.

Global Supply Chain Pressure Index. Here, 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.

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 A.17, 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 A.17, a one unit innovation in the GSCPI is associated with approximately 0.06 log-points increase, after 24 months, in overall 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 A.18 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 A.18 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 A.18 suggest that global supply chain pressures can act as negative aggregate supply shocks.

4 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 an initial one-time 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 producer price of energy have heterogeneous pass-through to PCE sectoral prices, as predicted by our model.

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A Appendix

A.1. Proofs

A.1.1. Proof of Lemma 1.

Proof. Differentiating Equation (16) and combining it with Equation (15) we can eliminate $p^{\#}_{i,t}$ and $\dot{p}^{\#}_{i,t}$ from Equations (15) and (16) and write them as one second-order differential equation in terms of $p_{i,t}$, which in the limit of $\rho \to 0$ reads:

$$\dot{\pi}_{i,t} = \theta_i^2 (p_{i,t} - p^*_{i,t}), \forall i \in \{u, d\} \tag{A.1}$$

where $\pi_{i,t} \equiv \dot{p}_{i,t}$ is the first time derivative of $p_{i,t}$; i.e., the instantaneous rate of inflation in the sectoral price of i. We now note that

$$\begin{aligned}
(1-a_{uu})(1-a_{dd})\lambda_d r_t - \alpha_u x_t &= (1-a_{uu})(1-\beta)\left((p_{u,t}-p_{d,t}) - (p_{u,t}-p_{d,t})^f\right) - \alpha_u y_t + \alpha_u y_t^f \\
&= (1-a_{uu})(p_{u,t} - p_t - p^f_{u,t} + p^f_t) - \alpha_u(-p_t + p^f_t) \\
&= (1-a_{uu})(p_{u,t} - p^f_{u,t}) = p_{u,t} - p^*_{u,t}
\end{aligned}$$

where we have used the expressions for λ_d and definitions of $p^f_{u,t}$ and $p^*_{u,t}$. Substituting this into Equation (A.1) we obtain the Phillips curve for sector u. Similarly, note that

$$\begin{aligned}
-(1-a_{uu})(1-a_{dd})\lambda_u r_t - \alpha_d x_t &= -((1-a_{dd})\beta + (1-\beta)a_{du})((p_{u,t}-p_{d,t}) - (p_{u,t}-p_{d,t})^f) - \alpha_d y_t + \alpha_d y_t^f \\
&= (1-a_{dd})(p_{d,t} - p^f_{d,t}) - a_{du}(p_{u,t} - p^f_{u,t}) \\
&= p_{d,t} - p^*_{d,t}
\end{aligned}$$

Substituting this into Equation (A.1) we obtain the Phillips curve for sector d. ∎

A.1.2. Proof of Proposition 1.

Proof. Considering the deviations of prices from the new steady state after a shock to relative prices, let $p_{u,0}$ and $p_{d,0}$ denote these log-deviations of prices in sectors u and d at time 0, right after the shock. Assuming that prior to the shock to sector u's productivity or wedge, the economy was in a steady state with zero inflation, the relationship between $p_{u,0}$ and $p_{d,0}$ is given by (comparing these prices across the two steady states under the assumption that monetary policy does not change m):

$$p_{d,0} = \frac{a_{du}}{1-a_{dd}} p_{u,0} \tag{A.2}$$

Given that prices are sticky, we are interested in how prices in sectors u and d start from these values and converge to the steady state. Under the assumption 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

$$0 = m_t = \beta p_{u,t} + (1-\beta) p_{d,t} + y_t \tag{A.3}$$

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

$$r_t = p_{u,t} - p_{d,t}$$
$$x_t = y_t - y_t^f = y_t = -p_{u,t} + (1-\beta) r_t$$

Plugging these into Equation (17), we have

$$\ddot{p}_{u,t} = \dot{\pi}_{u,t} = (1-a_{uu})(1-\beta)\theta_u^2 r_t - (1-a_{uu})\theta_u^2(-p_{u,t} + (1-\beta) r_t)$$
$$= (1-a_{uu})\theta_u^2 p_{u,t} \tag{A.4}$$

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

$$p_{u,t} = p_{u,0} e^{-\xi_u t}, \qquad \xi_u = \theta_u \sqrt{1-a_{uu}} \tag{A.5}$$

Now, plugging the expression for r_t and x_t, as well as the solution to $p_{u,t}$ into Equation (18), we have

$$\ddot{p}_{d,t} = \dot{\pi}_{d,t} = \xi_d^2 p_{d,t} - \frac{a_{du}}{1-a_{dd}} \xi_d^2 p_{u,0} e^{-\xi_u t} \tag{A.6}$$

which is a second-order differential equation in $p_{d,t}$ with the initial condition that $p_{d,0}$ is given as well as the boundary condition that $p_{d,t}$ should converge back to its steady state ($\lim_{t\to\infty} p_{d,t} = 0$). It follows that

$$p_{d,t} = \frac{a_{du}}{1-a_{dd}} \frac{p_{u,0}}{\xi_d^2 - \xi_u^2} \left(\xi_d^2 e^{-\xi_u t} - \xi_u^2 e^{-\xi_d t}\right) \tag{A.7}$$

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

$$\left.\frac{\partial \pi_{u,t}}{\partial \pi_{u,0}}\right|_{z_u} = e^{-\xi_u t} \tag{A.8}$$
$$\left.\frac{\partial \pi_{d,t}}{\partial \pi_{u,0}}\right|_{z_u} = \frac{a_{du}}{1-a_{dd}} \frac{\xi_d}{\xi_d + \xi_u} \left(\frac{\xi_d e^{-\xi_u t} - \xi_u e^{-\xi_d t}}{\xi_d - \xi_u}\right) \tag{A.9}$$

Moreover, to see why this spillover inflation is positive along the whole path, note that its sign depends only on the sign of the term within parentheses. Now, first consider the case of $\xi_u > \xi_d$, in which case this term is positive if $e^{-\xi_u t}/\xi_u > e^{-\xi_d t}/\xi_d$, which is true given $\xi_d > \xi_u$ because the function $f(x) = e^{-xt}/x$ is positive strictly decreasing in $x > 0$ for any positive $t > 0$. Now, consider $\xi_u > \xi_d$ and note that now the term inside parentheses is positive if $e^{-\xi_u t}/\xi_u < e^{-\xi_d t}/\xi_d$ which is true for same reason as before. Finally, the case of $\xi_u = \xi_d$ can be obtained by taking the limit of $\xi_u \to \xi \equiv \xi_d$ (or vice versa) which yields

$$\lim_{\xi_u \to \xi \equiv \xi_d} \left.\frac{\partial \pi_{d,t}}{\partial \pi_{u,0}}\right|_{z_u} = \frac{1}{2} \frac{a_{du}}{1-a_{dd}} (1+\xi t) e^{-\xi t} > 0 \tag{A.10}$$

■

A.1.3. Proof of Corollary 1.

Proof. From Equations (A.8) and (A.9) note that

$$\left.\frac{\partial \pi_{u,t}}{\partial \pi_{u,0}}\right|_{z_u} = e^{-\xi_u t} \tag{A.11}$$

$$\left.\frac{\partial \pi_{d,t}}{\partial \pi_{d,0}}\right|_{z_u} = \frac{\xi_d e^{-\xi_u t} - \xi_u e^{-\xi_d t}}{\xi_d - \xi_u} \tag{A.12}$$

Given that $\xi_d > \xi_u > 0$ by assumption we see that $\left.\frac{\partial \pi_{d,t}}{\partial \pi_{d,0}}\right|_{z_u} > \left.\frac{\partial \pi_{u,t}}{\partial \pi_{u,0}}\right|_{z_u}$ if and only if:

$$\xi_d e^{-\xi_u t} - \xi_u e^{-\xi_d t} > (\xi_d - \xi_u) e^{-\xi_u t} \iff e^{-\xi_d t} < e^{-\xi_u t} \iff \xi_d t > \xi_u t \tag{A.13}$$

where the last statement is true as long as $t > 0$. ■

A.1.4. Proof of Proposition 2.

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 (17) and (18) to re-write them as:

$$\ddot{r}_t = (1 - a_{uu})(1 - a_{dd})(\lambda_d \theta_u^2 + \lambda_u \theta_d^2) r_t$$

$$\frac{\dot{\pi}_{u,t}}{\lambda_d \theta_u^2} + \frac{\dot{\pi}_{d,t}}{\lambda_u \theta_d^2} = 0$$

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:

$$r_t = r_0 e^{-\bar{\xi} t}, \quad \bar{\xi} \equiv \sqrt{(1 - a_{uu})(1 - a_{dd})(\lambda_d \theta_u^2 + \lambda_u \theta_d^2)}$$

while integrating the second one twice implies:

$$\frac{p_{u,t}}{\lambda_d \theta_u^2} + \frac{p_{d,t}}{\lambda_u \theta_d^2} = K_0 + K_1 t$$

for some constants K_0 and K_1 that should be chosen to satisfy the boundary conditions implied by the equilibrium prices. First, since we are working with a log-linearized approximation around a zero-inflation steady state, there could be no-trends in prices implying $K_1 = 0$. Second, we must have prices converging back to their steady-state levels as $t \to \infty$, which gives:

$$\lim_{t \to \infty} \left(\frac{p_{u,t}}{\lambda_d \theta_u^2} + \frac{p_{d,t}}{\lambda_u \theta_d^2} \right) = 0$$

implying that $K_0 = 0$ (because $p_{d,t}$ and $p_{u,t}$ are defined as deviations from the steady-state as $t \to \infty$). Therefore,

$$\lambda_u \theta_d^2 p_{u,t} + \lambda_d \theta_u^2 p_{d,t} = 0$$

Dividing by $(\lambda_u\theta_d^2 + \lambda_d\theta_u^2)$ we get

$$\frac{\lambda_u\theta_d^2}{\lambda_u\theta_d^2+\lambda_d\theta_u^2}p_{u,t} + \frac{\lambda_d\theta_u^2}{\lambda_u\theta_d^2+\lambda_d\theta_u^2}p_{d,t} = 0, \forall t \geq 0 \tag{A.14}$$

$$\implies p_{u,t} = \frac{\lambda_d\theta_u^2}{\lambda_u\theta_d^2+\lambda_d\theta_u^2}r_0 e^{-\bar{\xi}t}, \quad p_{d,t} = -\frac{\lambda_u\theta_d^2}{\lambda_u\theta_d^2+\lambda_d\theta_u^2}r_0 e^{-\bar{\xi}t}$$

where we have used the fact that $r_t = p_{u,t} - p_{d,t} = r_0 e^{-\bar{\xi}t}$.

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

$$p_t = \beta p_{u,t} + (1-\beta)p_{d,t} = \left(\beta - \frac{\lambda_u\theta_d^2}{\lambda_u\theta_d^2+\lambda_d\theta_d^2}\right)r_t$$

$$\implies \pi_t = -\bar{\xi}\left(\beta - \frac{\lambda_u\theta_d^2}{\lambda_u\theta_d^2+\lambda_d\theta_d^2}\right)r_t$$

■

A.2. Proof of Proposition 3

Proof. Follows from definition of ζ and the expression for the the Domar weights λ_u and λ_d. ■

A.3. 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/gscpi	

Table A.1: Variables and data used in the regressions.

PPI energy. We construct a measure of PPI energy by calculating the 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)[26]. After this, we end up with 66 sectors. For the empirics, we also perform the following: (1) we collapse the retail summary sectors into a single retail sector. That 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.

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

Two-sector parameterization. In the theory section, we use a two-sector model with upstream and downstream sectors. We define the flexible 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 sticky 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:

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

$$\mathbf{A} = \begin{bmatrix} a_{uu} & a_{ud} \\ a_{du} & a_{dd} \end{bmatrix} = \begin{bmatrix} 0.3102 & 0.3668 \\ 0.1346 & 0.4703 \end{bmatrix}$$

where the sector u is the upstream sector, and sector d is the downstream sector. Finally,

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

A.4. Additional results for aggregate effects

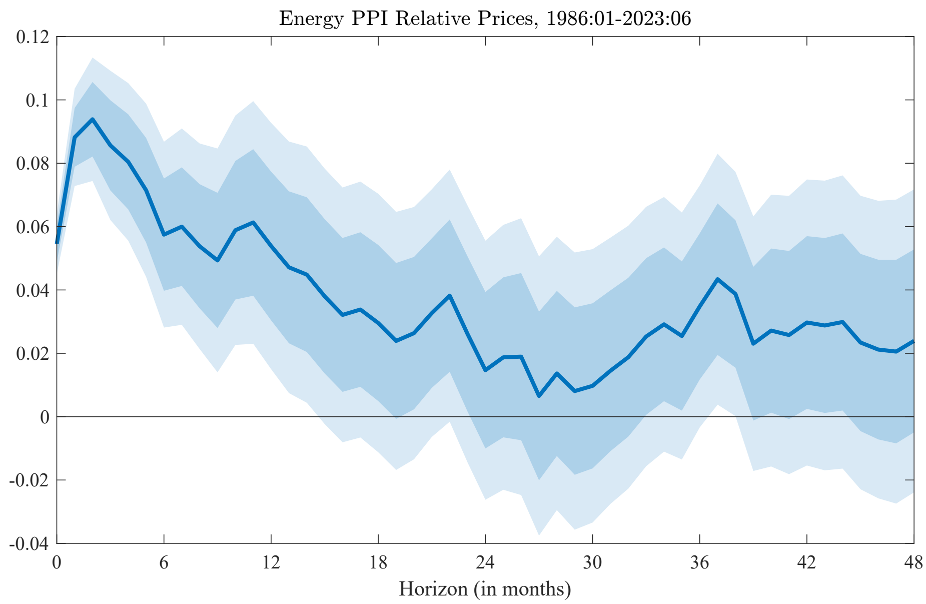

Figure A.1: Relative PPI energy prices impulse responses to an oil supply news shock

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: 1986:01 - 2023:06. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

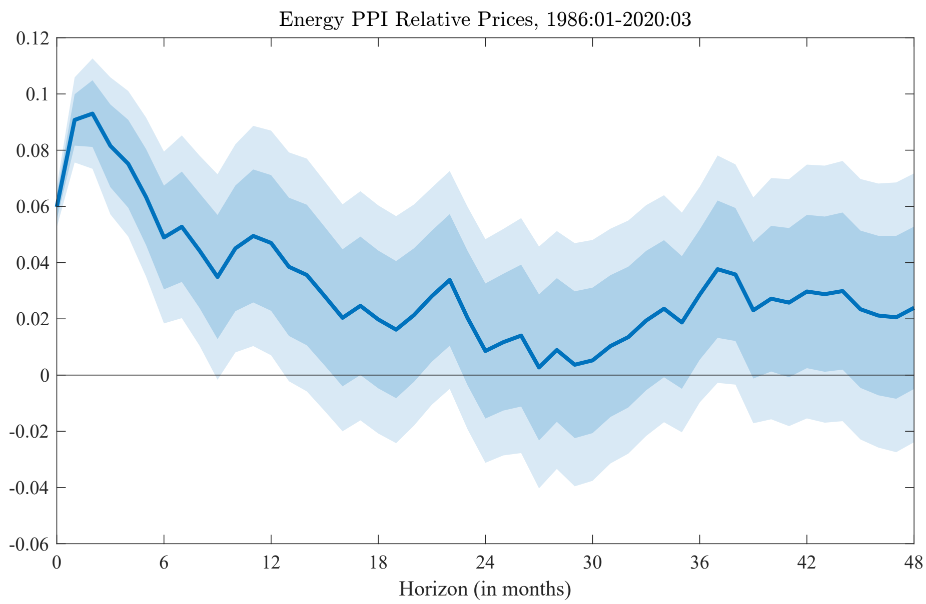

Figure A.2: Relative PPI energy prices impulse responses to an oil supply news shock

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: 1986:01 - 2020:03. Standard errors are robust to heteroskedasticity and autocorrelation. The shaded area corresponds to 68% and 90% confidence intervals.

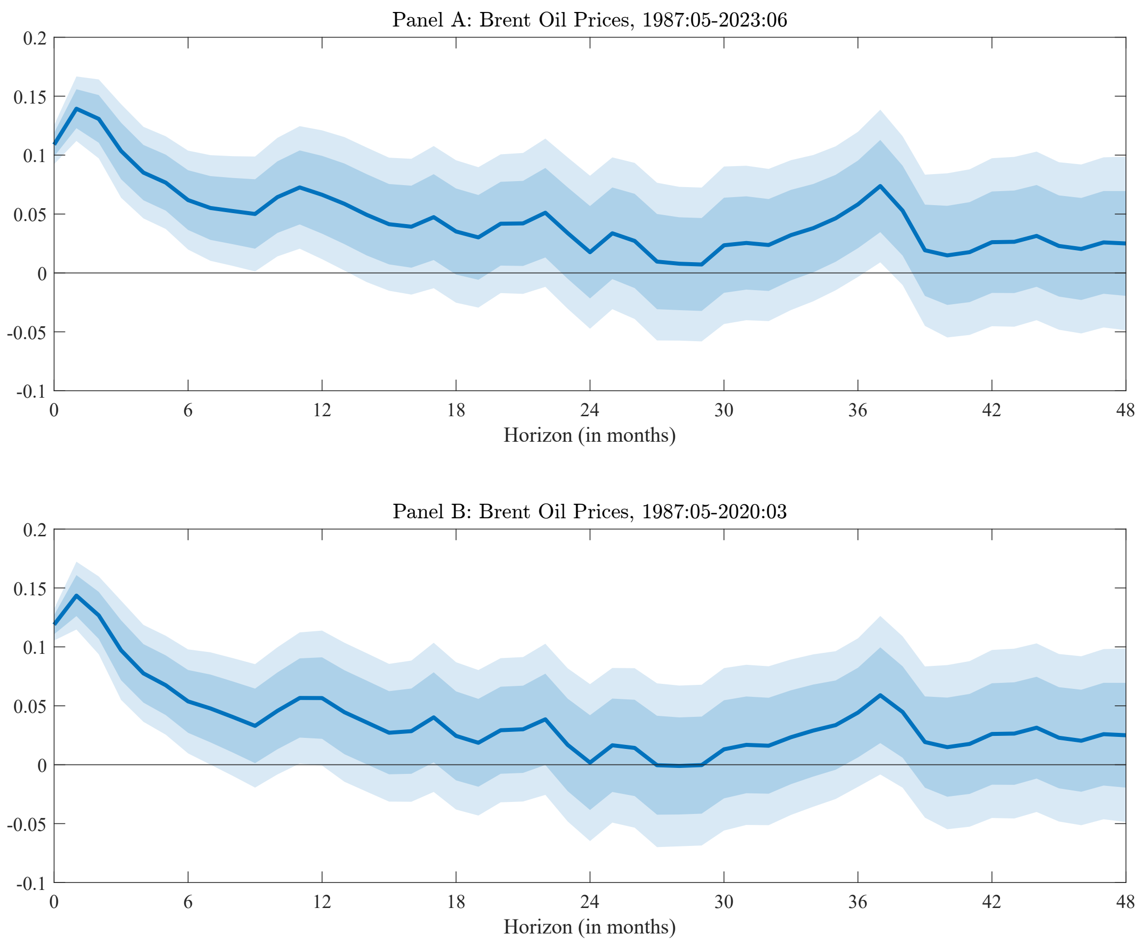

Figure A.3: Impulse responses to a Kanzig shock

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.

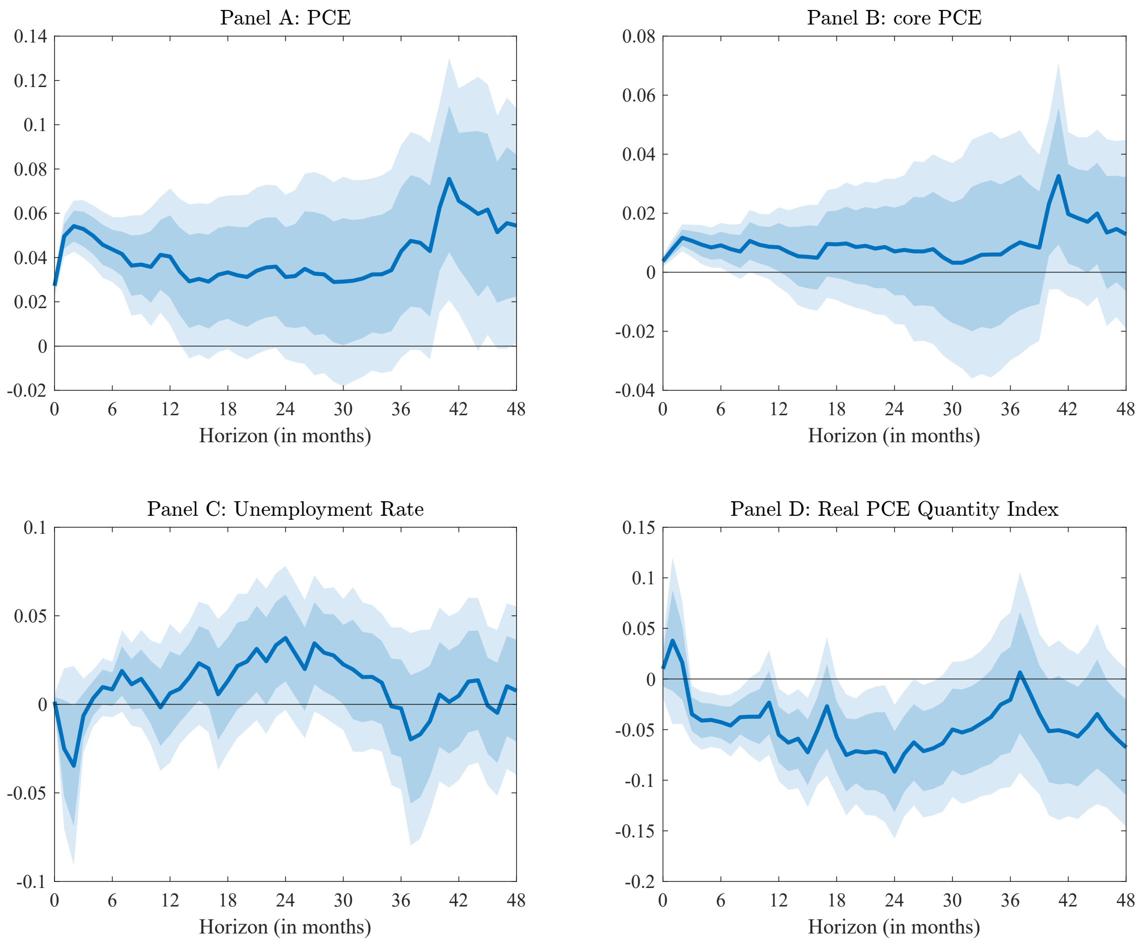

Figure A.4: Impulse responses to a shock to the relative price of energy

Notes: This figure plots impulse responses of PCE headline inflation, PCE core inflation, the unemployment rate, and the real PCE quantity index. The shock is to the relative price of energy. 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.

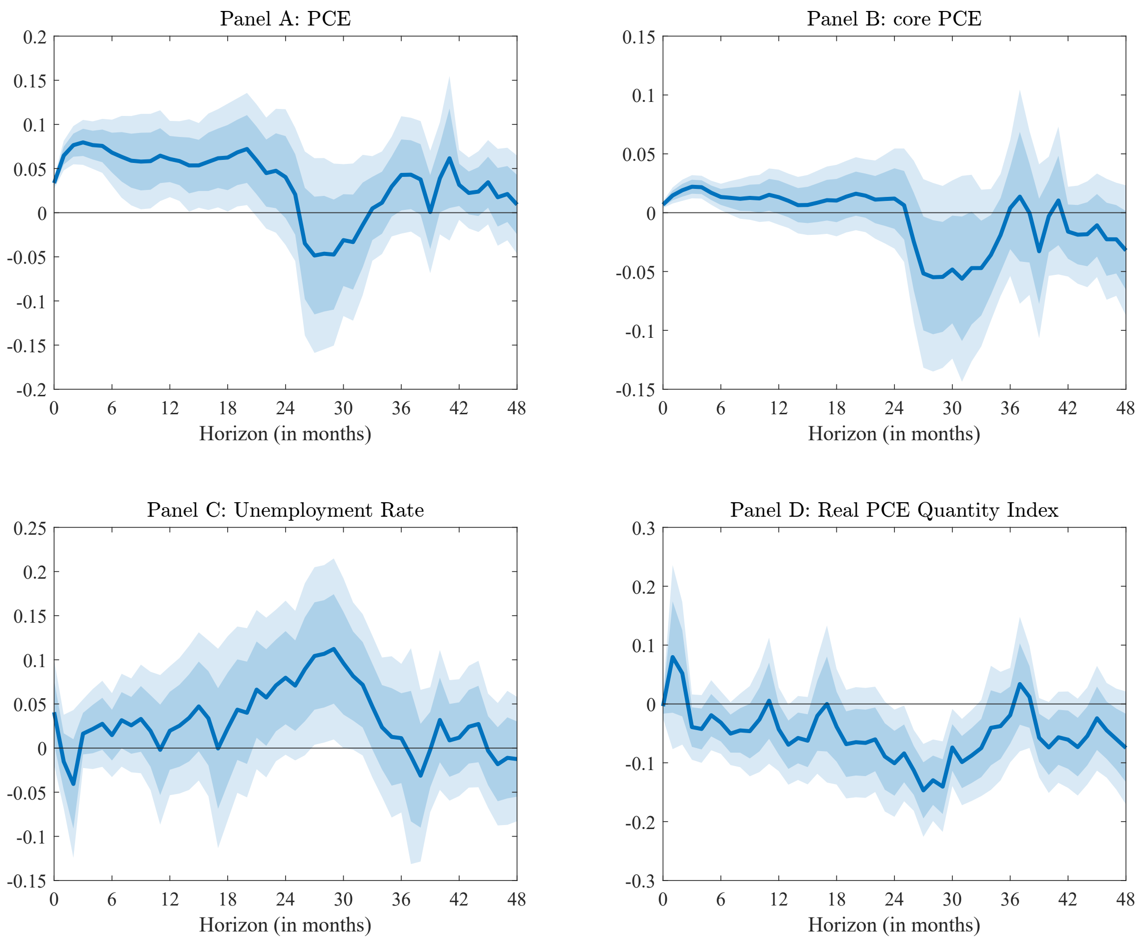

Figure A.5: Impulse responses to a shock to the relative price of energy

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.

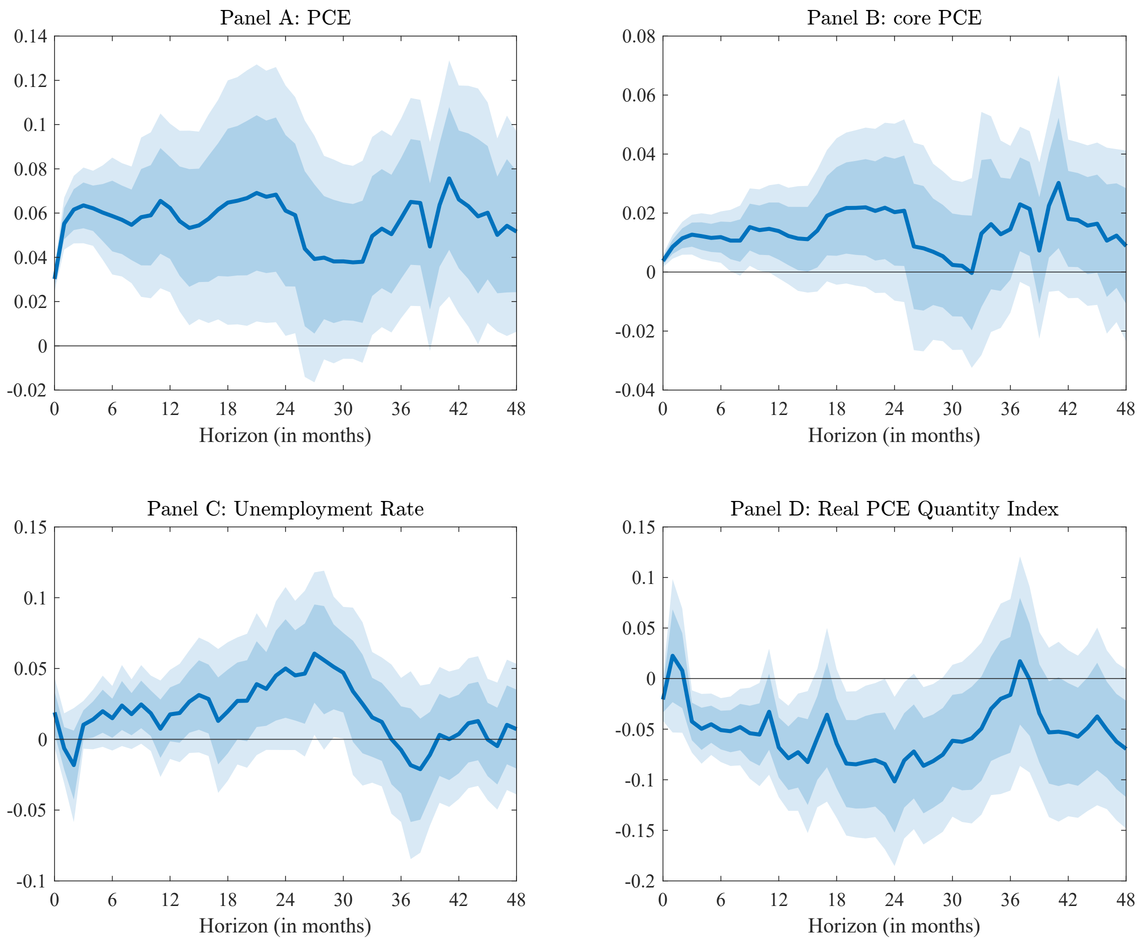

Figure A.6: Impulse responses to a shock to the relative price of energy

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.

A.5. Additional results for heterogeneous effects

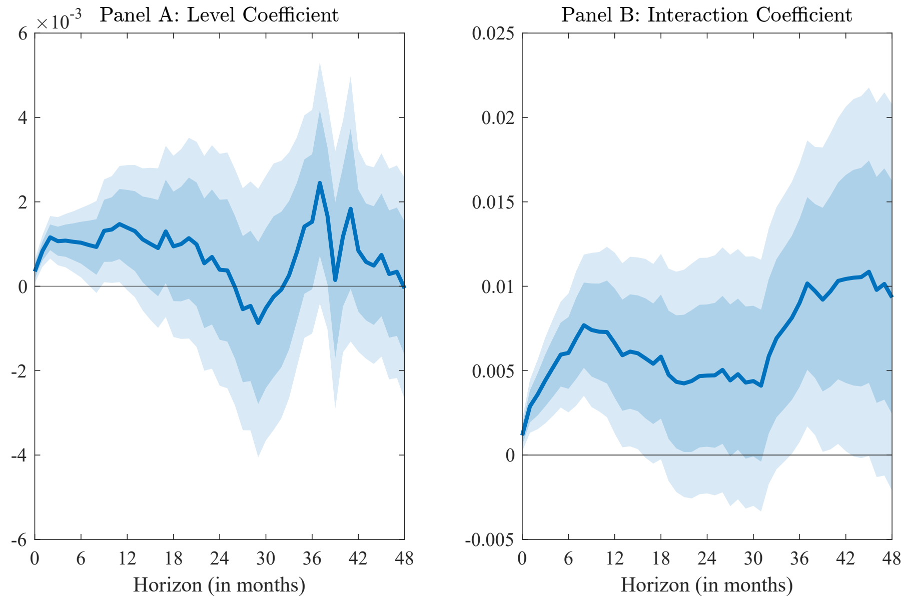

Figure A.7: Estimated panel Local Projections coefficients to a Kanzig (2021) shock

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: 1998:01 - 2023:06. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

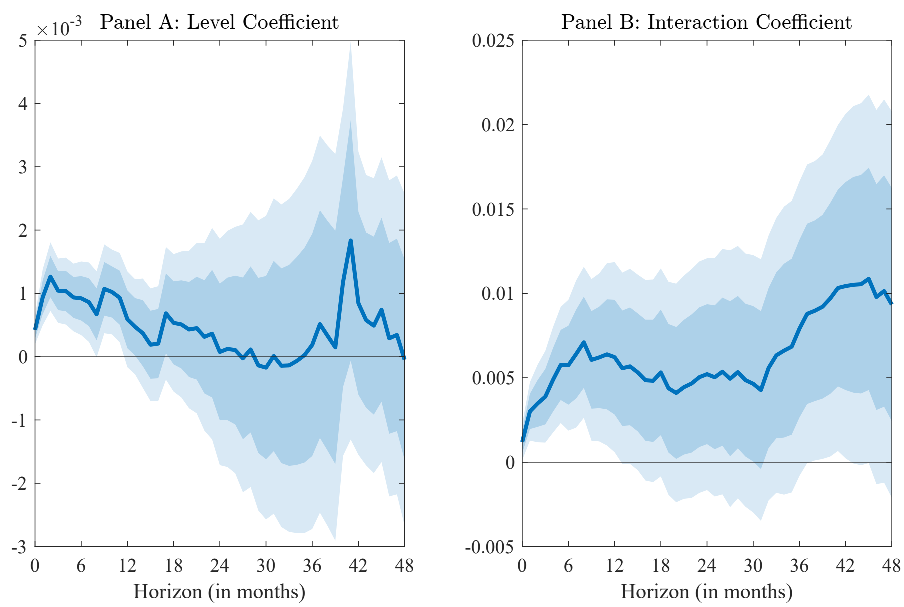

Figure A.8: Estimated panel Local Projections coefficients to a Kanzig (2021) shock

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: 1998:01-2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

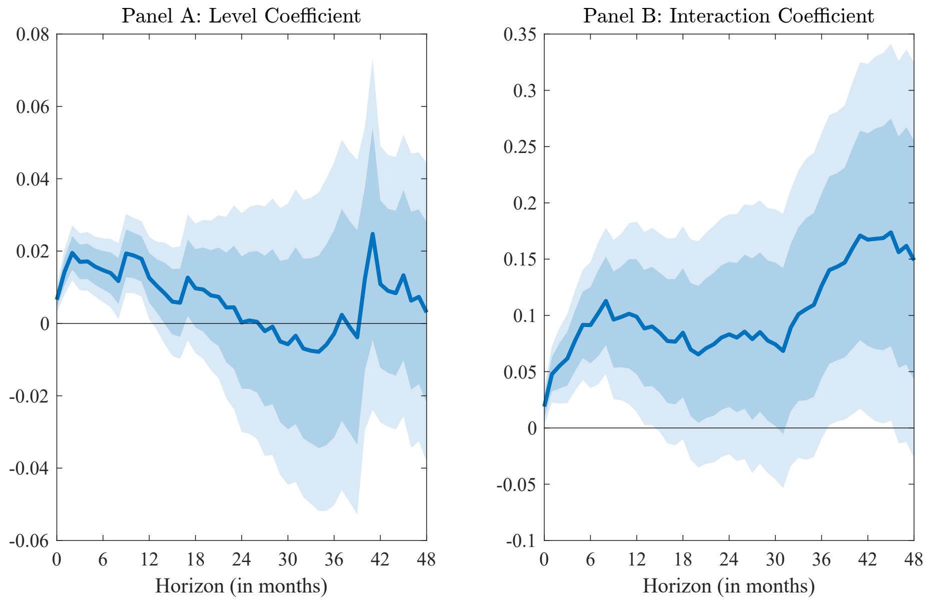

Figure A.9: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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 - 2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals. F-stat: 49.9697.

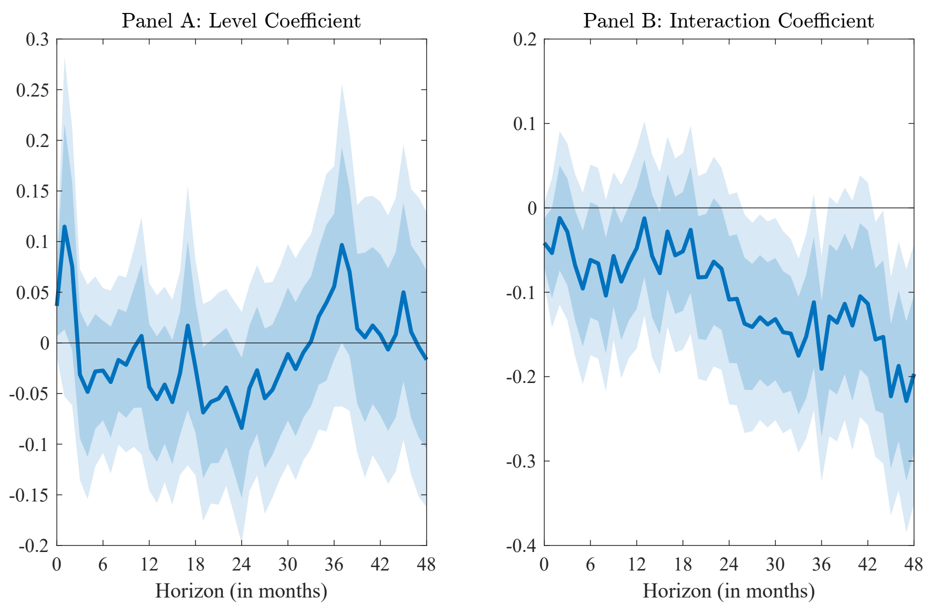

Figure A.10: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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 - 2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

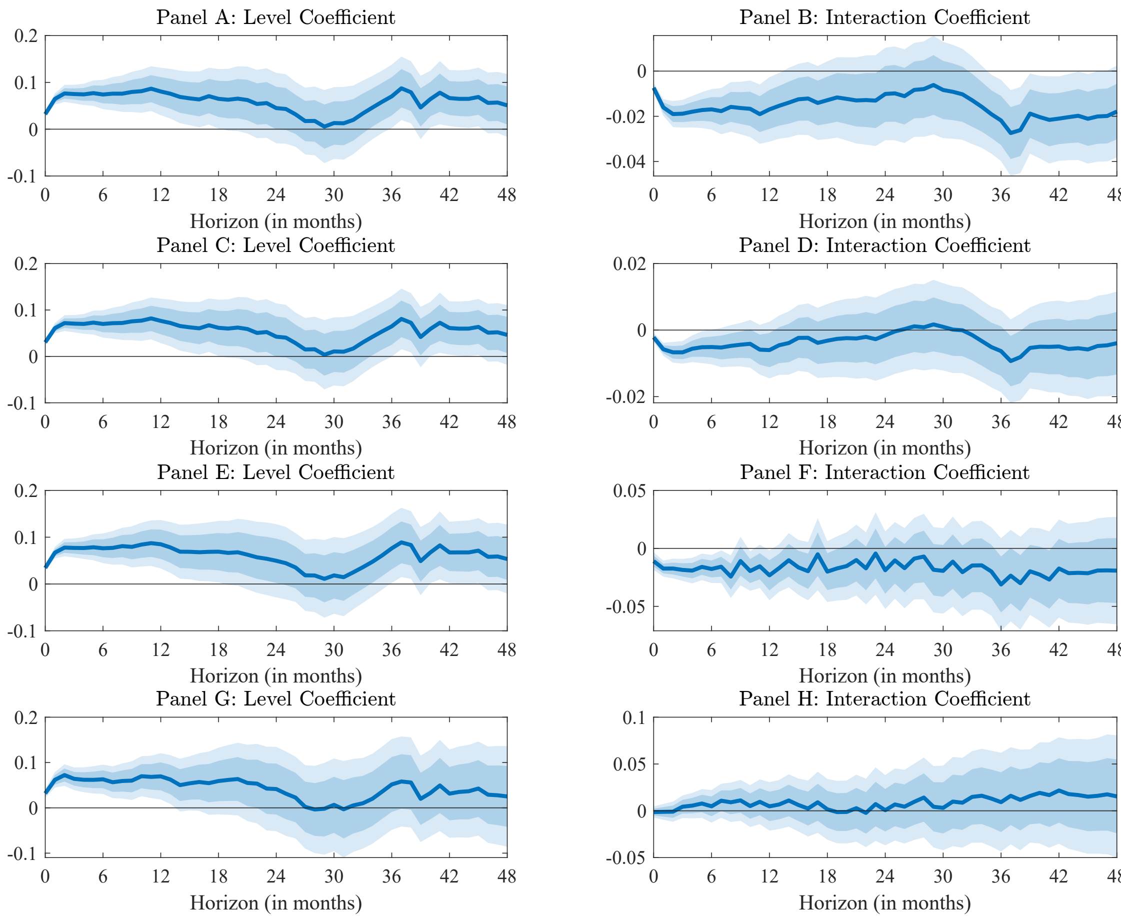

Figure A.11: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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.

A.6. Robustness and extensions on sectoral effects

A.6.1. 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 A.12 shows that our sufficient statistics do predict the response of sectoral inflation to oil supply shocks correctly even after taking into account time fixed effects. More specifically, 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.

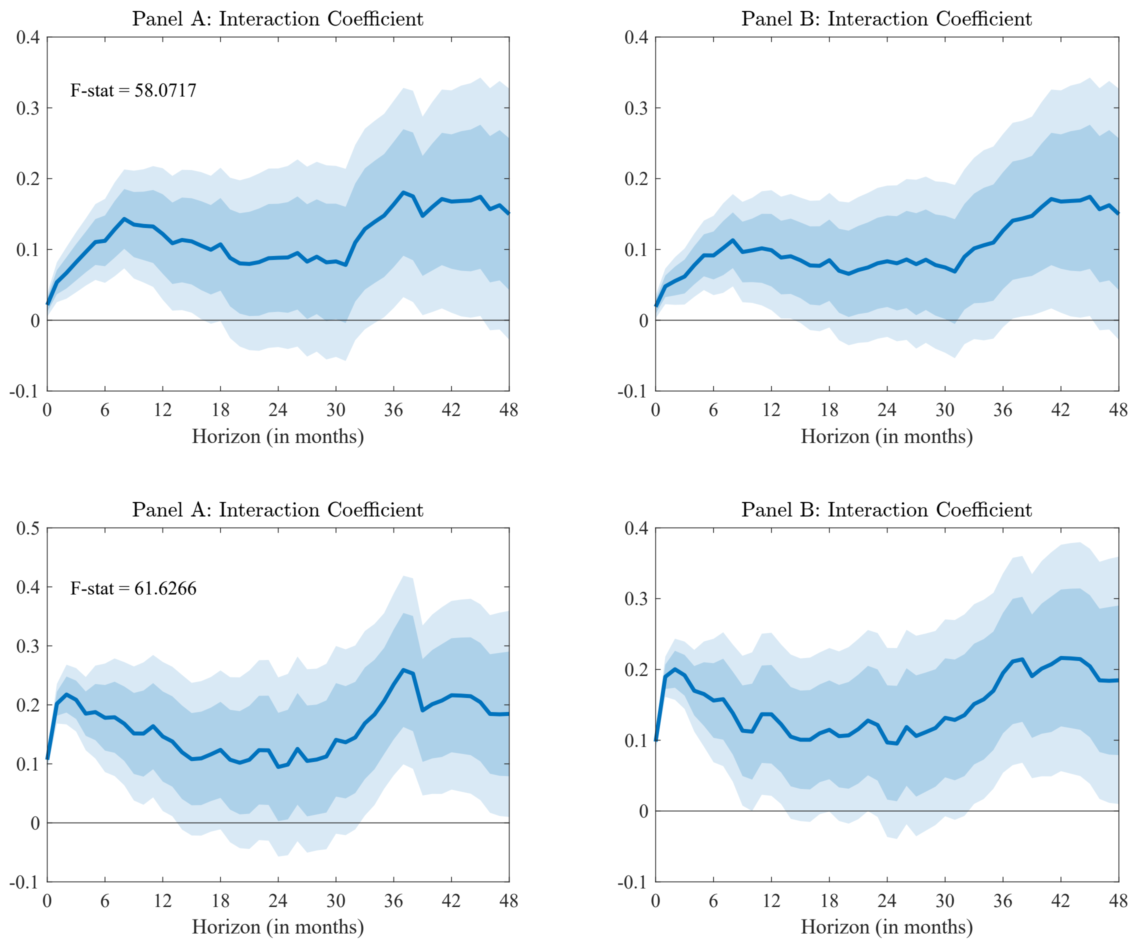

Figure A.12: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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 time fixed effects. Panel A: Ex-PCE categories with positive Petroleum and coal products or Oil and gas extraction producers' value. 1998:01-2023:06. F-stat: 58.0717. Panel B: Ex-PCE categories with positive Petroleum and coal products or Oil and gas extraction producers' value. 1998:01-2020:03. Panel C: All PCE categories. 1998:01-2023:06. F-stat: 61.6266. Panel D: All PCE categories. 1998:01-2020:03. Standard errors are Driscoll-Kraay. The shaded area corresponds to 68% and 90% confidence intervals.

A.6.2. 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 A.13 shows the result. For the sector fixed effects specification, we run

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

where FE_j is the sector fixed effect.

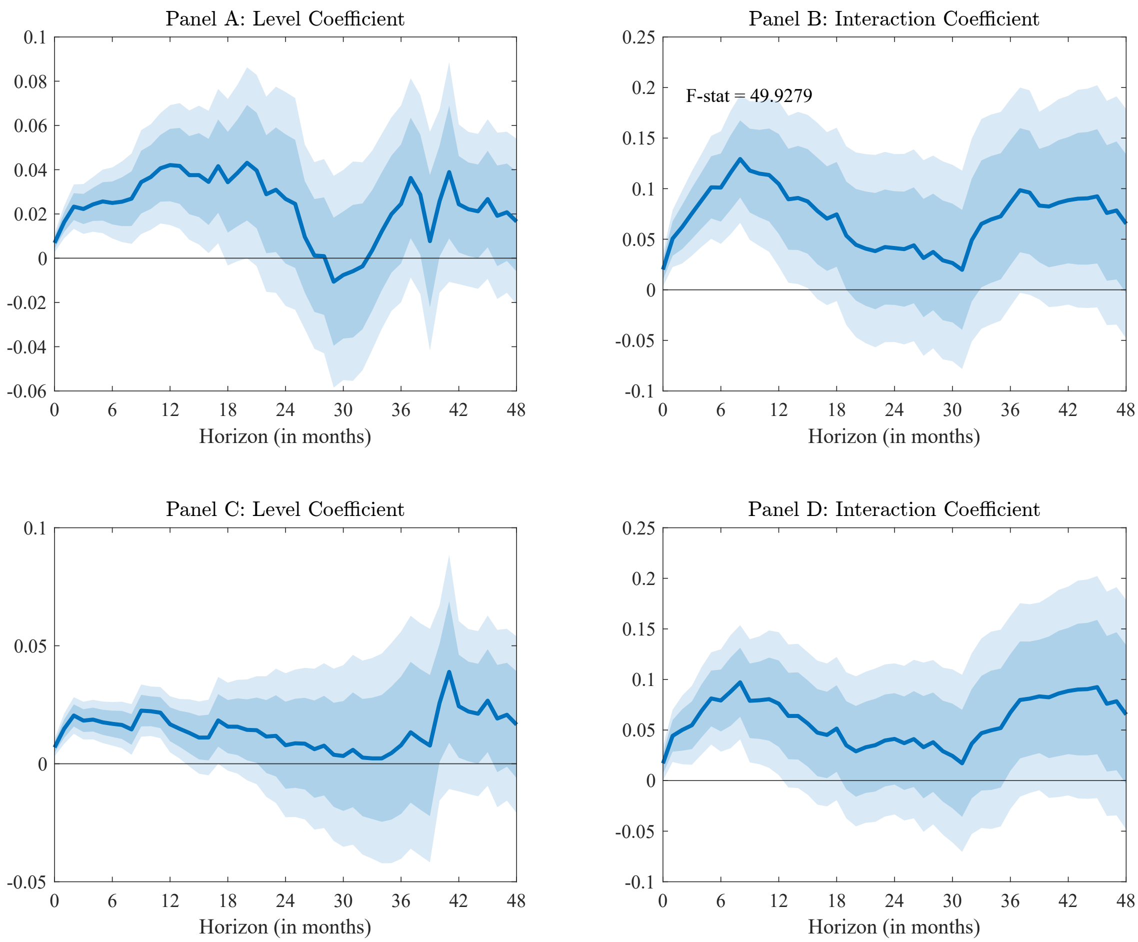

Figure A.13: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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. 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

A.6.3. 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 A.14 shows the results for prices and Figure A.15 for quantities.

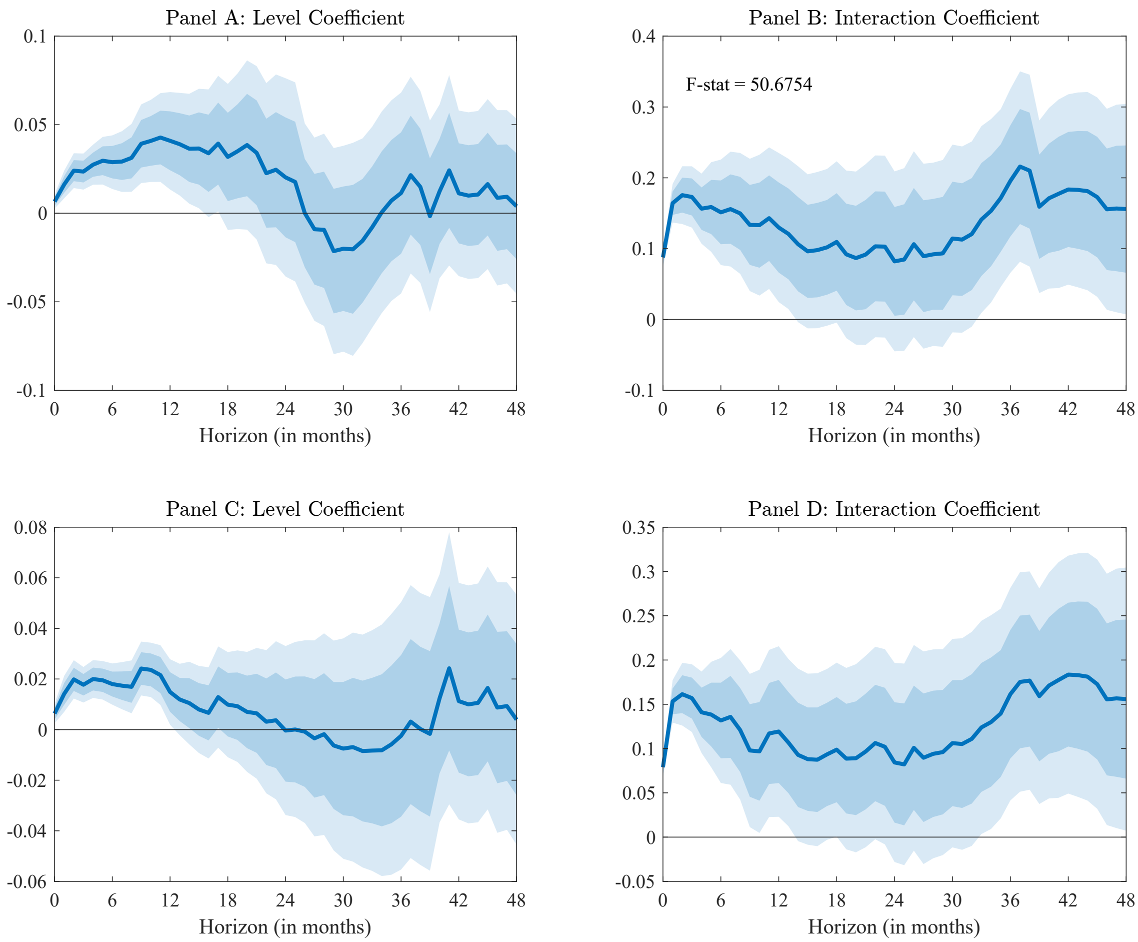

Figure A.14: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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. 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

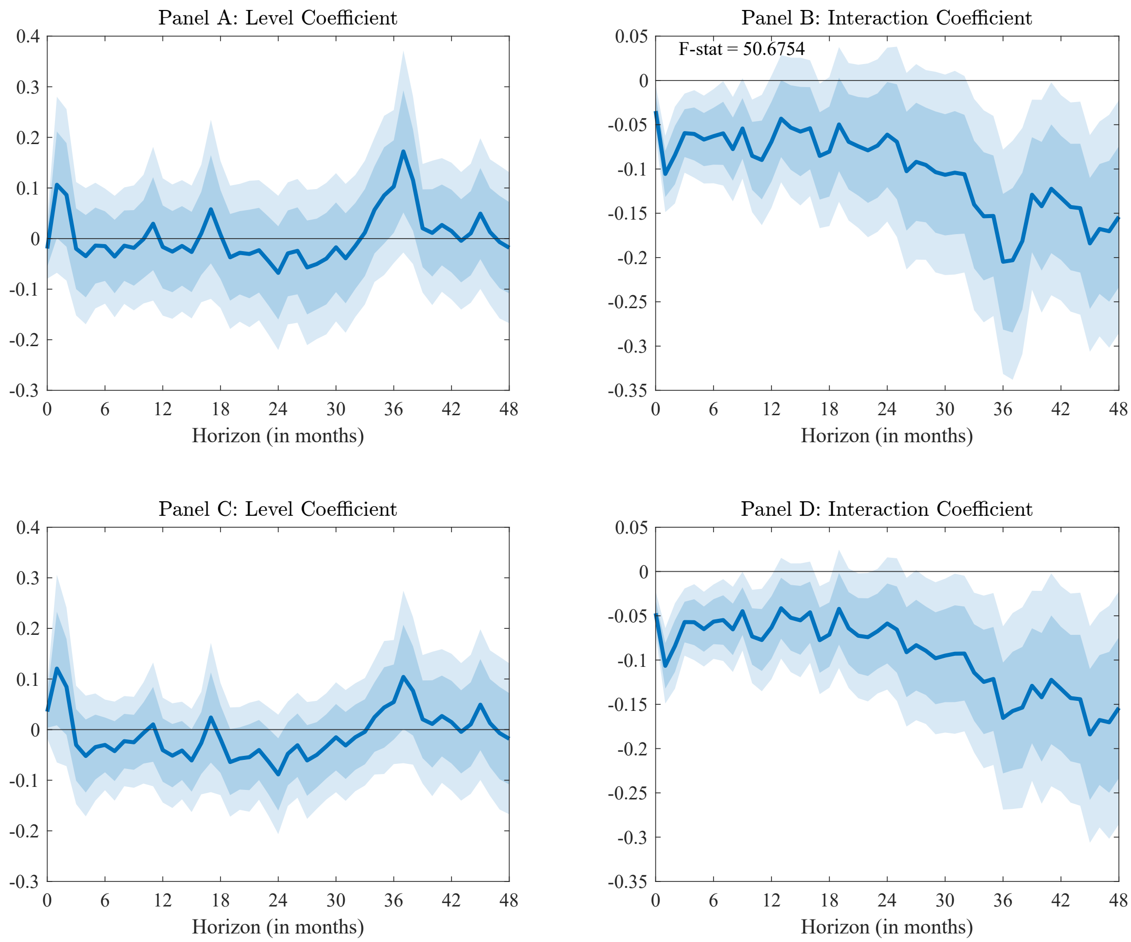

Figure A.15: Estimated panel Local Projections coefficients to a shock to the relative price of energy

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. 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

A.7. Additional Evidence

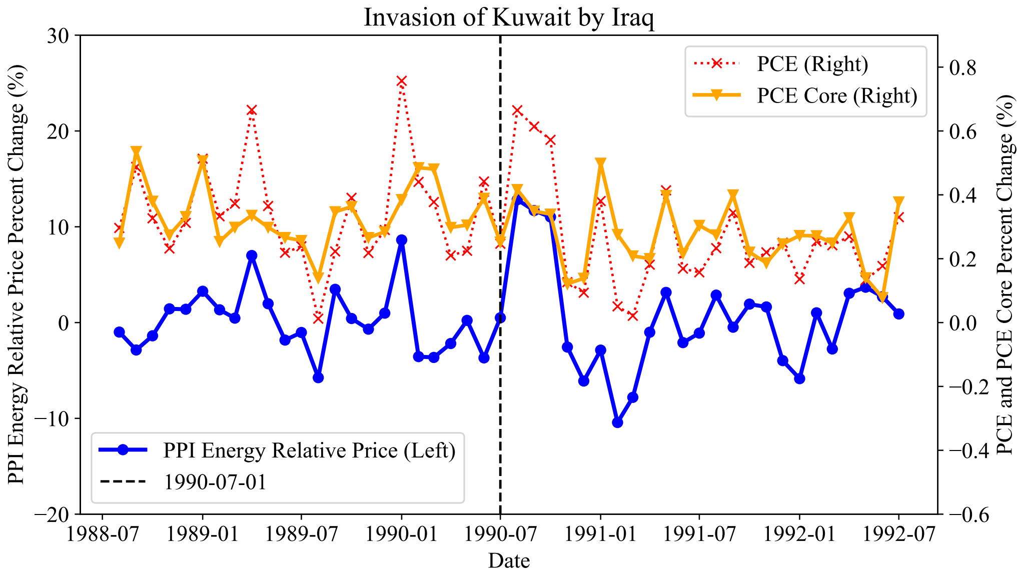

Figure A.16: Event Study Invasion of Kuwait

Notes: The figure plots the monthly percentage change of PPI energy relative price, PCE, and PCE core price indices during the Gulf War.

	(1)	(2)
Suff. Stat. × PPI Change	0.524**	0.285*
	(0.250)	(0.149)
Constant	2.187***	2.215***
	(0.381)	(0.382)
N. of obs.	73	70
Time period	1990:07 - 1991:03	1990:07 - 1991:03
Sample	Full	Ex-Energy

Table A.2: Event Study Gulf War.

Notes: Regression specification: $100\times(\log P_{i,1991:03} - \log P_{i,1990:07}) = \beta_0 + \beta_1 \times \text{Suff. Stat.}_i \times 100\big(\log\big(\frac{\text{PPI energy}}{\text{PPI}}\big)_{1991:03} - \log\big(\frac{\text{PPI energy}}{\text{PPI}}\big)_{1990:07}\big) + \varepsilon_i$. Dependent Variable: $\log P_{i,1991:03} - \log P_{i,1990:07}$, where i is a PCE category. Sample Ex-Energy excludes the categories with positive Oil and Gas Extraction or Petroleum and Coal Products in it.

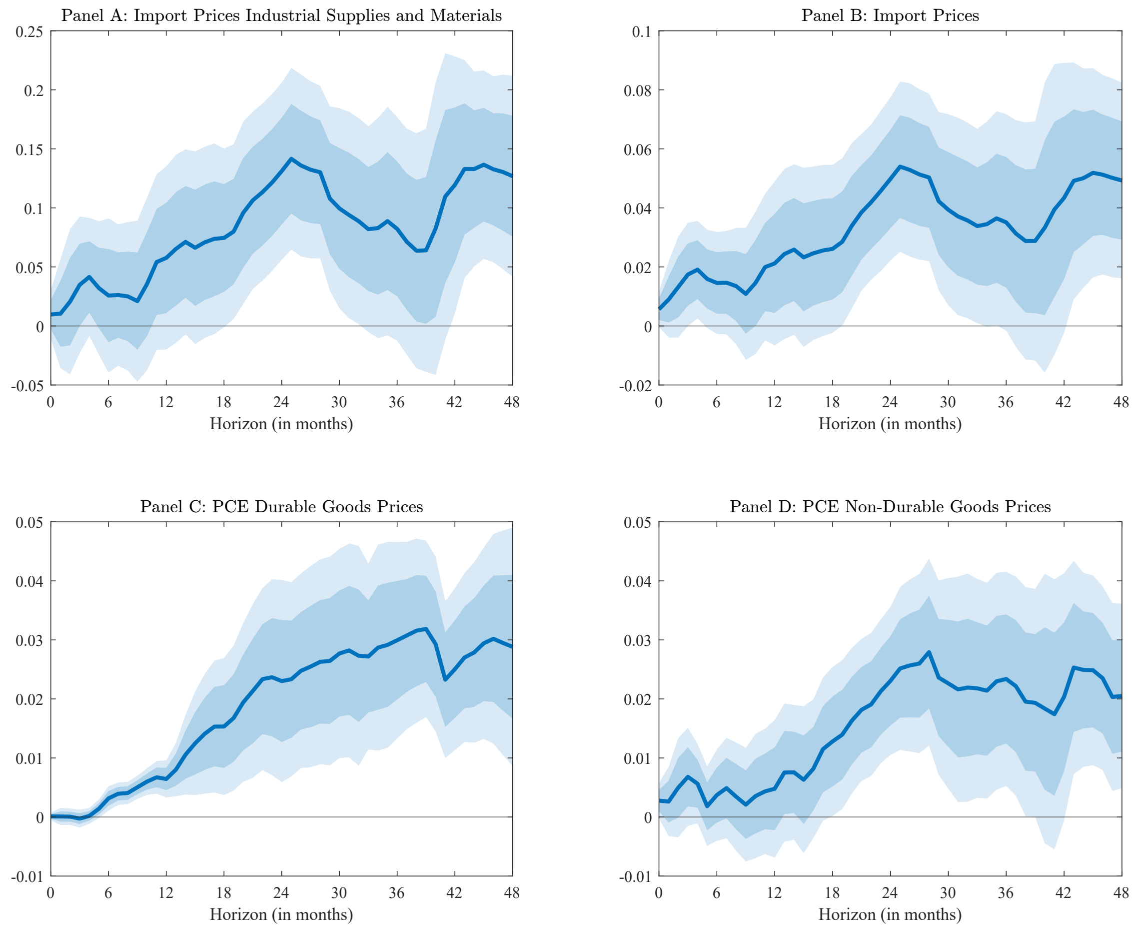

Figure A.17: Impulse responses to a global supply chain pressure innovation

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.

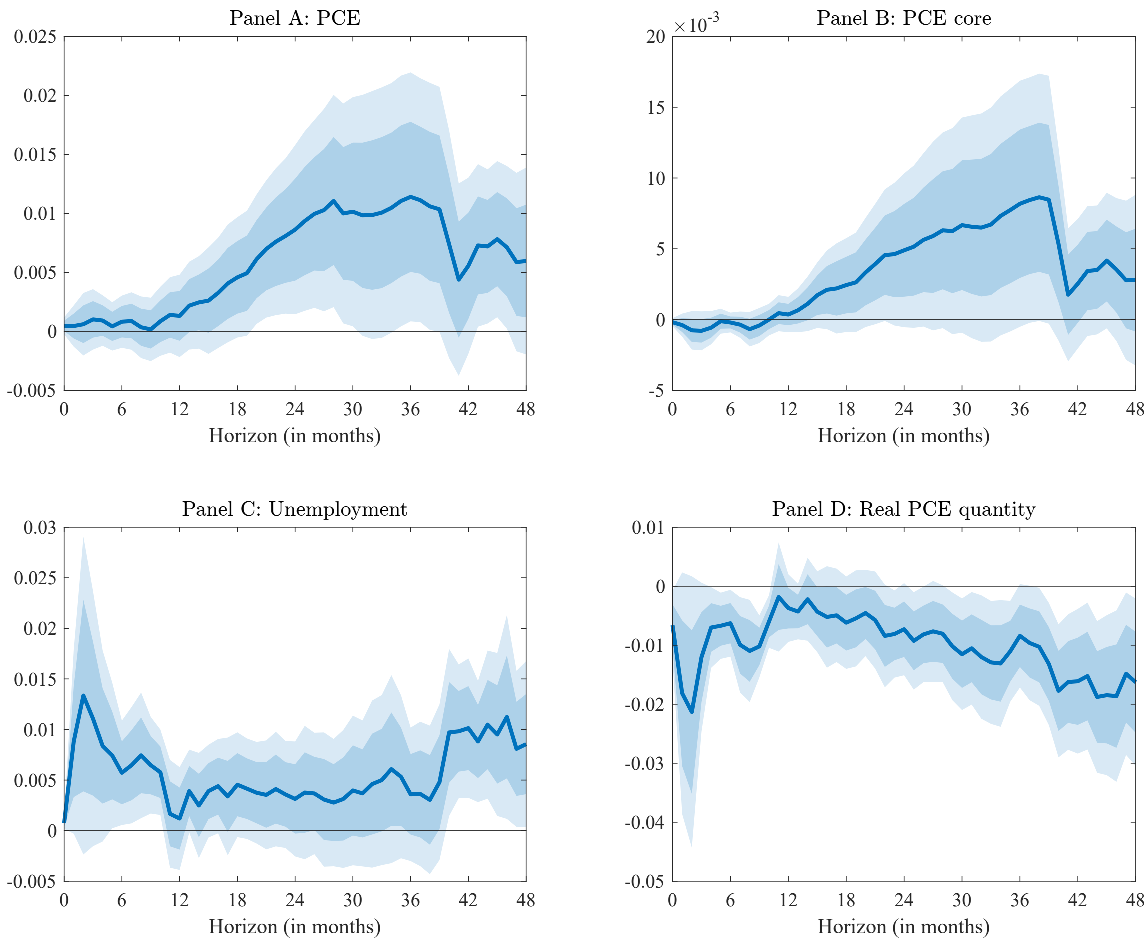

Figure A.18: Impulse responses to a global supply chain pressure innovation

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.