Transmissions of Structural Oil Shocks to Core Prices*

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Abstract

This paper investigates how structural oil market shocks transmit through real oil price changes to the U.S. core prices. Separating out the sources of oil price increases reveals that supply shocks lead to significant and persistent increases in core prices while oil inventory demand shocks pull them down. Other demand-driven shocks do not cause any significant core price fluctuations. Examining different sample periods, we find empirical evidence supporting the strengthening of the oil price pass-through to some degree since mid-1980; however, not much change in the pass-through has been observed since the outbreak of Covid-19. Our findings highlight that understanding the sources of oil price changes is crucial for gauging their impacts on core prices and furthermore, for the conduct of monetary policy.

JEL classification: E31, Q41, Q43

Keywords: Core inflation, Oil price, Pass-through, Local Projection

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1 Introduction

This paper investigates the pass-through of oil prices to the U.S. *core* prices. Core prices do not include components such as food and energy prices that are volatile and directly tied to oil prices. This implies that core prices are influenced by the spill-over effects of oil prices into various economic channels, rather than fluctuating hand in hand with oil price changes. Regular consumers do not buy raw physical crude oil, but some of the increased costs for producers due to crude price changes may eventually be reflected in the prices of other goods and services. Or changes in economic activity due to oil price hikes may have subsequent effects on them, while consumers adjust their demand accordingly. As such, it has been of great interest to researchers and policymakers to understand the timing and magnitude of the pass-through of oil prices to their non-energy counterparts. We differentiate the sources of oil market shocks and examine how they transmit to core prices through oil price increases. More specifically, we investigate the pass-through of the oil price increases caused by each oil market shock to core consumer prices.

The importance of distinguishing the structural source of unanticipated oil price changes is highlighted in the recent literature to fully understand the propagation mechanism of oil price shocks to real economic activity (e.g., Kilian 2009 and Baumeister and Hamilton 2019). Similar implications are brought up from the examination of other dimensions in the economy, such as the U.S. stock market (Kilian and Park 2009) and consumer sentiment (Güntner and Linsbauer 2018). More recently, Aastveit et al. (2020) demonstrate that the distinctive effects of structural oil shocks are also found in the responses of consumers' price expectations as well as the total consumer price index (CPI). Extending the vector autoregressive model of Baumeister and Hamilton (2019) with CPI and consumer price expectations, they find that demand-driven economic activity shocks have more persistent effects on both variables than other types of real oil price shocks. That is, oil price pass-through to inflation and inflation expectation may depend on underlying demand and supply conditions in the global crude oil market. However, little work has been done to investigate potential heterogeneity in the pass-through patterns of structural oil shocks to core prices. Our research is first motivated by the idea that if overall consumer prices as well as oil prices respond differently to oil shocks by their sources, then core prices likely show similar heterogeneity.

A number of previous studies have found in common that the core prices change little when the economy is hit by unanticipated oil price shocks without distinguishing their structural sources, especially in periods after the mid-1980s. For example, Clark and Terry (2010) document that the pass-through to core prices is infinitesimal. Conflitti and Luciani (2019) find that a 10-percent increase in real oil prices converges to a statistically significant, but very small, increase in the common component of core prices, only by 0.05 percentage points (p.p). Many of the studies have also suggested a variety of factors that likely have attributed to diminishing and muted influences of oil prices. Conflitti and Luciani (2019) point out that idiosyncratic components of core prices, which do not respond to oil price changes, explain increasing shares of price dynamics. Other studies call on changes in monetary policy intervention (Bachmeier and Cha 2011) and lowering real wage rigidity (Blanchard and Gali 2009). Some highlight decreasing dependence on oil, thanks to energy-efficiency improvement and energy-saving technology development (Hooker 2002). We extend this literature by examining core price responses to oil market shocks arising from different sources. If the pass-through patterns indeed differ depending on the nature of oil price increases, an alternative explanation for the muted core price response could be that such heterogeneous pass-throughs may offset each other and obscure the overall core price responses.

We use the local projection framework a la Jordà (2005), along with the structural oil market shocks identified by Baumeister and Hamilton (2019). The approach treats the oil shocks arising in the global market as predetermined with respect to the U.S. price dynamics, which is a reasonable assumption for investigating the U.S. inflation responses (Kilian and Vega 2011). Within this framework, we can examine the pass-through of oil price increases due to all of the structural shocks in one step and do not need to impose additional identifying restrictions such as block diagonality on the model.

Based on estimated impulse responses of core prices, we confirm that the pass-through of oil price changes into core prices is negligible, using the sample from September 1999 to December 2019; without distinguishing the sources of the variations, we find that core prices go up significantly only during the impact period and the size of the pass-through is extremely small. However, estimation results using the structural oil shocks uncover important heterogeneity in the pass-through patterns of oil price increases. For instance, oil supply shocks drive core prices to go up for an extended period, and the magnitude of core price change is sizable; a 10-percent increase in real oil prices due to an unanticipated supply shortage would result in a maximum of 0.3-percentage point increases in core prices almost for a year after the impact. In contrast, oil inventory demand shocks lead to negative responses of core prices of a similar magnitude, while the remaining two demand-side shocks are not significantly transmitted. This implies that the overall impacts of oil price increases on core prices may be confounding if multiple structural shocks simultaneously drive oil prices up.

We also examine if there exist any changes in such heterogeneous pass-through patterns over time and find that they indeed had become more noticeable compared to the period from the early-mid 1980s. When we extended our sample back to the beginning of 1984, oil price changes do not seem to significantly pass through to prices of other goods, unlike results using the benchmark sample. In contrast, this is not the case when our benchmark sample is extended forward to include the Covid-19 pandemic era. When we simply include post-Covid-19 observations, it appears that some oil market shocks, particularly supply shocks, incur much stronger responses of core price. Nonetheless, once the pandemic shock was explicitly controlled in our model following Ng (2021), no notable changes in the pass-through pattern is observed. This suggests that a careful treatment of data points during and after the Covid-19 period is crucial for economic analysis to understand the underlying relations of different variables.

Our findings highlight the heterogeneity in the oil price pass-through to core prices; the magnitude and persistence of core price inflation due to oil price increases can vary greatly depending on the sources of oil shocks and the time periods. Therefore, it would be crucial to differentiate the sources of oil price shocks and to account for possible time-variation in the pass-through mechanism, in order to gauge the impacts of oil price changes more precisely. Our findings, hence, reinforce the importance of considering structural sources of oil price shocks for understanding their macroeconomic implications. Furthermore, we highlight that accounting for these features can lead to different conclusions for policy decisions when policymakers consider monetary intervention in response to higher oil prices.

The rest of the paper proceeds as follows. Section 2 describes the empirical model and the data that are employed. Section 3 presents estimated oil price pass-through patterns from the benchmark sample period, i.e., September 1999 to December 2019, and explores changes in the pattern over different time periods. Section 4 concludes.

2 Data and Methodology

We use the local projection framework proposed by Jordà (2005) to examine the responses of core prices to oil market structural shocks as well as real oil price changes. This approach allows us to examine the transmissions of different crude oil market shocks through oil prices in one step as follows:

$$\begin{aligned} y_{t+h} - y_{t-1} = \alpha_h + \Sigma_{i=1}^{4}\beta_{i,h}\tilde{u}_{i,t} + \Phi_h(L)z_{t-1} + \epsilon_{t+h}, \\ \text{where} \quad h = 0, \cdots, 18. \end{aligned} \tag{2.1}$$

Here, y_t denotes a dependent variable of interest in month t. In our benchmark model, y is the logarithmic value of core prices in month t. In particular, we use the U.S. consumer price index for all urban consumers: all items less food and energy in U.S. city average (CPILFESL, index 1982-1984=100) obtained from the Federal Reserve Economic Data (FRED) database of the Federal Reserve Bank of St. Louis. We take the cumulative log difference of the index multiplied by 100.

Key variables of interest are structural oil market shocks, denoted as $\tilde{u}_{i,t}$ for $i = 1, \ldots, 4$. We use the structural oil market shocks identified in Baumeister and Hamilton (2019). The authors impose informative sign restrictions on a vector autoregressive model of the global oil market and identify four types of structural shocks: oil supply shocks, economic activity shocks, oil consumption demand shocks, and inventory demand shocks.[2] First, an *oil supply shock* occurs when there is an unexpected disruption in oil supply; for instance, a war, strike, or pipeline blockage can cause an unanticipated decline in oil production. Second, an *economic activity shock* is associated with changes in the global business cycle; if the economic activity grows faster than expected, then the

[2] For more details on the definition and identification of shocks, we refer to pp.1888 in Baumeister and Hamilton (2019).

Table 1: Description of Data and their Sources

Variable	Description	Source
structural oil market shocks	Structural oil market shocks identified by Baumeister and Hamilton (2019)	Baumeister's webpage[1]
refiner acquisition cost (RAC)	refiner acquisition cost from monthly energy review	EIA
headline CPI	Consumer Price Index for All Urban Consumers: All Items in U.S. City Average (CPIAUCSL)	FRED
core CPI	Consumer Price Index for All Urban Consumers: All Items Less Food and Energy in U.S. City Average (CPILFESL)	FRED
industrial production	Industrial Production: Total Index (INDPRO)	FRED
federal funds effective rate	Federal Funds Effective Rate (DFF)	FRED
one-year-ahead total price/ gasoline price inflation expectations	Expected changes in (gasoline) prices during the next year	Surveys of Consumers: University of Michigan
PPI for private capital equipment	Producer Price Index by Commodity: Final Demand: Private Capital Equipment (WPUFD41312)	FRED
hourly wage	monthly average hourly wage of age 25-54	IPUMS-CPS

Note: The benchmark sample period is from 1999M09 to 2019M12. The last three rows are variables used in Appendix B. The one-year-ahead gasoline price expectation is available only from 2006M02.

global economy would demand more oil for producing output. Third, an *oil consumption demand shock* comes from changes in demand specifically for oil that can have further impacts on global oil production, but are not particularly driven by the fluctuations in the global business cycle. Finally, an *inventory demand shock* incurs an unanticipated change in above-ground crude oil inventories. As noted in Baumeister and Hamilton (2019), the inventory demand shock has often been referred to as a "speculative demand shock" in the literature. We normalize all of the structural shocks to elicit a 10-percent increase in the real refiner acquisition cost (RAC) of oil.[3] We sometimes replace the structural oil shocks series with the real RAC to compare the magnitude of pass-through when the sources of oil price changes are not distinguished.

A set of control variables, z_t, is included in our baseline model. This contains 12 lags of a dependent variable. We also include the same number of lags of first-differenced logs of the U.S. industrial production index as well as the Federal Funds rate, to reflect the state of the economy as well as the financial conditions. The latter two series are obtained from the FRED database. Table 1 provides a summary of the description and sources of key data used in this paper.

The local projection framework is a flexible approach to estimating responses of y variables to structural oil price shocks, under the assumption that these shocks are exogenous with respect to the error term ϵ_{t+h}. That is, the shocks need to be pre-determined with regard to the U.S. core CPI changes. If this condition is satisfied, the estimates of the coefficients $\beta_{i,h}$ immediately become the responses to the structural shock i in horizon h.

[3] The historical realization of the four structural shocks before the normalization is available on Christiane Baumeister's website: https://sites.google.com/site/cjsbaumeister/datasets?authuser=0.

In our case, the structural oil market shocks are originally identified in the global-level oil market in Baumeister and Hamilton (2019); the monthly changes in the U.S core inflation or any other dependent variables of the U.S. are not likely to have impacts on the global oil market in the same month (Kilian and Vega 2011). This hence supports our use of the local projection framework.[4] It is worthwhile to note that while the corresponding standard errors of the coefficient estimates ($\hat{\beta}_{i,h}$) provide error bands for the responses, one needs to correct for the serial correlation in the error term ϵ_{t+h} emerging from directly projecting h-period ahead values. Hence, we use a Newey and West (1987) correction (see Jordà 2005 and Ramey 2016 for more details).

Our benchmark sample runs from September 1999.[5] However, in section 3, we employ data from other periods to investigate any changes in the pass-through dynamics. We present the estimated impulse responses for 18 months after the impact.

3 Pass-through of Oil Shocks to Core Prices

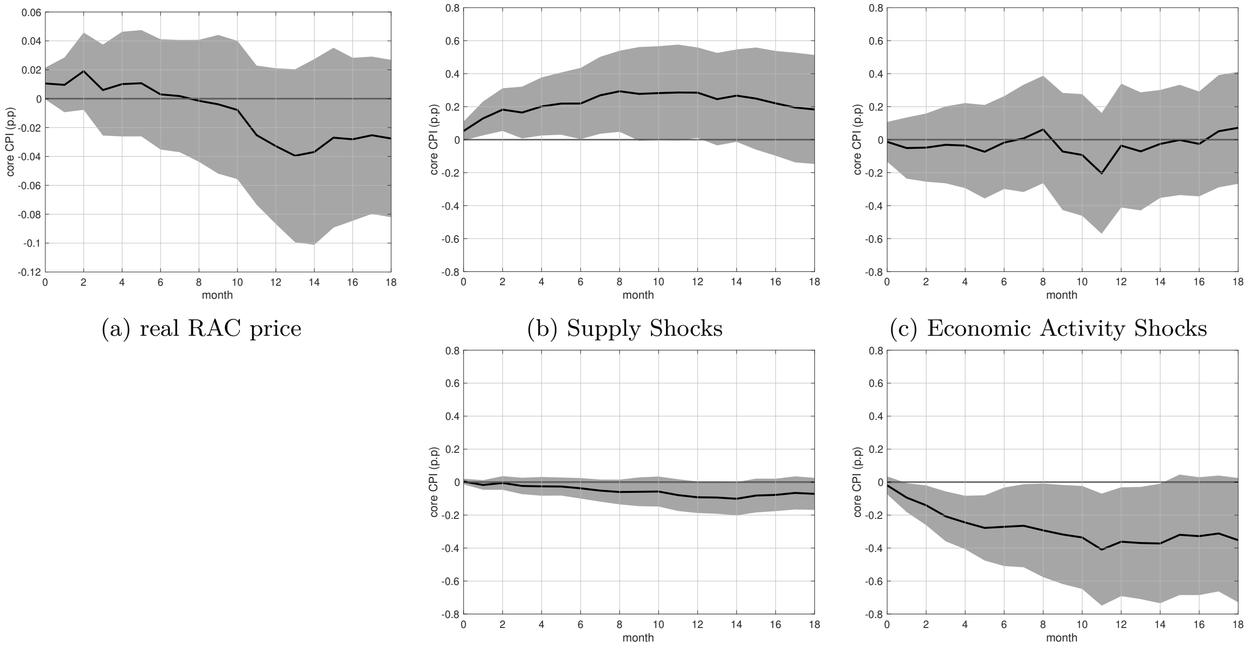
3.1 Heterogeneous Pass-Through of Structural Oil Shocks Figure 1 plots impulse responses of core prices to real RAC and four types of structural oil market shocks, estimated using Equation 2.1 with data from September 1999 to December 2019. As shown in panel (a), a 10-percent increase in RAC changes the core price little. It drives the core CPI up significantly on impact only, and moreover, the magnitude is very small. This result is in line with the findings from Clark and Terry (2010) and Conflitti and Luciani (2019), for instance, where oil price changes elicit little and limited increases in core inflation.

In contrast, distinguishing the sources of oil price changes provides different insights. First, we find that an oil supply shock is the only structural oil market shock that puts upward pressure on the core CPI; a 10-percent increase in RAC driven by unanticipated disruptions in oil supply results in the maximum 0.3 percentage point (p.p) increase in core prices. This pass-through of the supply shock starts on impact and remains to be effective for about a year. Second, among the remaining three demand-side shocks, only an inventory demand shock passes through to core prices; more specifically, a 10-percent increase in RAC due to the inventory demand shocks decreases the core CPI by about 0.4 p.p in about a year. Finally, the other two demand shocks do not incur any significant responses to core prices.

While our framework does not offer means to disentangle a precise transmission channel of these structural oil

[4] One can alternatively extend the VAR model of Baumeister and Hamilton (2019) by augmenting the U.S. core inflation in the system and by assuming a block diagonality in the impact matrix, similar in spirit to Aastveit et al. (2020). Compared to such an extended VAR model setup where the impulse responses are calculated as a non-linear function of structural shocks and reduced-form parameters, the local projection framework provides a simple way to calculate impulse responses without having to impose additional identification restrictions (Ramey 2016). In addition, both methodologies should result in similar impulse response estimates (Plagborg-Møller and Wolf 2021).

[5] The starting period of our sample was determined by the supremum Wald break test results for real RAC and core price observations between 1984 and 2019. The final period was selected to December 2019 to exclude potential impacts of the Covid-19 pandemic. In section 3, we conduct additional analysis by altering the sample periods.



(a) real RAC price (b) Supply Shocks (c) Economic Activity Shocks

(d) Oil Demand Shock (e) Inventory Demand Shock

Figure 1: Pass-through of Oil Price Shocks into Core Prices (1999M09-2019M12)

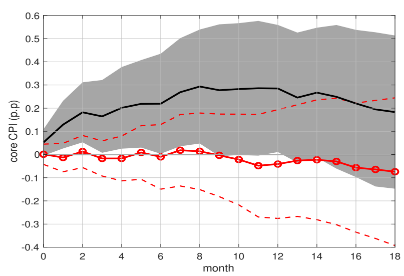
Note: This figure reports the impulse responses of the core CPI to oil shocks, using data from 1999M09 to 2019M12. The grey-shaded area represents Newey and West (1987)-corrected 95% error bands of the corresponding impulse responses in black solid lines. All of the structural shocks are normalized to elicit a 10% increase in the real RAC.

market structural shocks, considering their nature provides some insights to understand our findings. As shown in Figure 8 in Baumeister and Hamilton (2019), the supply shocks drag down oil production persistently, with which businesses may face higher costs for production. This may lead to cost-push inflation for overall prices other than energy and food. Also, Baumeister and Hamilton (2019) notes that an increase in oil prices that results from an increase in inventory demand alone has not only a persistent positive effect on both inventories and prices but also a negative effect on global economic activity. Hence, with no material change in oil supply, higher oil prices along with lower economic activity likely put a downward pressure on demand and lead to a deflationary response of core prices.

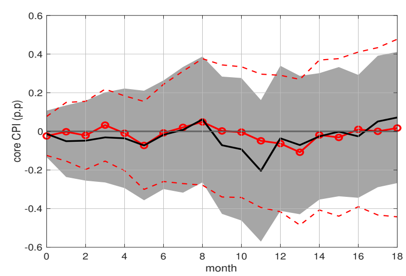
The responses of core prices differ greatly from those of the headline CPI as shown in Figure 2 of Aastveit et al. (2020). The authors find that overall inflation responded positively to all of the four types of structural oil shocks, but the responses did not last longer than 4 months. In fact, most responses lose statistical significance two months after the impact. In addition, economic activity shocks have the largest and longest impacts on headline inflation. Once we exclude food and energy prices from the scope and focus on recent time periods since around 2000, we see that supply shock is the only shock that moves up the core CPI.Still, we share the similarity in that our results also underscore the importance of discerning the source of oil price changes to understand their implications on the pass-through into other price dynamics, in addition to those on real economic activity.

Our paper analyzed a period starting in September 1999, based on a break test result of the oil-core price relation since 1984, as noted in section 2. In contrast, several papers on the pass-through of oil prices to core prices examine a sample starting in 1983 or 1984, in line with the start of the Great Moderation period. For instance, Conflitti and Luciani (2019) highlight that higher volatility in inflation during the 1970s and the early 1980s compared to a later period and a structural break found in the oil-inflation relation in the early-mid 1980s in related studies (e.g., Hooker 2002 and Clark and Terry 2010) as reasons to focus on periods after early 1980s.[6]

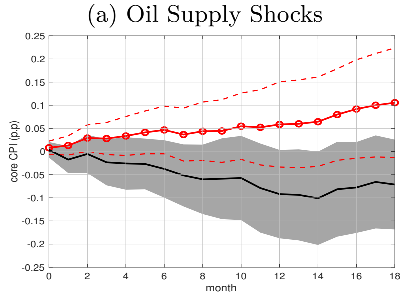
Moreover, some studies have documented the changes in the magnitude of the oil price pass-through mechanism into other prices. For example, Ramey and Vine (2011) find that the impacts of oil price shocks on the total CPI diminished by about a half since the mid-1980s. A number of other studies have also reported a similar decline in core price responses to oil price shocks since the mid-'80s (see Hooker 2002, Clark and Terry 2010, and Conflitti and Luciani 2019, for example). Therefore, we examine if there had been any change in the transmission of oil market shocks to core prices when we extend our sample back to the mid-1980s.



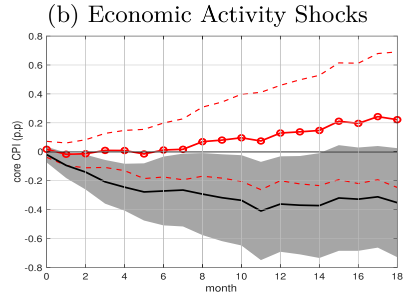
(a) Oil Supply Shocks



(b) Economic Activity Shocks



(c) Oil Consumption Demand Shocks



(d) Inventory Demand Shocks

Figure 2: Oil Price Pass-Through since January 1984

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the core CPI from the benchmark sample (1999M09 to 2019M12). The red solid lines in the charts are the responses using the sample from 1984M01 to 2019M12 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC.

Figure 2 compares the estimated responses using a sample starting in January 1984 to those from the benchmark. We find that none of the four structural oil shocks significantly moved core prices when the sample starts in 1984. This is in line with findings from previous studies that core prices move little in response to an oil price shock, as in Clark and Terry (2010) and Conflitti and Luciani (2019). More specifically, analyzing the period

[6] As such, these studies did not include the 1970s in their main analysis, during which two oil crises had happened.

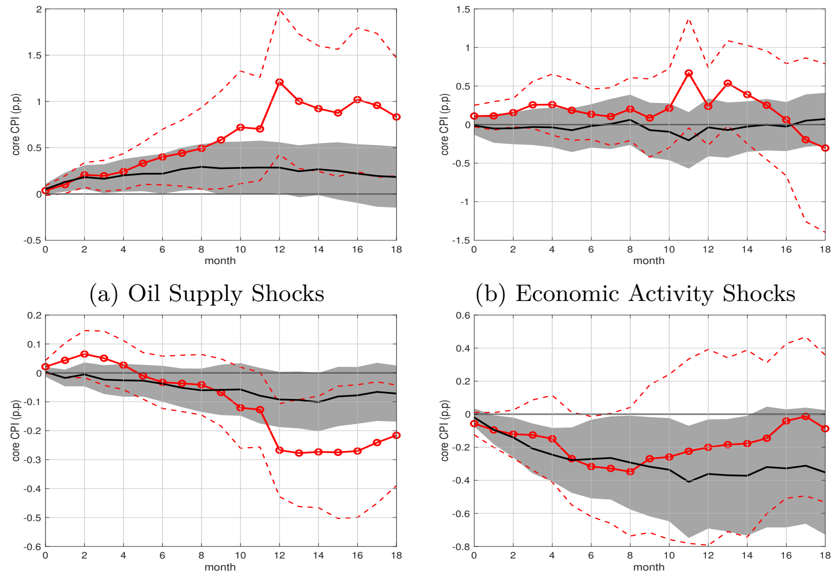
from January 1984 to June 2016, Conflitti and Luciani (2019) report that an unexpected oil price increase by 10 percent can lead to an infinitesimal increase by 0.05 p.p in core prices measured by Personal Consumption Expenditure (PCE) prices. While this positive pass-through remains statistically significant for about 2 years after the impact at the 10 percent significance level, the magnitude is indeed very small. Related to this result, our findings imply that there has been a change in the pass-through patterns of the structural oil market shocks via oil prices once we exclude the early part of the Great Moderation period, as we see in Figure 2 and suggested by the break test results. The pass-through of oil prices since 1984 is indeed very limited even when accounting for heterogeneous sources of oil price changes, but has become considerably noticeable for oil supply and inventory demand shocks since then.[7]

3.2 Has the Pass-Through of Oil Shocks Changed since the Coivd-19?

The arrival of the Covid-19 pandemic has affected the economy in a profound way; on impact, the economy went into a recession very rapidly and then again quickly recovered, leading to realizations of extreme outliers in observed values of economic indicators and further to some fundamental changes in a number of industries. Related to the focus of our paper, both headline and core inflation went up substantially soon after the economy recovered from the recession. As such, we examine the pass-through of oil prices extending the sample to include the Covid-19 period. More specifically, we re-estimate our model with samples from September 1999 to February 2022.

Figure 3 reports the response of core prices to oil price increases caused by structural oil market shocks. The black solid lines and the corresponding shaded area are the responses from the benchmark sample period, and are hence identical to the impulse responses in Figure 1. The red solid and dashed lines are the responses of core prices from the sample ending in February 2022 and their associated 95-percent error bands. Comparing the two responses, it appears to suggest a significant change in the pass-through of oil market shocks to core prices since the outbreak of the pandemic. In particular, the pass-through of oil prices due to supply shocks shows the most notable differences. As shown in panel (a), the impacts of the supply shocks recently become much larger and more persistent so that they affect the core CPI in a much greater magnitude once we include the Covid-19 periods into the sample; around one year after the impact, the supply shocks that increase RAC by 10 percent push core prices up by more than 1 p.p., and this increase remains statistically significant for one and a half years. This seems to be consistent with recent high core price inflation that was observed at the same time as persistent increases in crude oil prices. In contrast, an oil price increase due to oil inventory demand shocks loses statistical significance in pass-through to core prices. Rather, an oil consumption demand shock drags down the

[7] Alternatively, one may argue that the contradicting effects of oil supply and inventory demand shocks may have offset each other when passed through to core prices via oil prices increases, resulting in a muted response of core prices. To see if this is also feasible, we re-estimate our baseline model using data from the identical period as Conflitti and Luciani (2019), January 1984 – June 2016, and show resulting responses of core prices in Figure A.1. We find that real RAC prices as well as structural oil market shocks do not significantly transmit to the core CPI and hence, the offsetting effects of different structural shocks have not likely caused the observed change in the pass-through pattern in Figure 2.



(a) Oil Supply Shocks (b) Economic Activity Shocks

(c) Oil Consumption Demand Shocks (d) Inventory Demand Shocks

Figure 3: Comparison of Oil Price Pass-Through with Samples Extended to February 2022

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the core CPI from the benchmark sample (1999M09 to 2019M12). The red solid lines in the charts are the responses using the sample from 1999M09 to 2022M02 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC.

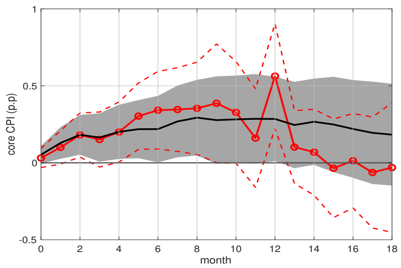
core prices significantly starting a year after the impact. No change is observed in the case of economic activity shocks with insignificant core price responses in both periods. These findings seem to provide evidence for the idea that Covid-19 has also changed the pass-through of oil price changes, particularly for the supply-driven ones.

However, it has been pointed out in recent studies, e.g., Carriero et al. (2022) and Ng (2021), that Covid-19 poses a notable challenge, especially for a linear time-series model such as our benchmark ones to accommodate extreme observations during the pandemic period and subsequent structural changes that might have happened.[8] Therefore, we follow the methodology proposed in Ng (2021) to "de-covid" data. The Covid-19 episode can be accommodated in a time-series model in different ways, but Ng (2021) treats it as an addition of new shocks rather than a realization of outliers or the distribution of existing shocks. Thus, this methodology uses some key indicators related to Covid-19 as controls, such as the number of deaths, hospitalized, or positive cases in addition to some dummy variables indicating the pandemic era. We adopt this methodology and expand our equation 2.1 by including a dummy variable for the outbreak month (i.e., March 2020) as well as the number of positive cases and its three lags.[9]

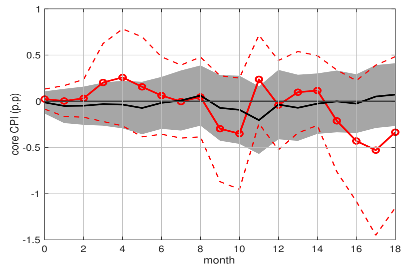
Figure 4 reports impulse responses after controlling for Covid-19 indicators. As before, the red solid and dashed lines are those from the sample extended to February 2022, overlaid on top of the baseline responses from September 1999 to December 2019. Interestingly, the difference in the estimated pass-through dynamics for the

[8]We thank an anonymous referee for pointing this out.

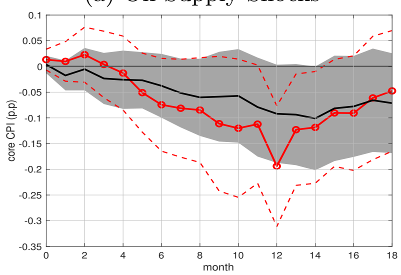
[9]Results using the number of deaths or hospitalized are very similar and available upon request.



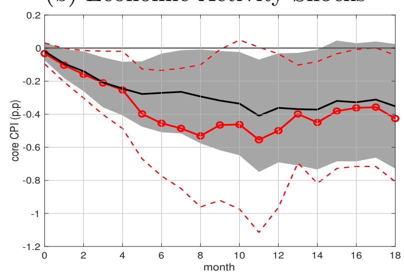
(a) Oil Supply Shocks



(b) Economic Activity Shocks



(c) Oil Consumption Demand Shocks



(d) Inventory Demand Shocks

Figure 4: Oil Price Pass-Through after Controlling for Covid-19 Indicators

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the core CPI from the benchmark sample (1999M09 to 2019M12). The red solid lines in the charts are the responses using the sample from 1999M09 to 2022M02 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC.

extended sample is no longer observed for all structural shocks, once we de-covid our data. Some point estimates of core price responses in four to eight months after the impacts still show an elevated degree of pass-through, but these are not distinguishable from the benchmark results statistically. This implies that once we control for the pervasive economic consequences of the Covid-19 shock, the pass-through of the structural oil shocks to core prices remains little changed from before.

Inflationary oil price shocks can propagate into prices of other goods in various ways, as noted in Conflitti and Luciani (2019). In Appendix B, we further investigate the responses of variables that may represent demand-pull and cost-push inflation channels. Similar to our findings for core prices, some variables show clear variations in the response patterns and appear to be capable of explaining the observed changes in the supply and inventory demand shocks' transmissions when post-Covid-19 observations are simply added to the analysis.[10] However, once we include the Covid-19 indicators as controls, their responses to structural oil shocks do not differ substantially from their pre-Covid dynamics, similar to the case of core prices. Together, these findings underscore the importance of explicitly accounting for the Covid-19 shock for economic analysis including recent observations.

[10] Appendix B provides a detailed description of the analysis and resulting impulse responses.

4 Conclusion

This paper investigated the oil price pass-through into core prices. We focused on oil price changes arising from different sources, by employing the four types of oil shocks identified in Baumeister and Hamilton (2019) in the local projection framework. Our estimation results confirmed that the pass-through of oil price changes into core prices was limited; when RAC fluctuations were used in the estimation model without distinguishing the sources of the variations, the core CPI responded significantly during the impact period only, and the size of the pass-through is very small in the sample from September 1999 to December 2019. However, estimation results based on the structural oil shocks revealed substantial heterogeneity in the pass-through mechanism. In particular, oil supply shocks were found to be the only structural shock that drove up the core CPI significantly. This pass-through of the supply shocks was sizable and lasted for about a year after the impact; a supply shock increasing RAC by 10 percent would lead to a maximum 0.3-p.p. increase in core prices. In contrast, an oil price increase due to oil inventory demand shocks would elicit deflationary pressure on core prices, while the other two demand-driven shocks would not eventually transmit to core prices.

Such heterogeneous pass-through of oil prices by structural sources had become more noticeable since around 2000. When we extended our sample back to the beginning of 1984, oil price changes did not seem to significantly pass through to the prices of other goods. Nonetheless, when our sample was extended to include the Covid-19 pandemic era, we did not find empirical support for any notable changes in the pass-through pattern recently, once the pandemic shock was explicitly controlled in our model. This, in turn, emphasizes the importance of carefully accounting for data since the outbreak of the pandemic for economic analysis.

Our findings highlighted the heterogeneity in the oil price pass-through to core prices; the magnitude and persistence of core price inflation due to oil prices could vary depending on the sources of oil shocks. Therefore, it would be crucial to understand the sources of oil price changes to gauge their impacts more precisely. Policy-wise, our findings imply that monetary policy intervention required in response to higher oil prices could greatly differ depending on these features.

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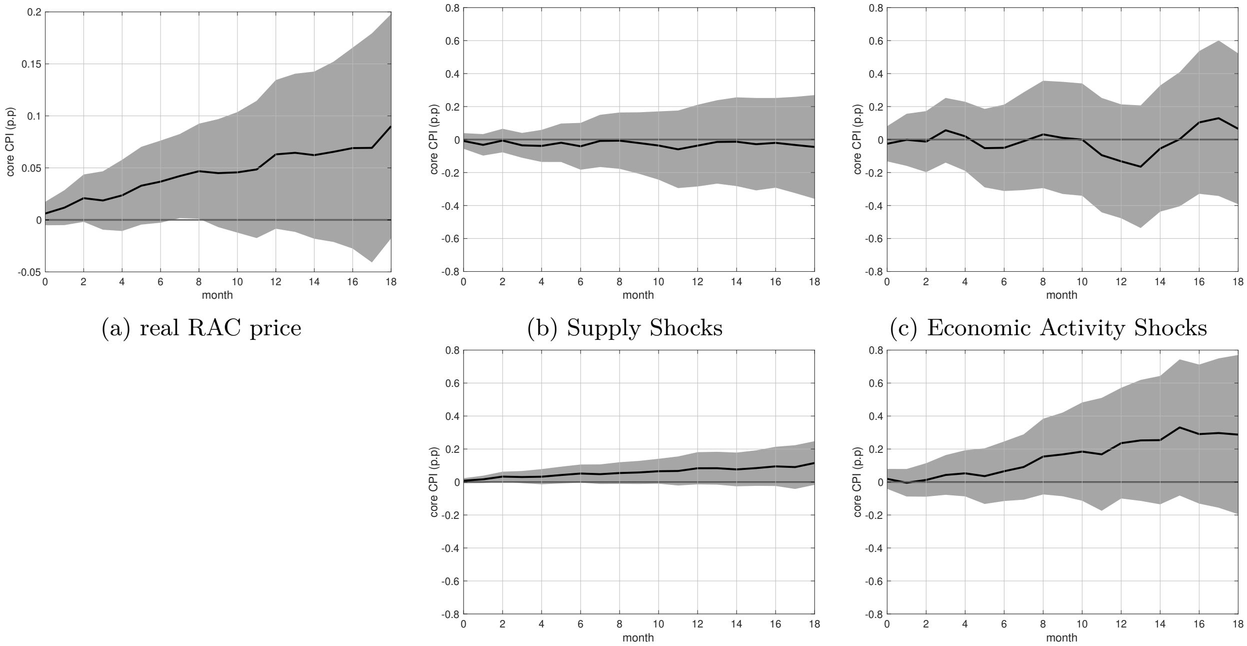
A Oil Price Pass-through Since January 1984



(a) real RAC price (b) Supply Shocks (c) Economic Activity Shocks

(d) Oil Demand Shock (e) Inventory Demand Shock

Figure A.1: Pass-through of Oil Price Shocks into Core Prices (1984M01-2016M12)

Note: This figure reports the impulse responses of the core CPI to oil shocks, using data from 1984M01 to 2016M12. The grey-shaded area represents Newey and West (1987)-corrected 95% error bands of the corresponding impulse responses in black solid lines. All of the structural shocks are normalized to elicit a 10% increase in the real RAC.

B Inclusion of the Covid-19 Observations

We investigate possible factors that may have driven the observed heterogeneity in oil price pass-through. In particular, we use the same framework, i.e., equation (2.1), to estimate the impulse responses of a set of economic variables that can represent different pass-through channels. We focus on comparing the responses from two periods, our benchmark period of September 1999 – December 2019 and September 1999 – February 2022.

As discussed earlier, inflationary oil price shocks may transmit to prices of other goods in various ways. First, oil price increases may lead to higher inflation expectations. A number of studies have shown that oil prices can drive the price expectations of consumers; see Aastveit et al. (2020) Binder (2018), Coibion et al. (2018), Wong (2015), for example. Second, workers may desire wage increases to make up for higher energy costs to pay (Blanchard and Gali 2009). Finally, energy price increases may put upward pressure on other production input costs than wage (Lee and Ni 2002). Considering these studies, we check the responses of the following variables. First, while we do not directly observe core price expectations, we have inflation expectations as well as gasoline price expectations survey data from the Michigan Survey of Consumers (MSC).[11] We use the mean responses of each month.[12] Second, we use the producer price index (PPI) by commodity for private capital equipment (WPSFD41312). This index is one of the re-grouped commodity-based PPIs according to the type of buyer by the Bureau of Labor Statistics and captures selling prices received by the U.S. domestic producers for capital equipment investment by businesses. It would be difficult to find an aggregate-level indicator to represent production cost, so we employ this series as a proxy for general production input costs other than wage.[13] Finally, we employ the average hourly earnings of all private employees (CES0500000003) to check for any changes in the wage pass-through of oil shocks.[14]

It should be noted that the variables investigated here do not completely cover all of the possible spillover channels and they would not be perfectly mapped into the underlying mechanism. We rather interpret our findings as suggesting more likely factors behind the heterogeneous pass-through. The goal of this section, hence, is to investigate any differences with and without controlling for Covid-19 indicators also in the response patterns of the factors to underlying oil market shocks.

Figures B.1 to B.4 plot the responses of the four variables under study to structural oil market shocks; ones on the left columns are obtained without controlling for Covid-19 while those on the right are after controlling for the pandemic. Three findings stand out. First, when we do not account for the Covid-19 shock, it appears that changes in the core price expectation responses are consistent with the strengthening transmission of oil supply shocks and the deflationary pressure with lags of oil consumption demand shocks since the pandemic outbreak.[15] Second, in the case of oil supply shock, PPI for capital equipment responses likely have contributed to the change in the oil price pass-through pattern as well, since the pandemic outbreak. Lastly but most importantly, all of these changes in the response patterns disappear almost completely, once we control explicitly for the Covid-19 indicators, similar to the result obtained for core prices.

[11] This monthly survey asks respondents by what percent they expect prices in general will go up or down in the next 12 months. It also asks about how many cents the respondents expect gasoline prices will go up or down in the next 12 months. Questions asking respondents about their gasoline price expectations were included in the MSC questionnaire only from February 2006 on a continuous basis, prior to which these questions were asked intermittently. Hence, the estimated impulse responses of this variable are for periods starting from February 2006. While the former asks about expected price changes in percentages, the latter requires answers in cents, which may imply changes of drastically different sizes depending on the level of gasoline prices in the corresponding months. We hence divide the mean responses by the average monthly U.S. city average price of unleaded regular gasoline prices, obtained from the FRED database, and convert the responses in cents to percentages.

[12] Since the raw data on price expectations is expressed in terms of the expected change, not the level of the price, we use the level of y_{t+h} instead of cumulative differences in logs in Equation 2.1.

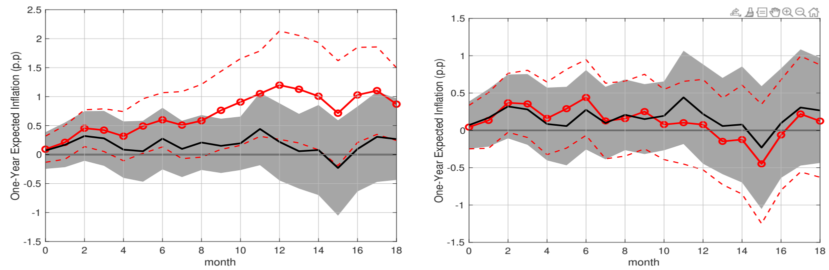
[13] This series is downloaded from the FRED database.

[14] The FRED data series of the average hourly earnings of all private employees start from March 2006. Hence, the estimated impulse responses of this variable are for periods starting from March 2006.

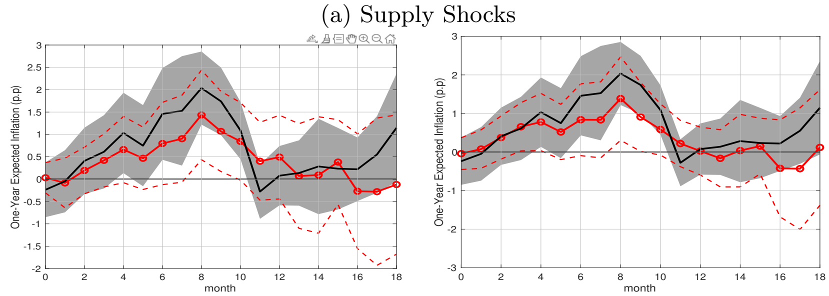
[15] For instance, expectations for total inflation did not respond significantly to the oil supply shocks in the period ending before the COVID-19 outbreak. This appears to change greatly, once we include survey responses since 2020 but do not "de-covid"; consumers expected the overall price to climb substantially and significantly. However, such a change in the response pattern is not observed in the gasoline price expectation responses, as they remain statistically insignificant in the two sample periods. Hence, one may infer that the drastic change in total inflation expectation responds to the supply shocks by differences in expectation formation for non-energy prices.

In sum, consistent with our earlier finding that the oil price pass-through pattern remains little changed since Covid 19, we see that the response patterns of several variables representing different price spill-over channels show no significant changes in a model where the Covid-19 shock is explicitly accounted for. Therefore, our finding highlights again the importance of carefully bringing in observations from the pandemic period in economic modeling.

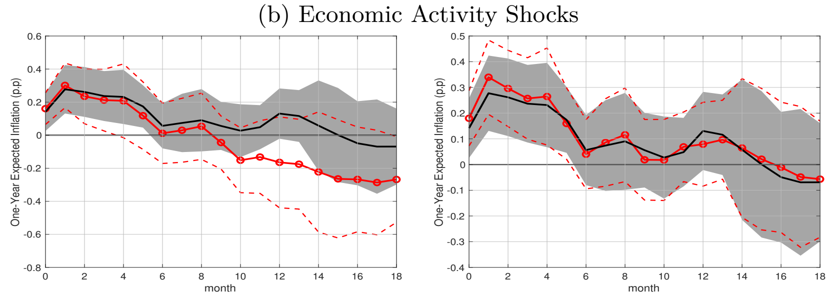
no Covid controls incl. Covid indicators



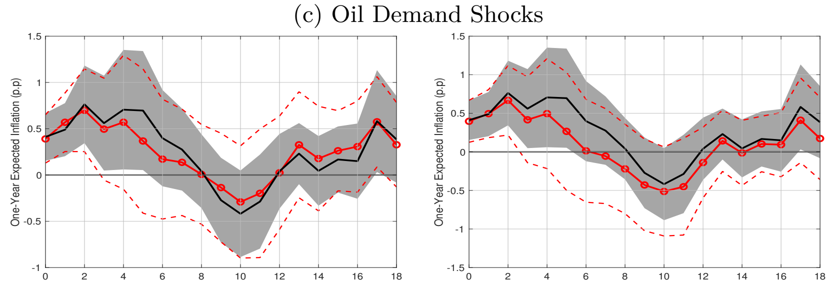
(a) Supply Shocks



(b) Economic Activity Shocks



(c) Oil Demand Shocks

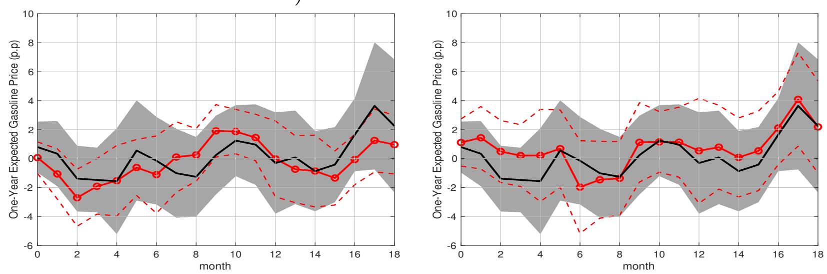


(d) Inventory Demand Shocks

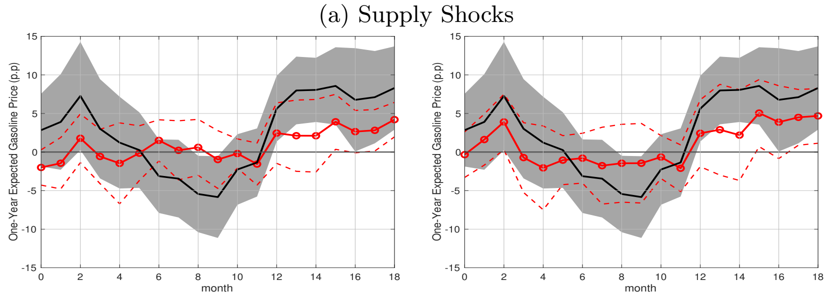
Figure B.1: Oil Price Pass-Through to One-Year Ahead Inflation Expectation

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the one-year ahead inflation expectation from the benchmark sample (1999M09 to 2019M12). The red solid lines in the charts are the responses using the sample from 1999M09 to 2022M02 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC. "incl. Covid indicator" stands for the figures derived by Local Projections with Covid-related controls following Ng (2021).

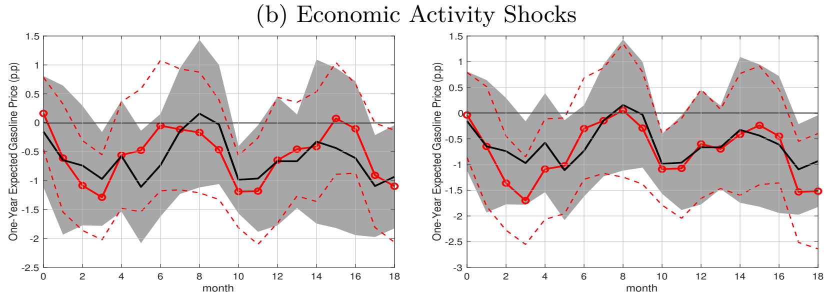
no Covid controls) incl. Covid indicators



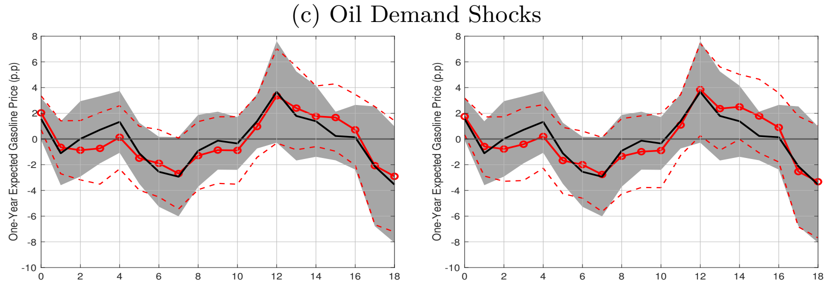
(a) Supply Shocks



(b) Economic Activity Shocks



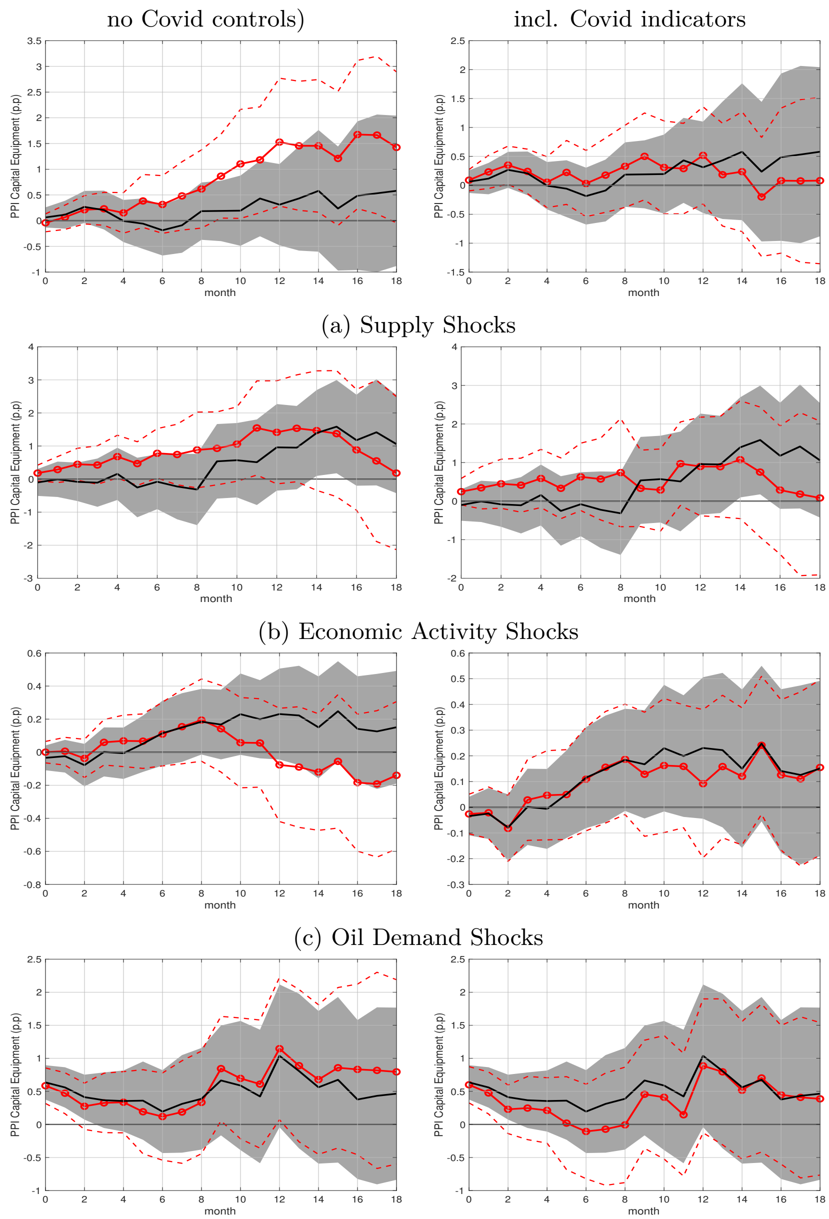
(c) Oil Demand Shocks



(d) Inventory Demand Shocks

Figure B.2: Oil Price Pass-Through to One-Year Ahead Gasoline Price Expectation

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the one-year ahead gasoline price expectation from 2006M02 to 2019M12. The red solid lines in the charts are the responses using the sample from 2006M02 to 2022M02 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC. ”incl. Covid indicator” stands for the figures derived by Local Projections with Covid-related controls following Ng (2021).



(a) Supply Shocks

(b) Economic Activity Shocks

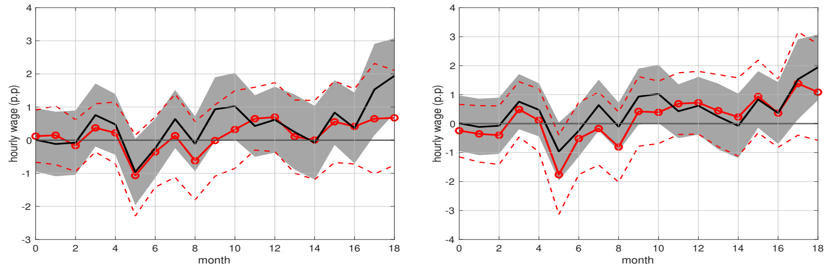
(c) Oil Demand Shocks

(d) Inventory Demand Shocks

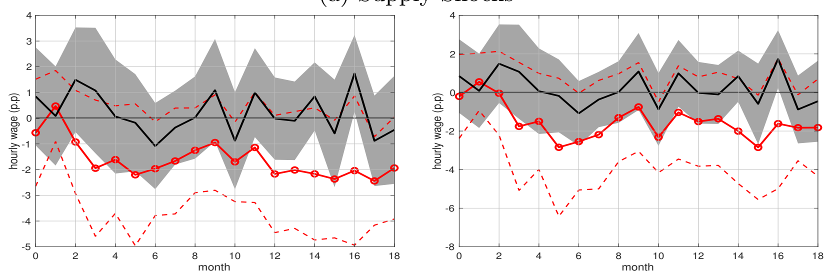
Figure B.3: Oil Price Pass-Through to PPI for Capital Equipment

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the PPI for capital equipment from the benchmark sample (1999M09 to 2019M12). The red solid lines in the charts are the responses using the sample from 1999M09 to 2022M02 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC. "incl. Covid indicator" stands for the figures derived by Local Projections with Covid-related controls following Ng (2021).

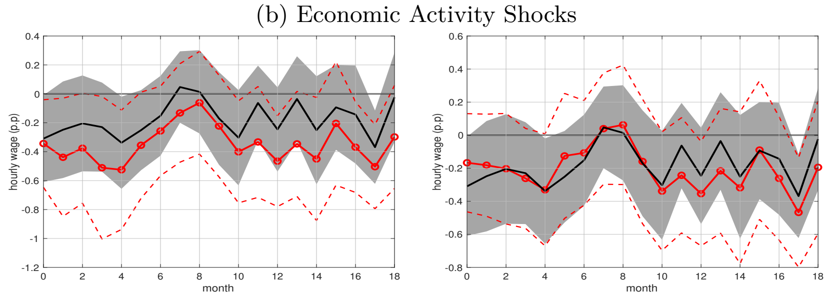
no Covid controls) incl. Covid indicators



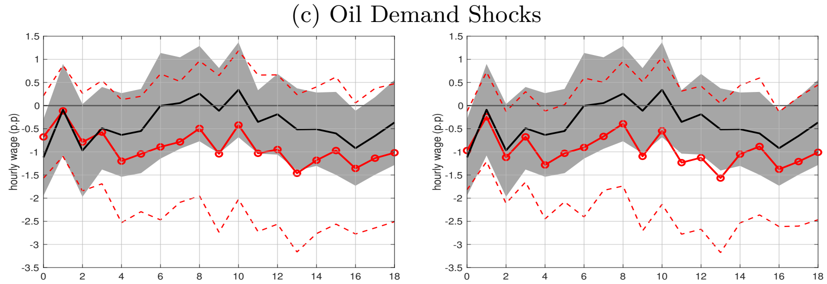
(a) Supply Shocks



(b) Economic Activity Shocks



(c) Oil Demand Shocks



(d) Inventory Demand Shocks

Figure B.4: Oil Price Pass-Through to Hourly Wage

Note: The black solid lines and grey-shaded area are the impulse responses and 95% error bands of the hourly wage from the benchmark sample (1999M09 to 2019M12). The red solid lines in the charts are the responses using the sample from 1999M09 to 2022M02 and the red dotted lines represent 95% error bands of the corresponding responses. All oil shocks are normalized to elicit a 10% increase in the real RAC. "incl. Covid indicator" stands for the figures derived by Local Projections with Covid-related controls following Ng (2021).

C Summary of Main Results

Table C.1: Response Summaries

	real RAC price shocks	supply shocks	economic activity shocks	oil demand shocks	inventory demand shocks
1999M09 - 2019M12	-	positive ($+0.29 p.p.$)	-	-	negative ($-0.41 p.p.$)
1984M01 - 2019M12	positive ($+0.04 p.p.$)	-	-	-	-
1999M09 - 2022M02	positive ($+0.09 p.p.$)	positive ($+1.21 p.p.$)	-	negative ($-0.28 p.p.$)	negative ($-0.35 p.p.$)
(decovid)	negative ($-0.09 p.p.$)	positive ($+0.56 p.p.$)	-	negative ($-0.19 p.p.$)	negative ($-0.56 p.p.$)

Note: The numbers in the parenthesis represent the peak responses. The dash (-) sign indicates the shocks cause no significant response.