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The Non-Linear Response of US State-Level Tradable and Non-Tradable Inflation to Oil Shocks: The Role of Oil-Dependence

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Abstract

This paper investigates the effects of oil supply, oil-specific consumption demand, oil inventory demand shocks, and global economic activity shocks on state-level tradable and non-tradable inflation in the US. We estimate both linear and non-linear impulse responses using a lag-augmented local projections model in a panel context. Our results from a linear model show that both supply and demand-side oil shocks have a statistically significant impact on both types of inflation. While supply, global economic activity, and demand shocks have a greater impact on tradable inflation, non-tradable inflation responds more strongly to inventory shocks. Further, the non-linear model results provide evidence of heterogeneity in the magnitude and persistence of impact between high- and low-oil dependence regimes. Non-tradable inflation is more sensitive to nearly all components of oil price shocks in the high-oil dependence regime.

JEL Classifications: E31, E32, Q43
Keywords: Phillips curve; Structural oil shocks; State-level inflation; Local projection method

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1. Introduction

There is both anecdotal and formal evidence highlighting macroeconomic effects of oil price swings (Hooker, 2002; Cunado et al., 2003, 2015; Blanchard and Galí, 2007; De Gregorio et al., 2007; Chen, 2009; Habermeier et al., 2009; Clark and Terry, 2010; Choi et al., 2018). Evidence also suggests the magnitude of impact is driven by oil export/import status (Baumeister et al., 2010; Bodenstein et al., 2012; De Michelis et al., 2020) and oil dependence of the economy (Greene et al., 1998; Hooker, 2002; De Gregorio, 2007; Hamilton, 2008). Almost all prior research focuses on country-level analysis and almost always uses the vector autoregression (VAR) framework. In this paper, we use the local projections approach to estimate the response of state-level inflation to oil price shocks. We also account for oil dependency, estimate the response of tradable and non-tradable inflation separately, and use four different components of oil price shocks namely, demand, supply, inventory, and economic activity shocks.

Existing research that focuses on the impact of oil price shocks on domestic inflation provides mixed evidence. Álvarez et al. (2011) find that the pass-through effects of oil price on inflation have increased over time in the Euro area. In contrast, De Gregorio et al. (2007) find decreased pass-through effect from oil prices to domestic inflation. An explanation for this decline in pass-through effects is greater central bank independence and inflation targeting regime (Habermeier et al., 2009), however, which Gelos and Ustyugova (2017) later refute. Using the VAR model, Zoli (2009) and Caceres et al. (2012) hint that region-specific factors might drive the responses of domestic inflation to global oil price shocks in developing economies. Given these mixed results, it is no surprise then to see active policy discussions and ongoing research interests on the topic, as highlighted in Baumeister and Kilian (2016) and Baumeister and Hamilton (2019).

The existing studies miss at least three important elements in assessing the impact. First, the distinction between tradable and non-tradable goods. Second, accounting for the degree of oil dependence at a state level. And third, likely misspecification of the underlying data generating process in the standard vector autoregressive model used in studying oil price-inflation nexus.

The lack of distinction between tradable inflation and non-tradable inflation could be one reason driving the contrasting evidence in the literature. Because tradable goods have markets at multiple locations, the price of these goods would be determined at the national level, barring the transport and regulatory costs differential across locations. In contrast, non-tradable goods are more likely affected by regional marginal costs. Thus, differences in inflation across various states are more likely explained by price changes in non-tradable goods and less by price variations in tradable goods. Given non-tradable inflation varies more than tradable inflation, it becomes necessary to distinguish tradable and non-tradable inflation in understanding the impact of oil shocks. In related literature, Kishor et al. (2021) also highlight the need to distinguish tradable and non-tradable components of employment in assessing its impact on future housing market movements.

Most studies focus on the impact of oil shocks on inflation at an aggregate country level. If the magnitude of pass-through effects of oil shocks on inflation is a function of the oil dependence of a country (Greene et al., 1998; Hooker, 2002; De Gregorio, 2007; Hamilton, 2008), it is only logical that the same would apply at a state level. In the US, this is particularly relevant. There is significant heterogeneity at the state level in terms of oil dependence. The oil independent Texas and Utah would respond differently to oil shocks compared to more oil-dependent states and Alaska, which produces substantially more oil than consumed. Several studies support this rationale in studying the impact of oil shocks on real housing returns (Sheng et al., 2021; Gupta et al., 2021) and consumption (van Eyden et al., 2021) at the state level in the US.

Supported by Jordà (2005), we also argue that the standard use of the VAR framework can be problematic. The impulse responses from VAR models require the specification and estimation of the unknown data generating process. This problem accentuates as the horizon of impulse response increases. The literature that uses local projections (LPs) modeling approach proposed by Jordà (2005) has grown exponentially because of its well-established merits (Kilian and Kim, 2011; Angrist et al., 2018; Stock and Watson, 2018; Equiza-Goñi and Perez de Gracia, 2019; Olea and Plagborg‐Møller, 2021). It is simple, provides appropriate inference, is robust to misspecification as it does not require the specification of the unknown data generating process, aptly handles persistence in data series because of lag augmentation, and easily accommodates nonlinear specification. These advantages are not available for impulse responses estimated from natural alternatives like the VAR models. Jordà (2005) proves these points in much greater detail.

In this study, we use lag-augmented local projections (LPs) within the augmented Phillips curve framework. We also control for the contemporaneous and lagged effects of the state-level unemployment rate and the federal interest rate. Several studies use this augmented Phillips curves framework (De Gregorio et al., 2007; Gelos and Ustyugova, 2017; Choi et. al., 2018). Since oil dependence differs across US states, we estimate both linear and non-linear (oil regime-dependent) impulse response of state-level inflation rates to structural oil shocks. Further, we estimate the impact of each component of oil price shocks - oil supply shock (OSS), global economic activity shock (EAS), oil-specific consumption demand shock (OCDS), and oil inventory demand shock (OIDS).

Results of the linear model show that global economic activity shocks (EAS), demand shocks (OCDS), and inventory shocks (OIDS) substantially increase consumer price inflation. However, while the impact of EAS is the highest, OCDS and OIDS impact persists for as long as 18 and 24 quarters, respectively. The impact of favorable supply shocks (OSS) reduces both tradable and non-tradable inflation up to 6 quarters but has a persistent positive impact in the long run. However, we find the response of tradable inflation is greater to supply, global economic activity, and demand shocks. In contrast, non-tradable inflation responds more strongly to inventory shocks.

These results, however, vary once we distinguish between high and low oil dependence regimes. We find significant heterogeneity in the magnitude and persistence of shocks across regimes. Inflation response to all components of oil price shocks is more in the high-oil dependence regime relative to the low oil dependence regime, perhaps except supply shocks. A favorable supply shock in a high oil dependence regime lowers non-tradable inflation up to 6 quarters before it exerts some positive impact on inflation in the long term. In contrast, in a low oil dependence regime, such shocks lower non-tradable inflation up to 18 quarters. These effects remain hidden in the linear model, thus highlighting the need to study the impact based on oil dependence.

We provide several contributions to the literature. First, unlike existing studies, we distinguish between tradable and non-tradable inflation to study the impact of oil shocks. In studying the relationship between house prices and employment, Kishor et al. (2021) also highlight the need to study tradable and non-tradable components. Second, we decompose the oil shocks into four unique components and estimate the impulse response of inflation to each component. This contributes to the existing understanding of oil shock on inflation in the spirit of Kilian (2009), Baumeister et al. (2010), and Kang and Ratti (2013). Third, we study the impulse responses from both linear and non-linear (oil-dependent regimes) models. Studies have not modeled the impact of oil shocks on inflation accounting for such regime switches, despite being otherwise natural and intuitively appealing.

2. Data

Data for inflation are calculated based on the new state-level price indexes for the US constructed by Hazell et al. (2020), which are categorized into tradable, non-tradable, and overall consumer prices.[1] Our study focuses on both non-tradable and tradable inflation. Note that there are more variations across US states in the former than the latter. This is consistent with the argument from Hazell et al. (2020) that tradable goods are normally priced at the national level and therefore may not respond to regional marginal costs and may not contribute to differences in inflation across various states. We also calculate state-specific oil dependence using state-level estimates of oil production and oil consumption from the State Energy Data System (SEDS) at the US Energy Information Administration (EIA) website.[2] The level of oil dependence is calculated as oil consumed minus oil produced as a ratio of oil consumed. Data for the state-level unemployment rate are available from the Local Area Unemployment (Lau) Databases on the website of the US Bureau of Labor Statistics.[3]

To capture structural oil shocks, this study utilizes the updated series of oil shocks data following the work of Baumeister and Hamilton (2019) and decomposes shocks to the real price of crude oil according to their nature into four components, i.e., the oil supply shock (OSS), global economic activity shock (EAS), oil-specific consumption demand shock (OCDS), and oil inventory demand shock (OIDS).[4] Our unbalanced panel dataset is at the quarterly frequency and covers the sample period from 1978: Q1 to 2017:Q4.

3. Methodology

[1] See the data appendix of Hazell et al. (2020) for more details about the procedure for constructing state-level consumer price indexes and the definition of non-tradables.
[2] Data Source: https://www.eia.gov/state/seds/seds-data-complete.php?sid=US#CompleteDataFile.
[3] Data Source: https://www.bls.gov/lau/data.htm.
[4] Data Source: https://sites.google.com/site/cjsbaumeister/research.

Following the work of Montiel Olea and Plagborg-Møller (2021), we employ lag-augmented local projections (LPs) that control for lagged variables in the regressions. Lag-augmented LPs are robust to highly persistent data and the estimation of impulse responses at long horizons. The linear model for computing IRFs using LPs is defined as follows:

$$\pi_{i,t+s} = \alpha_{i,s} + \beta_{i,s}\pi_{i,t-1} + \gamma_s OilShocks_t + \sum_{j=0}^{k} \delta_{i,j,s} UE_{i,t-j} + \sum_{j=0}^{k} \theta_{j,s} IR_{t-j} + \epsilon_{i,t+s}, \quad \text{for } s = 0,1,2, \dots H \tag{1}$$

where π_i represents inflation in the cross-section of US states. $OilShocks_t$ is the structural oil shock. γ_s captures the responses of state-level inflation at time $t + s$ to an identified oil price shock at time t. The LP-IRFs are calculated as a series of γ_s which are estimated separately at each horizon (s).[5] We also control for the contemporaneous and lagged effects of the state-level unemployment rate and the US federal interest rate in an augmented Phillips curve framework, where $UE_{i,t-j}$ and IR_{t-j} represent the unemployment rate at the state level and the federal interest rate, respectively.[6] We also include the fixed effects in a panel specification (captured by $\alpha_{i,s}$). Hazell et al. (2020) show that when the fixed effects are included in the regressions, it differences out across regions the influence of long-run inflation expectations on inflation, which otherwise can confound estimates of the parameters in the model.

This study also investigates whether the effects of structural oil shocks on state-level inflation rates are regime-dependent and contingent on the status of oil dependence across US states. Equation (1) can be revised into a regime-dependent model where IRFs are depending on the status of oil dependence in each US state (Gorodnichenko and Auerbach, 2013; Jordà et al., 2020). The nonlinear model includes a smooth transition function to distinguish the states in a high oil dependence regime from those in a low oil dependence regime and can be written as follows:

$$\pi_{i,t+s} = \left(1 - F\left(z_{i,t-1}\right)\right)\left[\alpha_{i,s}^{High} + \beta_{i,s}^{High}\pi_{i,t-1} + \gamma_s^{High} Oilshocks_t + \sum_{j=0}^{k} \delta_{i,j,s}^{High} UE_{i,t-j} + \sum_{j=0}^{k} \theta_{j,s}^{High} IR_{t-j}\right] + F\left(z_{i,t-1}\right)\left[\alpha_{i,s}^{Low} + \beta_{i,s}^{Low}\pi_{i,t-1} + \beta_s^{Low} Oilshocks_t + \sum_{j=0}^{k} \delta_{i,j,s}^{Low} UE_{i,t-j} + \sum_{j=0}^{k} \theta_{j,s}^{Low} IR_{t-j}\right] + \epsilon_{i,t+s}, \quad \text{for } s = 0,1,2, \dots H \tag{2}$$

[5] See Jordà (2005) for more details about the LP methodology.
[6] $\sum_{j=0}^{k} k$ is set to 1 so that we have controlled for the contemporaneous and one-period lagged effects of the state-level unemployment rate and the US federal interest rate in the model.

$$F(z_{i,t}) = \exp(-\gamma z_{i,t})/1 + \exp(-\gamma z_{i,t}), \gamma > 0, \quad (3)$$

where $z_{i,t}$ is a switching variable capturing the dependence of oil across US states and is normalized to have a zero mean and unit variance. $F(z_{i,t})$ is the smooth transition function that has a bound between 0 and 1, with values close to 1 representing the low oil dependence regime, and 0 otherwise. Superscripts *High* and *Low* denote the high and low oil dependence regimes, respectively. Oil Dependence is measured by oil consumed minus oil produced as a percentage of oil consumed.

4. Results

Figure 1 displays the estimated impulse response of state-level inflation rates for tradable (Panel A) and non-tradable (Panel B) inflation in the US to the four structural oil price shocks over 24 quarters for the linear model specified in Equation 1.[7] The figure tracks the impulse responses calculated by local projections to a 1-unit increase of the disaggregated oil shocks on the future path of inflation, along with the 95% confidence bands calculated based on panel-corrected standard errors.

Our results from the linear model show that both supply and demand-side oil shocks have statistically significant impacts on both tradable and non-tradable inflation. However, supply, global economic activity (EAS), and oil demand shocks (OCDS) have relatively greater impacts on tradable inflation, whereas non-tradable inflation responds more strongly to inventory shocks (OIDS). The results also highlight the importance to distinguish the origins of oil price shocks. For instance, the initial impact of OCDS and EAS on non-tradable inflation dies by 6 quarters, OIDS impact persists up to 18 quarters.

Moreover, our results show that a favorable oil supply shock (e.g., the OSS raises oil production and lowers oil prices) reduces consumer price inflation (both tradable and non-tradable) for 6 subsequent quarters before it exerts some positive impact on inflation in the long term. This finding contrasts with Kilian (2008) who reports that the average contribution of OSS to inflation tends to be small or negligible in the G7 countries and is partially in line with Zhao et al. (2016) who find that OSS mainly has some short-term impacts on inflation in China.

[7] In appendix, we also report the estimated impulse responses of US state-level inflation rates for tradable goods and for overall consumer prices that include tradable and non-tradable goods to the four structural oil price shocks. These results are qualitatively similar.

However, it is noteworthy that these studies use inflation data at the aggregate country level, not at the regional level. Moreover, these studies do not distinguish between tradable and non-tradable components of inflation.

[Inserts Figure 1 here]

Our results also show that the demand-side shocks tend to have positive and statistically significant effects on both tradable and non-tradable inflation. For example, a global economic activity shock (EAS) to the aggregate demand for industrial commodities causes a significant increase in consumer price inflation that extends from the 2nd to the 10th quarter and from the 15th to the 22nd quarter for tradables, and from the 4th to the 6th quarter and from the 16th to the 22nd quarter for non-tradables. In addition, an oil consumption demand shock (OCDS) that is specific to the crude oil market (and is designed to capture increases in the oil prices driven by higher precautionary demand for oil driven by fears about future oil supply shortfalls) leads to several periods of high inflation for both tradables and non-tradables shortly after the impact. These findings are consistent with results from Kilian (2008) who shows that both global aggregate demand expansions and oil-market specific increases in demand raise oil prices on impact and cause a significant increase in US consumer price index (CPI) inflation.

Moreover, our results show that a rise in oil prices as a consequence of an increased oil inventory demand (which is often described as an oil speculative demand shock) causes a substantial increase in consumer price inflation. For example, an oil inventory demand shock (OIDS) seems to have sustained and positive effects on non-tradable inflation until the 18th quarter after the impact. This finding aligns with the results from Baumeister and Hamilton (2019) who observe that OIDS seems to have a persistent and positive effect on real oil prices.

[Inserts Figure 2 here]

Figure 2 presents the estimated nonlinear IRFs of tradable (Panel A) and non-tradable (Panel B) inflation to the structural oil shocks. Here we distinguish the status of oil dependence in individual states into high- or low-oil dependence regimes in the model specified in Equations (2) and (3). Results show strong evidence of heterogeneous responses of inflation to oil price shocks between high- and low-oil dependence regimes in US states. Compared to the low-oil dependence regime, inflation is more sensitive to oil price shocks in the high-oil dependence regime.

Comparing the response of tradable and non-tradable inflation, the results are consistent with the linear model. The OSS, EAS, and OCDS have an overall greater impact on tradable inflation, whereas non-tradable inflation responds more strongly to OIDS. In a high oil-dependence regime, the positive impact of oil consumption demand shocks on non-tradable inflation is weaker in magnitude but persists longer (16 quarters) relative to tradable inflation's response (8 quarters). The global economic shock in a high oil-dependence regime raises tradable inflation for up to 9 quarters compared to 6 quarters in the case of non-tradable inflation. In contrast, an oil inventory demand shock has a positive and statistically significant impact on non-tradable inflation for up to 15 quarters, while the positive and statistically significant responses of tradable inflation to an oil inventory demand shock are only observed at the 4th, 6th, 7th, and 18th quarter. We also find that the overall impact on tradable inflation is relatively more certain (narrower confidence band) compared to non-tradable inflation. This is even true in the case of the linear model.

These findings corroborate with empirical evidence in the existing literature that estimate the impact of oil prices on macroeconomic and financial variables (see, for example, Cunado and De Gracia, 2005; Gupta et al., 2020; 2021; Gupta and Sheng, 2021; Sheng et al., 2020; 2021; Wen et al., 2021). Several studies show that macroeconomic variables tend to be more affected by oil price shocks in high-oil dependency economies at both country and regional levels. Wen et al. (2021) find that three types of oil price shock have the largest effect on U.S. inflation among the G7 countries. Sek et al. (2015) study comparative effects of oil price changes in inflation across a group of low and high oil dependency countries. They find real exchange rate and exporter's production cost (in high oil dependency group) and domestic output and exporter's production cost (in low oil dependency group) as key determinants of domestic inflation.

5. Conclusions

In this study, we use both linear and nonlinear impulse responses with lag-augmented local projections under a panel set-up to estimate the impact of oil shocks on state-level inflation. Since non-tradable inflation varies more than tradable inflation, we estimate the impact on each one of them separately. Linear impulse responses show that both supply and demand-side oil shocks have statistically significant impacts on inflation. However, results from the non-linear specification that account for high and low dependence show significant non-linearity in the impact and persistence of oil shocks on inflation. Inflation is more sensitive to oil price shocks in the high-oil dependence regime compared to the low-oil dependence regime. These results can help policymakers form a better understanding of the linkage between the origins of oil price shocks and tradable and non-tradable components of inflation.

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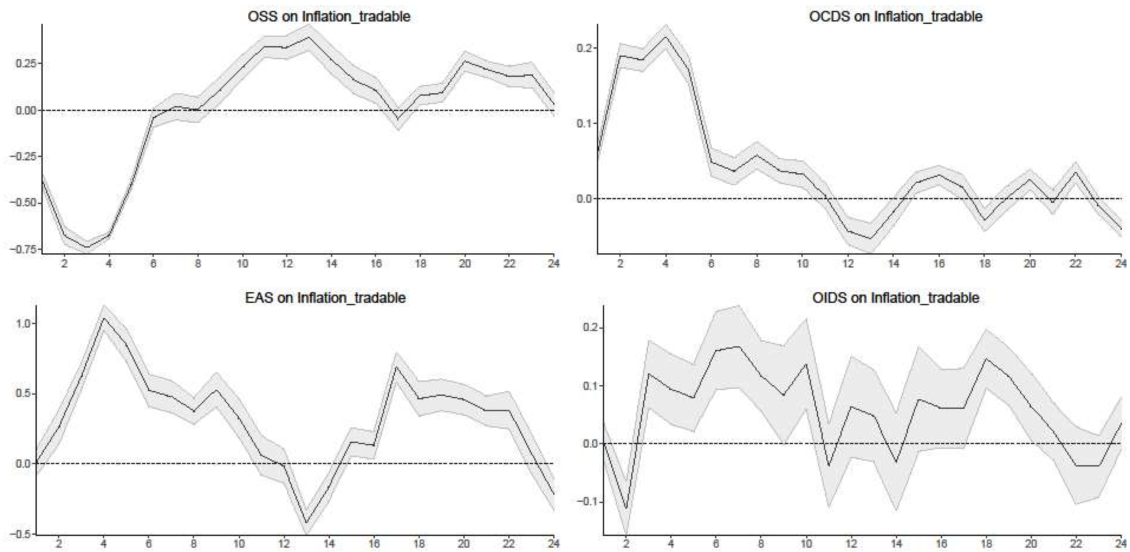
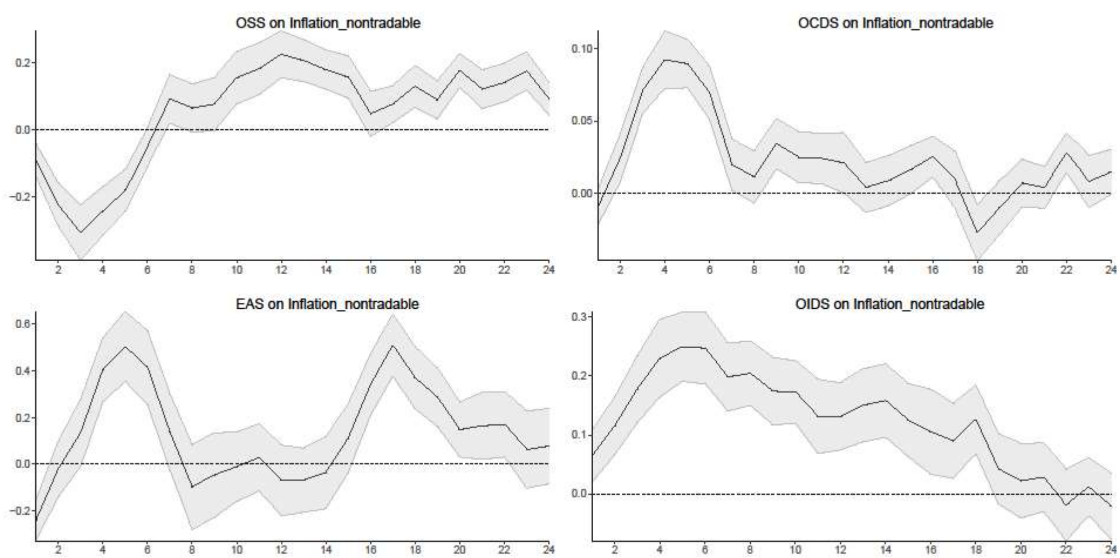
Figure 1. Response of tradable and non-tradable inflation to the four structural oil shocks

Panel A: Tradable inflation



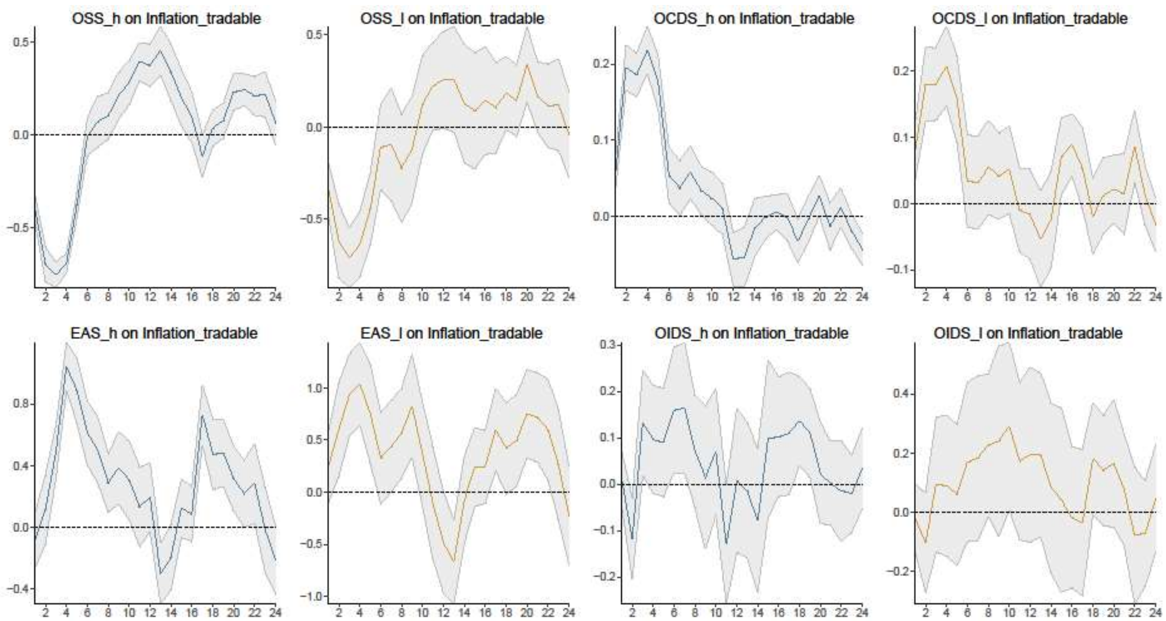
Panel B: Non-tradable inflation



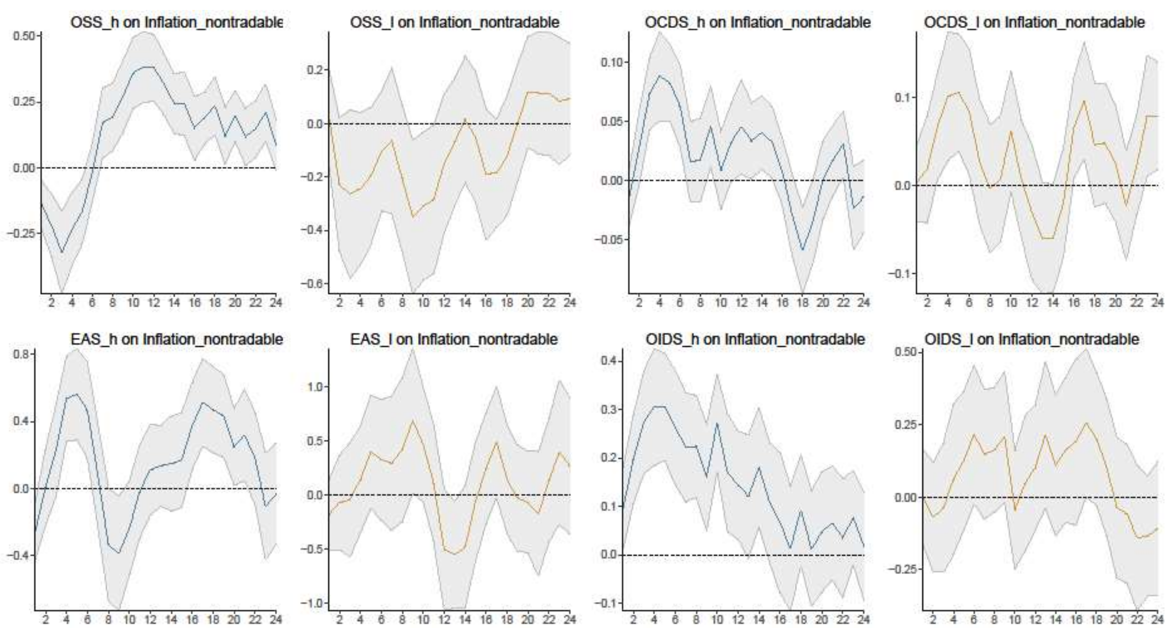
Note: OSS represents the oil supply shock; EAS represents the global economic activity shock; OCDS represents the oil-specific consumption demand shock; and OIDS represents the oil inventory demand shock. The figures show the impulse response (along with 95% confidence bands) of tradable (Panel A) and non-tradable (Panel B) inflation to a one-unit increase in a specific disaggregated oil shock.

Figure 2. Response of tradable and non-tradable inflation to the four structural oil shocks in high- (*h*) and low- (*l*) oil dependence regimes

Panel A: Tradable inflation



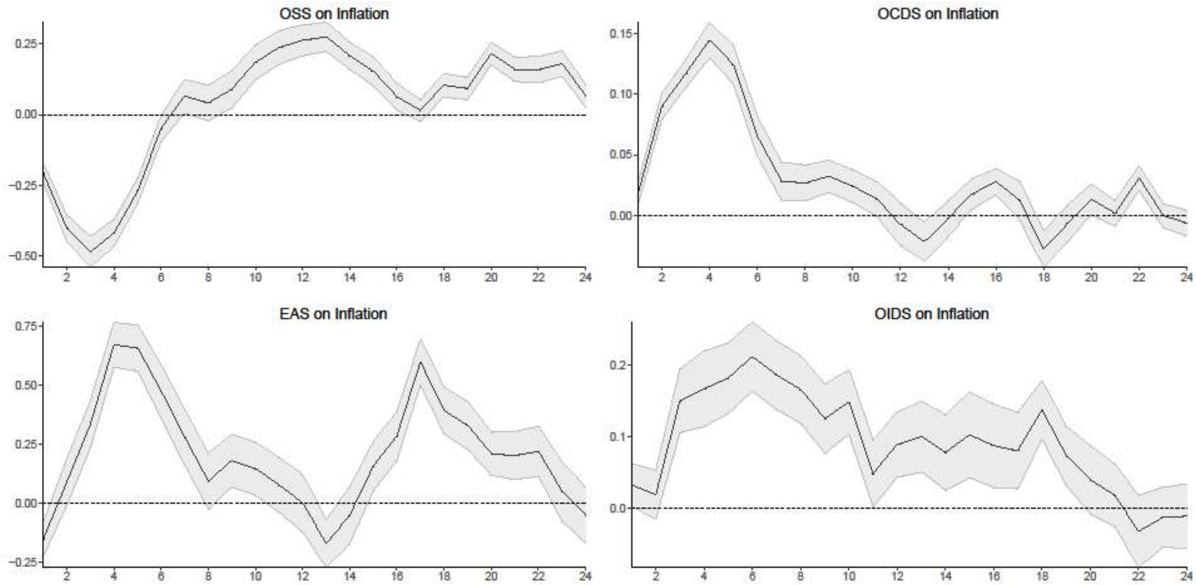
Panel B: Non-tradable inflation



Note: See Notes to Figure 1. Oil Dependence: oil consumed minus oil produced as a percentage of oil consumed, with *h* and *l* corresponding to high- and low- regimes of oil dependence respectively.

Appendix

A1. Responses of State-level Inflation Rates (Non-tradable and Tradable Goods) to the Four Structural Oil Shocks



Note: See Notes to Figure 1.

A2. Response of State-level Inflation Rates (Non-tradable and Tradable Goods) to the four structural oil shocks in high- (*h*) and low- (*l*) oil dependence regimes